Major Project-II

Comparative Analysis of Wind Turbine Power Generation for Different Turbine Rotors

Submitted in the Partial fulfilment of the requirement for the award of degree of

Master of Technology

In

Renewable Energy Technology

Submitted by

Abhishek

(2K14/RET/02)

Under the guidance of:

Dr Rajesh Kumar (Associate Professor)

DEPARTMENT OF MECHANICAL, PRODUCTION & INDUSTRIAL AND AUTOMOTIVE ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY,

NEW DELHI - 110042

CANDIDATE'S DECLARATION

I hereby declare that the project entitled "**Comparative Analysis of Wind Turbine Power Generation for Different Turbine Rotors**" being submitted by me is an authentic work carried out under the supervision of Dr Rajesh Kumar, Associate Professor, Mechanical Engineering Department, Delhi Technological University, Delhi.

Abhishek
2k14/RET/02

CERTIFICATE

This is to certify that report entitled "**Comparative Analysis of Wind Turbine Power Generation for Different Turbine Rotors**" which is submitted by ABHISHEK in partial fulfilment of the requirement for award of degree M tech. in Renewable Energy Technology to DELHI TECHNOLOGICAL UNIVERSITY, Shahbad Daulatpur, Delhi is a record of candidate's own work carried out by him under my supervision.

Dr Rajesh Kumar

(Associate Professor)

Department Of Mechanical Engineering

Delhi Technological University,

Delhi

Acknowledgement

It is my privilege to express my sincerest regards to the project coordinator, Dr Rajesh Kumar, Associate Professor, Department of Mechanical Engineering, for their valuable inputs, able guidance, encouragement, whole-hearted cooperation and constructive criticism throughout the duration of the project. His critics and suggestions on my work have always guided me towards perfection. This work is simply the reflection of his thoughts, ideas, concepts and above all their efforts.

I deeply express my sincere thanks to our Head of Department Dr Prof. R S Mishra for encouraging and allowing us to present the project on the topic "Comparative Analysis of Wind Turbine Power Generation for Different Turbine Rotors" at our department premises for the partial fulfilment of the requirements leading to the award of M-Tech degree. I take this opportunity to thank all my lecturers who have directly or indirectly helped my project.

Abhishek

2k14/RET/02

Table of Contents

Page NO.

List of Figures

List of Tables

List of Symbols/Abbreviations

m	mass of air	(kg)
v	velocity of wind	(m/s)
ρ	density of air	(kg/m^3)
$\mathbf{C_p}$	coefficient of power	
A	swept area	(m^2)
T	rotor torque	(Nm)
F	force experienced by rotor	
R	radius of rotor	(m)
$\mathbf{C_T}$	torque coefficient	
λ	tip speed ratio	
ω	angular velocity	(rad/s)
α	angle of attack	
L	lift	(N)
D	drag	(N)

Abstract

Ever since the industrialization has occurred, there has been a great increase in the burning of fossil fuels to meet the rising energy demands. The use of such fuels causes emission of carbon dioxide (CO_2) and other greenhouse gases which leads to global warming. This may have a highly injurious impact to the life on Earth. One way to alleviate this is to reduce the use of such kind of fuels. In recent years, wind turbines have become acceptable alternatives for electrical energy generation by fossil or nuclear power plants, because of the environmental as well as economic benefits. Power is extracted from flowing air with the help of the wind turbines which produce mechanical power or electrical power. For generating the mechanical power windmills are used, & for pumping the water wind pumps are used. Wind power is a substitute for the fossil fuels, which is renewable, spread over large scale, & clean

In my project I Am going to deal with how power is generated from wind energy and methods of increasing power and reducing losses and also will do analytic study for optimizing output power by using calculative softwares, such as wind turbine calculators, Foilsim3 etc.,Wind turbine calculator uses the site data and wind turbine input to produce output power for particular turbine for a particular site and also produces power coefficient curve, power curve etc.,Foilsim3 software produces different lift and drag ratio for different featured airfoil and helpful in comparing ratio to find better airfoil for fixed values of angle of attack, altitude, wind speed , camber, thickness etc. .

CHAPTER 1: Introduction

1.1 Overview

Energy is the most crucial inputs for the social and for economic development. The energy which is being consumed by a nation often reflects the level of prosperity that it could achieve. Social and economic well-being can be measured by the Human Development Index (HDI) which developed under the United Nations Development Programme (UNDP). It is found in most of the developed nations there is high HDI as compared to the developing nations.[1]

World population increasing very rapidly. This growth is more rapid in developing countries than the industrialized and developed nations.[3] As a result of which developmental activities, and the energy demand is also increasing. During the past 10 years, the primary energy use in the industrialized countries increased at a rate of 1.5 per cent per annum. The corresponding change in developing nations was 3.2 per cent. The future projections are indicating that the Total Primary Energy Supply (TPES) should be increased to 16,300 Mtoe by 2030 [2].

The need of world energy is met from variety of sources. Fossil fuel such as coal, natural gas and oil meets around 80% of energy need.[4] Unfortunately, these fossil fuels are finite resources and one day these will be completely exhausted.

In recent years, wind turbines have become an alternative for the production of electrical energy by nuclear power plants and fossils, because of the environmental and economic benefits.

Wind is air in motion. Wind is mainly formed due to the Earth's rotation and the uneven heating of Earth's surface by sunrays. The sunrays cover a much greater area at the equator than at the poles. The hot air rises from the equator and expands toward the poles that cause wind. Air has a mass and mass in motion has a momentum. Momentum is a form of energy that can be harvested.

Wind power is extracted from flowing air with the help of the wind turbines which produce mechanical power or electrical power. For generating the mechanical power windmills are used, & for pumping the water wind pumps are used. Wind power is a substitute for the fossil fuels, which is renewable, spread over large scale, & clean, and also doesn't produces any greenhouse gas while operating, and it uses a very little space or land.[5] The total effect on environment due to wind power is very much less problematic rather than the non-renewable sources of power.

The world is becoming hotter & hotter year by year, (by 1°C over the last century), and the enormous agreement for the scientific opinion and reason is that, the cause for the greenhouse gas emissions are human activities.

The biggest and largest source for such emissions are the energy sector, and if one want to tackle these climate changes, it is very clear that we are required to move away from the burning of limited reserves of fossil fuel towards more sustainable & renewable energy sources.

It is good for our planet, and also it is very good for economy and economic growth because it decreases the reliance on gas & oil imports. The wind power technology is very cost effective and supposed to be an important way through which industries greet to Government's objectives and hence it is an important electricity source in coming years.[6]

The Wind power can be extracted with the help of wind turbine - wind turbine is a machine that produces electrical power by converting the wind kinetic energy. This concept has migrated from hydroelectric technology with rotary propeller.

The result during the past few years of development of windmill & modern engineering, nowadays the wind turbines are designed and developed in a wide variety of horizontal & vertical axis types of turbines. The smallest turbine is used for the applications like battery charging for boat's and for caravan's auxiliary power and to supply power for traffic warning signs. And the slightly larger turbines are used for providing the domestic power supply. Wind farms which are the array of wind turbines, are becoming an important renewable energy source.

Kinetic energy of a stream of air is given by E= $\frac{1}{2}mV^2$ and the power in the wind is given by P=$\frac{1}{2}\rho\, A\, V^3$, but this power cannot be extracted completely because The efficiency of converting wind to other useful energy forms greatly depends on the efficiency with which the rotor interacts with the wind stream, hence only a part of the available power of wind is transferred to the wind turbine. Actual power produced by a rotor would thus be decided by the efficiency with which this energy transfer from wind to the rotor takes place. This efficiency is usually termed as the power coefficient (Cp). Actual power is given by P=$\frac{1}{2}C_p\, \rho\, A\, V^3$.

1.2 Literature Review

Tomas Petru (2003)[19] in his thesis, shows the impact of the power quality of a turbines on electric grid and responses of a turbine to faults in the grid are significantly investigated in this thesis report. A proper model of a wind turbine system that is stall regulated & of fixed speed is capable for predicting the impact on grid , is presented & compared over field measurements. Due to faults in the electric grid, the responses of fixed and variable speed wind turbine, are investigated and compared over field and laboratory measurements.

Heather Rae Martin (2009)[20] presents in his thesis report the buildup of a 1/50th scale of 5MW wind turbine intentionally planned for model testing of wind & wave basin of commercially feasible floating wind turbine. Design is generally based on a 5MW turbine designed by NREL (National Renewable Energy Laboratory). The model is to go with floating model platforms for the testing of wave basin model. The ultimate objective of the model buildup testing program is to collect the data to justify various simulation codes for floating wind turbine like those which are developed by NREL**.**

Toru Okazaki, Yasuyuki Shirai And Taketsune Nakamura (2014)[21] presents in their thesis that wind power is intermittent and cannot be used as the base load energy source. Conceptual study of wind power using direct thermal energy conversion and storage called as Wind powered Thermal Energy System (WTES) has been conducted. Thermal energy is produced from the rotating energy directly over the top of the tower by the heat of the generator, which is a kind of simple & light electric brake. The remaining system is same as the tower type concentrated solar power (CSP).

Luisa C. Pagnini, Massimiliano Burlando And Maria Pia Repetto (2014)[22] present in their research paper that instabilities is not caused by the small wind turbines in the power distribution and also they don't need any huge power storage capabilities. Nevertheless, the misuse of small turbines usually faces the several shortcomings and the net return is often lower than the expected, because of the power curve which is given by the manufacturer usually doesn't reflects the actual behaviour of the turbines during the operations.

Using the high resolution wind speed and energy production measurements, this research paper presents an in situ experimental analysis of two small size wind turbines with the same rated power, placed in the same urban environment and realized with vertical and horizontal axis, respectively.

BIBEK Samantara & Kaushik Patnaik And Prof. S.Rauta (2010)[23] showed in their thesis report, the wind power generation feasibiliy in India and some case studies related to it and also the study of installed plants in India.

Also the cost associated with development of a plant and new technologies that are to be used in wind power generation.

Jasmin Martinez, Prof. Pistikopoulos And Dr. Kouramas (2007)[24] their thesis report covers the modeling of wind turbines for study of power system. The operation of variable speed horizontal wind turbines with pitch control was investigated. Complexities of parts of a wind turbine model, such as aerodynamic conversion, generator representation and drive train were analyzed. The mathematical equations that describe dynamic behaviour of wind energy system were simulated successfully in gPROMS. The wind turbine model further tested with changes in the wind velocity and the blade pitch angle, confirming the need of power control.

A. Praveen Varma, K. Bala Chakri And Prof. K. B Mohanty (2012)[25] their project thesis clearly deals with the study of induction generators connected to the grid where voltage and frequency of the machine will be dictated by an electric grid. Based on the reactive power source induction generators are of two types- Standalone generator and Grid connected generator. Among these IGs, wind turbines with Doubly Fed Induction Generator (DFIG) are extensively and increasingly used in large farms of wind, because they have ability to supply power at constant frequency & voltage. Modern techniques of control like Vector control and magnitude & frequency control (MFC) have studied and some proposed systems are analytically simulated in the Matlab Simulink.

S. Masoud Barakati (2008)[26] In his thesis, wind energy converter system that is connected to grid including matrix converter is proposed. The matrix converter is a power electronic converter, used to interface the induction generator with grid and control the turbine shaft speed. The mechanical power at a wind velocity, available from a wind turbine is a function of its shaft speed. The frequency and terminal voltage of an induction generator is controlled through matrix converter, based on a constant V/f strategy, to adjust the turbine shaft speed and accordingly, control the active power which is injected into the grid to track maximum power for all wind velocities.

Prof. Tai-Ran Hsu (2009)[27] the tutorial presented by him represents and gives an overview of basic necessary details of large wind turbines, Wind Power Station, future of wind power, components of wind power plants.

Also it represents major tasks in construction and design of wind power generating systems, ways of site selection etc.

David Wright Combs (1995)[28] his thesis report presents the development and evolution of a substructure test for material of turbine blade (E-glass and polyester resins) and the results of the initial experiment obtained from this testing procedure. At MSU the ongoing research has established baseline data for the fatigue responses of rotor materials using coupon geometries to 108 stress cycles

1.3 Outline of Thesis

In my thesis my approach is completely based on comparative analysis for the power generation of different wind turbines on different location, and the power generation is compared by comparing and varying the different parameters. This can be done by using the WIND TURBINE CALCULATOR software.

Also power generation for different wind turbine rotors is compared by comparing the lift and drag coefficients and also by comparing the lift and drag ratio for an airfoil i.e., a cross section of a turbine blade and this can be done by using a java based software named FOILSIM3(Student version available from NASA’s site).

By this comparison one can find a way to define a better wind turbine rotor with an airfoil for a particular site or a location.

For this I have collected the data for different wind turbines that are available or manufactured in India by some manufacturers such as Regen Power limited, Gamesa, Vestas, Wind world, Suzlon etc. For sites or locations I have collected wind data such as wind velocity at different altitude, air density, temperature, pressure, etc. By using these parameters of a particular site with different turbine rotors in the wind turbine calculator we can obtain power outputs in kwh, power curves, power density curves, power coefficient curves and all this can be done by using wind turbine calculator and using these results we can conclude a better wind turbine for that location.

Now I have foilsim3 by using of which I can find lift and drag for an airfoil by using the same wind data that I have collected and whose result conclude that which airfoil is better in those wind conditions. By changing the chord length, camber ratio, thickness of airfoil etc we can evaluate lift and drag for a particular wind speed and we can also calculate the velocity of wind over upper side and lower side of an airfoil.

My thesis will provide to readers a basic and necessary information about the better wind turbine for a particular site and also a turbine with airfoil with better lift because all we know that lift is more than the drag then the lift and drag ratio is more than one and if the ratio is more, then coefficient of power is more that means power generation is more.

CHAPTER 2: Wind Power and Fundamentals

2.1 Power available in the wind spectra

The kinetic energy of a stream of air with mass m and moving with a velocity V is given by,

$$E=\frac{1}{2}mV^2$$

If a wind turbine is placed inside wind and a part of the wind power is transferred to this wind turbine then the power output P from wind turbine is given by

$$P=\frac{1}{2}C_p\,\rho\,A\,V^3$$

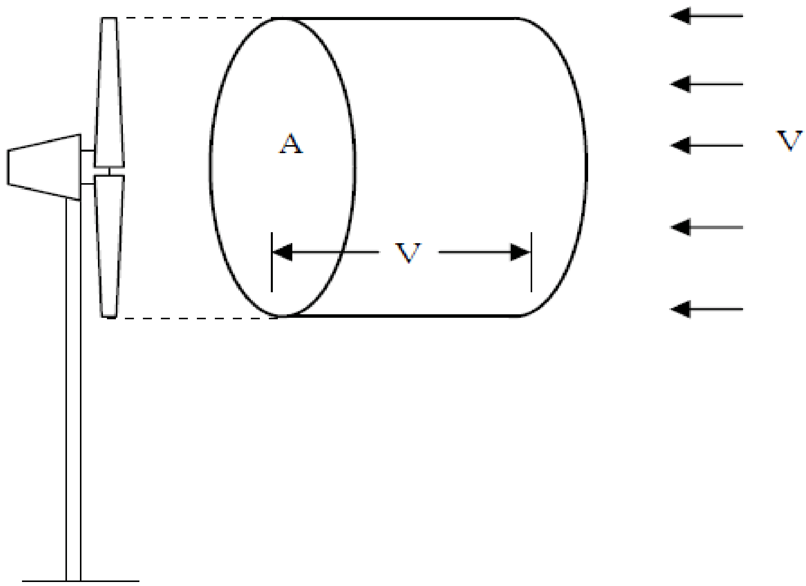

Figure: 2.1 rotor swept area [8]

The thrust force experienced by the rotor (F) can be expressed as

$$F=\frac{1}{2}\rho AV^2$$

Hence we can represent the rotor torque (T) [8] as

$$T=\frac{1}{2}\rho AV^2R$$

Here R is the rotor radius. This is the maximum torque which is theoretically available but in actual practice the rotor shaft can develop only a fraction of this maximum limit. The ratio between actual torque and theoretical torque is known as torque coefficient (C_T) [8]. Thus, the torque coefficient is given by $C_T=2T_T/\rho AV^2R$ Here T_T is the actual torque developed by the rotor.

Power which is developed by the rotor at a particular wind speed depends on the relative velocity of wind and the rotor tip. For example, consider a situation in which the rotor is rotating at a very low speed and the wind is approaching the rotor with a very high velocity. Under this condition, as the blades are moving slow, a portion of the air stream approaching the rotor may pass through it without interacting with the blades and thus without energy transfer. Similarly if the rotor is rotating fast and the wind velocity is low, the wind stream may be deflected from the turbine and the energy may be lost due to turbulence and vortex shedding.

In both the above cases, the interaction between the rotor and the wind stream is not efficient and thus would result in poor power coefficient.

The ratio of rotor tip velocity and wind velocity is termed as the tip speed ratio, represented by (λ) [8]. Thus,

$$\lambda = \frac{R\omega}{V} = \frac{2\pi NR}{V}$$

Here,

ω is the angular velocity and

N is the rotor rotational speed. The coefficient of torque and coefficient of power vary with the tip speed ratio.

C_p / C_T = R ω/V = λ

Hence, the tip speed ratio is also given by the ratio of coefficient of power to the coefficient of torque.

Power coefficient which is C_p i.e., part of K.E from wind and is transferred to turbine, and here A is the swept area.

The density of air is very low, about 800 times less than that of the water which powers the hydro power plant, and thus it leads to the large size of a wind turbine.

The maximum amount of energy that can be extracted from a stream of fluid by a device with same working area as the cross section area of stream is only 16/27 part of the energy in the stream. As it was derived by wind turbine pioneer ALBERT BETZ, hence this is known as the *Betz limit.* It has a maximum theoretical value of 0.593(the Betz limit)[7].

The C_p of a rotor varies with the tip speed ratio, that is, the ratio of rotor tip speed to free wind speed and is only a maximum value for a unique tip speed ratio. It is possible to obtain maximum power output over wide range of wind speed by operating at variable speed and to change the rotor design. However these measures will give only a modest increase in the power output. Major increase in power output can only be achieved by increasing the swept area of the rotor or by locating the wind turbines on sites with higher wind speeds [7].

A doubling of the rotor diameter leads to four times increase in power output.

Power Coefficient - Wind Turbine System Efficiency

The Power Coefficient is used to define the entire turbine power system efficiency. As shown in the given expression, it is the ratio of the "electrical power by the wind turbine" (P_{out} in the formula below) divided by "wind power input into the turbine" (P_{in}). P_{in} is sometimes also called "available wind power".

$$C_p = \frac{Actual\ electric\ power\ producedby\ turbine}{wind\ power\ into\ turbine} = P_{out} / P_{in}$$

The power coefficient represents the combination of efficiencies of the various power system components which includes the blades of turbine, shaft bearings and the gear train, & generator etc.

The C_p for a particular wind turbine is calculated and measured by the turbine manufacturer, and C_p is provided usually at various speed of wind. At a given wind velocity, if you know the C_p for a particular turbine you can estimate the output electrical power

The C_p of a specific turbine varies with various operating conditions like blade angle of a turbine, wind speed, rotational speed of turbine, and other parameters. C_p is a measure of overall system efficiency of a particular wind turbine.

2.2 Wind Turbine

Wind turbine is a system which transforms the kinetic energy available in the wind into mechanical or electrical energy that can be harnessed for any required applications. Mechanical energy is most commonly used for pumping water. Wind electric turbines generate electricity that can be utilized locally or transported to the desired location through grid.

Different configurations of Wind Turbines

There are two types of Wind Turbines- one is Vertical axis wind turbine and other is Horizontal axis wind turbine. The HAWT has proven technologically and economically better and it is the commonly used commercial turbines on a large scale and the VAWT are still for the demonstration purpose and for small scale applications.

Horizontal axis wind turbines (HAWT) these turbines have their axis of rotation horizontal and parallel to the ground and to the wind stream (Fig.2.). HAWT have some various advantages like low cut in speed & easy furling. Generally, they have high coefficient of power. Generator and the gear box placed at the top of the tower and makes its design very complicated and it also requires yaw mechanism to orient the turbine rotor.[9]

Vertical axis wind turbines (VAWT) is vertical to the ground and almost perpendicular to the wind direction. The VAWT can receive wind from any direction. Hence complicated yaw devices can be eliminated. The generator and the gearbox of such systems can be housed at the ground level, which makes the tower design simple and more economical.[9]

Figure:2.2 Horizontal axis wind turbine

(Source:edupic.net)

Figure:2.3 Vertical Axis wind turbine

(Source:edupic.net)

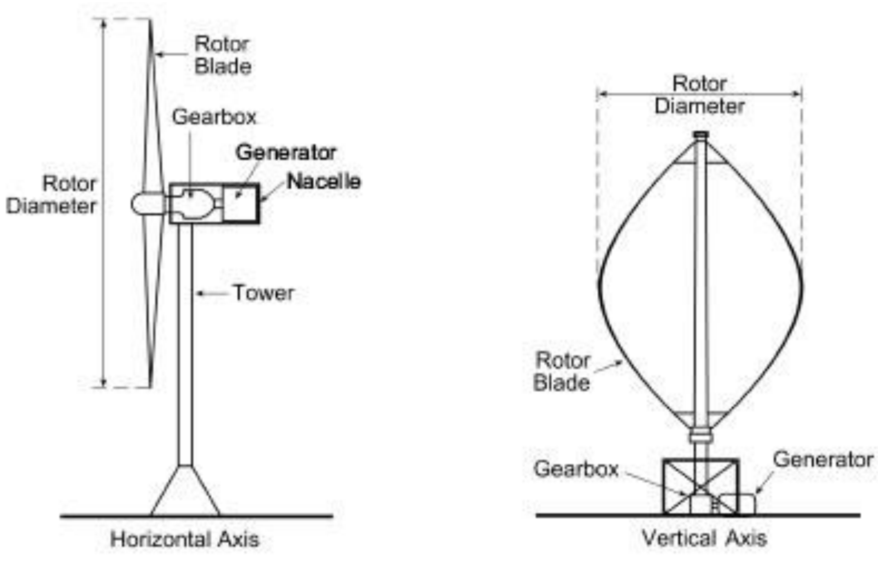

Figure:2.4 Components Of HAWT and VAWT

(Source: http://www.scotland.gov.uk/)

2.3 Components of wind turbine

Rotor:

Blades over the hub together called a rotor. It is a rotating part which converts the available kinetic energy in the wind to mechanical energy. The hub connects the blades of a rotor to the shaft. Hub is a place where the turbine power is controlled physically by pitching the blades (it is a method of controlling the speed of a turbine by varying the orientation, or pitch of the blades, and thereby altering its aerodynamic efficiency). Hub is a critical component of the rotor and requires high strength qualities.

Blades:

Blade is a rotating part and designed aerodynamically. It works on the principle of lift and drag and it converts K.E of wind into the M.E which is transferred through shaft and then converted to E.E using the generator. Mostly turbines are two bladed or three bladed. When wind blows over the blades causes the blades to lift and rotate. Applications like water pumping, grinding etc. uses more number of turbine blades as they requires more torque. Blade length is a key factor in determining the power generation capacity of a turbine.

Low-speed shaft:

Low speed shaft is the rotating element which transfers the torque from rotor to rest of the drive train, and it also supports the weight of a turbine rotor, it is connected to gearbox and use to increase the rpm.

Gear box:

According to the requirement of an electric generator, gear box stepping the speed.

A gear is use to connect the low speed shaft to the high speed shaft and hence increases the rpm from about 30 to 60 rotations per minute to about 1000 to 1800 rpm, (rpm is required by the generators to produce electricity).

The gear box too is the costliest (and heavy) part of the wind turbine and there are also "direct-drive" type of generators and these operates at a lower rpm and don't need gear boxes.

Types: Gear for parallel shaft, Planetary Gear Boxes

High-speed shaft:

It transmits the torque and speed from the gearbox and drives the generator.

Brake:

Brakes are used to stop turbine for its safety when there is extremely high winds and during maintenance,.

Types of Brakes: Aerodynamic brake (spoilers and Tip brake), Mechanical brake (clutch brake , Disc brake)

Generator:

The Generator is used to produce electricity by converting the rotational mechanical power. Usually wind electric generator produces 50-cycle AC electricity.

Types: Asynchronous generator (Slip ring , Squirrel cage), synchronous generator (permanent magnet, Electrically excited),

Controller:

The controller is used to start the machine at cut-in wind speed (usually 3 m/s) and stop the machine at cut-out wind speed (usually 25 m/s) as per the design requirement, and also operates the wind turbine to produce grid quality electricity. It measure as well as control the parameters- Current, Nacelle temperature, Voltage and frequency, Wind and Yawing direction, Over heating of generator, shaft and wind speed, Hydraulic pressure level, Valve function, Vibration level, Circuit of Emergency brake, etc.

Anemometer:

Anemometer is a sensor which is used to measure the wind speed. Anemometer is fixed at the top of a turbine and provides input to the controller for the regulation of power and braking above the cut out & survival wind speed.

Figure: 2.5 Cup Anemometer

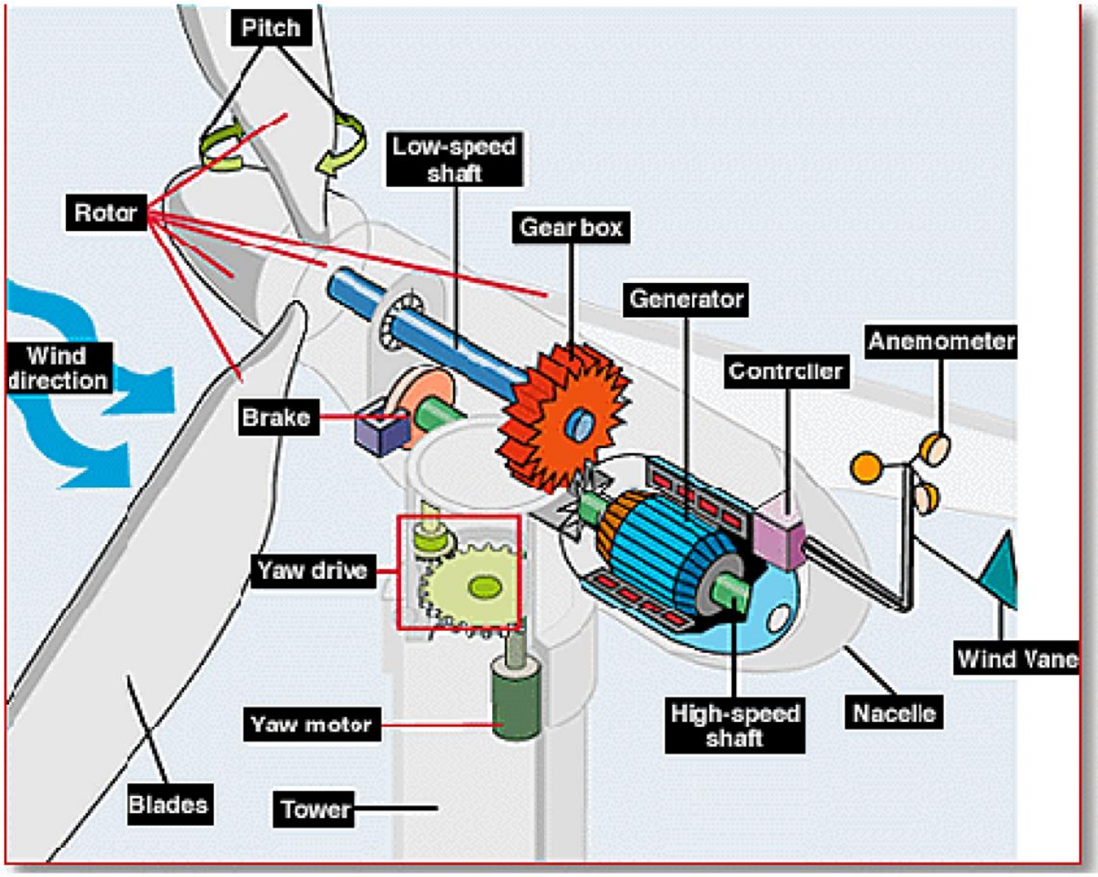

Figure:2.6 Sectional view of wind generator

(Source: http://www1.eere.energy.gov)

Pitch:

To control the speed of the rotor blades are pitched or turned out of the wind and keep the rotor from turning in the winds in case when winds are too high or too low to produce electricity.

Yaw drive:

According to the wind direction yaw mechanism turns the nacelle with rotor with the help of actuators engaging on gear rings. This mechanism keeps the system facing the winds.

CHAPTER 3: Wind Power in India

3.1 Renewable energy in India

The concern Renewable energy in India comes under the Ministry of New and Renewable Energy. Early India was being the first & only country in the world that set up a ministry for non-conventional resources of energy, in 1980s. India's cumulative grid connected renewable energy capacity (excluding the large hydro) has reached to about 42.75GW,[10] out of which 63% comes only from wind, while solar contributes nearly about 16%.[11]

3.2 Renewable energy sources

Table:3.1 Installed Grid Connected Renewable Power Capacity in India, 2016

Source	**Total installed capacity (MW)**
Wind Power	26,769.05
Solar Power	6,762.85
Biomass Power (Biomass & Gasification and Bagasse Cogeneration)	4,831.33
Small Hydro Power	4,273.90
Waste to Power	115.08
Total	**42,752.21**

3.3 Wind Power in India

Development for wind power in India has started in year of 1986 with the earliest wind farms which was being set up in the coastal areas of Tamil Nadu (Tuticorin) Maharshtra (Ratnagiri), and Gujarat (Okha) with Vestas turbines of 55 kW. These are the confirmation projects and were supported by MNRE. Renewable energy capacity has increased significantly during last few years. Though India is a relatively newcomer in the field of wind industry as compared to Denmark & United States, India has become the 4th largest with its installed wind power capacity around the world.[12]

Dr. Jami Hossain was the first person who assessed the potential of wind farms in the country using a GIS programme which will be more than 2 thousand GW in year of 2011, which was subsequently re-approved by Lawrence Berkley National Laboratory (LBNL) in US in a separate study in year 2012. As a result of which, MNRE has set up a bureau to assess again the actual potential and with the help of the National Institute of Wind Energy (NIWE, previously was C-WET) has declared a re-evaluated estimation for potential of wind energy in India, and from 49,130 MW to 302,000 MW which is evaluate over 100m Hub height.[13] Wind energy at a Hub height higher than 50-80m that is existing is even more. In year of 2015, MNRE has set the target for capacity of Wind Power generation by the year of 2022 will be at 60,000MW.[14]

In India the installed capacity for wind power was 26,769 MW till 31 March 2016, which is mostly spread across the South regions, West regions and in North regions.[15][16] East and the North east regions have no such wind power plant till the end of March, 2015. There is no any offshore wind farm utilizing technologies of fixed-bottom turbine in shallow sea region or technologies of floating turbine in deep sea regions are under execution. An Offshore Wind policy has already announced in 2015 and the LIDARs & weather stations are being developed by NIWE at some places.

3.3.1 Monthly electricity generation

Wind power claims around 8.6% of the total installed capacity of power generation in India and produced around 28,604 million Kwh(MU) in the revenue year of 2015-16 which is nearly about 2.5% of the total generation of electricity .

Table:3.2 Monthly electricity generation

Month	**North**	**West**	**South**	**East**	**North East**	**Total (MU)**
April, 2015	331	859	338	-	-	1528
May, 2015	373	1265	924	-	-	2562
June, 2015	348	1342	2030	-	-	3720
July, 2015	510	2527	3122	-	-	61157
August, 2015	472	1605	2328	-	-	4405
September, 2015	319	792	1344	-	-	2455
October, 2015	307	414	393	-	-	1113
November, 2015	250	7334	414	-	-	1061
December, 2015	156	801	522	-	-	1480

January,2016	149	462	553	-	-	1164
February,2016	220	728	463	-	-	1411
March,2016	293	830	425	-	-	1548
Total(MU)	3728	12359	12856	-	-	28604

Table:3.3 State wise Capacity[17]

State	**Capacity(MW),as on 31st March 2015**
Tamil Nadu	7455.2
Gujarat	3645.4
Maharashtra	4450.8
Rajasthan	3307.2
Karnataka	2638.4
Andhra Pradesh	1031.4
Madhya Pradesh	879.7
Kerala	35.1
Others	4.3
Total	23447.5

3.3.2 Present India Scenario

Total installed capacity in India of 263.66 GW and the RE capacity of 34.35 GW (about 13% of Installed capacity and approximately 7% of total electricity produced) (as on March 2015)

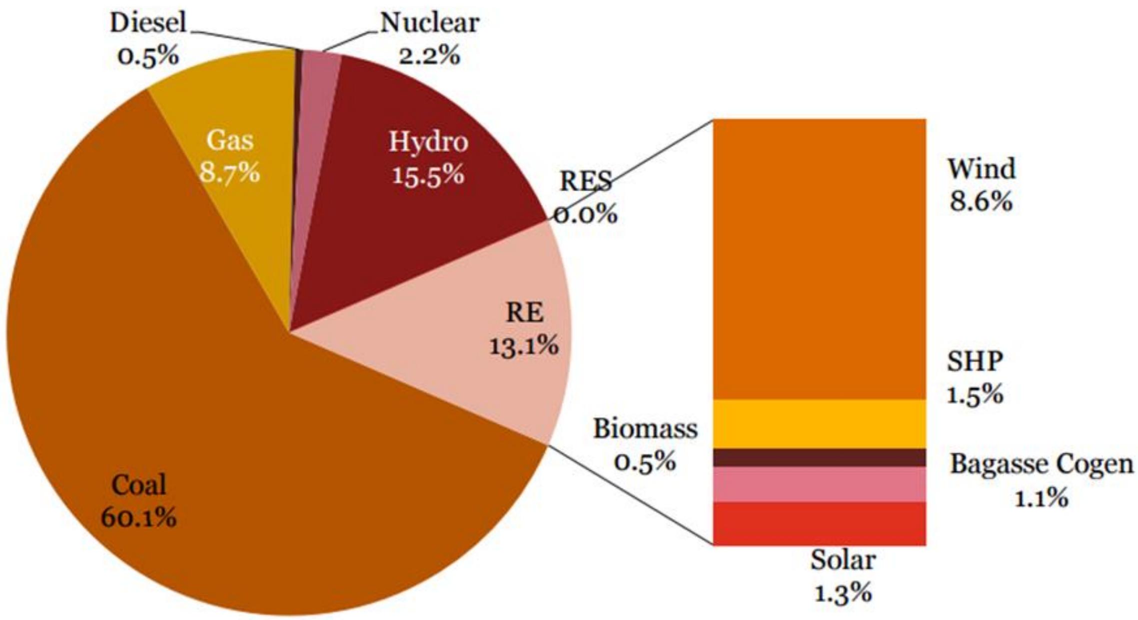

Figure:3.1 Power Scenario of India

(Source: MNRE, GoI ; CEA Statistics)

3.3.3 Renewable Energy: World and India's position

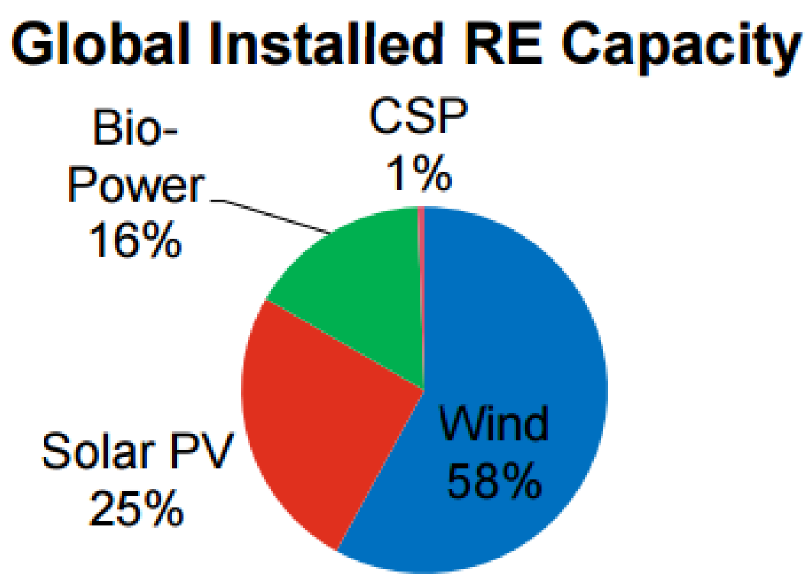

Figure:3.2 Position of world and India

(Source: MNRE)

- Global Renewable energy installed capacity of 673 GW
- Global Wind energy: 370 GW and India at 4th with 26.7 GW
- Global Solar energy: 177 GW and India is at 11th with 3.3 GW

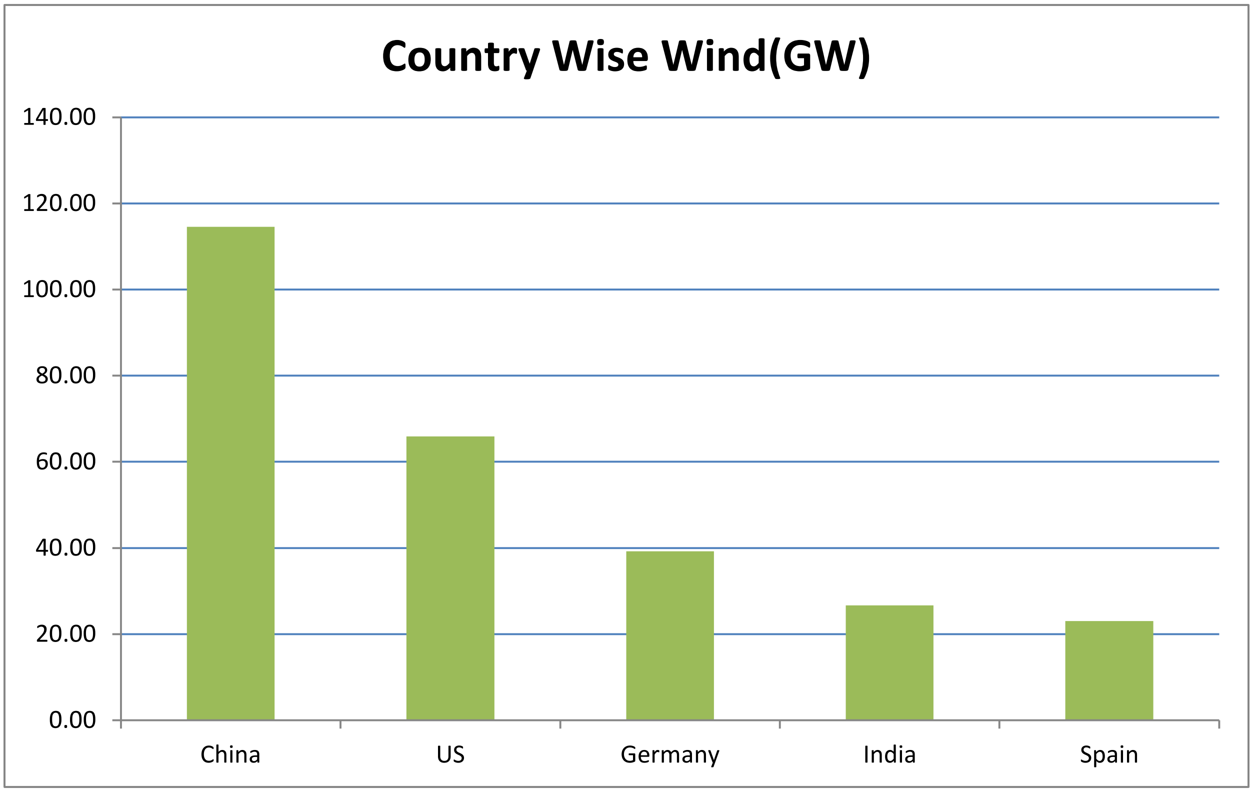

Figure: 3.3 Country wise wind power capacities

China with114.6 GW, US with 65.9 GW, Germany with 39.2 GW, India with 26.7 GW, Spain with 23 GW

CHAPTER 4: System Descriptions and Analysis with Software

This chapter includes the direction to use the wind turbine calculator and foilsim3 software and also it provides knowledge about the correct use of wind data and different parameters in the software that are essential to calculate the turbine power.

4.1 Power Calculator tool

Wind turbine power calculator interface

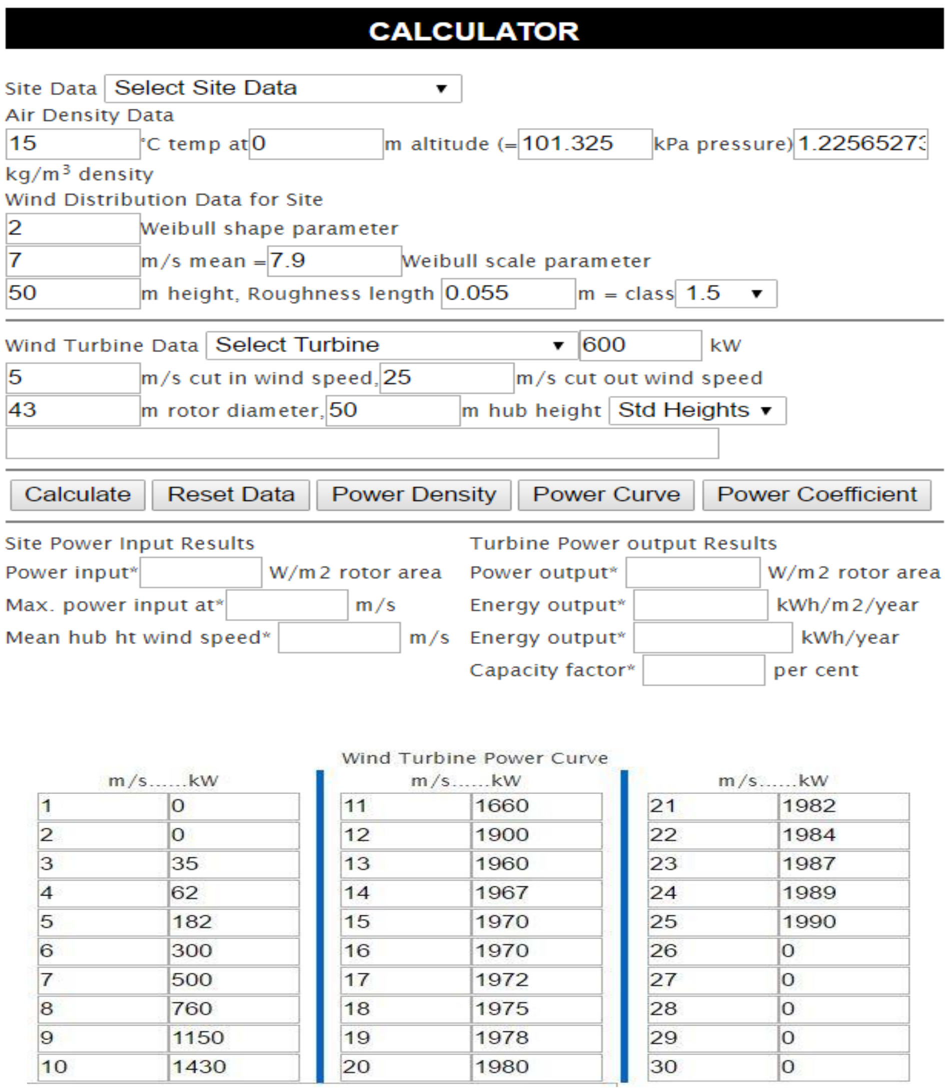

Figure:4.1 Wind Turbine Power Calculator

4.2 Guide to use the calculator

Using Power Curve and the Weibull distribution to Determine Power & Energy Output

To use the power curve completely, we need to combine ones information and knowledge of the power curve with Weibull curve.

For each small 0.1m interval of various wind speeds, one can multiply the probability value of that particular wind speed interval (from Weibull distribution) with the value obtained from power curve of a given wind turbine.

After that we take the summation of all the multiplications in order to get the mean power output.

And now if we multiply the power with 365 days & with 24 hours (the number of hours in a year) then we obtain the total output energy annually.

Data for the Site or Location

Use the pop-up bar menu option in order to fill the wind distribution data automatically or one can manually put the wind data for a particular site. The data has calculated for the roughness classes of 0, 1, 2, & 3.

Air Density Data

The energy available in wind varies with the density of air proportionally. Try to change the air temperature from, say 40^{o}C, to -20^{o}C. There are almost 25 % more air molecules in one cubic meter of cold air than in one cubic meter of warm air.

Data for Wind Distribution

In Northern Europe countries and in Asian region, Weibull shape parameter is around 2 generally. The height measurement for wind speed is very much important, because as the height increases above the ground level wind speed increases, Meteorological studies are made at 10 m height generally, but anemometer observations are generally taken at a hub height of turbine (say 50 to 100 m). For a particular surrounding terrain average roughness is very important to decide the wind speed at a particular hub height, if it is different from height at which the measurements for wind speed were made. You may set the roughness length or you may set the roughness class.

Data for the Wind Turbine

This part of the turbine calculator allows you to specify the generator's rated power, diameter of rotor, the cut in speed, and the cut out speed, and height of a hub of the turbine. At the bottom of calculator interface you may enter the power curve of your turbine. It is easier, to use first menu pop-up option that allows, to set all specification of turbine. The second menu pop-up option allows you to select the hub height for your turbine. If you wish you can enter your own hub heigh.

Suppose you modify the specification of standard turbine, written text in the first menu pop up option changes to the User example, which shows that you are dealing with other than a standard turbine. It is all right to change all of the variables or parameters, but it doesn't make any sense, if you change size of the generator or rotor dia of a standard turbine, until you change the turbine power curve. You can only use the rotor dia to show the input power and to compute efficiency, and you can only use the generator rated power to compute capacity factor.

Power Curve of Turbine

For practical purposes (keeping in view, your input data & your results at same time) there is placed, at the bottom a listing of the turbine power curve. You have to use this section to specify your turbine if it is not listed in table. There is only requirement that is wind speeds should be in ascending (increasing) order.

Site Power Input

The amount of energy in the wind is the Power input per square meter of the area or rotor which is theoretically flows through the circle of same rotor area, but in reality, a part of wind diverted from the rotor area because of the high pressure in front of the rotor.

The Maximum power input at Xm/s shows that, at what value of wind speed we could achieve the highest value of total power output.

Turbine Power Output

The power input per square meter is converted to electricity by the turbine is obtained by Power output per square meter of rotor area. Generally one can find it as cost effective to build up the turbine to use 30% of available power. The output energy per square metre of the rotor area in a year, is nothing but simply a mean output power per square metre of rotor area and is multiplied with total number of hours in one year. The Energy output in kWh/yr, shows that how much of electrical energy a wind turbine can generate in an average year.

4.3 Analysis of Lift and Drag for an Airfoil

Airfoil analytic software FOILSIM3 interface

Figure:4.2 FOILSIM3 interface

4.4 Guide to use the FOILSIM3 Application

Steps

1. There are some inputs and outputs in the software red colour shows outputs and blue colour shows input, now first of all select the option shape as input and select airfoil shape as airfoil in the given box to ensure your analysis over an airfoil only.
2. Then select the unit imperial or meteric.

3. After that one can select the flight option in blue colour text as input. In flight option you will observe boxes for wind data input for a site and you can enter your site data such as wind speed km/h, altitude in meter, pressure, density of air in kg/cubic meter.
4. Then select basic shape in airfoil shape option and enter the values of dimensions or measurements of an airfoil such as angle of attack, camber percentage, thickness percentage etc.
5. And always remember hit enter key so that result is obtained in terms of lift and drag forces.
6. You can select the select plot in the application and define your plot and obtain the resulting plots as lift vs wind speed, lift vs altitude, lift vs wind density, lift vs camber, etc. and also for drag you can obtain drag vs wind speed, drag vs altitude, drag vs camber etc .
7. One can easily find the pressure and velocity of flowing air above the airfoil and below the airfoil and this can be done by using probe option in the application by adjusting the velocity or pressure probe under the stream of air in 2d view display.

By using this application we can find lift and drag ratio for particular airfoil for a particular site so that the best airfoil dimension and angle of attack can easily be decided.

4.4.1 Terminology

Angle of attack, the lift on an airfoil is primarily the result of its angle of attack and shape. When oriented at a suitable angle, the airfoil deflects the oncoming air (for fixed-wing aircraft, a downward force), resulting in a force on the airfoil in the direction opposite to the deflection. This force is known as aerodynamic force and can be resolved into two components: lift and drag. Most foil shapes require a positive angle of attack to generate lift, but cambered airfoils can generate lift at zero angle of attack.

Camber, the maximum distance between the two lines is called the **camber**, which is a measure of the curvature of the **airfoil** (high **camber means** high curvature).

Thickness, the maximum distance between the upper and lower surfaces is called the **thickness**.

4.5 Turbines used for the Analysis

4.5.1 Specification of turbines- SUZLON S97

Table:4.1 Technical specification of SUZLON S97

Rated power	2100 kw
Rotor diameter	97 m
Cut-in-wind speed	3.5 m/s

Cut-out-wind speed	20 m/s
Rated wind speed	11 m/s
Swept area	7386 m^2
Hub height	80 m, 90 m, 100 m
Wind Class	IEC IIIA

4.5.2 SUZLON S95

Table:4.2 Technical Specification of SUZLON S95

Rated power	2100 kw
Rotor diameter	95 m
Cut-in-wind speed	3.5 m/s
Cut-out-wind speed	25 m/s
Rated wind speed	11 m/s
Swept area	7085 m^2
Hub height	80 m, 90 m, 100 m
Wind Class	IEC IIA

4.5.3 VESTAS V90

Table:4.3 Technical Specification of VESTAS V90

Rated Power	1800 kw
Rotor Diameter	90 m
Cut-in-wind speed	4 m/s
Cut-out-wind speed	25 m/s
Rated wind speed	11 m/s
Hub height	80 m, 95 m, 105 m
Wind Class	IEC IIA

4.5.4 GAMESA G80

Table:4.4 Technical Specification of GAMESA G80

Rated Power	2000 kw
Rotor Diameter	80 m
Cut-in-wind speed	2.8 m/s

Cut-out-wind speed	25 m/s
Rated wind speed	12 m/s
Swept area	5027 m^2
Hub height	78 m, 100 m
Wind Class	IEC IIA

4.5.5 WIND WORLD 750/48

Table:4.5 Technical Specification of Wind World Turbine

Rated Power	750 kw
Rotor Diameter	48 m
Cut-in-wind speed	2.5 m/s
Cut-out-wind speed	25 m/s
Rated wind speed	13 m/s
Hub height	50 m, 60 m
Wind Class	IEC IIA

4.6 Site or Location for which Analysis has been done

4.6.1 All India wind atlas or wind data

Table:4.6 Wind Data[18]

Height	**Parameter**	**Roughness class1 (0.030)**	**Roughness class2 (0.100)**	**Roughness class3 (0.400)**
50 m	Weibull A [m/s]	7.2	6.6	5.8
	Weibull k	1.78	1.80	1.86
	Mean speed [m/s]	6.40	5.88	5.13
	Power density [W/m²]	347	265	171
100.0 m	Weibull A [m/s]	8.2	7.6	6.7
	Weibull k	1.76	1.79	1.84
	Mean speed [m/s]	7.28	6.73	6.00
	Power density [W/m²]	518	401	275
200.0 m	Weibull A [m/s]	9.5	8.8	7.9
	Weibull k	1.84	1.85	1.87
	Mean speed [m/s]	8.46	7.79	7.01
	Power density [W/m²]	776	603	431

4.6.2 Location/Site- Kayathar

Table:4.7 Wind Data

Height	Parameter	R Class 2	R Class 3
50 m	V (m/s) P(w/m^2)	5.53 238	4.78 153
100 m	V (m/s) P(w/m^2)	6.20 324	5.48 219

4.6.3 Odisha

Table:4.8 Wind Data

Height	Parameter	R Class 2	R Class 3
50 m	V (m/s) P(w/m^2)	4.2 190	3.9 147
100 m	V (m/s) P(w/m^2)	4.7 254	4.32 180

4.6.4 Rajasthan (Barmer)

Table:4.9 Wind Data

Height	Parameter	R Class 2	R Class 3
50 m	V (m/s) P(w/m^2)	5.5 229	4.6 152
100 m	V (m/s) P(w/m^2)	6.2 310	5.23 198

4.6.5 Karnatak (Gadag)

Table:4.10 Wind Data

Height	**Parameter**	**R Class 2**	**R Class 3**
50 m	V (m/s) P(w/m^2)	3.84 143	3.0 122
100 m	V (m/s) P(w/m^2)	4.8 186	3.9 148

CHAPTER 5: Results and Discussion

This chapter includes the analytical results of different wind turbines at different sites or locations and provides the annual output power and capacity factor along with the curve plots such as power density curve, power curve, & power coefficient curve.

5.1 SITE 1- KAYATHAR

With turbine SUZLON S95

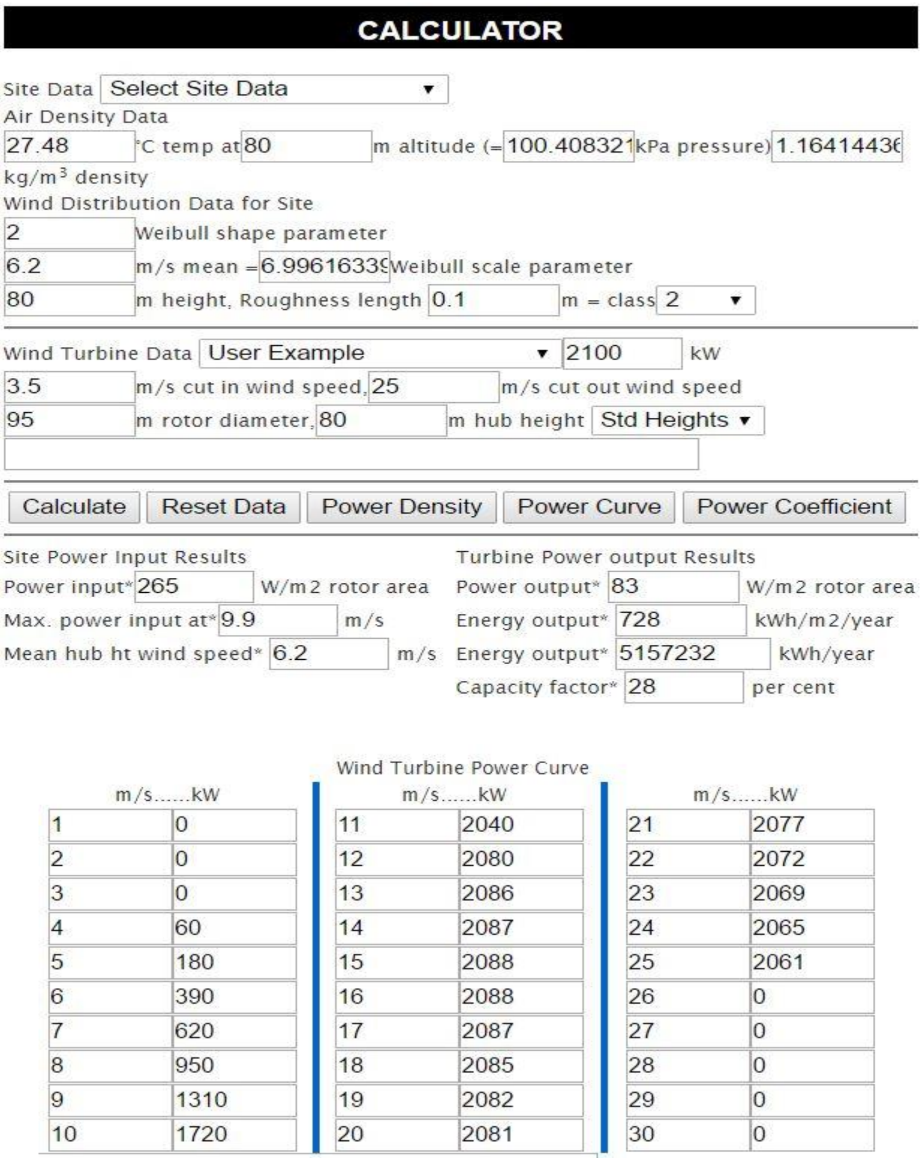

Figure: 5.1 Result for S95

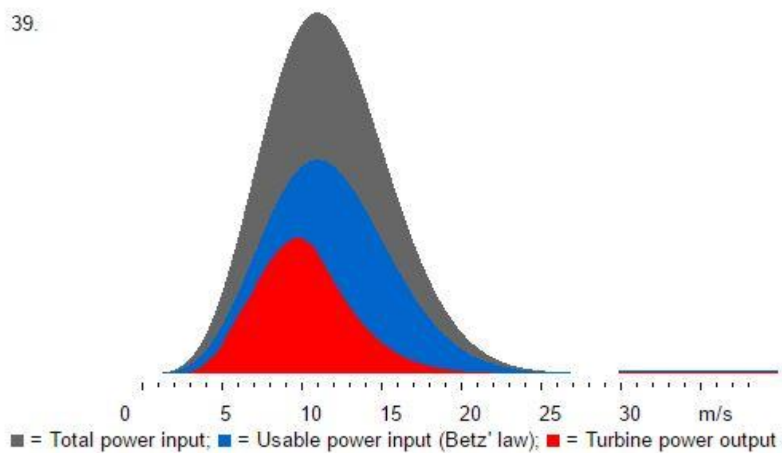

Fig: 5.2 Power Density curve

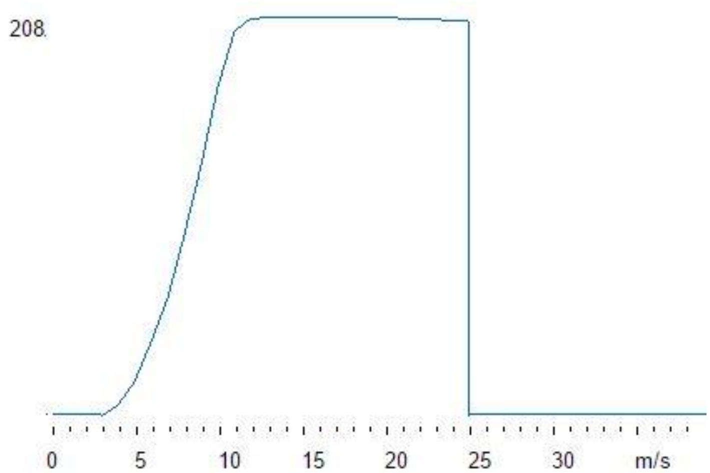

Fig: 5.3 Power Curve

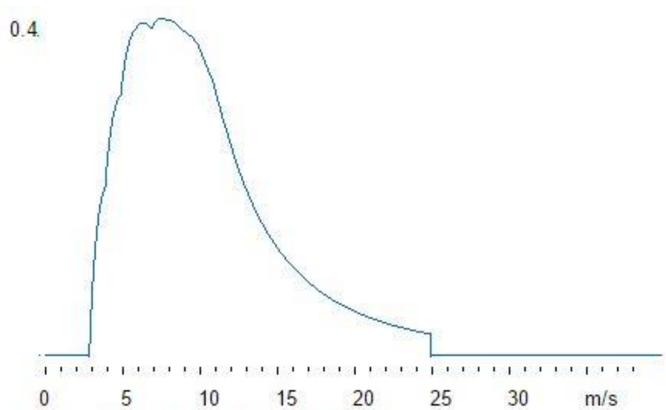

Fig: 5.4 Coefficient of Power

With turbine GAMESA G80

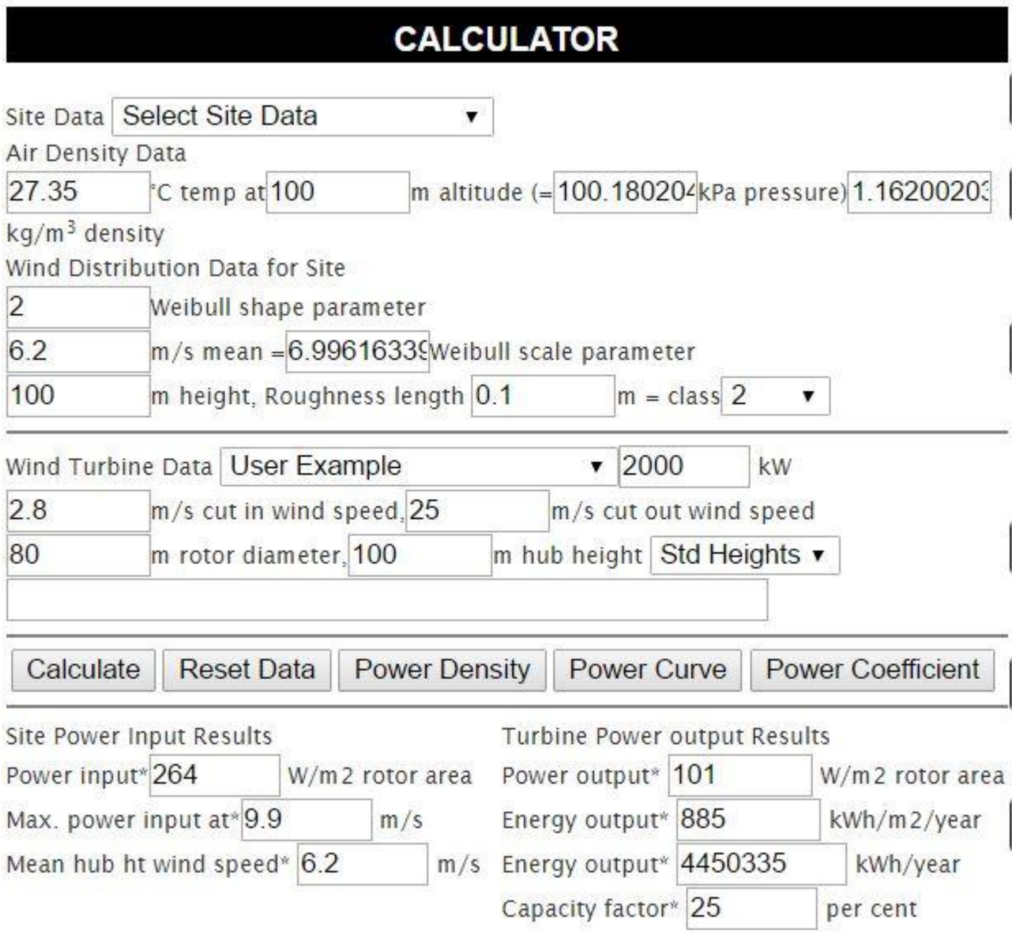

Fig: 5.5 Result for G80

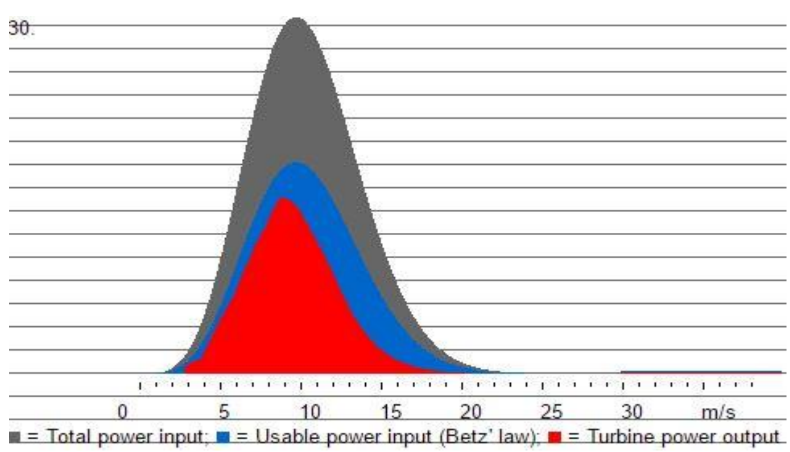

Fig: 5.6 Power Density Curve

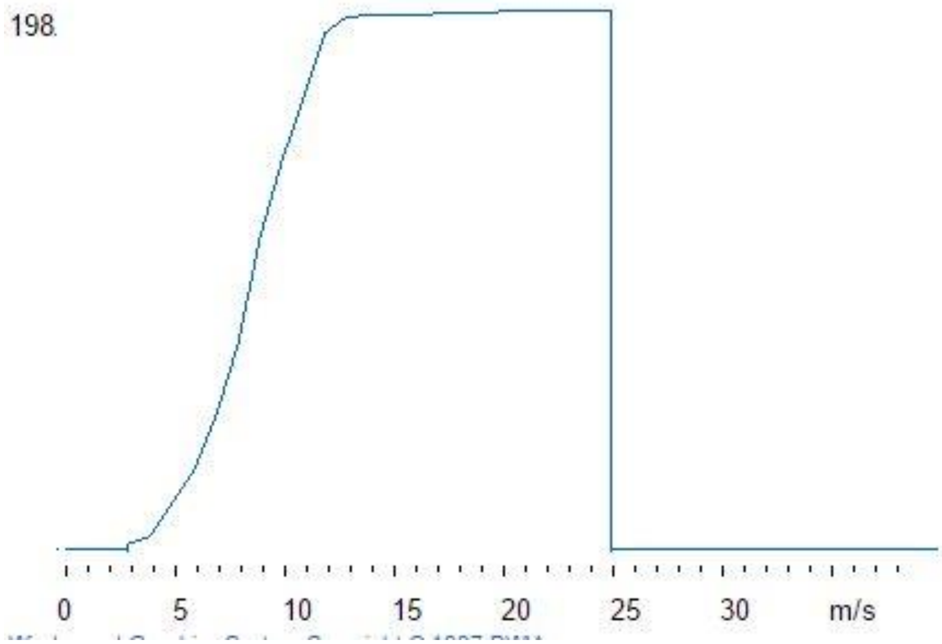

Fig: 5.7 Power curve

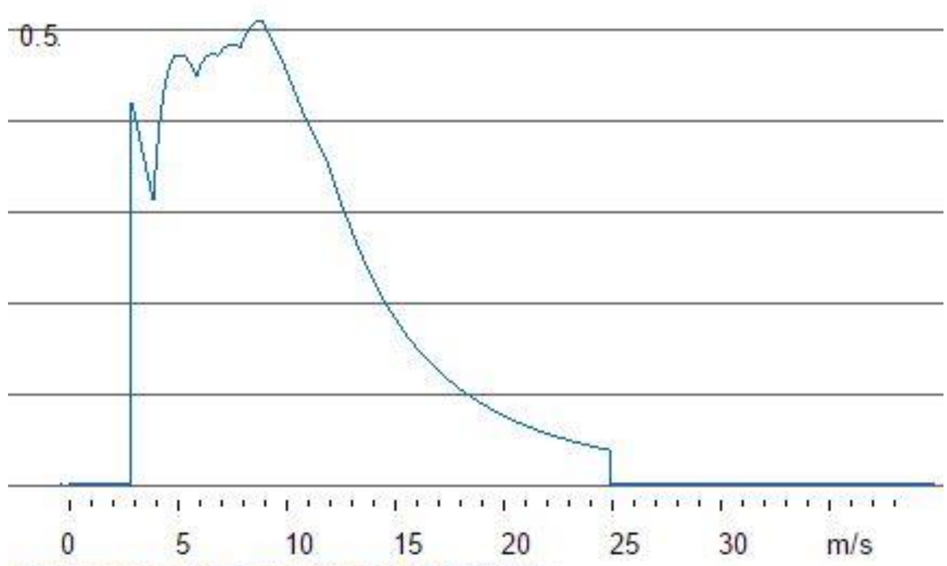

Fig: 5.8 Coefficient of power

With turbine WIND WORLD750/48

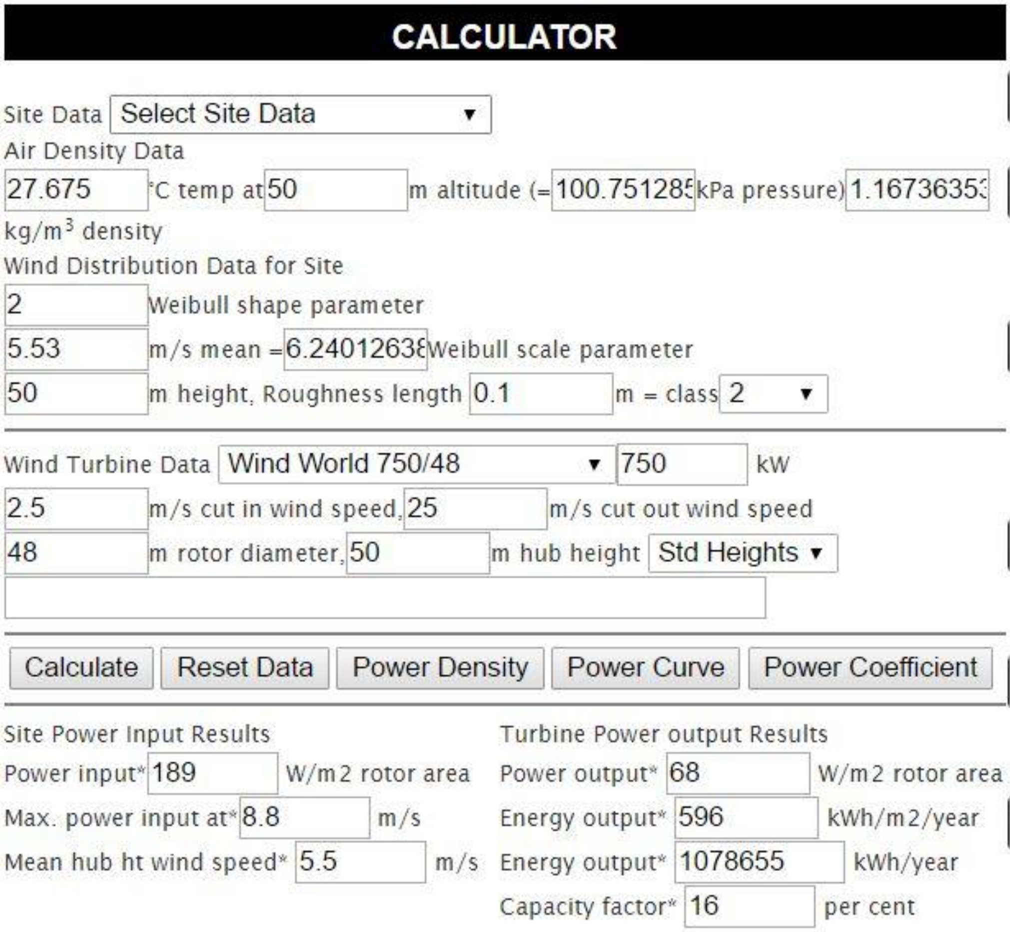

Fig: 5.9 Result for turbine Wind World

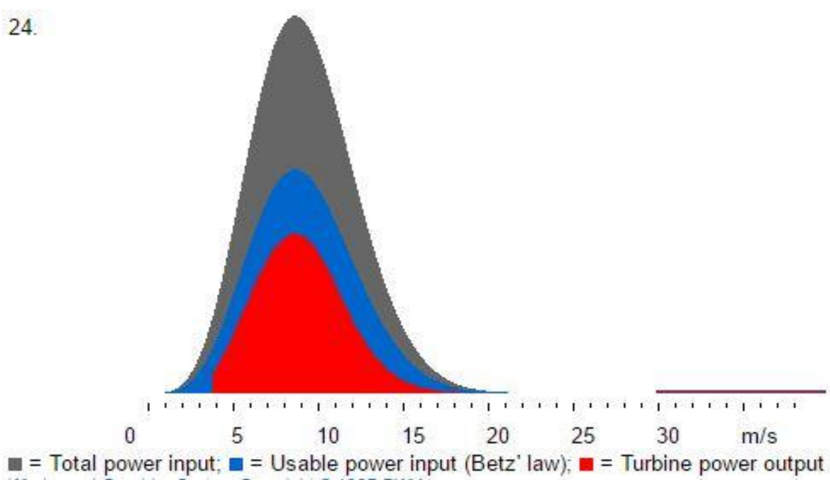

Fig: 5.10 Power Density curve

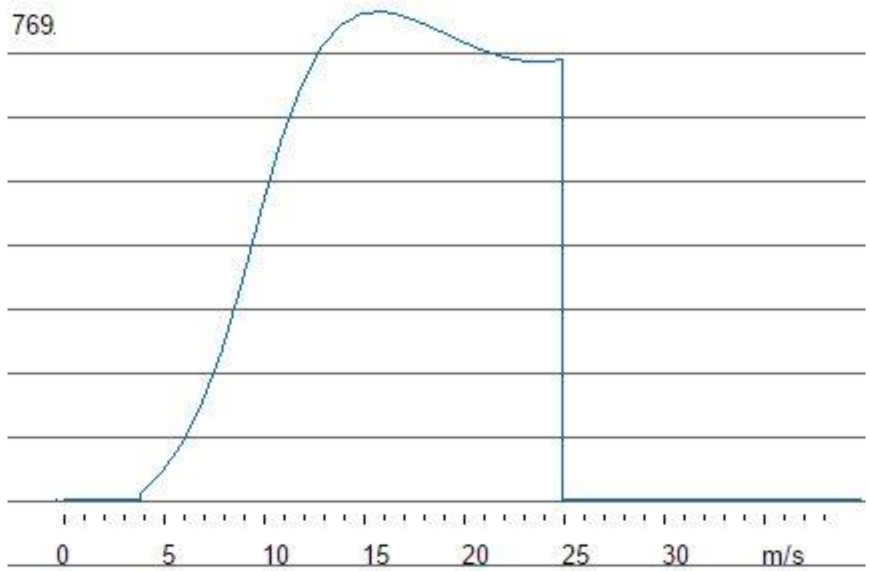

Fig: 5.11 Power curve

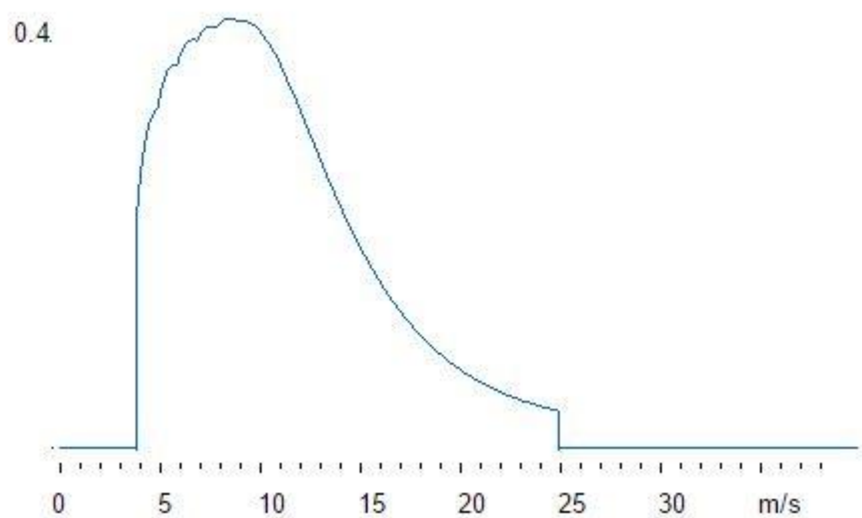

Fig: 5.12 Coefficient of power

Discussion-By observing the output of these turbines (Suzlon S95, Gamesa G80, and Wind World 750/48), the power output which is better for this particular location (Kayathar) is 5157232 kwh/yr with capacity factor of 28, that means this (Suzlon S95) available turbine extract more power from available power to turbine to produce electricity.

5.2 SITE 2- Rajasthan (Bamer)

With turbine SUZLON S97

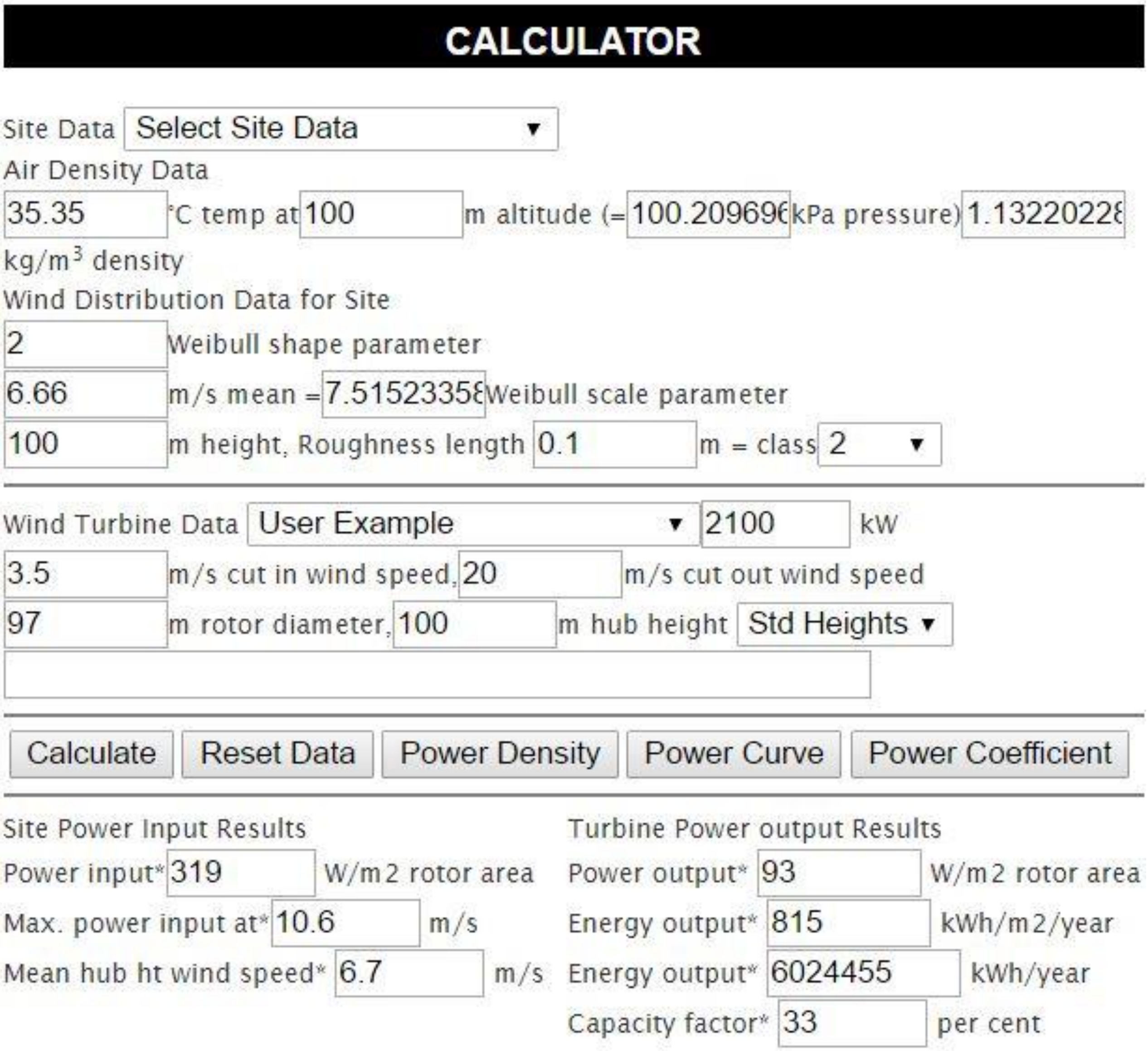

Fig: 5.13 Result for turbine S97

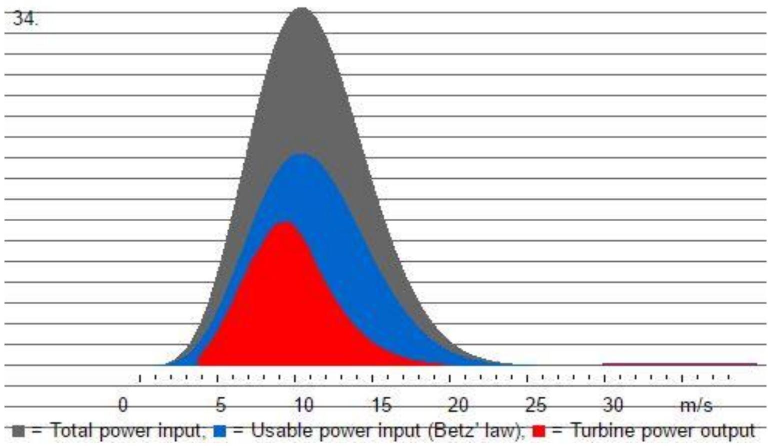

Fig: 5.14 Power Density curve

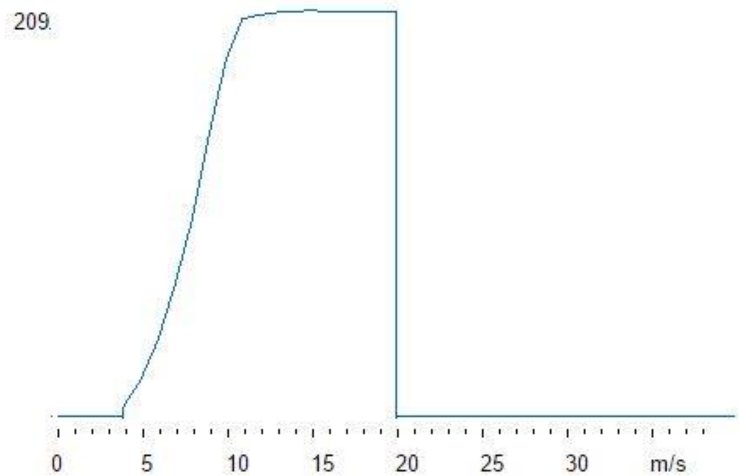

Fig: 5.15 Power curve

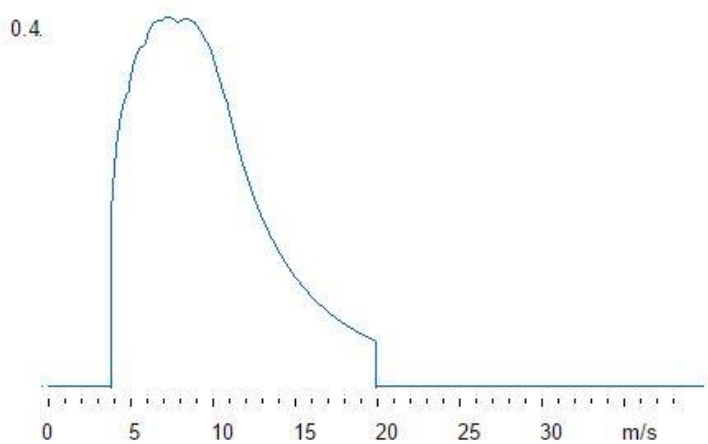

Fig: 5.16 Coefficient of Power

With turbine SUZLON S95

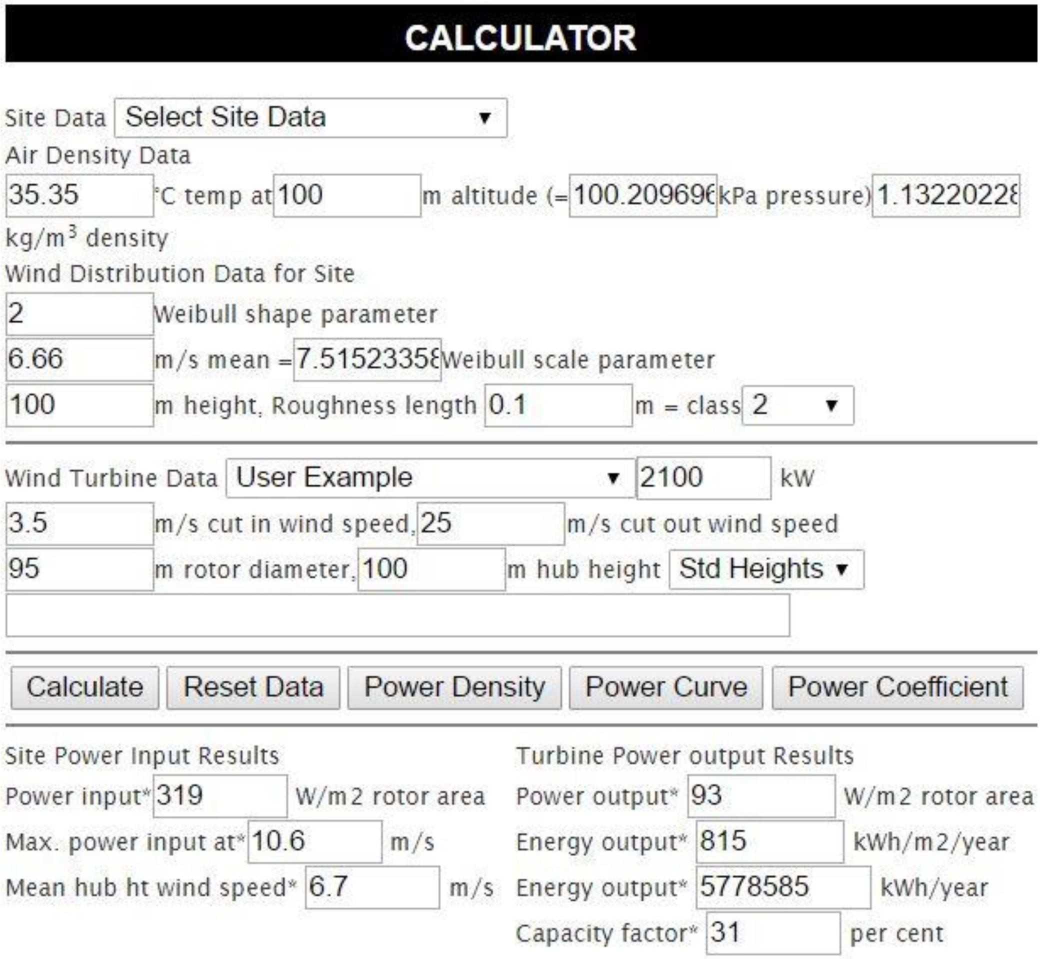

Fig: 5.17 Result for Turbine S95

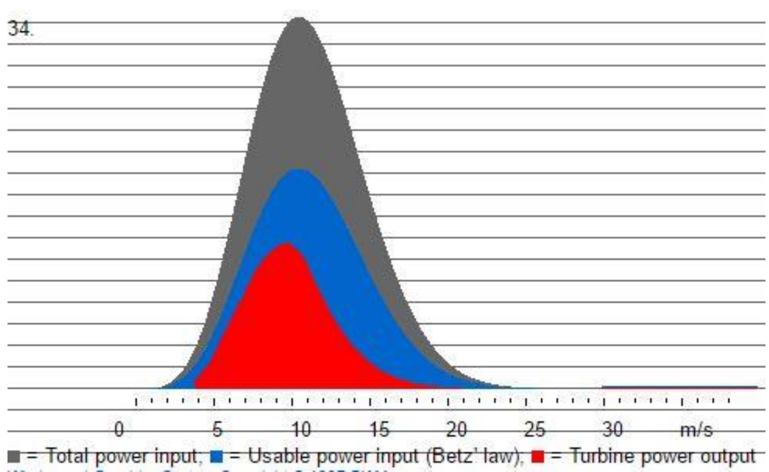

Fig: 5.18 Power Density curve

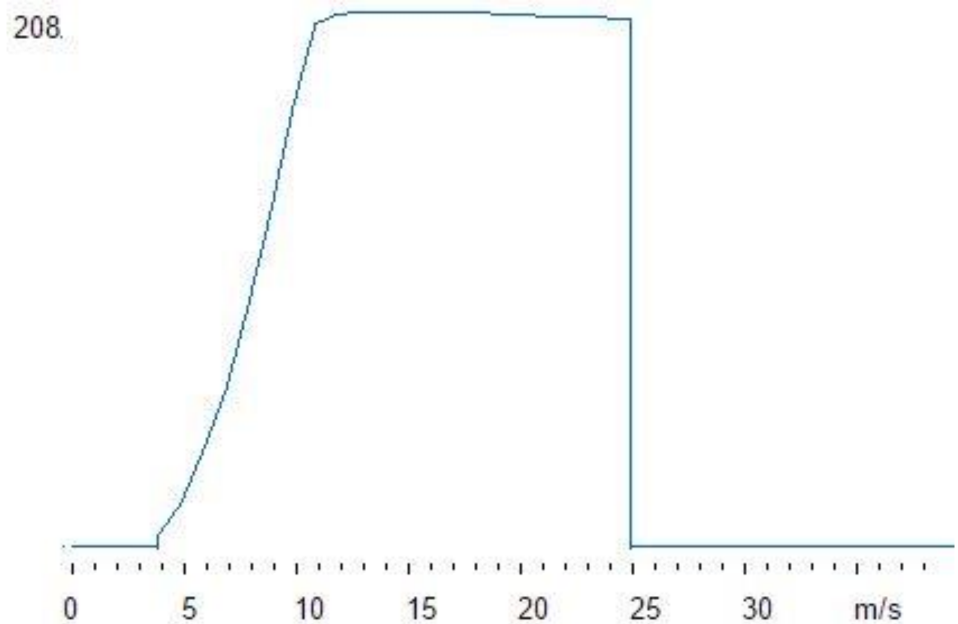

Fig: 5.19 Power curve

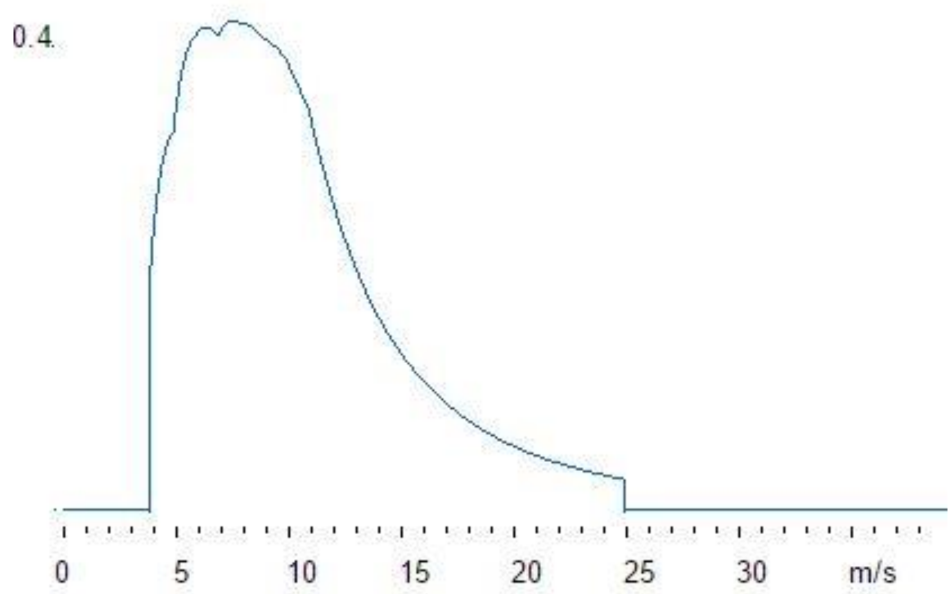

Fig: 5.20 Coefficient of Power

With turbine VESTAS V90

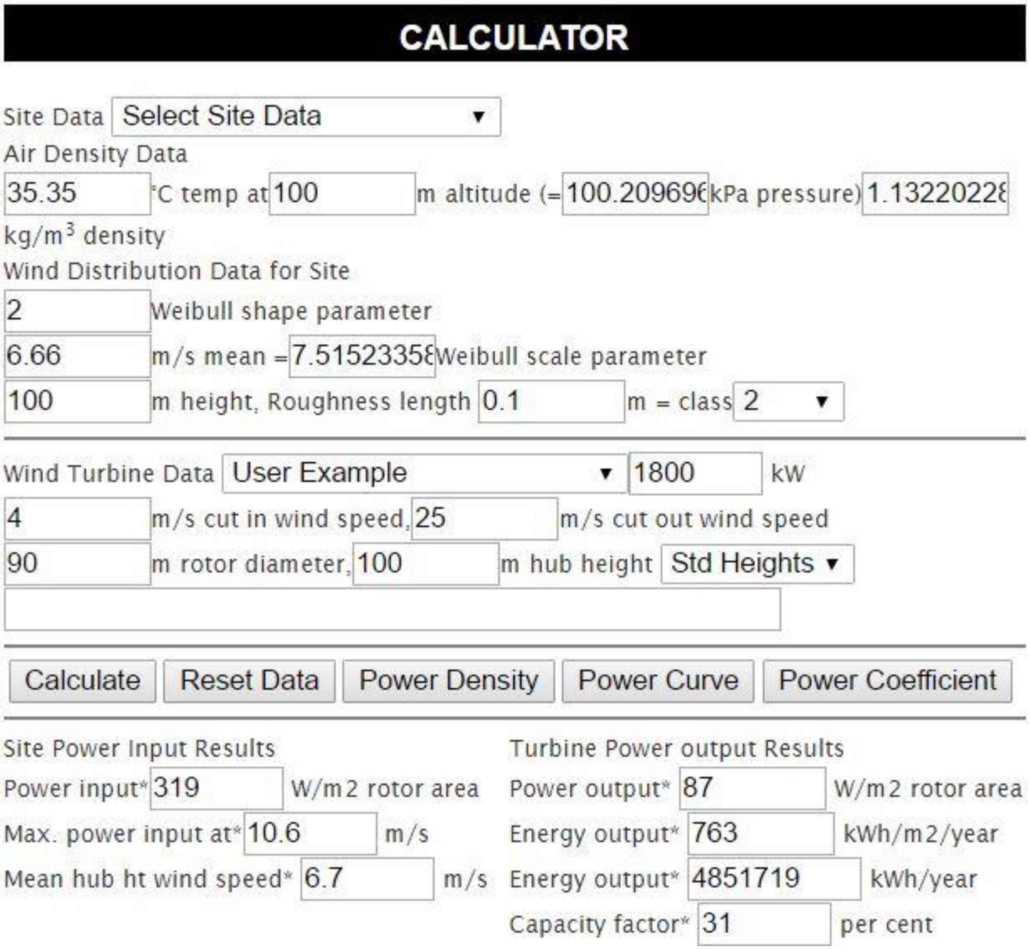

Fig: 5.21 Result for turbine V90

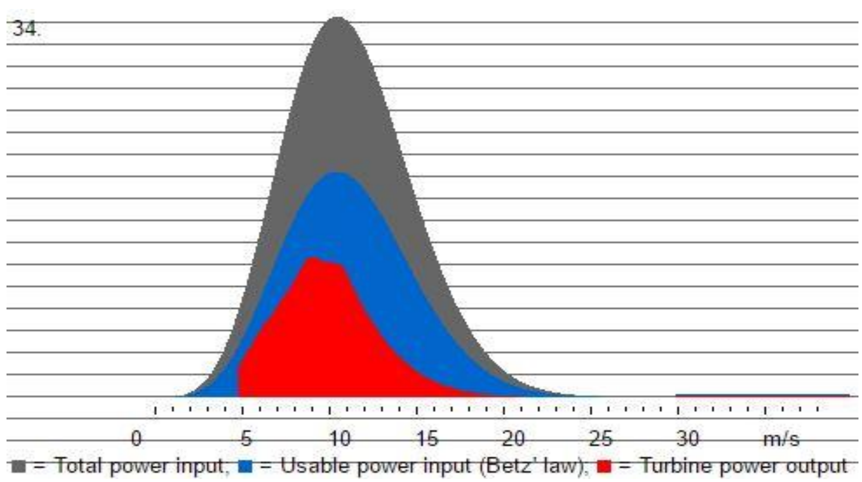

Fig: 5.22 Power Density curve

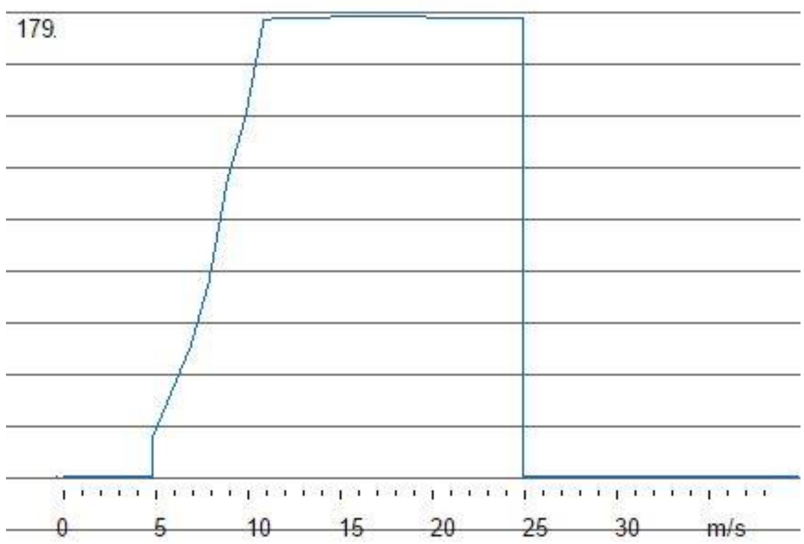

Fig: 5.23 Power curve

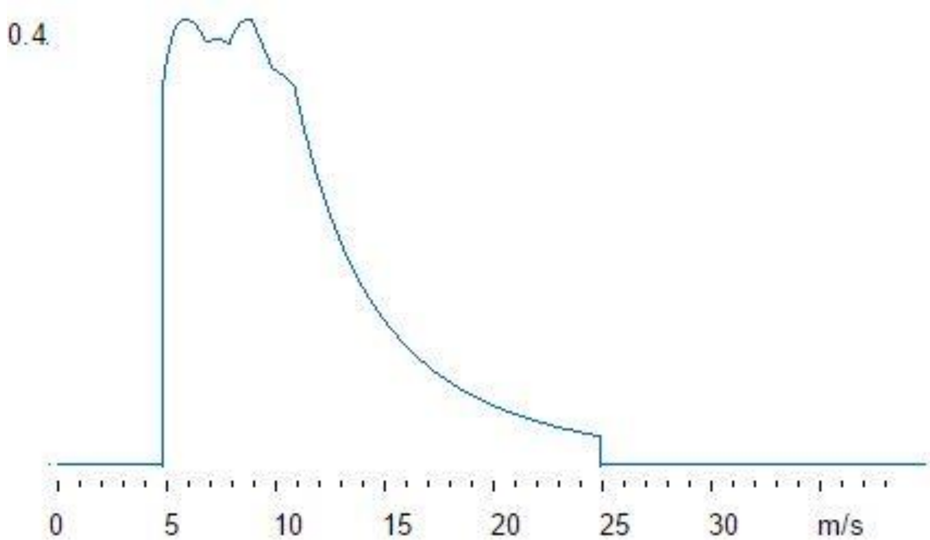

Fig: 5.24 Coefficient of Power

With turbine GAMESA G80

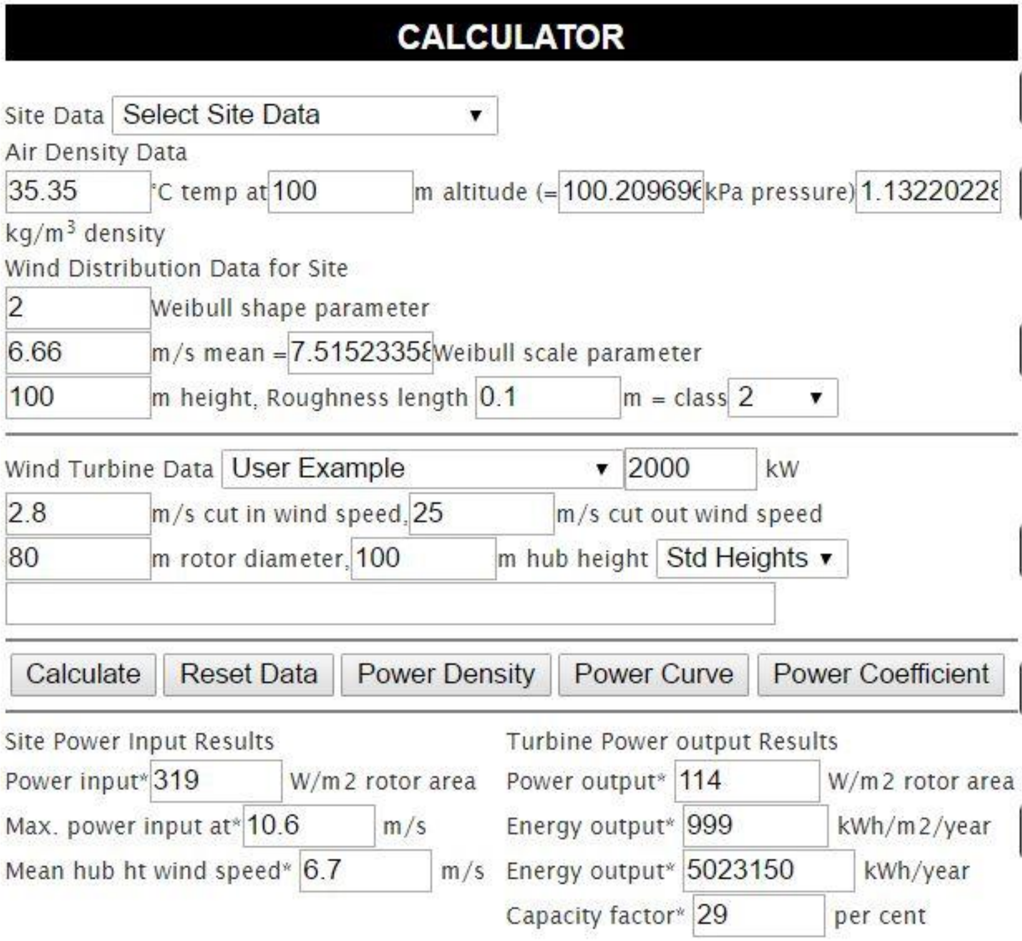

Fig: 5.25 Result for turbine G80

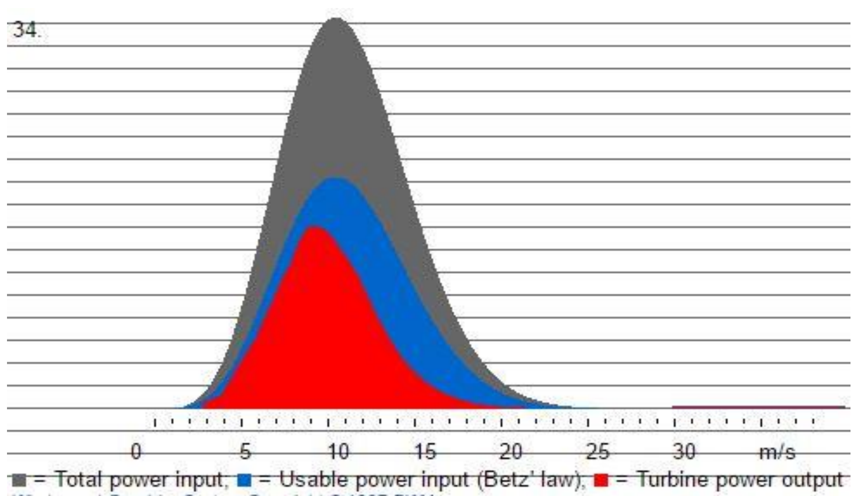

Fig: 5.26 Power Density curve

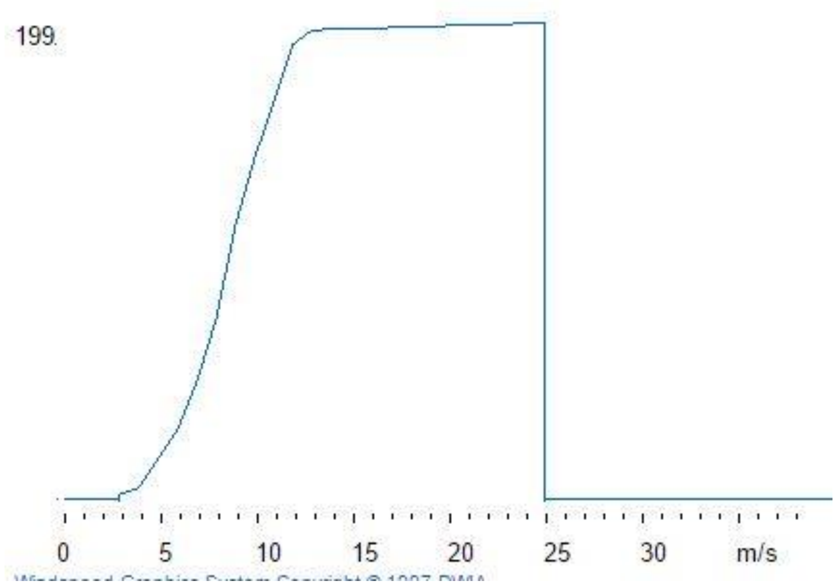

Fig: 5.27 Power curve

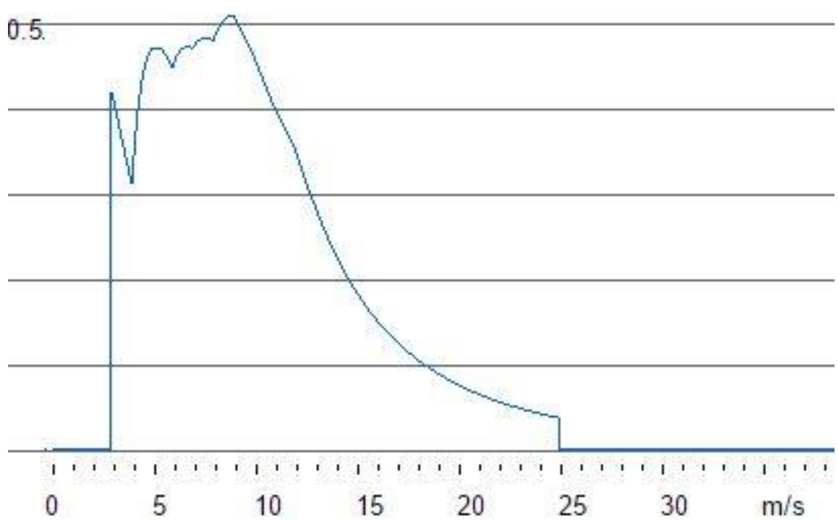

Fig: 5.28 Coefficient of Power

Discussion- By observing the output of these turbines (Suzlon S97, Suzlon S95 Gamesa G80, and Vestas V90), the power output which is better for this particular location (Bamer) is 6024455 kwh/yr with capacity factor of 33, that means this (Suzlon S97) available turbine extract more power from available power to turbine to produce electricity.

Here the next suitable turbine is Gamesa G80 even though its capcity factor is low but output energy is more that is 5023150 kwh/yr.

5.3 SITE 3- Odisha

With turbine SUZLON S97

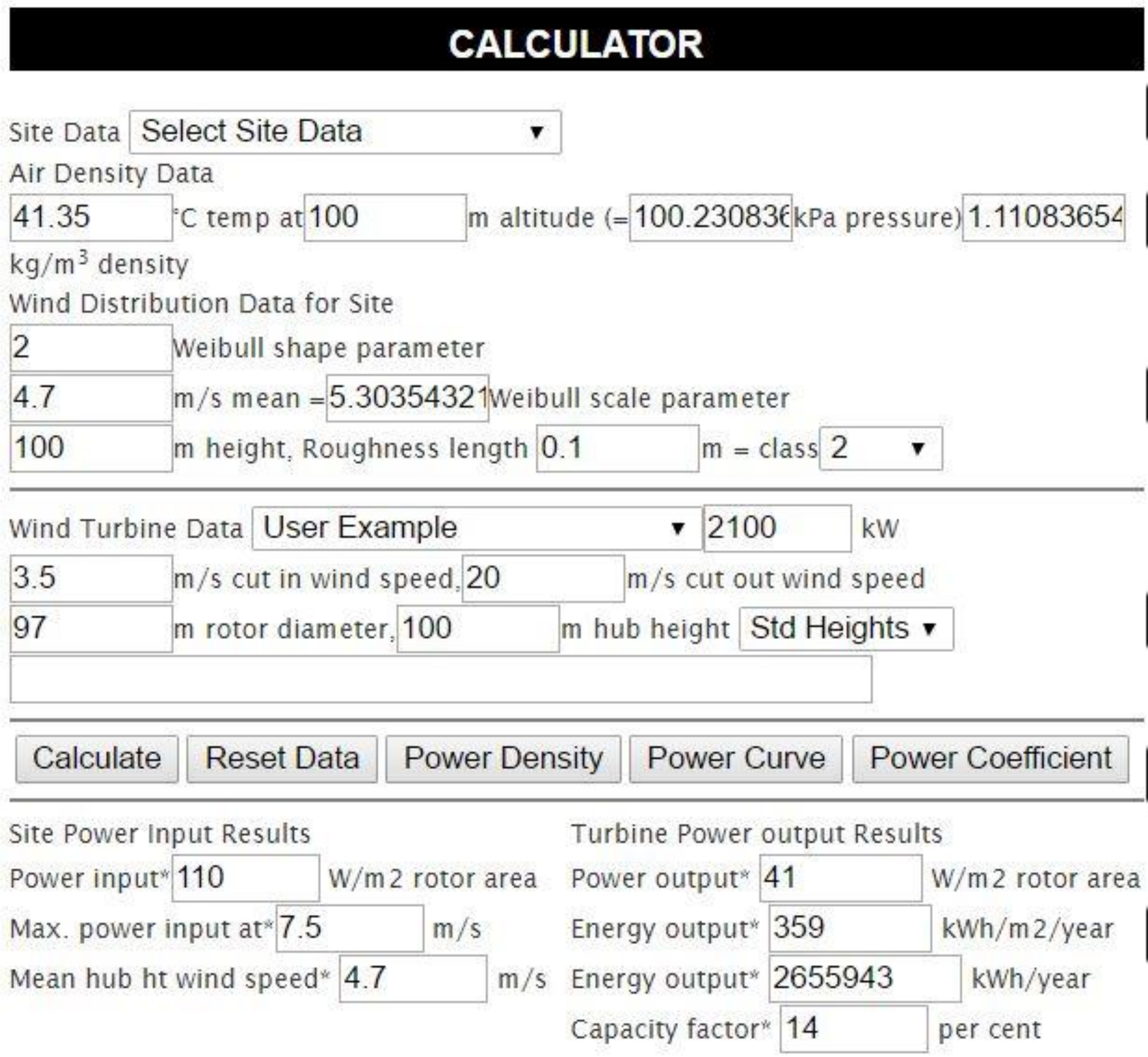

Fig: 5.29 Result for turbine S97

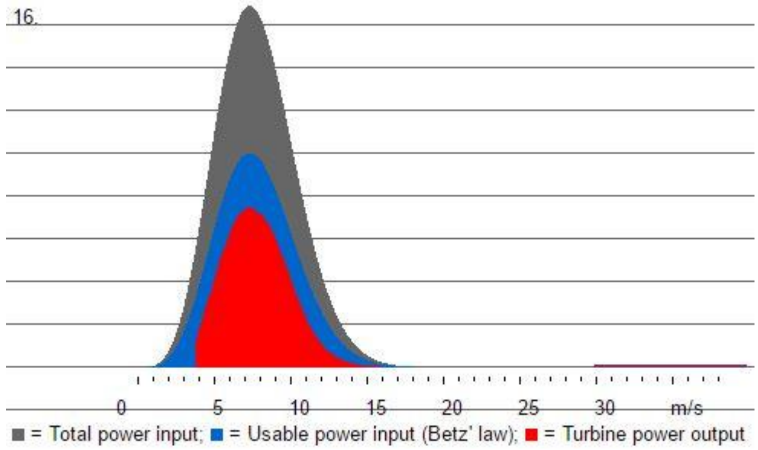

Fig: 5.30 Power Density curve

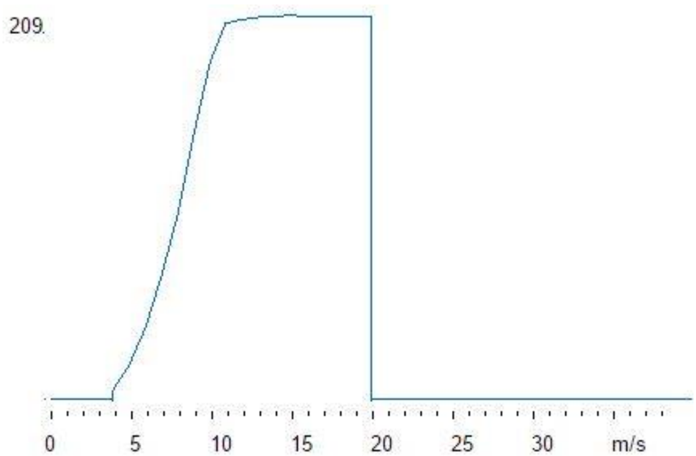

Fig: 5.31 Power curve

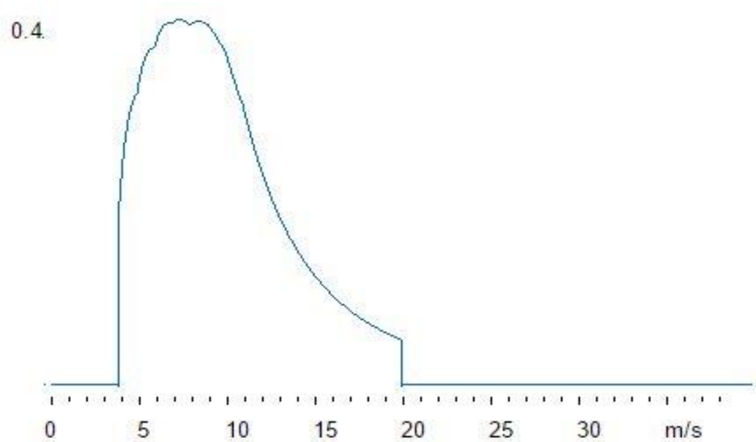

Fig: 5.32 Coefficient of Power

With turbine SUZLON S95

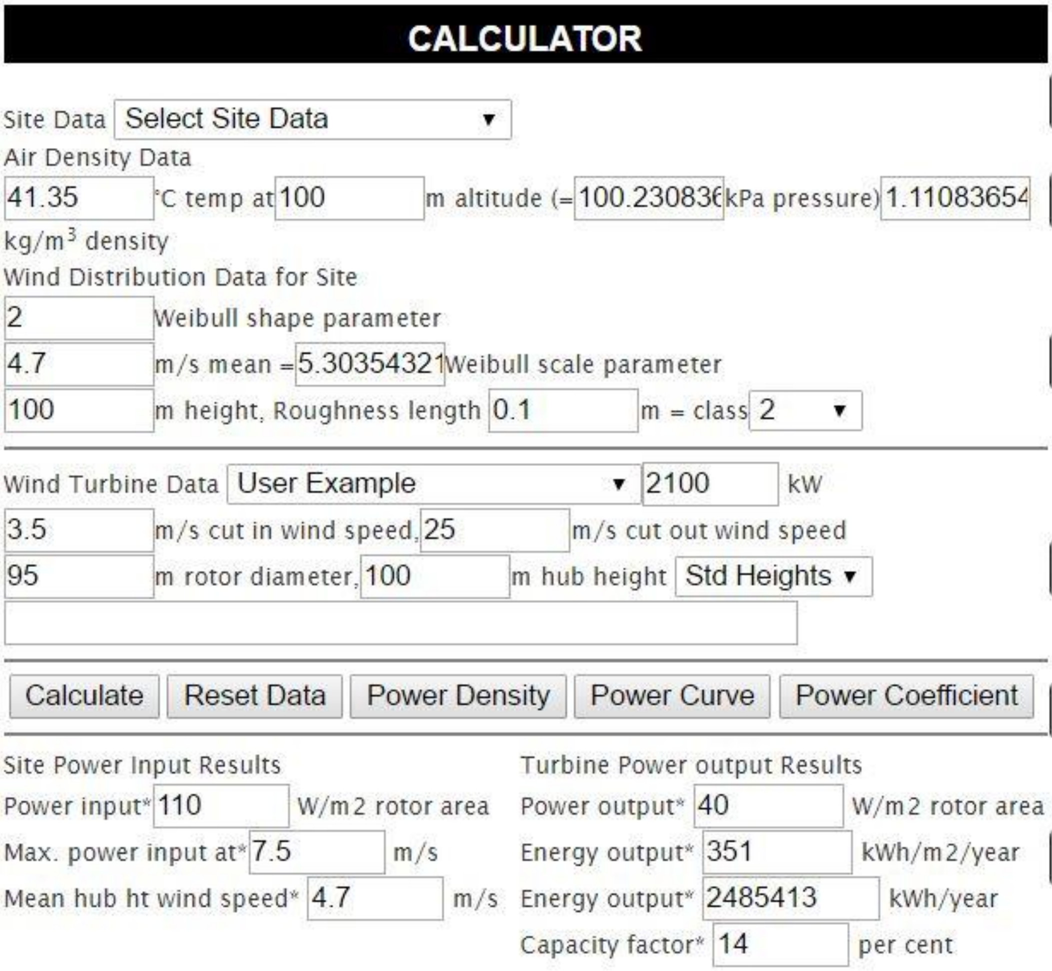

Fig: 5.33 Result for turbine S95

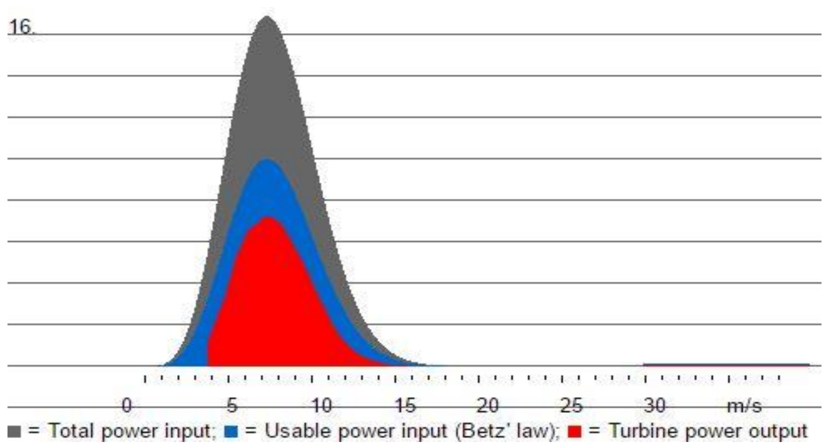

Fig: 5.34 Power Density curve

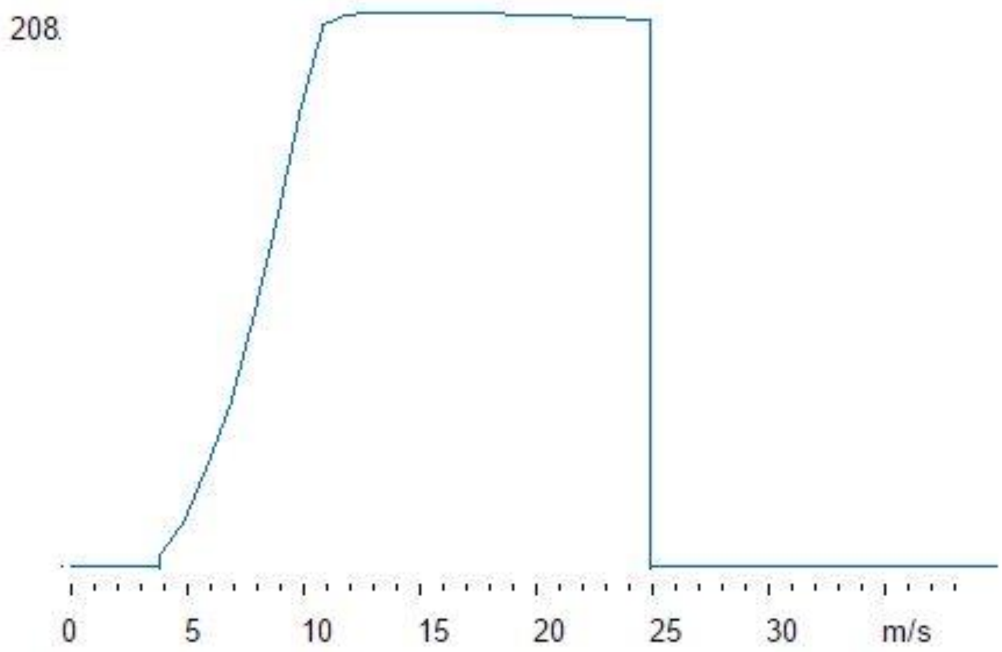

Fig: 5.35 Power curve

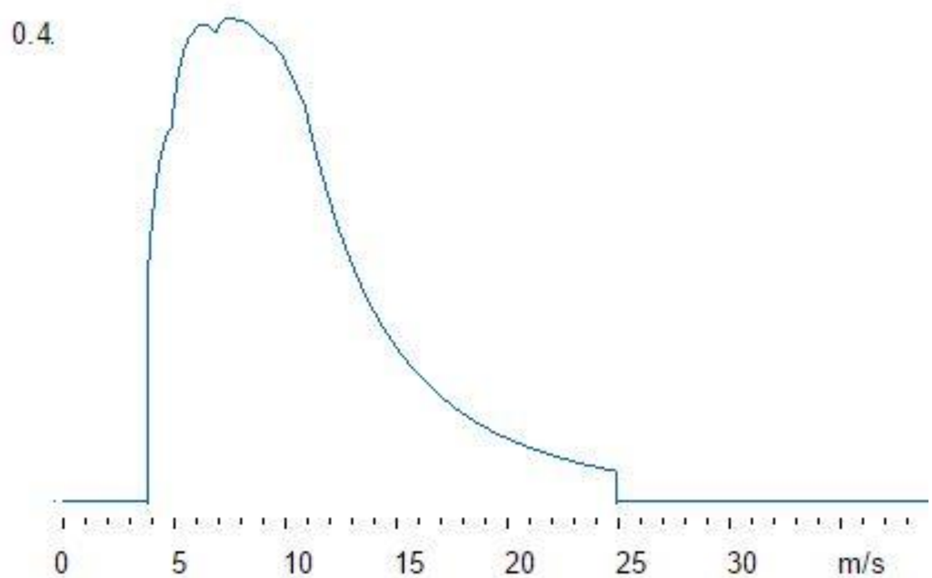

Fig: 5.36 Coefficient of Power

With turbine VESTAS V90

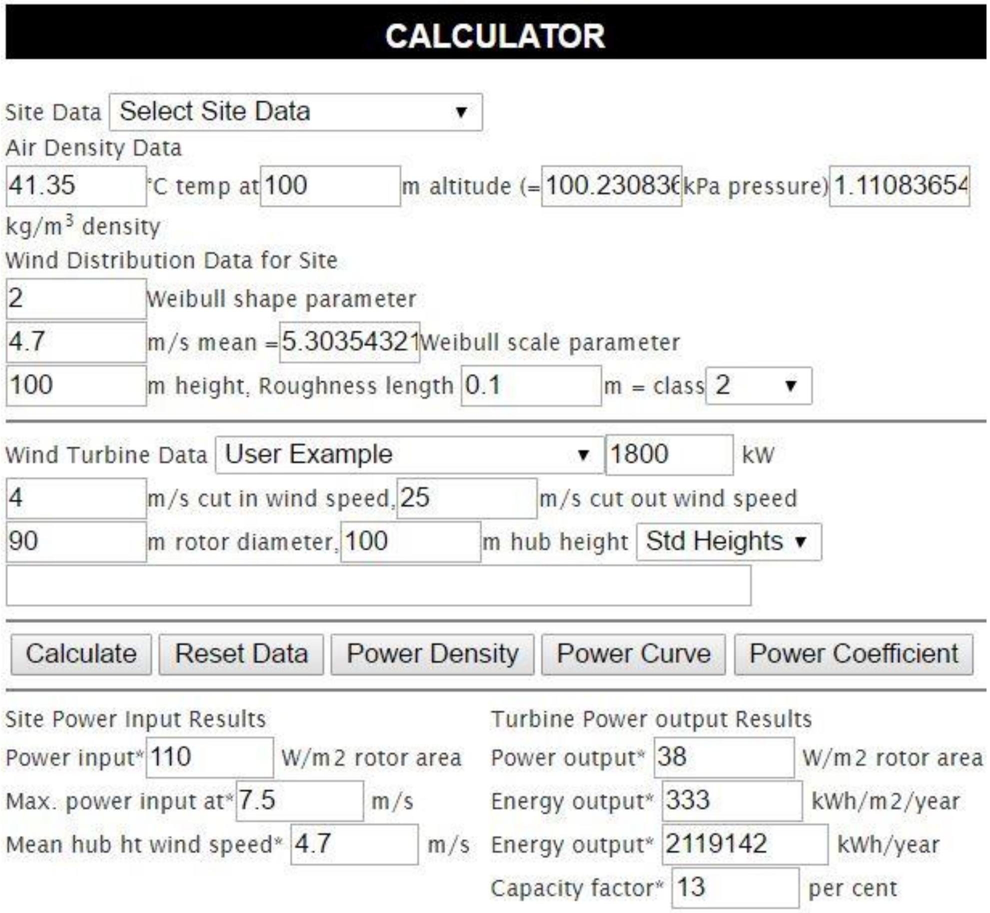

Fig: 5.37 Result for turbine V90

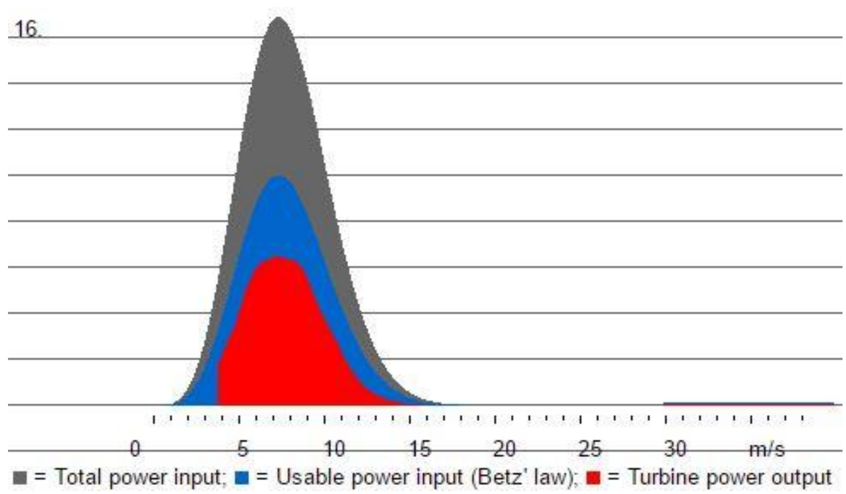

Fig: 5.38 Power Density curve

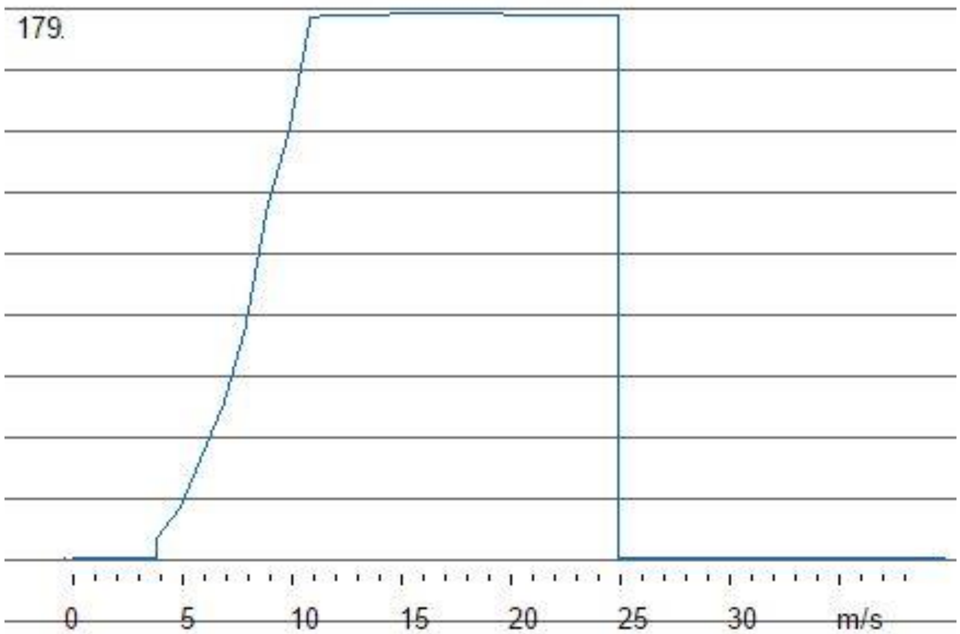

Fig: 5.39 Power curve

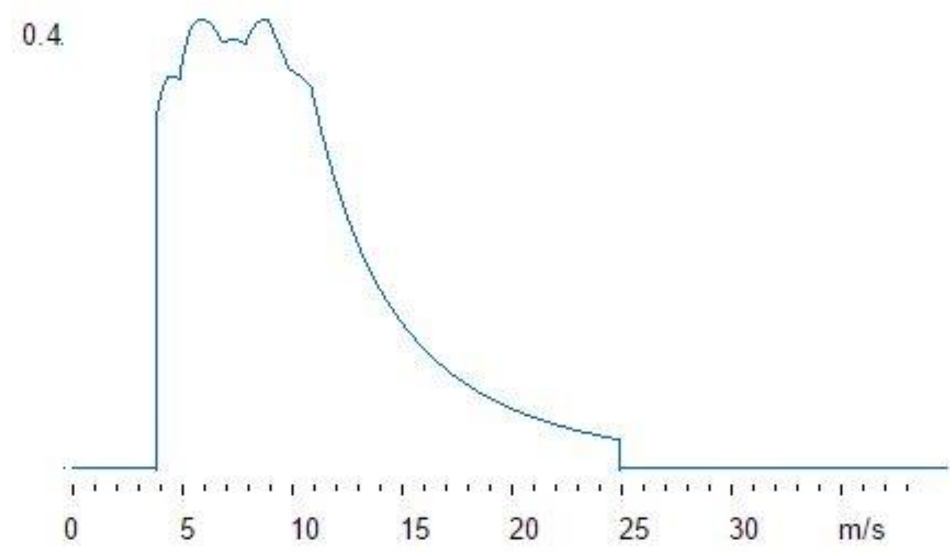

Fig: 5.40 Coefficient of Power

With turbine GAMESA G80

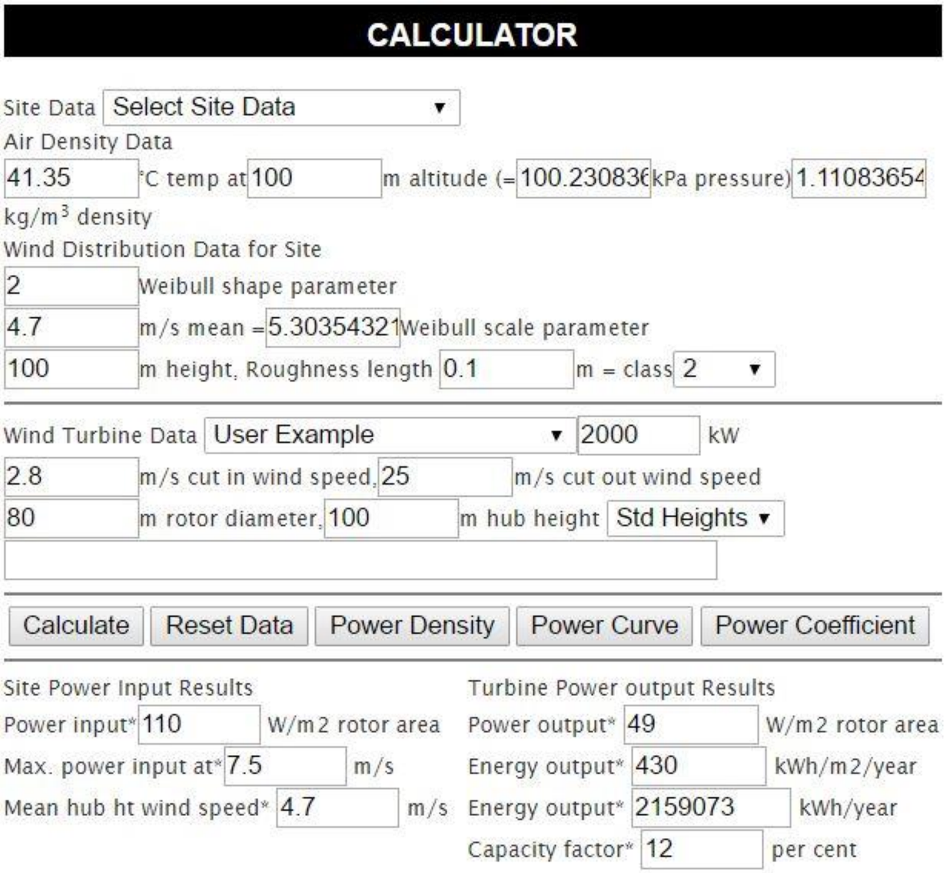

Fig: 5.41 Result for turbine G80

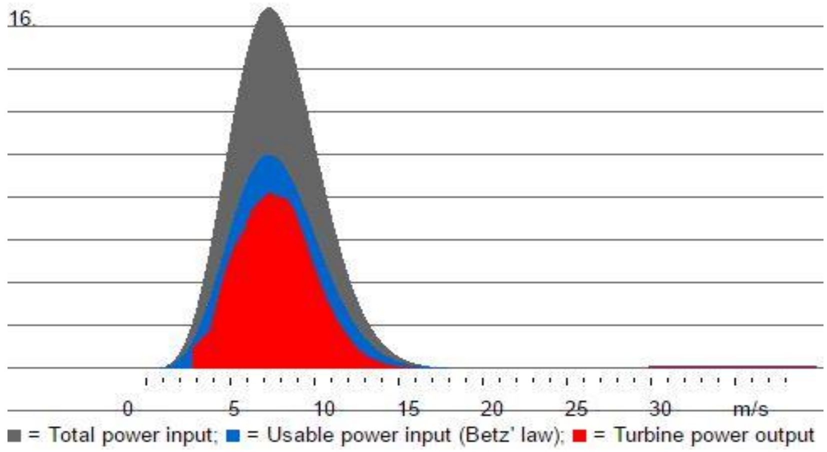

Fig: 5.42 Power Density curve

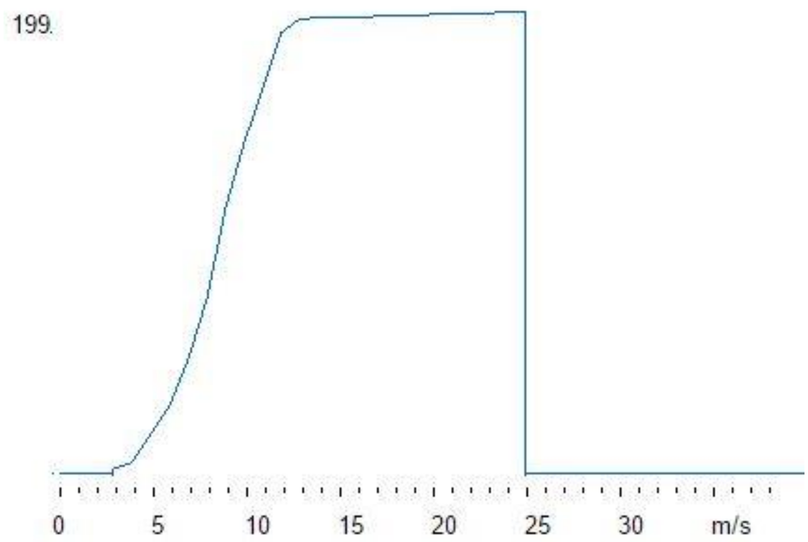

Fig: 5.43 Power curve

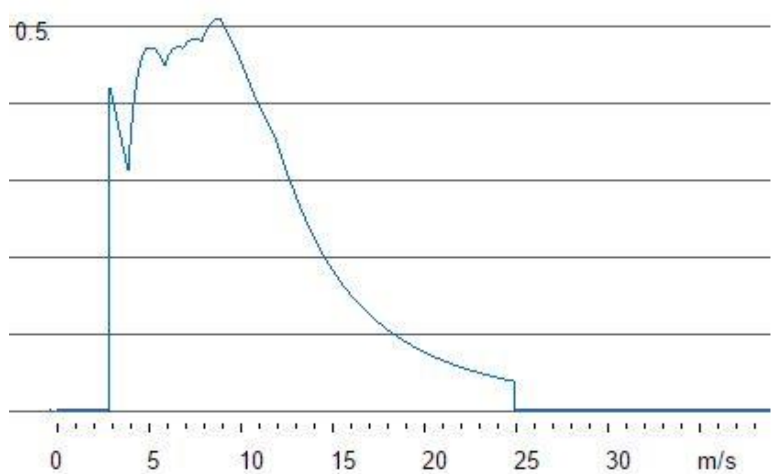

Fig: 5.44 Coefficient of Power

Discussion- By observing the output of these turbines (Suzlon S97, Suzlon S95 Gamesa G80, and Vestas V90), the power output which is better for this particular location (Odish) is 2655943 kwh/yr with capacity factor of 14, that means this (Suzlon S97) available turbine extract more power from available power to turbine to produce electricity.

But actually no one turbine is better because capacity factor is very low for all turbine but if the roughness class is more at that location and wind speed is not high at any time period during the year (say not more than 6m/s) than capacity factor 14 is good enough.

5.4 SITE 4- KARNATKA (GADAG)

With turbine SUZLON S97

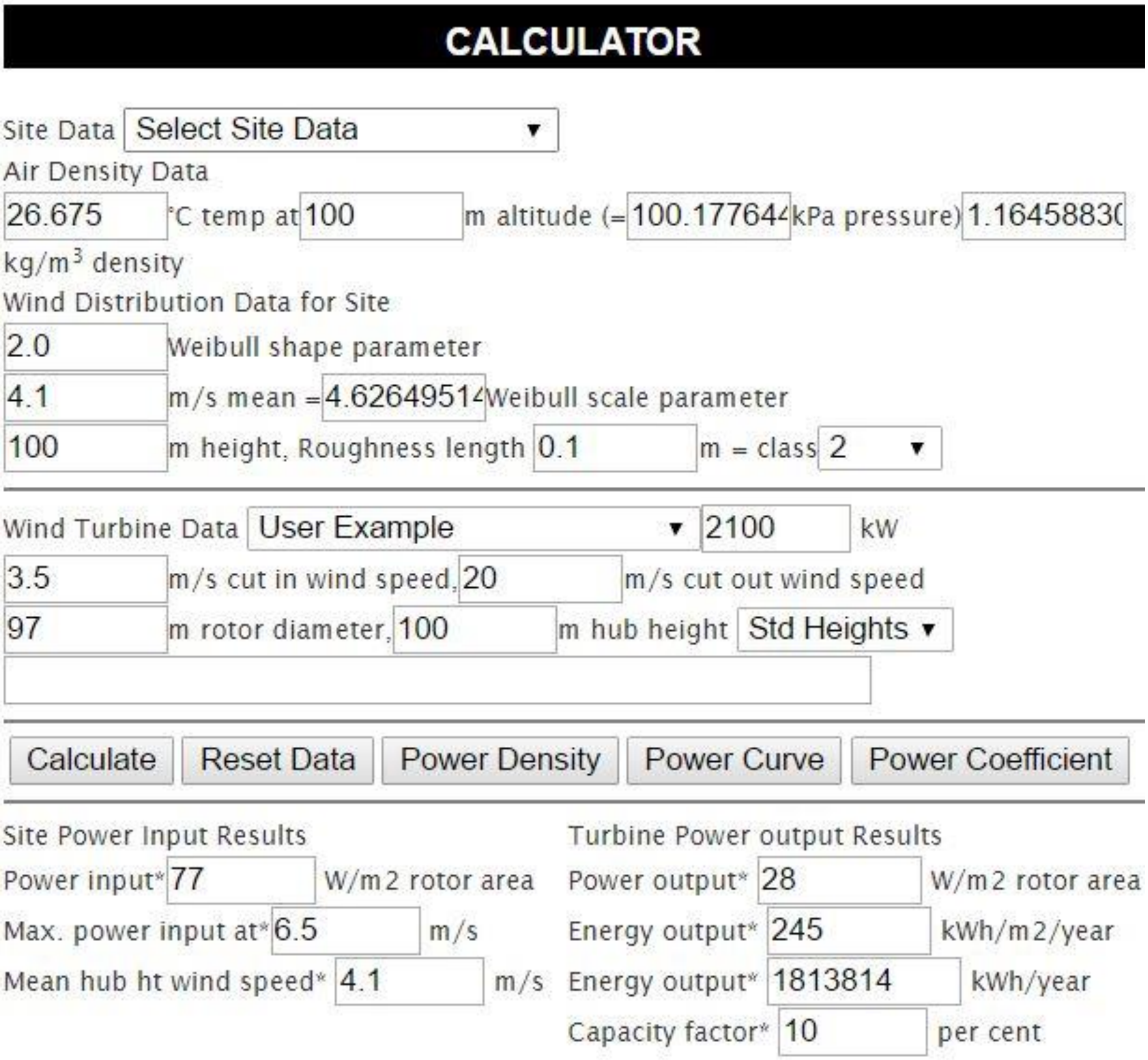

Fig: 5.45 Result for turbine S97

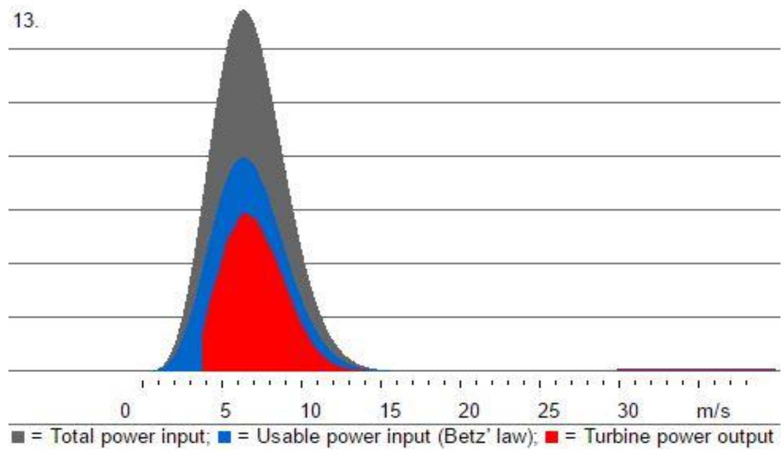

Fig: 5.46 Power Density curve

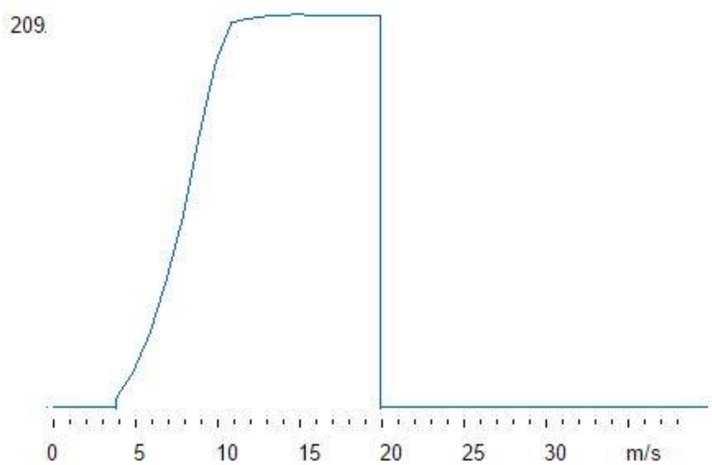

Fig: 5.47 Power curve

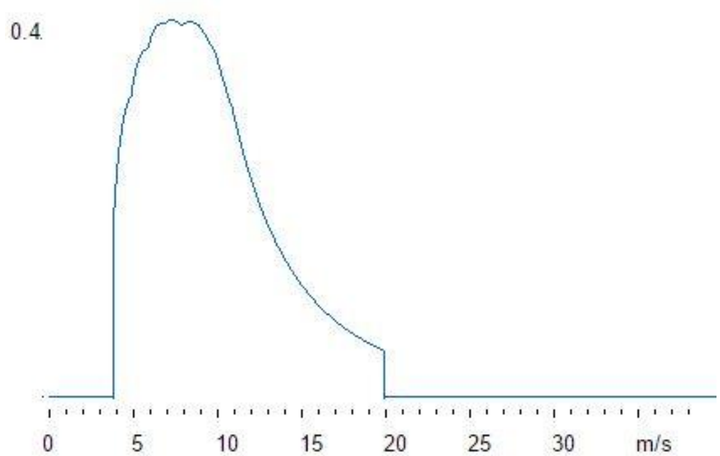

Fig: 5.48 Coefficient of Power

With turbine SUZLON S95

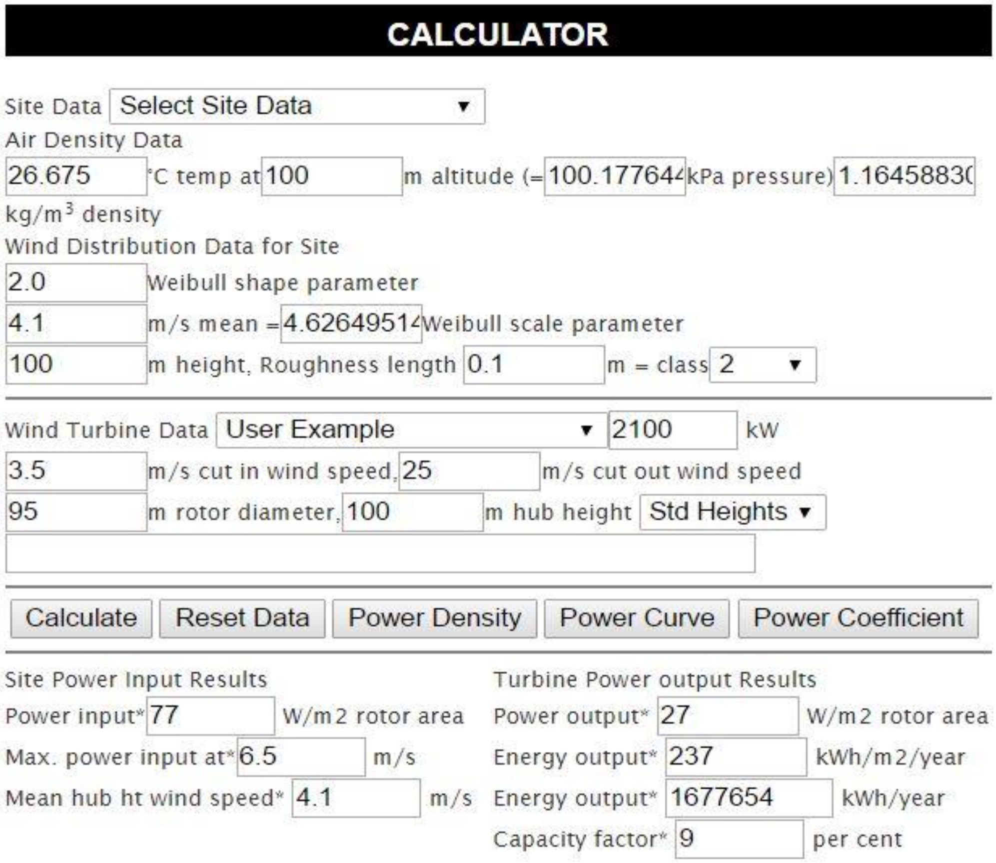

Fig: 5.49 Result for turbine S95

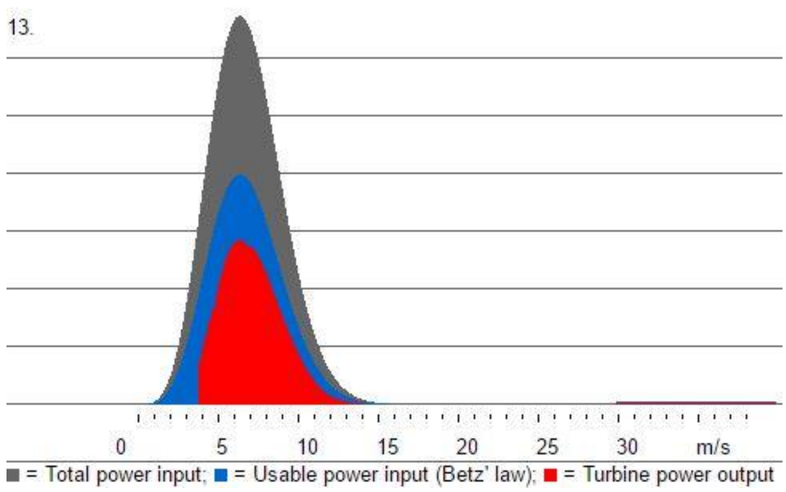

Fig: 5.50 Power Density curve

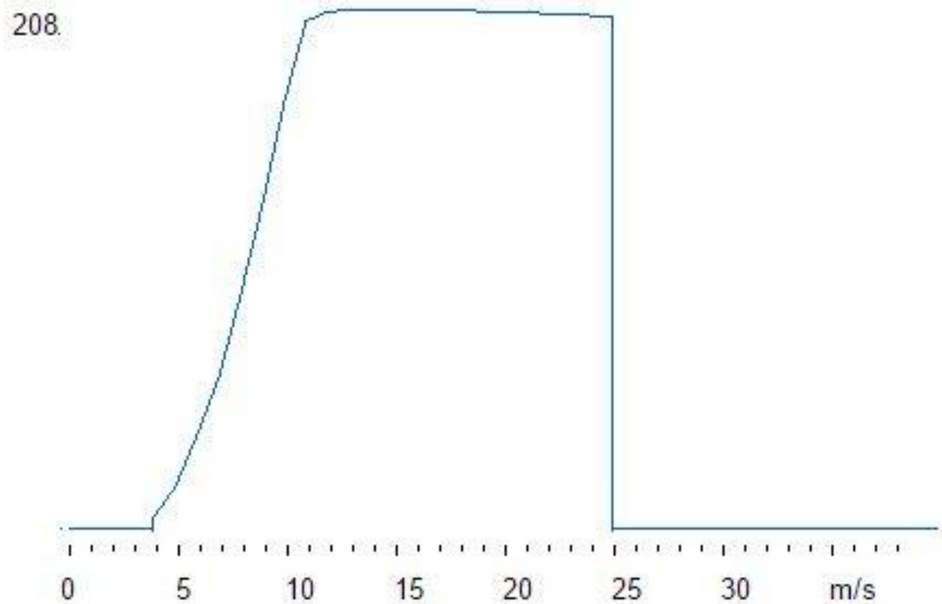

Fig: 5.51 Power curve

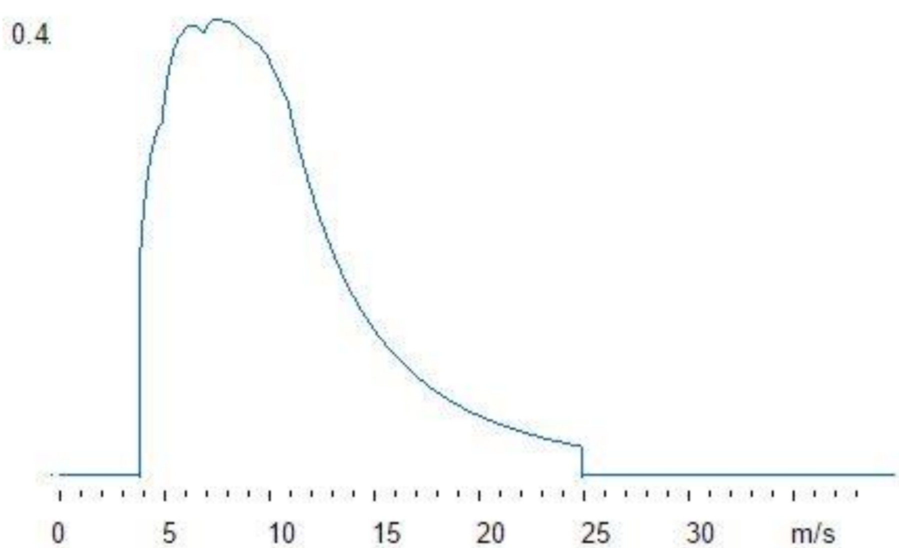

Fig: 5.52 Coefficient of Power

With turbine GAMESA G80

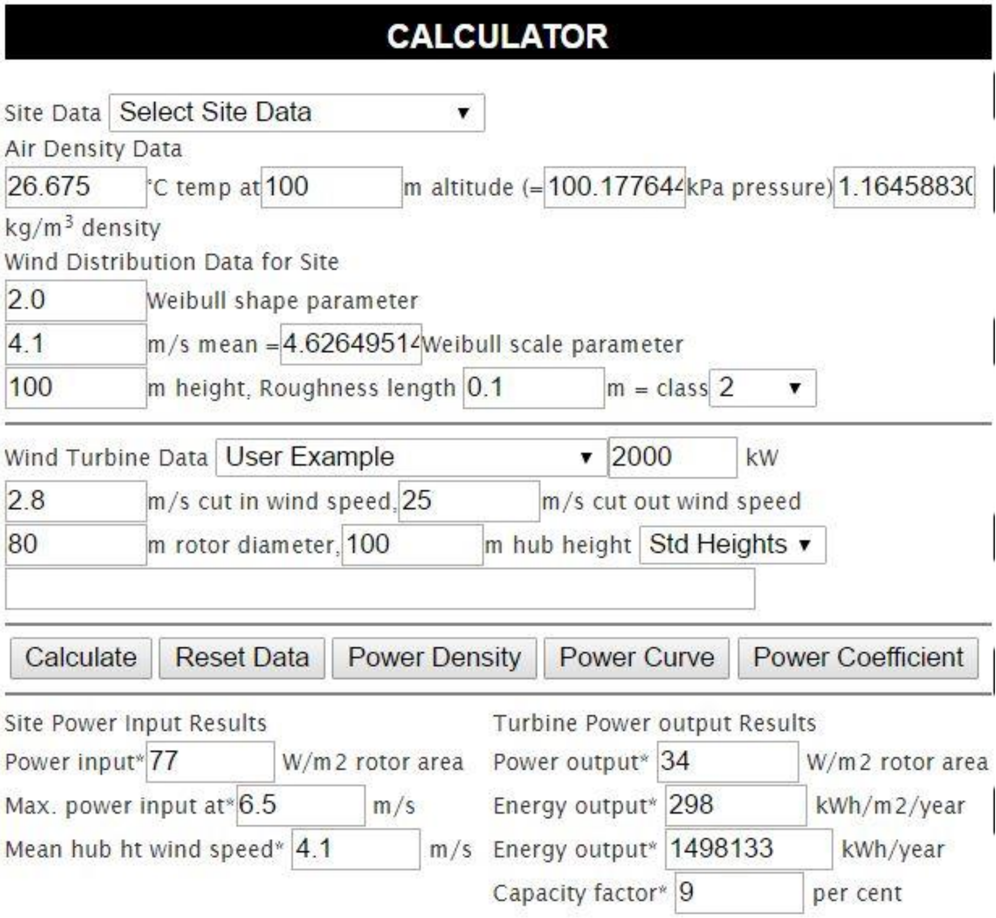

Fig: 5.53 Result for turbine G80

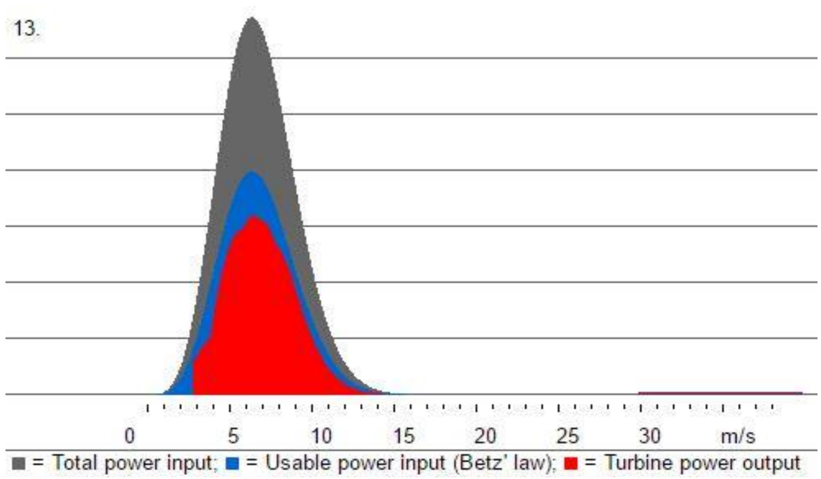

Fig: 5.54 Power Density curve

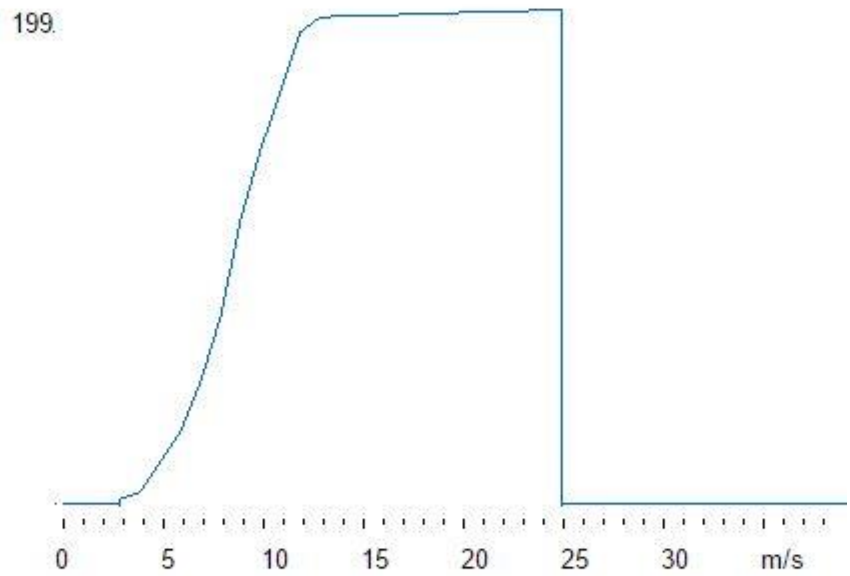

Fig: 5.55 Power curve

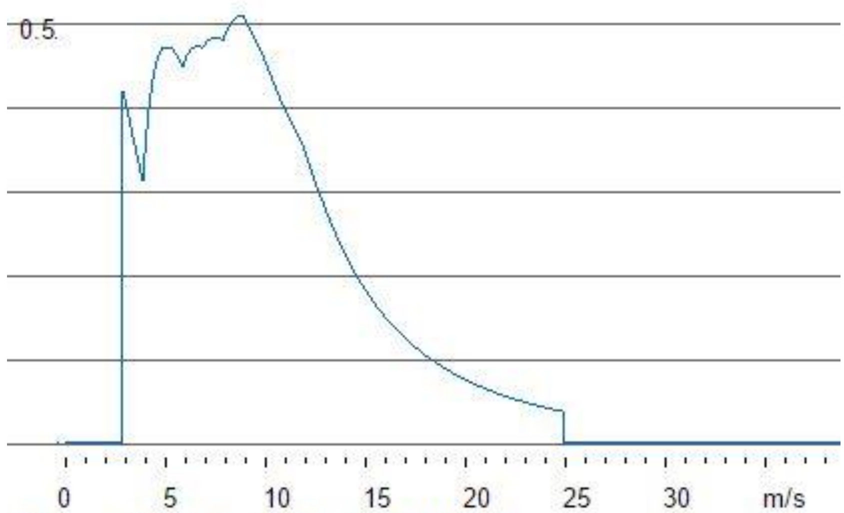

Fig: 5.56 Coefficient of Power

With turbine WIND WORLD 750/48

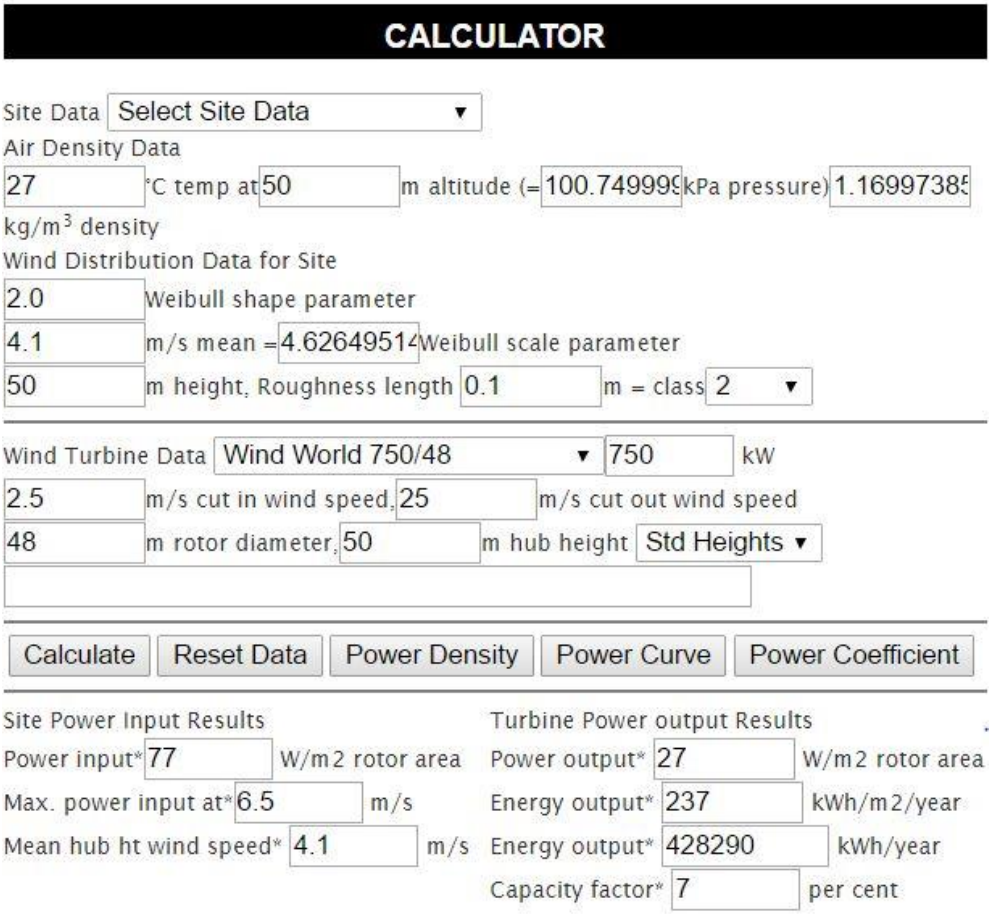

Fig: 5.57 Result for turbine WIND WORLD

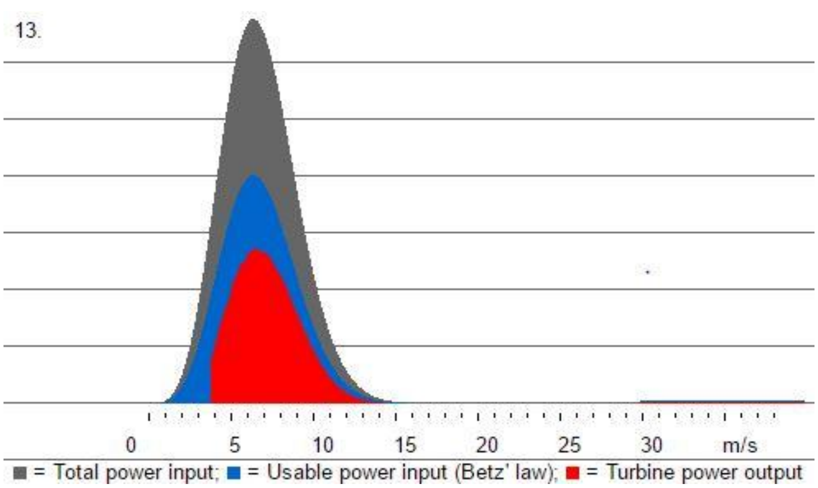

Fig: 5.58 Power Density curve

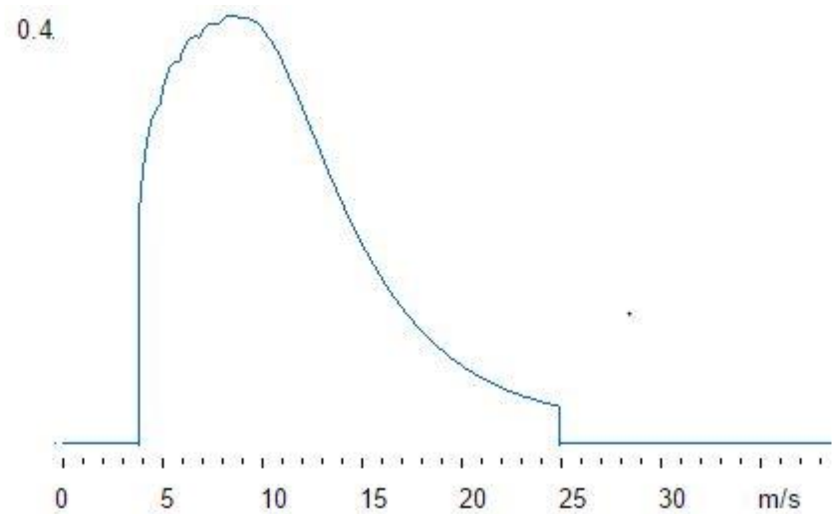

Fig: 5.59 Coefficient of Power

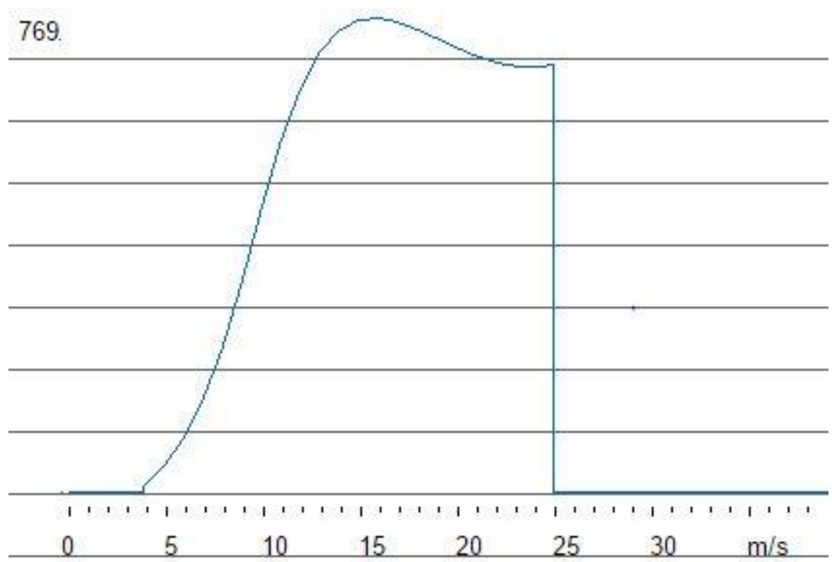

Fig: 5.60Power curve

Discussion- By observing the output of these turbines (Suzlon S97, Suzlon S95 Gamesa G80, and Vestas V90), the power output which is better for this particular location (Gadag) is 1813814 kwh/yr with capacity factor of 10, that means this (Suzlon S97) available turbine comparatively extract more power from available power to turbine to produce electricity. But capacity factor is too low because in this location, wind speed at which approximate rated power is obtain is flowing for very short period during the year

5.5 Calculative tool on Excel for Capacity Factor

Result of example to show how capacity factor is calculated
In above result we compare the capacity factor, but how it is calculated?

This is shown in excel calculation spreadsheet for an example, a 2.1 MW turbine has considered and the wind data for a complete year has collected that shows different wind speed flowing for different period of time during a year.

Speed (m/s)	power (kw)	Speed (m/s)	hrs/yr	Output (kwh/yr)
0	0	0	0	0
1	0	1	50	0
2	0	2	765	0
3	0	3	1578	0
4	65	4	1750	113750
5	200	5	1645	329000
6	400	6	1460	584000
7	680	7	526	357680
8	1010	8	235	237350
9	1440	9	179	257760
10	1830	10	207	378810
11	2050	11	148	303400
12	2070	12	127	262890
13	2082	13	55	114510
14	2090	14	21	43890
15	2092	15	5	10460
16	2090	16	7	14630
17	2088	17	2	4176
18	2087	18	0	0
19	2086	19	0	0
20	2085	20	0	0
21	0	21	0	0
22	0	22	0	0
23	0	23	0	0
24	0	24	0	0
25	0	25	0	0
total	26445	total	8760	3012306
		maximum output		18325920
		capacity factor		16%

Maximum output=total no. of hours in a year x Maximum power output

Capacity factor= Actual power output / maximum power output

Figure: 5.61 Excel calculations for Capacity factor

This is the capacity factor for turbine S97 at location Odisha, which near to the capacity factor that calculated by Wind turbine calculator

5.6 Comparative Analysis of AIRFOIL for Lift and Drag

Comparison of different AIRFOILs has been done for obtaining better lift drag ratio of AIRFOIL by changing its dimensional parameters in a particular wind condition with a given wind turbine specification. That means if we fix a site or location with its annual average wind data and having a wind turbine for that site we can compare AIRFOIL (section) of blade by changing dimensions of AIRFOIL.

5.6.1 Analysis with the help of an example

We have a turbine VESTAS V90 whose technical specification given in table no. . This turbine has chord length of 3.9m, and length of 49m. The location we have is Barmer district in Rajasthan whose wind data is given in table no. .

Lift and drag experienced by an airfoil is influenced by α. Fig. tells the effect of angle of attack on the lift coefficient of an airfoil. At lower angles of attack, the lift increases with α. The lift reaches its maximum value at certain α (optimum range 8^o-13^o) for an airfoil and then decreases rapidly on further increase in α, at high angles of attack, the airflow enters in excessive turbulent region and boundary layers get separated from airfoil. In this region, lift decreases and drag force is built up very fast, resulting in the stall of the blade.

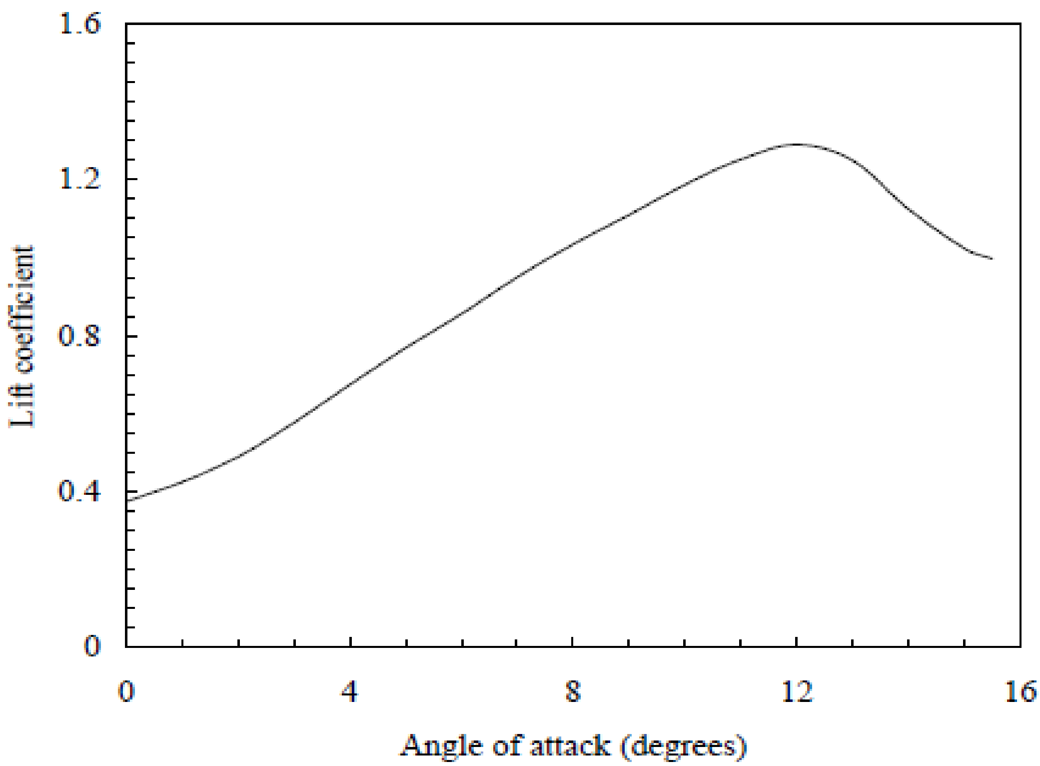

Figure: 5.62 curve for C_L [4]

Results

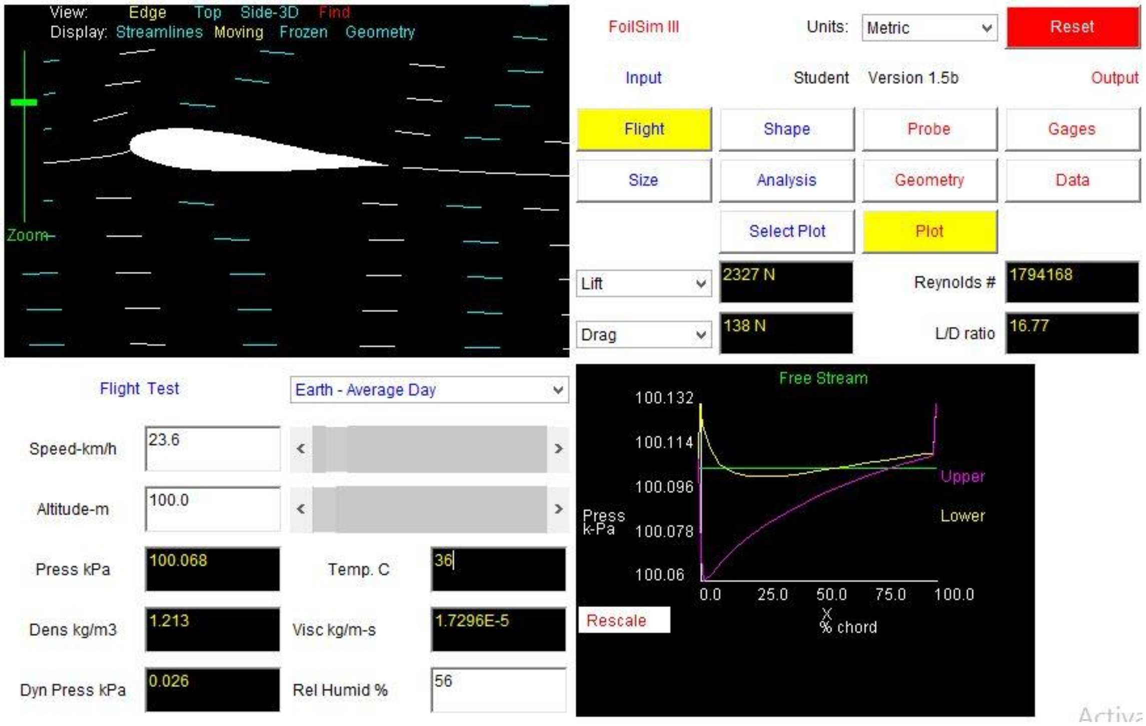

Fig: 5.63 Flight input

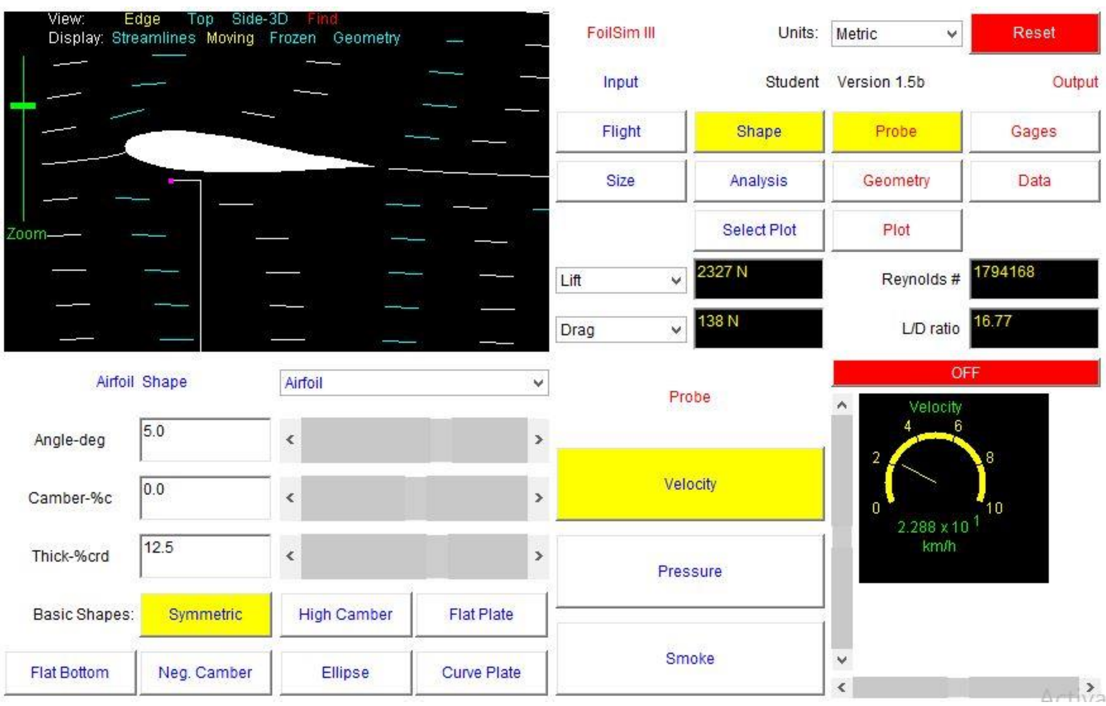

Fig: 5.64 Shape input

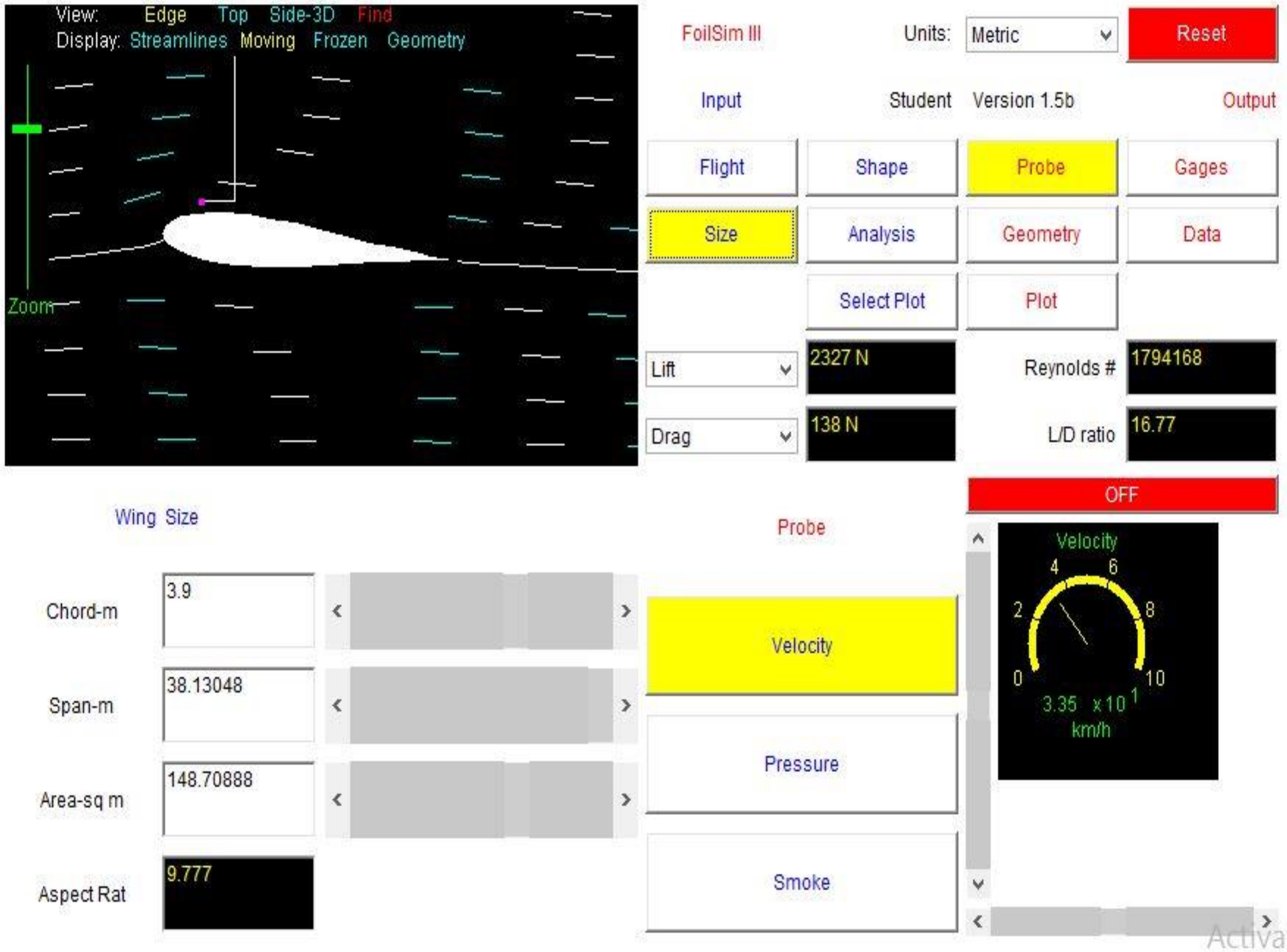

Fig: 5.65 Size input

By observing **fig no. 63, 64 & 65** we have lift and drag ratio **(L/D)** of **16.77** for particular size of an airfoil with fix wind data and altitude, and the angle of attack is 5^o and camber is 0%.
Now,
If we increase only the camber percentage and rest of the things remains unchanged, then there is an observable change in the lift and drag ratio.
Give the camber percentage as 3% and rest all the values remained unchanged then the value of L/D ratio decreases from 16.77 to 14.62 in the result as we can see in **fig 5.66**

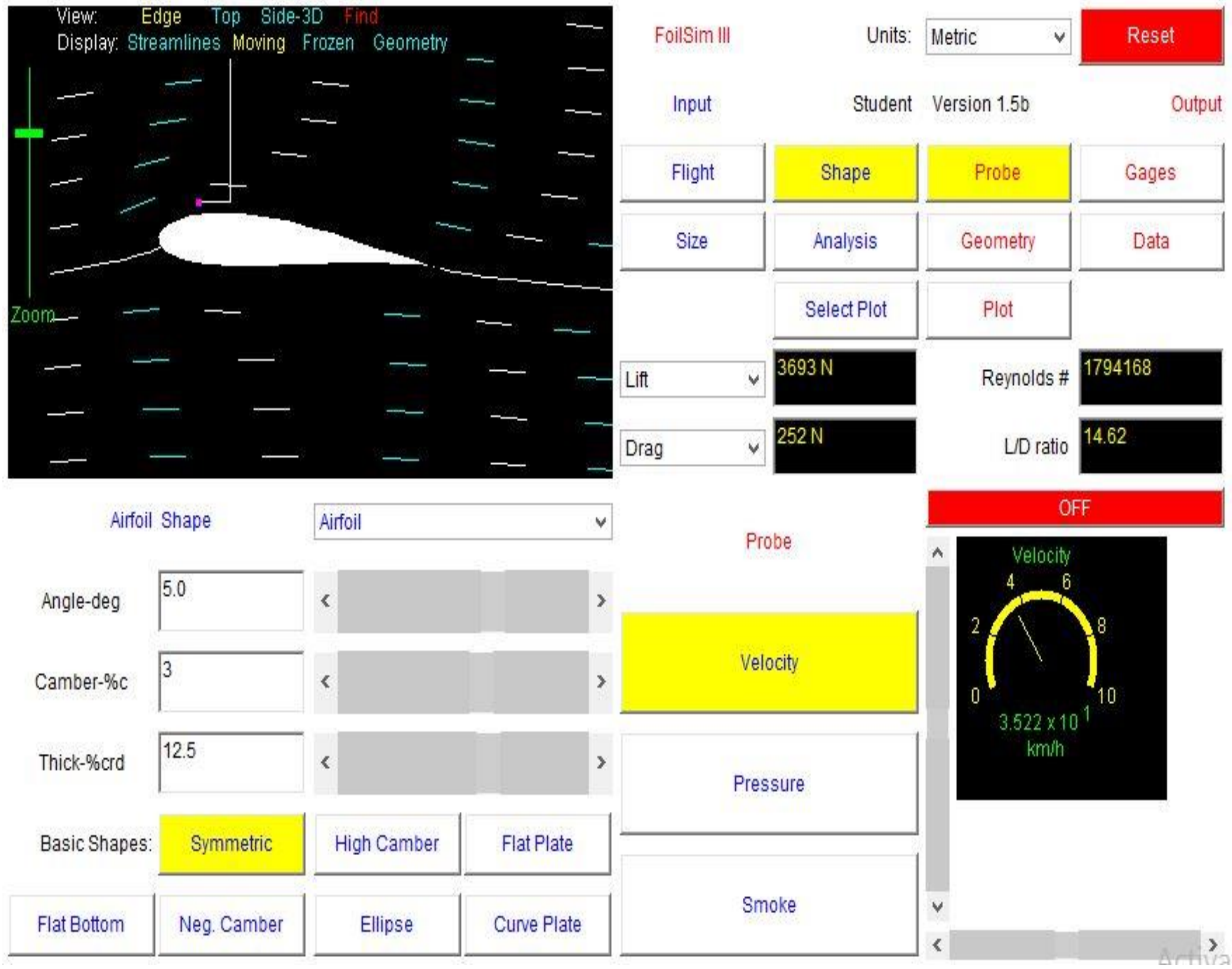

Fig: 5.66 Effect on L/D with increasing Camber

Now

If we increase angle of attack only and rest of all the values remains unchanged such as wind data, altitude, temperature, camber percentage etc. then there is an appreciable change in the lift and drag ratio.

By observing figure no. 5.67 we see that L/D ratio decreases from 16.77 to 14.68.

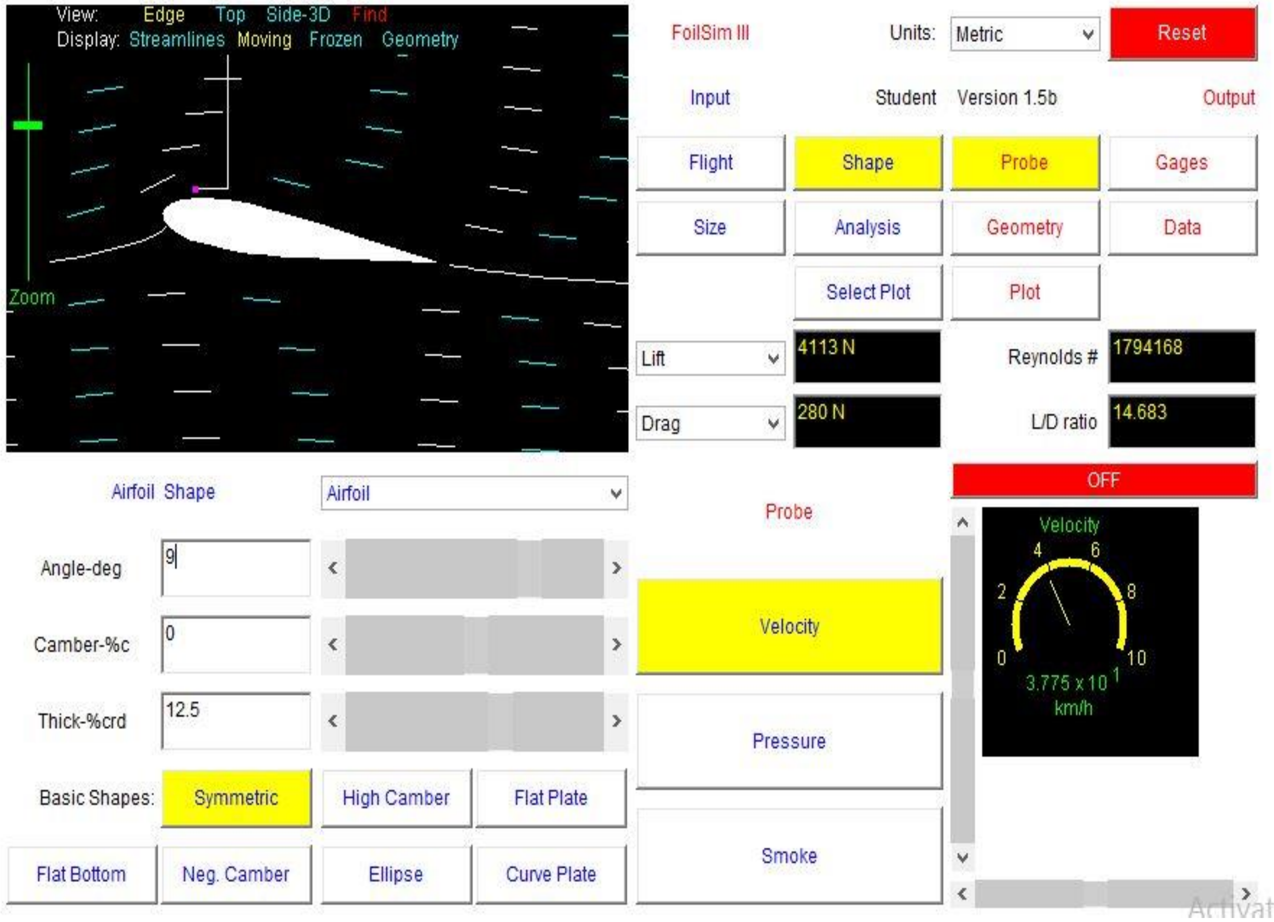

Fig: 5.67 Effect on L/D with increasing Angle of attack

Now,

If we increase both camber percent and the angle of attack the value of lift and drag ratio very much decreases.

By observing the figure no. 5.68 we can see there is a great fall in L/D ratio from 16.77 to 11.48.

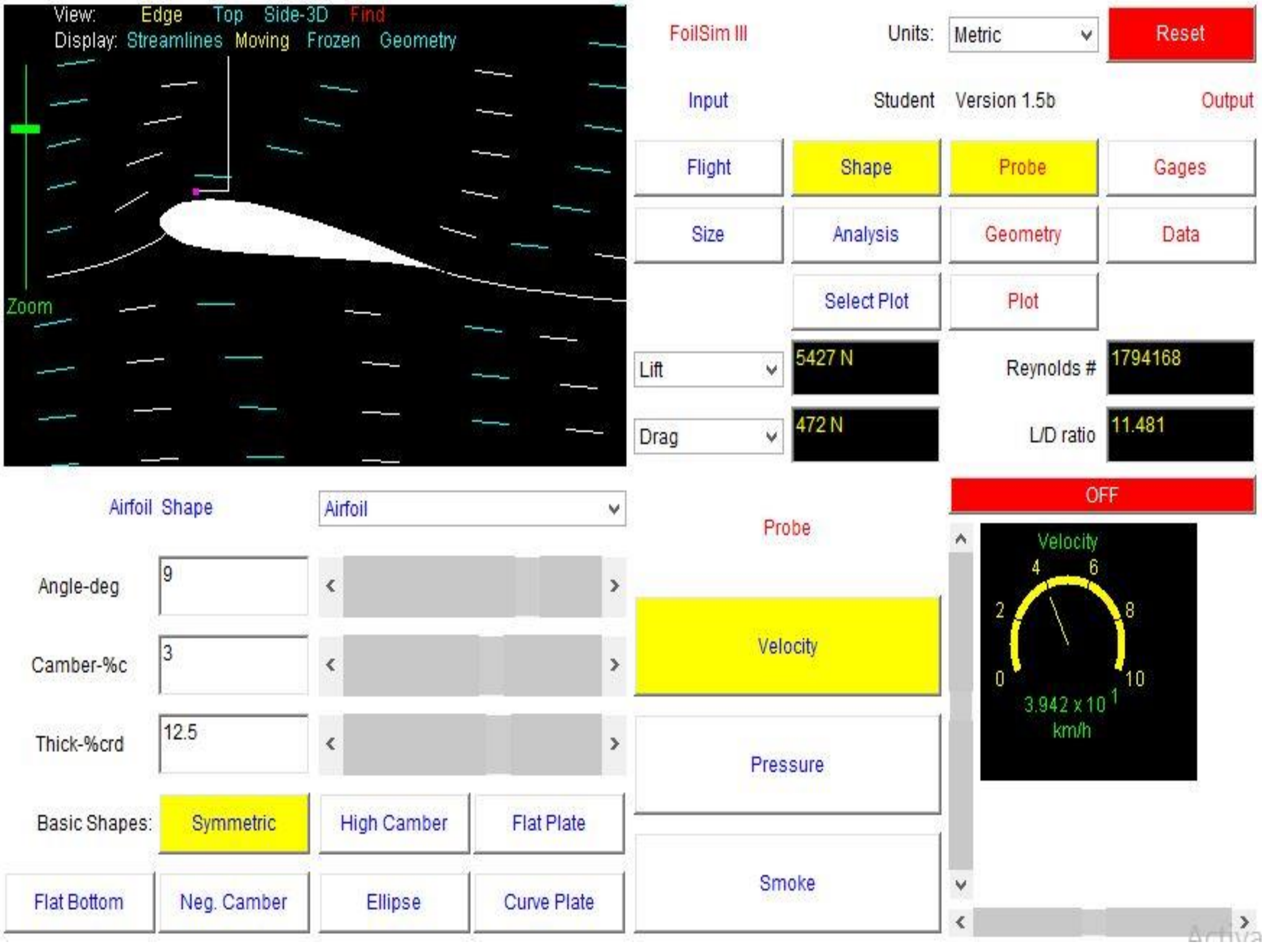

Fig: 5.68 Effect on L/D with increasing both camber and angle of attack

CHAPTER 6: CONCLUSION

Based on the thesis work, the aims and objections of the thesis project have been achieved. The significant findings are summarized below

- The software Wind Turbine Calculator has been used significantly and efficiently in work. It shows a good performance in calculating the power output and the plots such as Power Density curve, Power curve, and Coefficient of Power curve by using the technical specification of wind turbines and wind data of a particular location.
- Using user example for wind turbine in the wind turbine calculator it is necessary to define a new power curve for that turbine in order to ensure the correct energy and power output.
- In Wind Turbine Calculator by entering the wind data of particular location one can calculate power outputs for different turbines and then by comparing the outputs and curve plots one can conclude the comparatively better turbine for that location corresponding to the wind data in term of output power and capacity factor.
- FOILSIM3 is the software that shows a good performance in calculating the lift and drag ratio for an airfoil by changing the dimensions of an airfoil and it compares the lift and drag forces for an airfoil having same technical specification apart from angle of attack under the same wind condition. So thus software has a good ability to calculate the optimum angle of attack
- According to my work one can observe that the optimum angle of attack at which lift and drag ratio is more, decreases by increasing in camber percentage because I have seen there is decrease in the L/D ratio with increase in camber percentage and also lift and drag ratio decreases with increase in the angle of attack from its optimum value.

REFERENCES

[1].http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-overview-2004-update/World%20Energy%20Assessment%20Overview-2004%20Update.pdf

[2].https://www.iea.org/publications/freepublications/publication/KeyWorld_Statistics_2015.pdf

[3].https://www.iea.org/publications/freepublications/publication/WorldTrends_NonOECD_countries2015.pdf

[4]. Ptasznik, J., Suazion. World Energy Assessment: Energy and the challenge of sustainability. World Energy Council, New York, (2000). ISBN: 92-1-126126-0

[5].Fthenakis, V.; Kim, H. C. Land use and electricity generation: A life-cycle analysis. Renewable and Sustainable Energy Reviews, (2009)13 (6–7): 1465. doi:10.1016/j.rser.2008.09.017

[6]. http://www.coriolis-energy.com/wind_energy/wind_index.html

[7]. Ahmed, S. Background. In: Wind Energy Theory And Practice. Delhi: PHI Learning Private Limited, (2011) pp. 2-3.

[8].Mathew, S. Basics of Wind Energy Conversion. In: Wind Energy Fundamentals, Resource Analysis and Economics. Berlin Heidelberg: Springer-Verlag, (2006) pp. 11-15.

[9]. Mathew, S. Basics of Wind Energy Conversion. In: Wind Energy Fundamentals, Resource Analysis and Economics. Berlin Heidelberg: Springer-Verlag, (2006) pp. 16-22.

[10].http://www.cea.nic.in/reports/monthly/executivesummary/2016/exe_summary-04.pdf. "Executive Summary Power Sector April 2016" (PDF). *report*.

[11]. http://www.renewindians.com/2013/02/indian-renewable-installed-capacity-has-reached-27.7GW.html

[12].http://www.wwindea.org/home/images/stories/worldwindenergyreport2008_s.pdf

[13]. http://niwe.res.in/department_wra_est.php.

[14]. http://mnre.gov.in/file-manager/UserFiles/Tentative-State-wise-break-up-of-Renewable-Power-by-2022.pdf

[15]. http://www.cwet.tn.nic.in/html/information_isw.html

[16]. http://indianwindpower.com/news_views.html#tab0

[17]. http://www.windpowerindia.com/state-year-wise-weg-installations/

[18]. http://niwe.res.in/assets/Docu/Wind_Atlas_Report.pdf

[19]. Petru, T., Modeling of Wind Turbines for Power System Studies. Ph.D. thesis, Chalmers University of Technology Sweden, (2013), ISBN 91-7291-306-1

[20]. Martin, H R. Development of A Scale Model Wind Turbine for Testing of Offshore Floating Wind Turbine System. MS thesis, Graduate School The University of Maine, (2011).

[21]. Okajaki, T.,Shirai Y., Nakamura T. Concept study of wind power utilizing direct thermal energy conversion and thermal energy storage. International Superconductivity Technology Center, Kyoto University Japan, 2014. Journal Renewable Energy 83 (2015) 332-338.

[22]. Pagnini, L C., Burlando M., Repetto M P. Experimental power curve of small-size wind turbines in turbulent urban environment. Department of Civil Chemical and Environmental

Engineering Polytechnic School University of Genova, (2014), doi:10.1016/j.apenergy.2015.04.117
[23]. Samantaray, B., Patnaik, K. A Study of Wind Energy Potential In India. Thesis, Department of Electrical Engineering National Institute of Technology Rourkela, (2010).
[24]. Martinez, J. Modelling and Control of Wind Turbines. MS thesis, Department of Chemical Engineering and Chemical Technology Imperial College London SW7 2AZ UK, (2007).
[25]. Varma, A P., Chakri, K B. Study of Grid Connected Induction Generator for Power Application. Thesis, Department of Electrical Engineering National Institute of Technology Rourkela, (2012).
[26]. Barakati, S M. Modeling and Controller Design of a Wind Energy Conversion System Including a Matrix Converter. Ph.D thesis, University of Waterloo Ontario Canada, (2008).
[27]. Hsu, T R. Introduction to Design of Wind Power Generating Stations. ME 195-3 Senior Design Projects Class Department of Mechanical and Aerospace Engineering, San Jose State University, (2009).
[28]. Combs, D W. Design Analysis and Testing of a Wind Turbine Blade Substructure, MS thesis. Montana State University Bozeman Montana, (1995).