MODELLING THE PERFORMANCE OF WIND ENERGY CONVERSION SYSTEM AT POTENTIAL WIND FARM SITES IN KERALA

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PROJECT REPORT

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2013

DECLARATION

We hereby declare that this project report entitled **''MODELLING THE PERFORMANCE OF WIND ENERGY CONVERSION SYSTEM AT POTENTIAL WIND FARM SITES IN KERALA"** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associate ship, fellowship or other similar title of another University or Society.

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CERTIFICATE

Certified that this project work entitled **''MODELLING THE PERFORMANCE OF WIND ENERGY CONVERSION SYSTEM AT POTENTIAL WIND FARM SITES IN KERALA''**s a record of project work done jointly by Mr. Dhanmon Francis and Mr. Younus A under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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YOUNUS, A

DEDICATION

This project is dedicated to our parents and the Almighty God who has seen me through for period of my course.

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SYMBOLS AND ABBREVIATIONS

A	-	Area, Square meter
BCR	-	Benefit cost ratio
Dist	-	District
et al.	-	and other
EPF	-	Energy pattern factor
EWEA	-	European Wind Energy Association
Fig.	-	Figure
GW	-	GigaWatt
J.	-	Journal
KCAET	-	Kelappaji College of Agricultural Engineering & Technology
m/s.	-	Meter per second
MSL	-	Mean sea level
PBP	-	Payback period
WE	-	Wind Economics
WECS	-	Wind energy conversion systems
WERA	-	Wind energy resource analysis
B_A	-	Benefit
C	-	Cost per kWh
C	-	Weibull scale factor
C_F	-	Capacity factor

C_I	-	Initial vestment
F (V)	-	Cumulative density function
f(V)	-	Probability density function
GW	-	Giga watt
I	-	Discount rate
k	-	Weibull shape factor
kWh	-	kilo Watt hour
M&O	-	Maintenance and operation
m/sec	-	meter per second
MW	-	Mega Watt
No.	-	Number
NPV	-	Net present value
P_R	-	Rated power
P_V	-	Power at velocity
Rs	-	Rupees
V	-	Actual velocity
V_m	-	Mean wind velocity
V_R	-	Rated wind velocity
V_I	-	Cut-in wind velocity
V_O	-	Cut-out wind velocity

Z	-	wind data is available at a height
Z_0	-	roughness height
Z_R	-	wind data is available at proposed height
$V(Z_R)$	-	wind velocity at height Z_R
$V(Z)$	-	wind velocity at heght Z
%	-	One hundredth (Percentage)
/	-	Per
º	-	degree
ºE	-	degree East
ºN	-	degree North
ρ	-	Air density
σ	-	Standard deviation
∞	-	Infinity
Π	-	Pie$\left(\frac{22}{7}\right)$

Chapter I

1 INTRODUCTION

As the level of energy use is closely correlated with the development, availability of energy resources and its efficient use play a key role in the holistic prosperity of communities and Nations. Adequate access to energy directly or indirectly influences all the areas of development like industrial growth, food and water security, environmental sustainability, health and education levels, development of infrastructures and even the gender parity. Hence, with the developmental initiatives intensifying around the globe, the energy demand has also increased significantly in the recent years.

However, of late, it has been identified that the excessive use of energy - which is mainly derived from fossil fuels today - can cause irreversible environmental ill effects. For example, the global emissions of carbon dioxide (CO_2) reached its all-time peak of 34 billion tones in 2011, of which the major share comes from the energy sector (Olivier *et.al.*, 2012). On the other hand, conventional fossil based energy resources are running out at a frightening rate. For most of the countries, the peak oil period has already been passed and economically recoverable oil reserve has become limited. Similarly, it has been estimated that, even at today's consumption rate, the global coal reserves will not last for more than 112 years (WEC, 2012).

With this energy crisis and growing environmental consciousness, the global perspective in energy generation and consumption is shifting towards sustainable resources and technologies. Judicious use of the available conventional energy forms, along with the utilization of new and renewable energy resources are the viable ways towards a sustainable and secure energy future. It is in this context that actions are being initiated at various levels to exploit the available renewable energy resources to supplement the energy base.

With its global installation of over 235 GW (EWEA, 2012), wind is emerging as the fastest growing energy source in the world. Wind power could register an annual growth rate of over 25 per cent for the past seven years and several Multi-Megawatt projects- both on shore and offshore-are in the pipeline. Hence wind energy is going to be the major player in realizing our dream of meeting a major share of the global energy demand from renewable and sustainable resources.

India ranks fifth in the world in terms of global wind power capacity. The total installed capacity in the country by the end of November 2012 was 18321 MW (MNRE, 2012) out of which the major share comes from Tamil Nadu, Gujarat, Maharashtra, Karnataka and Rajasthan. Though Kerala has an estimated wind power potential of 1000 MW at 50 m level (ANERT 2012), till date, the installed capacity in the state is only 32 MW. Performances of these installed systems are very impressive with the plant load factor ranging from 21.92 to 31.9 per cent.

The power scenario in Kerala is unique. Out of the 2867 MW installed capacity in the state,1998 MW is from Hydroelectric projects (KSEB, 2012). Due to the uncertainty in monsoons and consequently falling water levels in the rivers, generations from these hydroelectric plants are to be restricted well below the capacity. On the other hand, the power demand in the state is steadily increasing.   The peak has reached to a level of 2998 MW and the daily consumption has crossed 56.26 million Units. This has put the state in to increasing pressure of power shortage resulting in wide spread power cuts and power failures. Hence, it is high time that the power base of the state has to be strengthened by taking initiatives to exploit available renewable energy resources like wind. It is in this context that wind energy projects were given due emphasis in the recent Emerging Kerala initiative (ANERT, 2012).

Keeping these in view, an investigation titled “Modeling the performance of Wind Energy Conversion System (WECS) at potential wind farm sites in Kerala” has been formulated and undertaken. The major objectives of the projects are:

1. To characterize wind resource available at the some potential wind farm sites in Kerala.
2. To simulate the performance of different wind energy conversion systems at these sites using WERA model.
3. To analyse the economics of Wind Energy Conversion Systems at these sites with the economic model “ecoREN”.

Chapter II

2 REVIEW OF LITERATURE

In this chapter a brief view of research works carried out related to wind turbine performance and analysis have been presented under the following heads

Wind energy resource assessment and instrumentation

Presentation of data

Analysis of wind data

Energy content of wind

2.1 Wind energy resource assessment and instrumentation

Bryukhan and Diab (1995) investigated the European Centre for Medium-Range Weather Forecasts (ECMWF) which consists of numerically analyzed, gridded meteorological parameters on isobaric surfaces, for the period 1982-89. The domain extended from 0^0-50^0S and 0^0 to 45^0E with a grid interval of 2.5^0 and included the set of isobaric surfaces 1000,850, 700, 500, 300, 200 1nd 100hPa.These data were taken on daily basis replicated the wind energy resource in the upper atmosphere over southern Africa region. Wind speeds increase from summer to winter at all levels but are best defined at the 300hPa level. There is northward shift of the zone of the maximum wind speeds in winter and highest continental wind speeds are experienced over the southern tip of the subcontinent.

Coppin et al (2003) has piloted a wind resource assessment survey in Australia and the wind scape system provided wind speed at a chosen height above the surface. There are crucial effects of regional scale variations in wind climate due to large scale surface features, like the roughness change from sea to land as well as the regional variation in weather patterns caused by atmospheric patterns caused by sea breezes, katabatic and anabatic winds. Maps of the statistical measure like mean annual wind speed are displayed with finer details over a broad area. Wind speed statistics at each point can be combined with the power curve of a chosen wind turbine to yield a map of the annual turbine energy yield over the region.

Albanyet (1997) presented the industry-accepted guide lines for planning and conducting a wind resource measurement program to support a wind energy feasibility initiative. These detailed and highly technical guidelines highlighted the tasks of selecting, installing, and operating wind measurement equipment as well as collecting and analyzing the associated data. This scope compasses state of the art measurement and analysis techniques at multiple heights on tall towers (e.g,50m) for duration of at least one year. They include measurement plan, monitoring strategy, quality assurance plan, monitoring duration and data recovery.

In Taiwan, a study was steered by Chang (2002) and analysed the wind characteristics and wind turbine characteristics. A two-stage procedure for estimating wind resource is proposed. The yearly wind speed distribution and wind power density for the entire Taiwan is firstly evaluated to provide annually spatial mean in formation of wind energy potential. A mathematical formulation using a two parameter Weibull wind speed distribution is further established to estimate the wind energy generated by an ideal turbine. Three types of wind turbine characteristics like a viability factor, capacity factor and the wind turbine efficiency are investigated. The monthly wind and wind turbine characteristics for four meteorological stations with high winds are investigated and compared with each other. The results showed the general availability of wind energy potential across Taiwan.

Sreevalsan (1998) studied about C-WET(Centre for Wind Energy Technology) as an Autonomous Organization under the Ministry. To serve as a Technical Focal Point for promoting Wind Power development in India .And to coordinate and support Research and Development programs in Wind Power systems. To analyze and assess wind resources and prepare Wind Energy Density Map, Wind Atlas and reference wind data. For develop procedures the testing & carry out testing; prepare Standards for Certification of Wind Power systems. He prepared State Wise Wind Atlas & Estimation of potential at 80/100 m level.

Anna Mani mentioned in Wind Energy Resource Survey in India Vol.III in1994 .Initially chosen for a wind energy resource survey, based on the conclusions drawn from an analysis of conventional meteorological data for the country. The programme involved the identification of location with strong winds, close to the state electricity grids and with adequate land available nearby for wind farms, and establishing wind monitoring stations for the collection of time series data on wind speed and direction at 10 meters and 20 meters levels for periods of three to five years at these sites.

Almost all wind monitoring stations are equipped with identical instrumentation. It consists of a 20 meters tall, guyed tubular steel mast, and with booms fixed at two levels 10m and 20m.and a wind resource logging system. Two pairs of wind speed and direction sensors and a data logger include in the data logging system, in which the data collected is stored in a removable EPROM chip. At the end of each boom mounted by one set of wind sensors, which points to the north. The separation and height between the wind wanes and anemometers are so chosen that the exposure of either sensor is not vitiated. The data logger is fixed on the mast at eye level, the cables connecting the sensors to the data logger being brought down through the mast.

2.1 Presentation of data

Justus et al (1978) accessed forty sites in United States and spatial cross correlations, inter-annual and month-month variations of monthly mean wind speed were identified. Sites were selected on the basis of availability of 10 or more years of data from a fixed anemometer location with a climatological mean speed of 11 mph or higher. Spatial cross correlations of monthly deviations from climatic means were found to be about 0.5 for sites separated less than 200 km, with annual mean wind deviations from the climatic mean correlated with coefficient value 0.32forsimilarly separated sites. Applications for using nearby "climatological" site wind speed data to adjust short-term "candidate" site data are examined with several methods. The best results show only minimal improvement in estimating the long-term annual mean over that obtained from one year of on-site data. These results indicate that, for candidate wind energy site evaluation, on-site data must be relied on more than originally considered and climatological data relied on less. Probability distributions of monthly and annual mean speeds were found to be nearly Gaussian with respect to climatological monthly or annual mean.

Wan(2002) studied the wind power data from wind power plants (WPPs) in different parts of the country suggest that one can expect relatively large inter-annual changes. The climate and regional weather pattern are the driving forces behind indent wind plant out puts. Changes in climate and weather patterns were reflected in the long-term performance of wind power plants (WPPs). In this respect, wind power is similar to hydropower, especially run-of-the-river type, in that there are high energy production (wet) years and low energy production (dry) years. The available data show that during the highest production year, total wind energy from the same WPP can be almost 40% higher than the annual production of the lowest production year. The available data do not appear to be enough to establish along term pattern or trend. However, short term variations of wind power appear to be less than long term variations. The data showed that distinctive seasonal and diurnal patterns are persistent over the years independent of the overall annual wind energy production.

Jong and Thomann (1981) projected the mean wind speed by sampling the wind data for Great Plain region in the United States. Two sampling techniques were adopted to wind data at 3h intervals for six stations in order to investigate the reduction in the number of data needed to estimate the mean wind speed. When wind speed characteristics were used to determine the energy output of wind energy conversion systems, only one parameter, the average annual wind speed often can be used to accurately predict the performance of Wind Energy Conversion Systems (WECS).Two sampling methods have been demonstrated which yield estimates of average wind speed with5%accuracy using 500-600 values of wind speed over a 5 year period.

Babcock & Brown(2007)demonstrated that wind energy is predictable over the long term .And define the process behind forecasting wind energy generation like Industry standard and Independent source, which discuss interpretation of wind assessments is to forecast the long-term mean energy generation of a wind farm. He concluded Wind energy is a predictable energy source.

Anna Mani mentioned in Wind Energy Resource Survey in IndiaVol.III. During the period of 1988-1993, summary of the mean monthly and annual wind speeds and their standard deviations, the maximum hourly wind speeds, and the peak winds and their time , date and year of occurrence at the different wind stations are tabulated.

2.2 Analysisofwind data

Yilmas *et al* (2005) investigated the theoretical distributions of wind potential for five different topographic regions of Turkey Wind Atlas by fitting the Weibull distribution as the key function. Maximum Likelihood Estimation (MLE), Method of Moments (MOM) and Least-Squares Method (LMS) were the graphical techniques used for estimating Weibull distribution. He emphasized the need of recording wind speed data with minimum errors for determining the actual wind energy potential analyzed with Weibull distribution.

Youm *et al* (2005) conducted a study on analysis of wind data and wind energy potential along northern coast of Senegal. The main objective of this is more knowledge about the coastal wind resource by correlating the results of qualitative studies with statistical analysis of available records. The wind data are made up as time series and frequency statistics based on observations of wind speed and wind directions recorded every 10 min time intervals. Diurnal variation of wind speeds, wind direction, frequency distribution were analyzed for the study.

EI-Mallah *et al* (1989) developed a nomogram estimating capacity factors of wind turbine using site and machine characteristics. It was suggested that the wind speed at the site has to be fitted to the appropriate Weibull probability distribution function for the required period of time. The wind turbine should b characterized by its cut-in, rated and cut-out speeds. The nomogram was sufficient to define the average wind speed at the sites and the shape factor of the fitted Weibull distribution.

The annual and monthly wind speeds and wind density are estimated by Ahmed and Muhammed (2001) in Penjwan region of Iraq. The Weibull and Rayleigh distribution functions have been derived from the available data and both Weibull and Rayleigh probability density functions are fitted to the measured probability distributions on yearly basis, it was shown that the Weibull distribution is fitting the measured monthly probability density distributions better than the Rayleigh distribution for the whole years. For the estimation of power density and monthly probability density distributions, Weibull distribution and Rayleigh distribution were better options respectively for the whole years.

Wan (2004) perused long term wind power data to study the unique characteristics of large scale installations in National Renewable Energy Laboratory, Colorado. In this study time series data were used for the analysis of wind power. When more wind power plants are connected to the system, the diverse wind resources of various locations will make the aggregate output less volatile. The statistics of power fluctuations (step changes and ramping rates), when expressed in terms of total wind power capacity, will be smaller than those of an individual wind power plant. Output of a wind power plant follows the changes of wind speed, and wind speed does not change suddenly over a wide are at affect every wind turbine in a large wind power plant at the same time. It may not be Possible to forecast the exact output level of a large wind power plant for any given time. Although the win power is stochastic in nature, it is not completely random.

Settler and Saxton(1993) calculated the soil losses due to wind erosion after collecting the wind data. These analyses have indicated that the smaller the time scale over which wind speed data are acquired, the more likely the high energy fluctuations in wind speed will be represented in the calculated wind energy. These short-term fluctuations usually contain significant amounts of wind energy that are not adequately represented by long-term averages, such as hourly averages.

Mathew (2000) stated that in the design of wind energy conversion devices wind speed is the most important parameter. The energy content of wind is directly proportional with the cubic power of the wind speed. As the wind speed increases, the cost of the wind power decreases. It is well explained that the probability distribution related to wind speeds can be described by Weibull distribution and it is accepted so well without any statistical examination. The wind speed probability density function is expressed as

$$f(V) = \left(\frac{k}{C}\right)\left(\frac{V}{C}\right)^{k-1} e^{-\left(\frac{V}{C}\right)^{k}}$$

f(v) is the probability of observing wind speed v

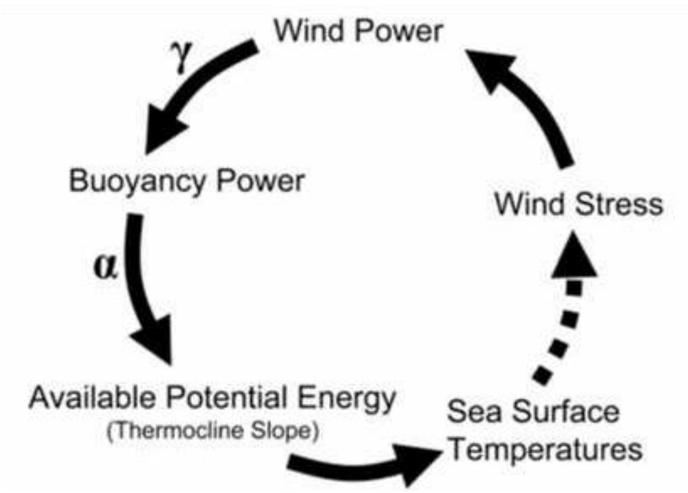
c is the Weibull scale parameter.

K is the Weibull shape parameter.

Anna Mani mentioned in Wind Energy Resource Survey in India Vol. III in 1994.The long-term mean wind speed, wind roses, the persistence of wind speed above selected threshold values and the frequency distributions of wind speed of stations are presented in this chapter. The discussion also covers the energy pattern factor and the Weibull distribution parameter

2.3 Energy content of wind

Brown and Fedorov (2009) studied the dynamics of El Nino Southern Oscillation (ENSO) in terms of the balance between energy input from the winds and changes in the storage of available potential energy in the tropical ocean. Presently there are broad differences in the way global general circulation models simulate the dynamics, magnitude and phase of ENSO events. They found that ocean model sand data assimilations are approximately 50%–60% efficient in converting wind to buoyancy power.Only a fraction of wind power is converted to buoyancy power and efficiency of this conversion is estimated as 50%–60%. Once the energy is delivered to the thermo cline it is subject to small, but important, diffusive dissipation.



Morrissey and Cook (2009) reinstated the role of wind power density (WPD) distribution curve for wind power assessment and wind turbine engineering. First estimated that wind speed probability density function (PDF) using a nonparametric or parametric method for the usual practice of estimating the curve from wind speed data. The density function is then multiplied by one-half the wind speed cubed times the air density. Instead of this, they have proposed a new method of estimating the wind power density distribution curve using a Gauss–Hermite expansion. The results of the study indicated that the Gauss–Hermite expansion, used as an estimate or of the wind power density distribution function, does not appear to be an efficient or convergent if firstly applied to estimate the wind speed probability density function, and then subsequently using this estimate to construct the wind power density distribution function.

Auwera *et al* (1980) estimated the mean wind power densities by using the Weibull distribution with three-parameter. Using wind speed observations, it is shown that this model generally gives a more reliable fit to the empirical wind speed frequency data than the density functions with one or two parameters. Wind power variation with respect to height, Description of the data and statistical analysis, were done in his study. The Weibull three parameter and other models for statistical wind power analysis.

Sedefian (1979) developed a simple method for estimating the height variation of the mean wind power density with a variation of the exponent *p* of the wind speed power law, with stability and roughness. The estimation of the mean of the speed cubed, and therefore of the mean wind power density, at aero generator hub heights, can be determined by this method. This is applicable to sites where turbulent state of the atmosphere has been determined by the Pasquill A-F stability classes and an estimate of the surface roughness (Z_0) is available.

Power spectra covering a frequency range of 0.002 to 100 cycles/h of scalar surface-wind speed at Palmyra Island were investigated and presented by Hwang (1967). The distribution of eddy kinetic energy in the -medium and high-frequency range in the Tropics was quite similar to that at the middle latitudes. For the low-frequency range beyond about 10 days, it could not be investigated by those data. He also inferred that the atmospheric turbulence followed the minus five thirds power law.

Anna Mani mentioned in Wind Energy Resource Survey in India Vol.III.That for calculating the energy content of the wind while considering the factors like wind power density . The power P due to the kinetic energy of the wind, with a constant speed V passing through an area 'A' normal to the wind is given by $P=1/2\rho.A.V^3$. Where ρ is the density of air and P is expressed in Watts or kilowatts. With ρ in kg/m^3 and V in $kmph=0.01073.\rho.V^3$ in watts. The annual variation is seen to be large at most of the stations with the maximum values occurring during the months June-August. The maximum wind power density of 25W per sq metre in the 31-32 kmph interval at Kanjikode.

CHAPTER III

3 MATERIALS AND METHODS

The materials used and the methodology adopted for the studies are discussed in this chapter under the following heads:

- **Wind regime analysis**
- **Wind Resource Analysis**
- **Simulation of the wind data performance using "WERA" model**
- **Wind Economics analysis using the computer programme "EcoREN"**

3.1 Wind regime analysis

Kerala where intense electricity shortage is felt has been taken as the study location. Along a sun drenched coastline, to the extreme south west of the Indian peninsula, lies Kerala, beautiful and benign. Flanked by the Arabian sea on the west and the mountains of the Western Ghats on the east, this land stretch north-south along a coast line of 580 km with a varying width of 35 to 120 km. This is located between north latitudes 8 degree 18' and 12 degree 48' and east longitudes 74 degree 52' and 72 degree 22'

3.1.1 Weather

Kerala is fortunate in that it can boast of balmy weather almost all the year through. Unlike the north, it never gets too cold in the winter months, while the summers do not have the harshness of some of the other parts of the country.

The result is a destination that is accessible year round. Best time is November-February with light breeze in morning and evening. Warm (but not hot) months are March-May and September - October: at such times the flowers are out and though there is humidity, it is not daunting. Mid-May to August is the monsoon period, with a cold and wet time. In addition, January to June has been identified as windy season

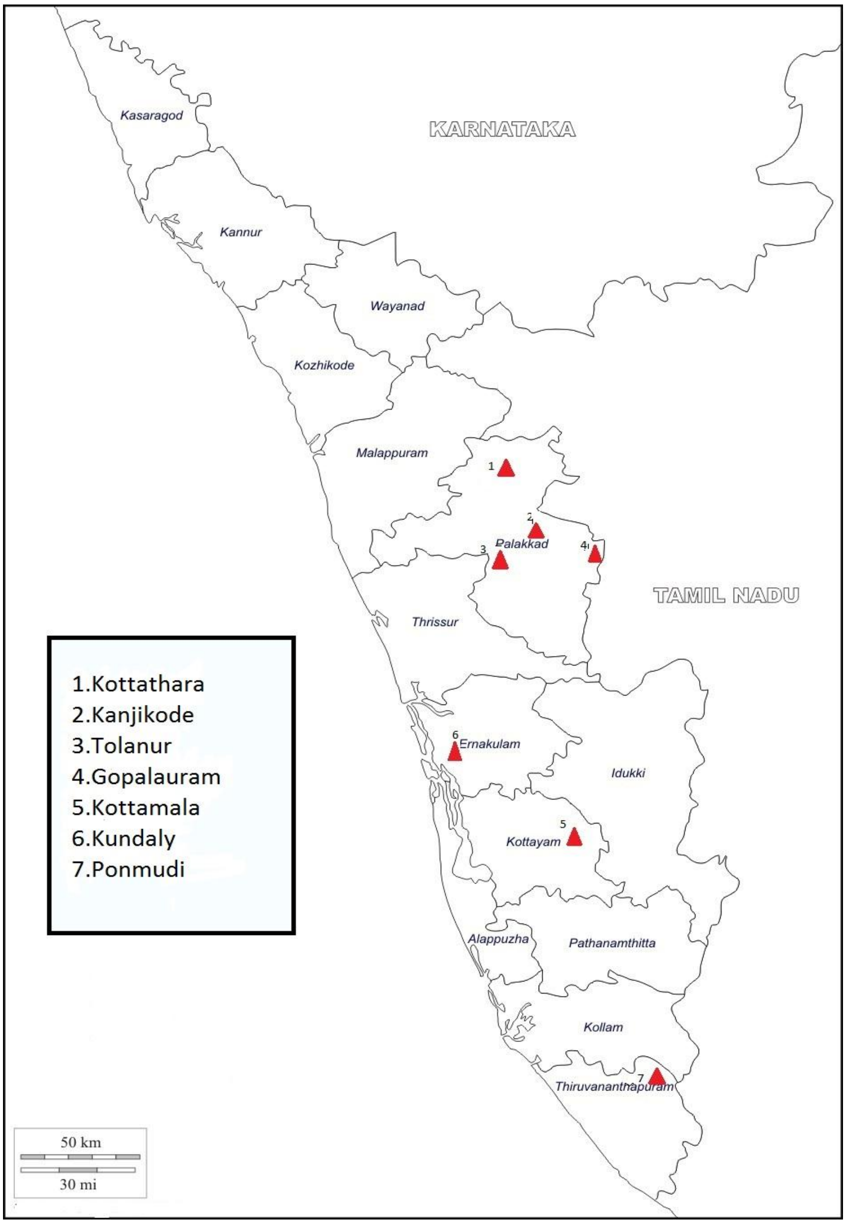


Fig.3.1 selected sites are marked in Kerala map

3.2 Wind Resource Analysis

For a concrete wind energy resource analysis, seven sites from Kerala state, Fig.3.1, were initially identified and wind data collected by Mani, A (1994) has been taken as the indirect yardstick for this programme. A national wind energy resource assessment programme was organised and the winds were categorised as very strong (>25kmph), strong (20-25kmph), moderate to strong (15-20kmph), moderate (10-15kmph) and light (<10kmph). Among these sites ne station was grouped into strong category and four sites under moderate category and the remaining one under light category.

3.3 Presentation and interpretation of wind data

The wind data available at these meteorological stations have been logged from different sensor heights (10m and 20m) as per the recommendations of the World Meteorological Organization (WMO). In wind energy calculations, the velocity available at the rotor height (100m) can be obtained by extrapolating to other heights on the basis of the roughness height of the terrain. The outputs were obtained from two pairs of anemometers and wind vanes are sampled by the microprocessor controlled data logger. Almost all wind monitoring stations are equipped with identical instrumentation. It consists of a 20 meters tall, guyed tubular steel mast and with booms fixed at two levels 10m and 20m and a wind resource logging system. Following data were recorded by these systems. 1) Hourly mean wind seed, 2) Peak wind seed and the time of occurrence on a monthly basis, 3) Duration of the longest lull 4) Frequency distribution for wind speed and direction for each month.

3.3.1 Determination of proposed rotor height

Collected mean wind velocity (Vm), standard deviation (σV), Weibull shape factor (k) and Scale factor(C) for these sites a. Due to the boundary layer effect, wind speed increases with the height in a logarithmic pattern. Frequency distribution of wind data can be statistically analysed by the Weibull distribution and for this distribution,

$$f(V) = \left(\frac{k}{C}\right)\left(\frac{V}{C}\right)^{k-1} e^{-\left(\frac{V}{C}\right)^{k}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.1)$$

and

$$F(V) = \int_0^{\infty} f(V)dv = 1 - e^{-\left(\frac{V}{C}\right)^{k}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.2)$$

Where:

k - Weibull shape factor

C - Weibull scale factor

k is dimension less ,and C values are in km/h. After converting all the values of k and C to m/s we have to convert it for 100m height. If the wind data is available at a height Z and the roughness height is Z_0, then the velocity at a height Z_R is given by where V (Z_R) and V (Z) are the velocities at heights Z_R and Z respectively.

For this we use the expression

$$V(ZR) = V(Z)\frac{ln\left(\frac{Z_R}{Z_0}\right)}{ln\left(\frac{Z}{Z_0}\right)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

For this we need a small derivation as follows.

$$V(Z_R) = V(Z)\frac{ln\left(\frac{Z_R}{Z_0}\right)}{ln\left(\frac{Z}{Z_0}\right)}$$

or

$$\frac{V(ZR)}{V(Z)} = \frac{ln\left(\frac{Z_R}{Zo}\right)}{ln\left(\frac{Z}{Z_0}\right)}$$

Expanding the log

$$\frac{V(Z_R)}{V(Z)} = \frac{lnZ_R - lnZ_0}{lnZ - lnZ_0}$$

Take

$\frac{V(Z_R)}{V(Z)}$ as A, ln ZR as B and ln Z as C

Then

$$A = \frac{B - lnZ_0}{C - lnZ_0}$$

Or

$$AC - B = lnZ_0(A - 1)$$

This gives

$$lnZ_0 = \frac{AC-B}{A-1}$$

Or

$$Z_0 = e^{\frac{\left(\frac{V(Z_0)}{V(Z)}lnZ - lnZ_R\right)}{\left(\frac{V(Z_R)}{V(Z)} - 1\right)}} \quad \text{.....................(3.4)}$$

Using wind data at 10 m and 20m for all the sites, Z_o for all the months for a station can be determined by this equation. Once we have Z_o, convert all c values to 100m height using the same expression.

$$C(Z_R) = C(Z)\frac{ln\left(\frac{Z_R}{Z_0}\right)}{ln\left(\frac{Z}{Z_0}\right)} \quad \text{................................(3.5)}$$

Here we took Z as 10m and $Z_R$as 100m.Then proceed to plot the probability and cumulative distribution curve.

3.3.2 Effect of proposed tower height on the velocity

Wind velocity increases with height due to wind shear. Hence, the taller the tower, the higher will be the power available to the rotor. Rate at which the available power increases with height depends on the surface roughness of the ground. Effect of proposed tower height on the velocity at hub height can be found out.

3.3.3 Effect of tower height on the capacity factor

The velocity at 100 m hub height is 7.97 m/s, which means that, the available power is 1.40 times higher than that at 10 and 20 m height. In tune with the increase in velocity, capacity factor of the turbine also improves. Apart from the increase in wind velocity, better matching between the wind spectra and the turbine also improves the capacity factor.

3.3.4 Effect of tower height on the cost

Towers account for around 20 per cent of the total systems cost. At present, cost of every additional 10 m of tower is approximately Rupees 7.5 lakhs. This means that, while we increase the tower height from 10 and 20 m to 100 m, the system cost would shoot up to manifold. This additional cost can be justified by the improvement in system performance. In other words, the optimum tower height has to be designed and work out the wind energy economics in terms of cost per kWh of electricity generated.

3.4 Simulation of the wind data performance using "WERA" model

The Wind Energy Resource Analysis (WERA) program is based on the Analysis of wind regimes and performance of wind energy conversion systems. WERA can be used for:

(1) Analyzing the wind energy potential at a given site.

(2) Estimating the performance of a Wind Energy Conversion System (WECS) at the site.

Present version of WERA has three modules, viz. site, wind turbine and wind pump. The site and wind turbine modules have provision to perform the analysis on the basis of either Weibull or Rayleigh distribution. Pump characteristic study is not included in this investigation. Screenshot of the WERA program is given in fig 3.2

Fig.3.2 Screenshot of WERA programme

3.4.1 Wind resource analysis using WERA

As described earlier, once we have k and C values at 100 m height for all the locations, then we have to find out the performance of wind turbines at these sites. Wind energy conversion systems are wind turbine, generator, inter connection apparatus and control systems and 2MW Enercon, Gamesa, Goudian, Siemens, Sinovel, Suzlon, Vestas technical specifications are given below in Table 3.1.

Table 3.1 Technical specifications of wind turbine.

	ENERCON	GAMESA	GOUDIAN	SIEMENS	SINOVEL	SUZLON	VESTAS
Ratedpower(kw)	2000	2000	2500	2200	3000	2100	2000
Diameter(m)	82	90	90	93	113.3	88	80
Hub height(m)	85	67	80	78	90	80	67
No: of blade	3	3	3	3	3	3	3
Swept area(m^2)	5281	6362	6362	6800	10039	6082	5027
Rational speed(rpm)	6-18	9-19	8.5-16	6-16	7-18	15	16.7
Cut in speed(mps)	2	3	3	4	3	4	4
Cut out speed(mps)	24	21	25	25	25	25	25
Rated speed(mps)	13	15	15	14	11	14	15

Obtained turbine specifications (cut-in wind speed, Rated wind speed, cut out wind speed, rated power) are simulated for studying the performance of the different wind energy conversion systems. A simulation technique called WERA is used to model the data on yearly basis Duration (h) is 8760.screenshot of WERA analysis of wind turbines, wind recourse analysis were given in the fig 3.3

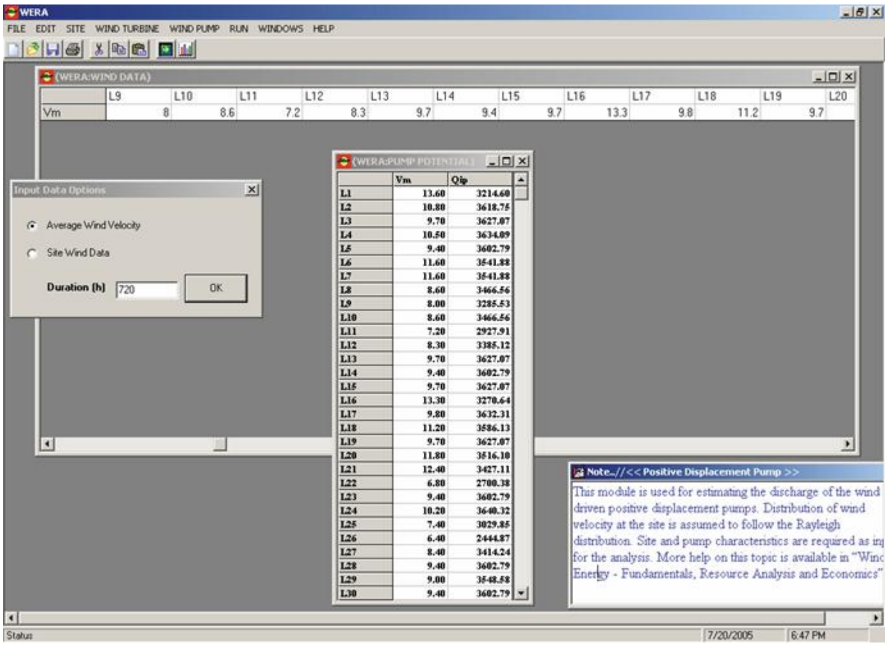


Fig.3.3 Performance analysis of Wind Energy Conversion System using WERA

3.5 Wind Energy Conversion Systems

For the efficient and reliable performance of a WECS, all its components are to be carefully designed, crafted and integrated. Constructional features of WECS giving emphasis to various components, systems and sub-systems are explained.

3.5.1 Wind turbine performance

Electricity generation is the most important application of wind energy today. The major components of a commercial wind turbine are:

1. Tower
2. Rotor
3. High speed and low speed shafts
4. Gear box

5. Generator
6. Sensors and yaw drive
7. Power regulation and controlling units
8. Safety systems

3.6 Economics of wind energy conversion systems

The economic aspect of energy generation also plays a key role in the decision making. With rigorous research and developmental efforts, cost of wind-generated electricity is further falling down. Economic issues of wind energy systems are multidimensional and this has to be obtained by using the software EcoREN. There are several factors that affect the unit cost of electricity produced by a wind turbine. These may vary from country to country and region to region. Economic merit of a wind powered generation plant heavily depends on the local conditions. For making an intelligent investment decision, the net financial return from the project that is being planned for a given energy profile is to be assessed. For this, we have to estimate the costs involved in the generation as well as the benefits expected from the project. Computing the cost is relatively simple and straightforward as it can be determined by adding the fixed and variable costs. However, assessing the benefits is rather a complex process, as the value of electricity generated is influenced by several factors related to the local energy industry.

3.6.1 Factors influencing the wind energy economics

3.6.1.1 Site specific parameters

Energy available in wind spectra is proportional to the cube of the wind speed and this implies that when the speed of the wind at a location doubles, the energy increases by eight times. Hence, the strength of the wind spectra available at the project site is one of the critical factors deciding the cost of wind generated electricity. Cost of land, installation charges and labor wages vary from place to place. Expenditure on foundation depends on the strength of soil profile as well as the extreme loads expected at the site. In case of grid connected systems, a major concern would be the distance from turbine to existing grid as the cost of developing additional transmission network should also be taken into our calculations. Transportation also affects the expenditure. As the wind velocity increases with height, taller towers generally produce more power and hence also the cost. Local climatic conditions like high turbulence also influence the wind energy economics. Further, presence of corrosive and other harmful substances in the atmosphere reduces life span of the turbine. Frequent maintenance may be necessary due to these factors, which in turn would increase the system's operational and maintenance costs.

3.6.1.2 Machine parameters – Effect of cost reduction through scaling up

Cost of the wind turbines can be considerably reduced by scaling up the system size. This means that the cost per kW of a 2 MW machine is lower than that of a 2 kW unit. Unit cost of wind turbines dropped from Rs134130.00 /kW to Rs 40239.00 /kW in the last 20 years. This cost reduction is achieved mainly through scaling up the turbine size. Thus, transition of wind energy technology from small units in the earlier days to the MW capacity machines today, has resulted in reducing the cost of wind-generated electricity.

$$PV(A)1-n = A\left[\frac{(1+i)^n-1}{i(1+i)^n}\right]$$

The discount rate corrected for inflation is termed as the real rate of discount (interest). We will use the real rate of discount in our calculations. The real discount rate (I) can roughly be Taken as the between the nominal Interest rate and inflation. More precisely, I is given by

$$I = \frac{1+i}{1+ea} - 1$$

Where, r is the rate of inflation

The price of some commodities may increase at a rate higher than that of inflation. Electricity is a good example. This increase, which is over and above inflation, may be caused by many factors like scarcity of fuels, international market pressure or political and policy changes. For example, during the years of gulf war, which in turn reflected as the rise in electricity tariff . The increase in the cost of a commodity, in comparison with the general inflation is termed as the escalation (e).

When the escalation rate e is combined with the inflation r, it is termed as the apparent escalation rate, which is given by.

$$ea = \{(1+e) * (1+r)\}\text{-}1$$

3.7 Wind Economics analysis using the computer programme "EcoREN"

One of the major factors limiting the wide spread acceptance of many renewable energy technologies is the high generation cost. However, with today’s technology and institutional support, wind energy is economically competitive with other conventional sources like coal and natural gas. It is cheaper than all other renewable like solar, hydro, biomass and geothermal. With rigorous research and developmental efforts, cost of wind-generated electricity is further falling down. For example, during the past two decades, the cost of wind energy has dropped by more than 80 per cent. It is expected that this trend will continue in the future years also. In this situation analysis of wind energy economics have a prominent role. For the convenient tool for wind energy economics analysis is software which named as **EcoREN .**It is a decision **s**upport system for the economics appraisal of renewable energy projects. The software which developed under the Energy Resource Programme University of Brunei Darusslam. Models based on Sathyajith Mathew, Wind energy: Fundamentals, resource analysis and economics. Springer-Verlag Berlin Heidelberg 2006.The screenshot of the **EcoREN** program were given in fig 3.4

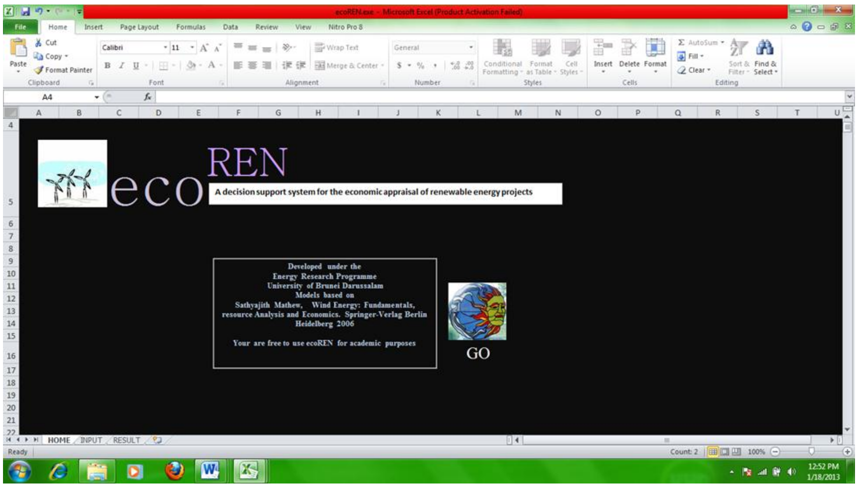


Fig 3.4 Screenshot of **ecoREN** program

CHAPTER IV

4 RESULTS AND DISCUSSION

The results obtained from various investigations conducted under the study are presented and discussed under the following heads.

- **Wind regime analysis**
- **Wind Resource Analysis**
- **Simulation of the wind data performance using "WERA" model**
- **Wind Economics analysis using the computer programme "EcoREN"**

4.1 Wind regime analysis

Kerala is fortunate in that it can boast of balmy weather almost all the year through. Unlike the north, it never gets too cold in the winter months, while the summers do not have the harshness of some of the other parts of the country. Kerala is located between north latitudes 8 degree 18' and 12 degree 48' and east longitudes 74 degree 52' and 72 degree 22'.. Along a sun drenched coastline, to the extreme south west of the Indian peninsula, lies Kerala, beautiful and benign. Flanked by the Arabian sea on the west and the mountains of the Western Ghats on the east, this land stretch north-south along a coast line of 580 km with a varying width of 35 to 120 km.

4.2 Wind Resource Analysis

A national wind energy resource assessment programme was organised and the winds were categorised as very strong, strong, moderate to strong, moderate and light .Geographical details and wind classification of these sites in Kerala are given in Table 4.1.

Table 4.1 Details of the sites selected for wind farm resource analysis

Sl.No	**Location of site**	Latitude (˚N)	Longitude (˚E)	Altitude > MSL (m)	Wind classification	Wind speed (km/h)
1.	Kanjikode	10.47	76.49	130	Strong	22.3
2.	Kottathara	11.65	76.02	529	Moderate to strong	19.4
3.	Ponmudi	8.36	77.00	912	Moderate to strong	18.1
4.	Kottamala	10.85	76.27	700	Moderate to strong	18.7
5.	Tolanur	10.70	76.50	114	Moderate to strong	15.9
6.	Gopalapuram	13.25	80.15	105	moderate	14.7
7.	Kundly	10.49	71.68	95	Light	9.1

4.3 Wind Resource Analysis

Wind velocity and hence wind power is affected by the surface roughness of the ground, wind shear, wind turbulence, acceleration effect and time variation. Effect of proposed tower height on the wind velocity, capacity factor and the cost are analysed and variations are shown below. These parameters will help to detect economically viable and technologically feasible wind energy conversion systems for that location.

4.3.1 Effect of wind velocity over time variation

Collected data has to be shown in graphical format. Velocity can be drawn against time in monthly. From the graph the maximum wind velocity is obtained in the month of June to August and minimum velocity is obtained at the month of October and November. Fig4.1which shows the variation of wind velocity over time of the Kanjikode site.

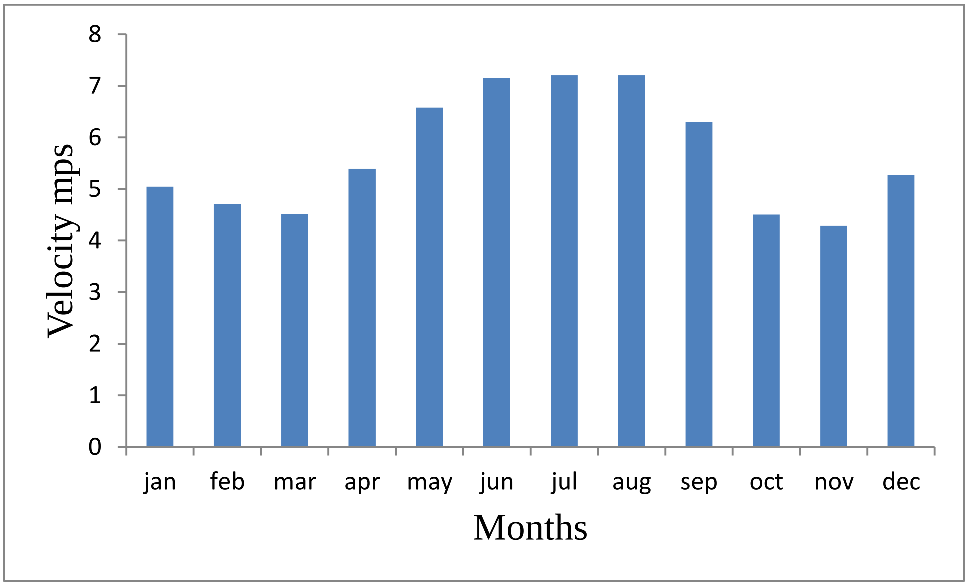


Fig4.1 variation of wind velocity over time of Kanjikode site

The wind data which collected from the seven selected sites were graphically plotted with the probability distribution curve. Weibull distribution is used to study the wind characteristics. The wind characteristic of these sites described by probability density and cumulative distribution function of the prevailing wind spectra in seven locations are shown in Fig. 4.2 through Fig. 4.8

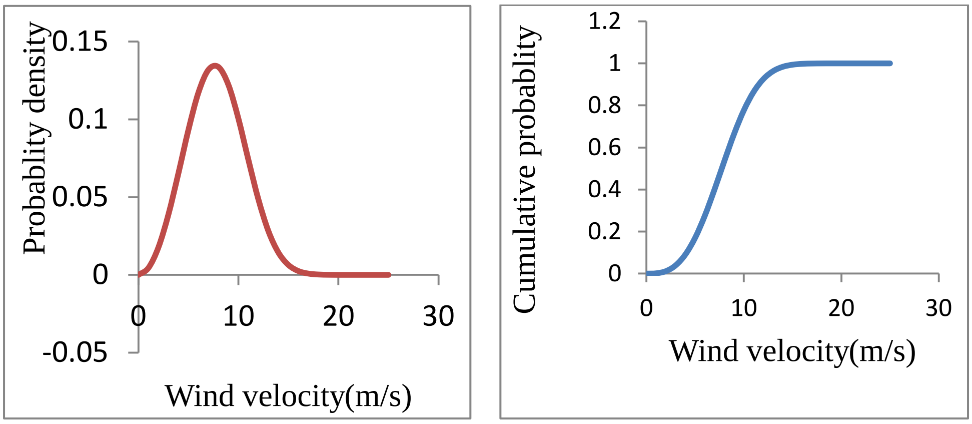


Fig.4.2 Probability and cumulative distribution curves at Kanjikode

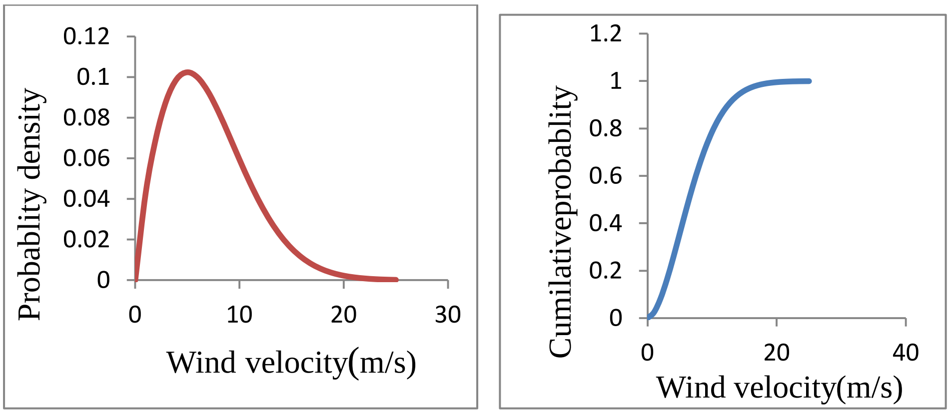


Fig.4.3 Probability and cumulative distribution curves at Kottathara.

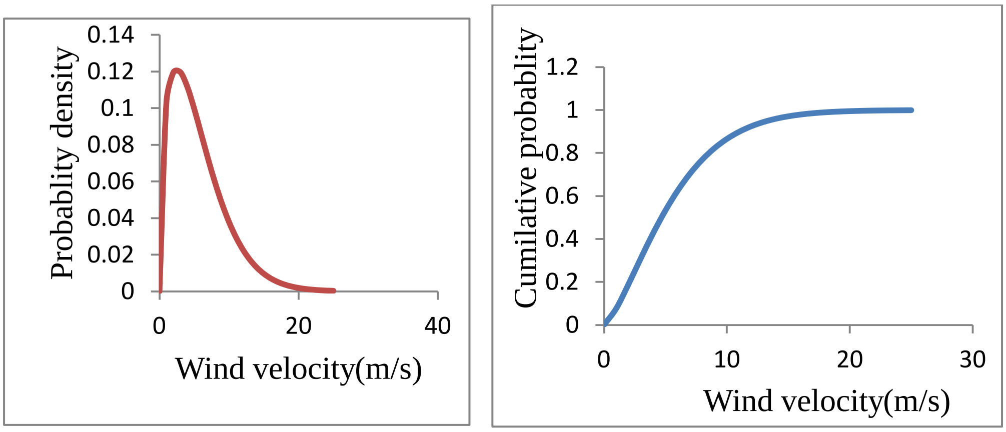


Fig.4.4 Probability and cumulative distribution curves at Ponmudi.

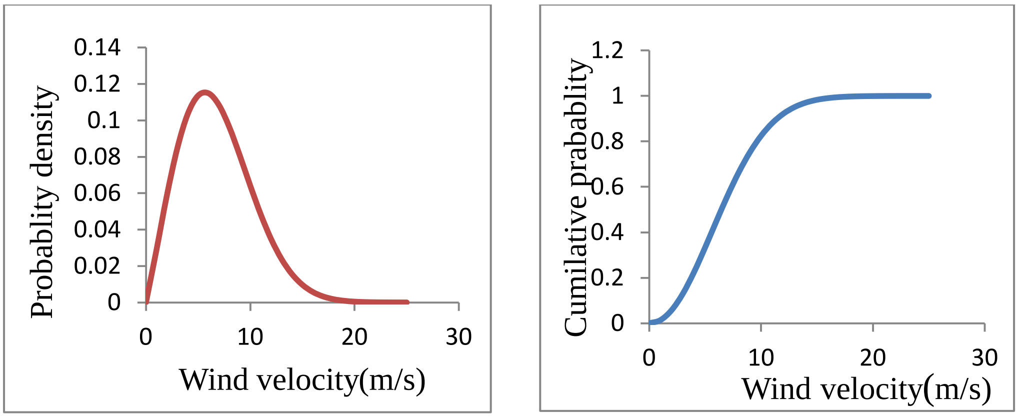


Fig.4.5 Probability and cumulative distribution curves at Kottamala.

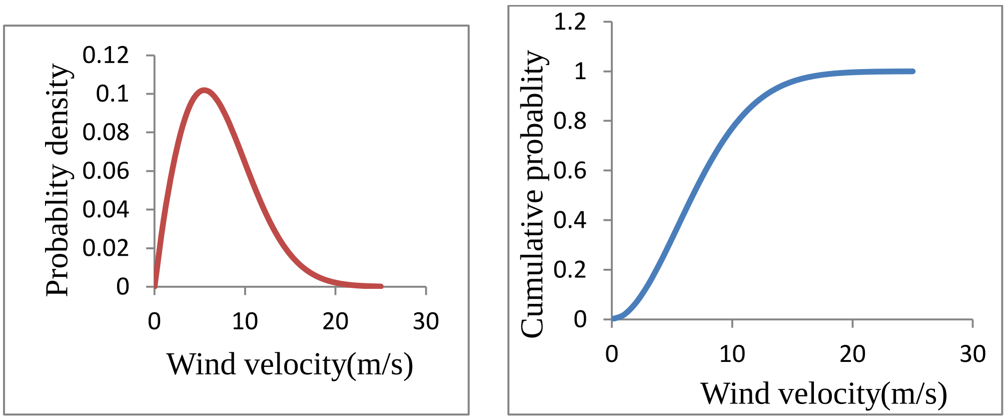


Fig.4.6 Probability and cumulative distribution curves at Tolanur.

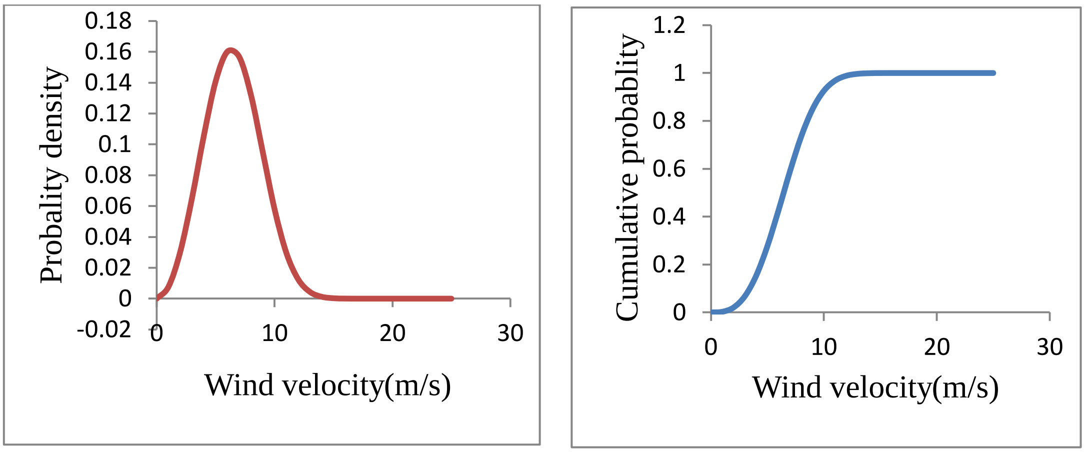


Fig.4.7 Probability and cumulative distribution curves at Gopalapuram.

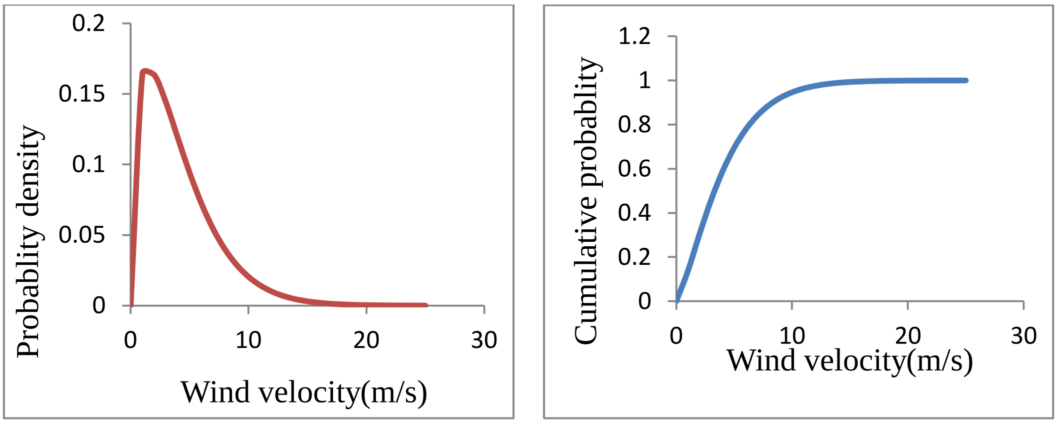


Fig.4.8 Probability and cumulative distribution curves at Kundly.

Peak of the probability density curve indicated the most frequent wind velocity at the regime. Similarly, the cumulative distribution functions tell us the fraction of time for which the velocity is above a given value in the regime. Indication on the time for which a given turbine is functional could be deduced from the cumulative distribution function. From the above plotted graph, it is indicated that Weibull distribution curves of these sites showed the wind energy content of the locations. Maximum energy density is found to be at

Gopalapuram (0.16kW/m^2) and minimum at Tolanur and Kottathara (0.1kW/m^2). Depending on the Weibull scale and shape factors, it is suggested that the rated wind speed will be about twice the average wind speed for regimes with k = 2. In trade winds with higher k, V_R may be 1.3 times mean wind velocity (V_m).

4.3.2 Variation of wind velocity on the power

The wind velocity is the one of the major component which affects the power generation from the wind turbine. The wind velocity of a location mainly depend on the topographical features of the land such as the obstructions, surface friction etc .The generation of the power is the cube power of wind velocity. When the velocity which doubles the generation of power is to be increased for 8times.The power curve which plotted in the Fig 4.9

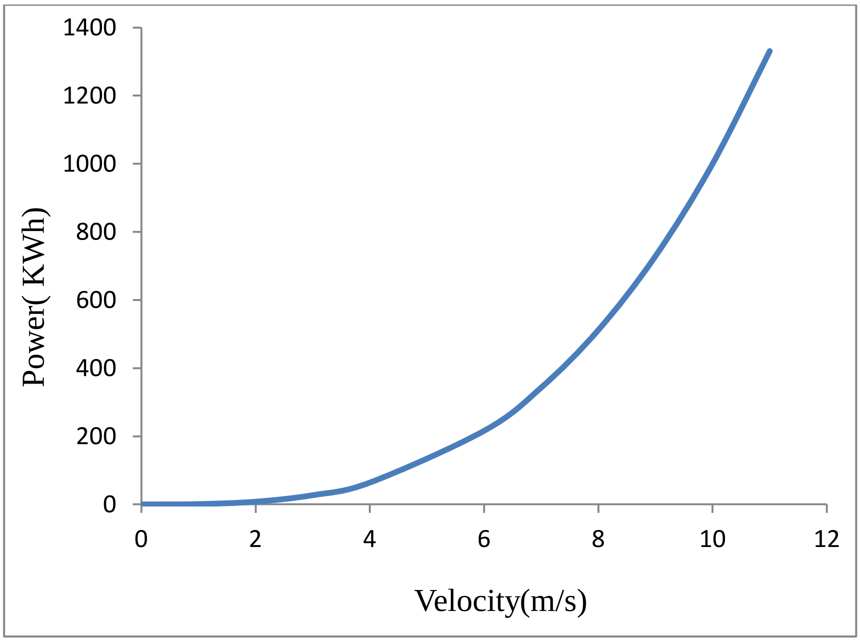


Fig 4.9 Variation of wind velocity on the power

For example the velocity at 4mps is 64 KWh, when velocity doubles the power become 512KWh.

4.3.3 Estimation wind velocity at different locations at 100m height V (Z_R)

The wind velocity for 10m and 20m height are to be converted to corresponding values for 100m height. Both the velocity at 10m and 100m are tabulated in table 4.2 and graphically represented in Fig. 4.10. From the graph it is evident that wind velocity increases with the turbine hub height.

Table 4.2 Velocity of wind V (Z_R) at 100m height of the selected sites.

Sl.No	Locations	Velocity at 10 m	Velocity at 100m
1	Kanjikode	5.69	7.97
2	Kottathara	4.94	6.38
3	Ponmudi	5.12	5.57
4	Kottamala	4.72	6.52
5	Tolanur	3.56	6.39
6	Gopalapuram	2.81	5.59
7	Kundly	2.17	3.55

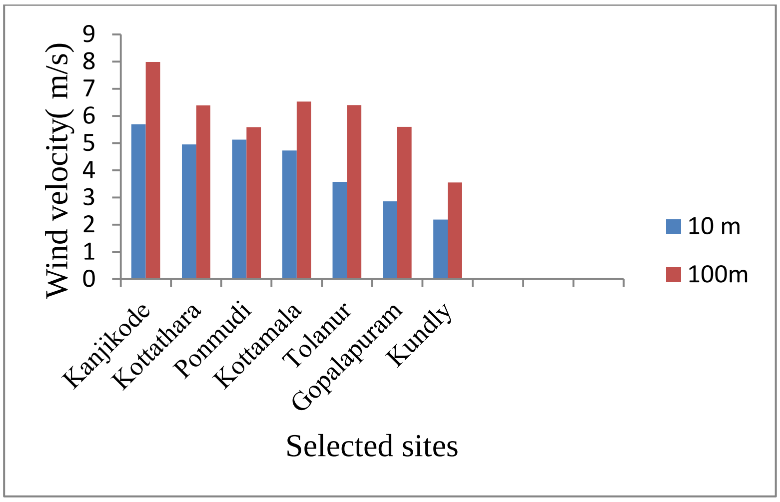


Fig4.10 Wind velocity at different height of selected sites.

4.3.4 Estimation of scale factor C (Z_R) at 100m height

Scale factor C (Z_R) at 100m height has been estimated, based on the wind data at 10m and 20m height. They are tabulated in Table 4.3 and graphically represented in Fig.4.11

Table 4.3 Scale factor C (Z_R) at 100m height for the selected sites.

Sl.No	Site	C(Zr) at 10 m	C(Zr) at 100 m
1	Kanjikode	6.77	8.73
2	Kottathara	5.57	7.86
3	Ponmudi	5.38	6.06
4	Kottamala	5.53	7.68
5	Tolanur	4.888	8.15
6	Gopalapuram	4.13	7.27
7	Kundly	2.66	4.38

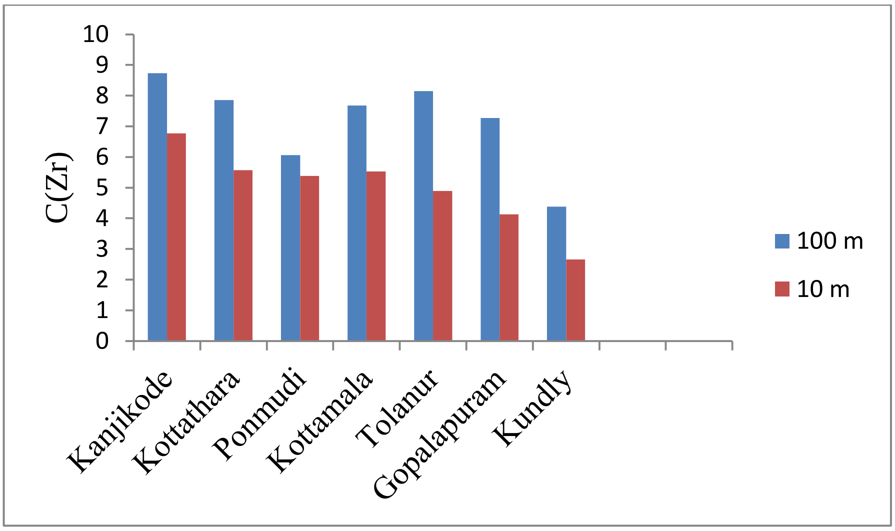


Fig4.11 Scale factor at different height of selected sites.

4.3.5 Effect of proposed tower height on the velocity

Velocity at hub height is plotted against tower height and displayed in Fig. 4.12. Here we can observe that taller the tower, higher will be the velocity harnessed by the turbine. Due to boundary layer effect, wind speed increases with the height in a logarithmic pattern. Wind velocity increases with height up to 20m and above that surface influence is rather feeble. From the graph, we can observe that at 100 m hub height velocity is 1.29times greater than at 10m.

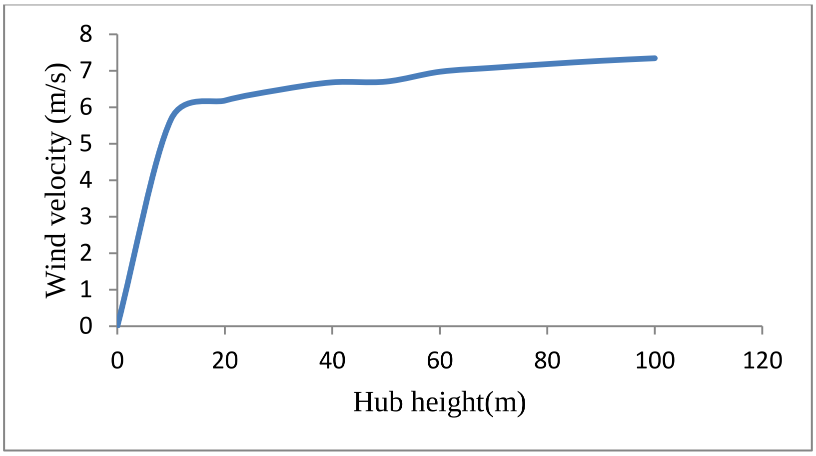


Fig. 4.12 Variation of wind velocity with hub height.

4.3.6 Variation of capacity factor on the tower height

In tune with the increase in wind velocity, capacity factor of the turbine also improves as shown in Fig. 4.13.Apart from the increase in wind velocity, better matching between the wind spectra and the turbine also improves the capacity factor. When we compare both 10m and 100m, we can perceive a clear distinction of 40-60 % hike in capacity factor. The capacity factor reflects how effectively the turbine could harness the energy available in the wind spectra. A capacity factor of 0.4 or higher indicates that the system is interacting with the regime very efficiently and it is well understood after 90m of tower height.

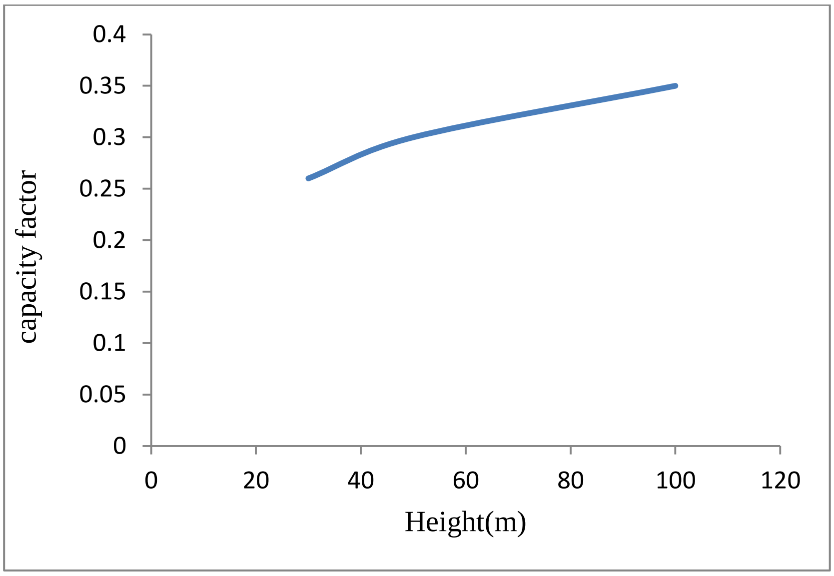


Fig 4.13 Variation of capacity factor on the tower height.

4.3.7 Effect of cost on the tower height

At present, cost of every additional 10 m of tower is approximately Rupees 7.5 lakhs. This means that, while we increase the tower height from 10 and 20 m to

100 m, the system cost would shoot up to manifold. Towers account for around 20 per cent of the total systems cost. This additional cost can be justified by the improvement in system performance. In other words, the optimum tower height has to be designed and work out the wind energy economics in terms of cost per kWh of electricity generated.

4.4 Wind Energy Resource Analysis at the Selected Sites Using WERA model

The energy potential of wind spectra available at 7 prospective sites were analyzed using the WERA model. The Weibull parameters k and C are displayed along with mean wind velocity and standard deviation of seven sites in Table 4.4

Table 4.4 Wind characteristics of the selected sites

Location	Mean velocity(m/s)		S D (σV) (m/s)		Weibull shape factor (k)	Scale Factor (C)
	10m	20m	10m	20m		
Kanjikode	5.69	6.19	2.08	2.12	3	8.73
Kottathara	4.94	5.38	2.29	2.47	1.8	7.86
Ponmudi	5.12	5.26	2.91	2.88	1.4	6.08
Gopalapuram	2.88	3.55	1.35	1.57	3	7.27
Kottamala	4.72	5.26	2.49	2.07	2.1	7.68
Tolanur	3.57	4.28	2.15	2.21	1.3	8.15
Kundly	2.18	2.51	1.57	1.86	1.3	4.38

In order to simulate the performance of the turbines for the seven sites the WERA wind turbine module was used. Technical specifications of the turbines in terms of cut-in, cut-off and rated velocity along with rated capacity were punched in to turbine specification forms of the programme. Results of this analysis are shown in Table 4.5. Screen shot of this analysis is shown in Fig.4.14.

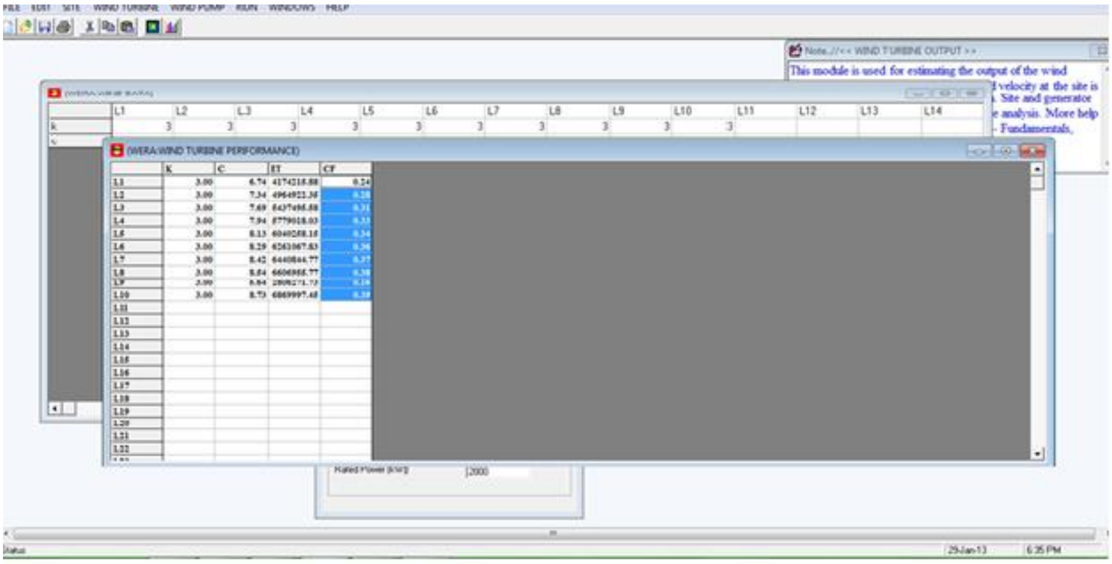


Fig 4.14 Screenshot of WERA analysis

4.5 Wind Economics analysis using the computer programme "Eco-REN"

Economic analysis of every energy resource is mainly focused on its beneficial side in future. As the capital investment required for WECS is proportional to the rotor area, this will increase the unit cost of energy produced. By using the computer programme "Eco-REN" for the wind economics study is more convenient and accurate. Different input parameters like rated power, capital investment, lifespan, capacity factor, operation and maintenance cost, discounting rate and electricity cost are used to produce the outcome. We acquire the output in the form of Net present value, Benefit cost Ratio, Payback period. From this output, the liability of the wind energy consumption of the particular location can be interpreted. By doing the Wind Economics analysis using the computer programme "EcoREN" for different wind energy conversion systems at seven selected sites were tabulated below in the Table 4.5 and some of the screen shots of **ecoREN** were given in fig4.15 and fig4.16.

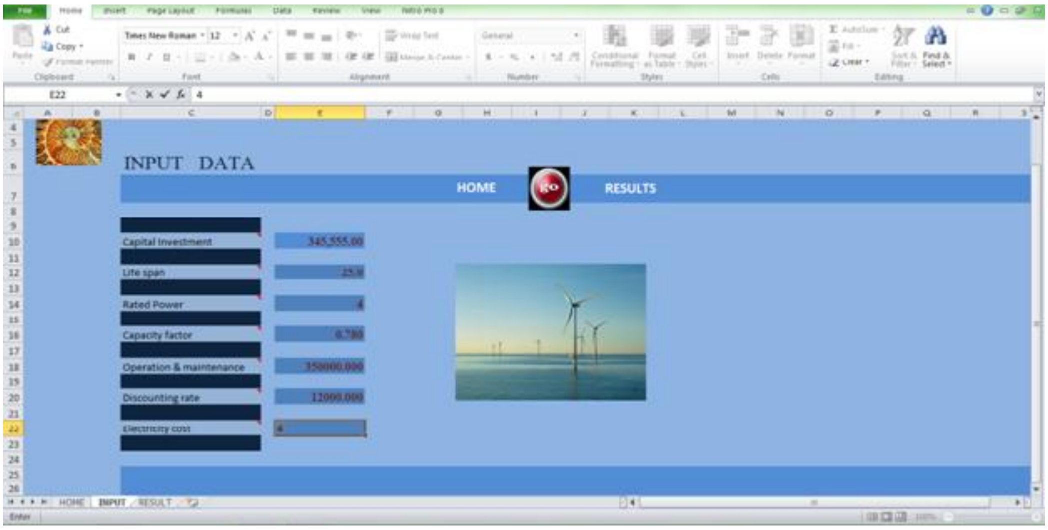


Fig. 4.15 Screen shot of input data window of **Eco-REN**

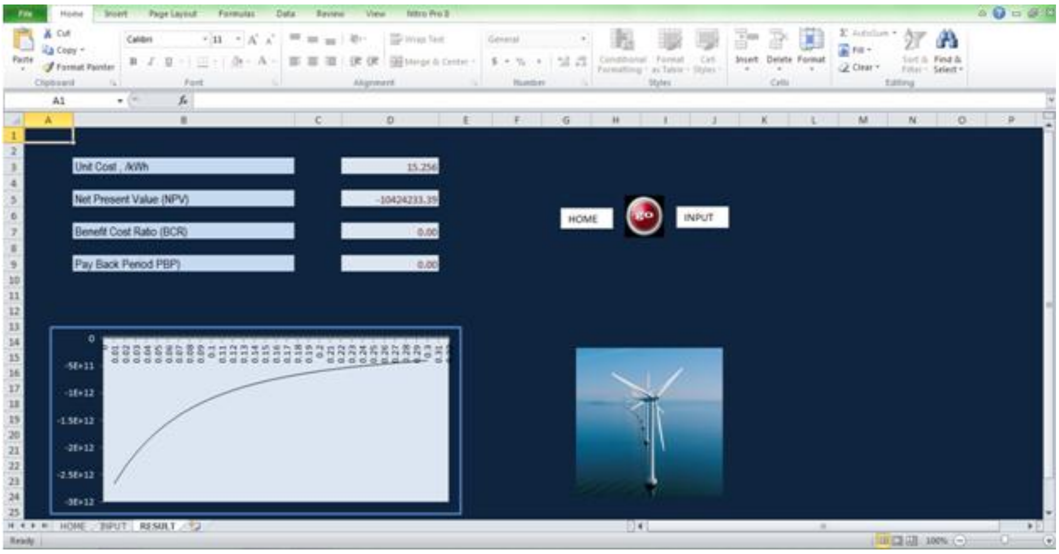


Fig. 4.16 Screen shot of output window of **Eco-REN**

CHAPTER V

5 SUMMARY AND CONCLUSION

Fossil fuel based power plants, contributing more than seventy per cent to our energy needs today, dominate the global energy scenario. These plants pollute the atmosphere with harmful gases and particulates. As per the estimates of the International Energy Agency (IEA), 23683Mt of CO has been released to the atmosphere by the power sector during 2010. With the increase in energy demand, level of environmental pollution caused by the power sector is expected to increase further in the coming years. Hence a clean energy policy has to be evolved for the sustainable world.

In contrast, wind energy does not pollute the air or water with harmful gases and materials. Nor does it generate hazardous wastes, which cannot be safely disposed as in case of nuclear power plants. Being a non depletable source, extracting energy from wind does not pose the threat of over exploiting the limited natural resources like coal, oil or natural gas. Hence wind is considered as one of the cleanest sources of energy available today.

The wind regime analysis of seven selected sites was done. The WERA model has been validated using wind data of seven selected sites. From wind farm, Kerala. The energy yield is maximum estimated as 8437421 MWh for wind site at Kanjikode. Economics of wind energy conversion systems at these sites was estimated using the software called 'Eco-REN'. Based on economic viability, the 3MW turbine was finally selected for the wind farm activity. The sites were selected as Kanjikode because it is economically liable and technically feasible at this site. It was found that the cost of wind energy that can be tapped on a kWh basis ranges from Rs.0.28 to Rs 0.82 from out of the seven leading wind turbines company in the world. The economical side the Kanjikode is suited to its minimum capital investment by comparing with the other sites for every wind turbines. While in the case of payback period it is within the range of 2-5 years for Kanjikode. Then we easily conclude that Kanjikode more preferable for installing wind turbine due to its high wind velocity compare with other seven sites.

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Table 5.1 Result of EcoREN anlaysis

		KANJIKODE	TOLANUR	PONMUDI	KOTTAMALA	KOTTATHARA	GOPALAPURAM	KUNDALY
ENERCON	Unit cost/kwh	0.502	0.506	0.843	0.621	0.590	0.625	1.389
	NPV(crore)	31.43	26.99	14.54	23.43	25.21	20.77	47.7
	BCR	4.04	3.61	2.49	3.27	3.47	3.01	1.46
	PBP	3.18	3.63	5.93	4.08	3.84	4.50	11.99
GAMESA	Unit cost/kwh	0.814	0.874	1.312	0.984	0.944	1.124	2.16
	NPV(crore)	15.43	13.65	56.59	10.99	11.88	86.32	-14.82
	BCR	2.49	2.32	1.55	2.06	2.15	1.81	0.86
	PBP	5.68	6.22	10.96	7.26	6.88	8.73	40.76
GOUDIAN	Unit cost/kwh	0.394	0.472	0.694	0.492	0.492	0.512	1.124
	NPV(crore)	42.99	34.10	19.88	32.32	32.32	30.54	83.25
	BCR	5.16	4.30	2092	4.13	4.13	3.95	1.81
	PBP	2.42	2.97	4.66	3.11	3.11	3.26	8.73
SIEMENS	Unit cost/kwh	0.587	0.642	1.027	0.733	0.684	0.893	1.866
	NPV(crore)	25.43	22.37	10.10	18.28	20.32	13.17	90.33
	BCR	3.46	3.16	1.98	2.77	2.97	2.27	1.09
	PBP	3.81	4.24	7.69	4.98	4.58	6.35	20.59
SINOVEL	Unit cost/kwh	0.286	0.342	0.508	0.366	0.358	0.394	0.87
	NPV(crore)	62.99	50.99	30.99	46.99	48.32	42.99	13.65
	BCR	7.09	5.93	4.0	5.54	5.67	5.16	2.32
	PBP	1.71	2.02	3.22	2.23	2.18	2.42	6.22
SUZLON	Unit cost/kwh	0.642	0.703	1.12	0.803	0.730	0.978	2.044
	NPV(crore)	22.32	19.52	83.25	15.79	17.65	11.12	-7.450
	BCR	3.14	2.89	1.81	2.53	2.71	2.08	0.99
	PBP	4.24	4.73	8.73	5.5	5.12	7.20	23.46
VESTAS	Unit cost/kwh	0.732	0.814	1.312	0.944	0.874	1.124	2.146
	NPV(crore)	18.10	15.43	56.59	11.88	13.65	83.25	-5.63
	BCR	2.75	2.49	1.35	2.15	2.32	1.81	0.95
	PBP	5.02	5.68	10.96	6.88	6.22	8.73	29.5

Table 4.5 Result of WERA analysis

Wind turbine and its specification			Suzlon S 88 2.1 MW		Vestas-V 80 2MV		Enercon-E 82 2Mw		Sinovel-SL3000/113		Siemens-SWT2.3		Goudian-UP96		Gamesa-G90 2MW	
			V_I=4 V_O=25 V_R =15, $P_R = 2000$		V_I=4 V_O=25 V_R=15, $P_R = 2000$		V_I=2 V_O=25 V_R=13 , $P_R = 2050$		V_I=3 V_O=25 V_R= 11, $P_R = 3000$		V_I=3, V_O=25 V_R=11, $P_R = 3000$		V_I=3 V_O=25 V_R= 10.1, $P_R = 2000$		V_I=3 V_O =21 V_R= 17, $P_R = 2000$	
Site	K	C	ET	CF	ET	CF	ET	CF	ET	CF	ET	CF	ET	CF	ET	CF
Kanjikode	3	8.73	6471750.78	0.35	5522299.79	0.32	8437421.51	0.47	14349766.04	0.55	7088108	0.35	10563939.37	0.6	5121025.68	0.29
Kottathara	1.8	7.86	5486143.35	0.3	4756807.82	0.27	7104919.77	0.4	11526265.59	0.44	6008633	0.3	8365951.61	0.48	4430576.53	0.22
Ponmudi	1.4	6.08	3713905.51	0.2	3220761.15	0.18	5103944.17	0.28	8092876.88	0.31	4067611	0.2	5911144.75	0.34	3068876.33	0.18
Kottamala	2.1	7.68	5118464.55	0.28	4394380.43	0.25	6894721.14	0.38	11343295.11	0.43	5605937	0.28	8331803.9	0.48	4163555.11	0.24
Tolanur	1.9	8.15	5811154.93	0.32	5035518.61	0.29	7464984.44	0.42	12160865.04	0.46	6364598	0.32	8820002.85	0.5	4676124.93	0.27
Gopalapuram	3	7.27	4280862.29	0.23	3640467.87	0.21	6311448.92	0.35	10573923.71	0.4	4688563	0.23	7994238.93	0.46	3612237.22	0.21
Kundaly	1.3	4.38	1984969.92	0.11	1704070.3	0.1	3049575.43	0.17	4853006.81	0.18	2174015	0.11	3611495.23	0.21	1747006.35	0.1

APPENDIX I

Probability Density and Cumulative Density of the site Kanjikode

Wind Velocity	Probability Density	Cumulative Density
0	0	0
1	0.00450221	0.001501865
2	0.017820364	0.011951954
3	0.038967002	0.039768464
4	0.065527412	0.091710048
5	0.09341697	0.171281096
6	0.117324509	0.277217347
7	0.131942311	0.402814186
8	0.133676349	0.536770639
9	0.122099701	0.665688699
10	0.100308212	0.777536909
11	0.07380134	0.864730354
12	0.048361836	0.92551621
13	0.028047295	0.963193396
14	0.014295866	0.983823824
15	0.006357065	0.993733924
16	0.002447299	0.99787984
17	0.000809198	0.999379019
18	0.000227946	0.99984397
19	5.42535E-05	0.999966669
20	1.08194E-05	0.999994001
21	1.79256E-06	0.999999099
22	2.4464E-07	0.999999888
23	2.7266E-08	0.999999989
24	2.46034E-09	0.999999999
25	1.78182E-10	1

APPENDIX II

Probability Density and Cumulative Density of the site Tolanur

Wind Velocity	Probability Density	Cumulative Density
0	0	0
1	0.034632952	0.018398163
2	0.06143033	0.066956894
3	0.08164565	0.139066162
4	0.094858737	0.227907732
5	0.101154091	0.326470997
6	0.101201954	0.428128269
7	0.096128478	0.527164923
8	0.087317597	0.619138877
9	0.076206673	0.701034827
10	0.064114641	0.771227895
11	0.052124018	0.829301258
12	0.041022651	0.87577573
13	0.031298878	0.911808729
14	0.023176241	0.938909508
15	0.016671154	0.958701965
16	0.011658104	0.972750045
17	0.007930649	0.982447033
18	0.005251051	0.988960564
19	0.003385684	0.993220245
20	0.002126615	0.995933622
21	0.001301763	0.997617787
22	0.000776814	0.998636729
23	0.000452032	0.999237816
24	0.000256568	0.99958365
25	0.000142076	0.99977776

APPENDIX III

Probability Density and Cumulative Density of the site Gopalapuram

Wind Velocity	Probability Density	Cumulative Density
0	0	0
1	0.007787315	0.002599152
2	0.030586929	0.020605043
3	0.065500305	0.067856471
4	0.105755001	0.153429936
5	0.140985564	0.277701663
6	0.160207496	0.430016465
7	0.15668683	0.590439192
8	0.131826054	0.73618271
9	0.094850219	0.850019327
10	0.057843018	0.925914551
11	0.029574534	0.968694942
12	0.012525036	0.988859659
13	0.004337185	0.996712973
14	0.001211494	0.999208325
15	0.000269184	0.999846768
16	4.69012E-05	0.999976535
17	6.31559E-06	0.999997201
18	6.47658E-07	0.999999744
19	4.98337E-08	0.999999982
20	2.83427E-09	0.999999999
21	1.17369E-10	1
22	3.48562E-12	1
23	7.31163E-14	1
24	1.06691E-15	1
25	1.06653E-17	1

APPENDIX IV

Probability Density and Cumulative Density of the site Kundaly

Wind Velocity	Probability Density	Cumulative Density
0	0	0
1	0.164576118	0.136345969
2	0.163525776	0.30297202
3	0.143756022	0.4574214
4	0.118763163	0.588815487
5	0.094158912	0.695109831
6	0.07238403	0.778093319
7	0.054281383	0.841110761
8	0.039865848	0.887889317
9	0.028754051	0.92194526
10	0.020409817	0.946320049
11	0.014279437	0.963502234
12	0.009859707	0.97544824
13	0.006725828	0.983649322
14	0.004536588	0.989213914
15	0.003027821	0.992948593
16	0.002000873	0.995429577
17	0.001309883	0.997061872
18	0.000849916	0.998126011
19	0.000546805	0.998813741
20	0.000348953	0.999254529
21	0.000220965	0.999534809
22	0.000138879	0.999711674
23	8.66622E-05	0.999822465
24	5.37043E-05	0.999891378
25	3.3058E-05	0.999933951

APPENDIX V

Probability Density and Cumulative Density of the site Ponmudi

Wind Velocity	Probability Density	Cumulative Density
0	0	0
1	0.103267541	0.076789335
2	0.119537266	0.190105786
3	0.119665287	0.310623205
4	0.111642061	0.426754274
5	0.099534767	0.532562254
6	0.08582387	0.625299243
7	0.072061146	0.704199487
8	0.059177503	0.769719261
9	0.047674822	0.82301802
10	0.037762336	0.865601065
11	0.02945763	0.899079892
12	0.022661172	0.925019758
13	0.017209914	0.944850913
14	0.012914334	0.959824824
15	0.009582668	0.971000739
16	0.007035562	0.97925145
17	0.005113855	0.985280067
18	0.00368167	0.989642073
19	0.002626474	0.992768829
20	0.001857367	0.994990172
21	0.001302467	0.996554787
22	0.000905969	0.997647761
23	0.000625258	0.998405205
24	0.000428267	0.998926092
25	0.000291193	0.99928164

APPENDIX VI

Probability Density and Cumulative Density of the site Kottamala

Wind Velocity	Probability Density	Cumulative Density
0	0	0
1	0.028638849	0.013732269
2	0.058660934	0.057556667
3	0.084619697	0.129683226
4	0.103480031	0.224414243
5	0.113627355	0.333722482
6	0.114899533	0.448695986
7	0.108418934	0.560927176
8	0.096203843	0.663618036
9	0.080664039	0.752227861
10	0.064114144	0.824614729
11	0.048413224	0.88074645
12	0.034784015	0.922139066
13	0.023805766	0.951204053
14	0.015531816	0.970655908
15	0.009666251	0.98307234
16	0.005740902	0.99063544
17	0.003254833	0.995033228
18	0.001762003	0.997475089
19	0.000910934	0.998770022
20	0.000449802	0.999425979
21	0.00021215	0.999743409
22	9.5581E-05	0.999890164
23	4.11354E-05	0.999954985
24	1.69113E-05	0.99998234
25	6.64118E-06	0.999993369

APPENDIX VII

Probability Density and Cumulative Density of the site Kottathara

Wind Velocity	Probability Density	Cumulative Density
0	0	0
1	0.042943198	0.024151353
2	0.070366105	0.081609054
3	0.088817939	0.161907864
4	0.099177811	0.256545144
5	0.102400854	0.357880806
6	0.099751477	0.459387089
7	0.09269515	0.555914436
8	0.082730643	0.643809374
9	0.071238364	0.72086904
10	0.059373235	0.786165001
11	0.048009462	0.839785887
12	0.037732309	0.882549068
13	0.028865297	0.915722929
14	0.021518993	0.940788291
15	0.015648428	0.959253924
16	0.011109018	0.972529425
17	0.007704398	0.981850376
18	0.005223016	0.988245845
19	0.003463	0.992536583
20	0.002246647	0.99535272
21	0.001426753	0.997161679
22	0.000887273	0.99829938
23	0.000540514	0.9990002
24	0.000322651	0.999423164
25	0.000188781	0.999673342

MODELLING THE PERFORMANCE OF WIND ENERGY CONVERSION SYSTEM AT POTENTIAL WIND FARM SITES IN KERALA

By

DHANMON FRANCIS

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ABSTRACT OF A PROJECT REPORT

Submitted in partial fulfillment of the requirement for the degree

Bachelor of Technology
In
Agricultural Engineering

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ABSTRACT

As the level of energy use is closely correlated with the development, availability of energy resources and its efficient use play a key role in the holistic prosperity of communities and Nations. It has been identified that the excessive use of energy which is mainly derived from fossil fuels today can cause irreversible environmental effects and the demand for the energy increased dramatically. With this energy crisis and growing environmental consciousness, the global perspective in energy generation and consumption is shifting towards sustainable resources and technologies. Hence wind energy is going to be the major player in realizing our dream of meeting a major share of the global energy demand from renewable and sustainable resources. India ranks fifth in the world in terms of global wind power capacity. The power scenario in Kerala is unique. Though Kerala has an estimated wind power potential of 1000 MW at 50 m level and the installed capacity in the state is only 32 MW. Hence, it is high time that the power base of the state has to be strengthened by taking initiatives to exploit available renewable energy resources like wind.

The wind data available at these meteorological stations have been logged from different sensor heights (10m and 20m) of seven sites in Kerala and the wind data convert for 100m height. The Wind Energy Resource Analysis (WERA) program is based on the Analysis of wind regimes and performance of wind energy conversion systems. WERA can be used for analyzing the wind energy potential at a given site and estimating the performance of a Wind Energy Conversion System (WECS) at the site. For the convenient tool for wind energy economics analysis is a software which named as **EcoREN .**It is a decision **s**upport system for the economics appraisal of renewable energy projects. Different input parameters like rated power, capital investment, life span, capacity factor, operation and maintenance cost, discounting rate and electricity cost are used to produce the outcome

The sites were selected as kanjikode because it is economically liable and technically feasible at this site. Because of the high wind velocity at this site. It was found that the cost of wind energy that can be tapped on a kWh basis ranges from Rs.0.28 to Rs 0.82 from out of the seven leading wind turbines company in the world. The economical side the kanjkode is suited to its minimum capital investment by comparing with the other sites for every wind turbines. While in the case of payback period it is within the range of 2-5 years for kanjikode. Then we easily conclude that kanjikode more preferable for installing wind turbine due to its high wind velocity compare with other seven sites