COMPUTER AIDED DESIGN OF A STAND ALONE AERO GENERATOR

By

Gawas Narayan Dasharath
Mayarani. N
Vijaya Gandheevam . V

PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree

BACHELOR OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering & Technology
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Department of Farm Power Machinery and Energy
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING & TECHNOLOGY
TAVANUR - 679 573
MALAPPURAM

1999

DECLARATION

We hereby declare that this project report entitled **"Computer Aided Design of a Stand Alone Aero Generator"** is a bonafide record of project work done by us and this work has not previously formed the basis for the award to us of any degree, associateship, fellowship or other similar title of any other university or society.

Gawas Narayan Dasharath

Mayarani. N

Vijaya Gandheevam. V

Tavanur

6-4-1999

CERTIFICATE

Certified that this project report, entitled **"Computer Aided Design of a Stand Alone Aero Generator"** is a record of project work done jointly by Gawas Narayan Dasharath, Mayarani. N, Vijaya Gandheevam. V under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

Sathyajith Mathew
Assistant Professor
Department of FPME
KCAET, Tavanur.

Assistant Professor.
AICRP on Energy Requirement in Agrl. Sector,
KCAET, Tavanur - 679 573

Tavanur

6-4-1999

OFFICE OF THE DEAN, KELAPPAJI COLLEGE OF AGRL. ENGG & TECH. ★
KERALA AGRL. UNIVERSITY
6 APR 1999
TAVANUR

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A word of thanks is also due to N.C.C Computer Centre, Kuttippuram for their neat typing and prompt service during the preparation of the final report.

Above all we bow our head before god almighty for all blessings showered upon us.

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SYMBOLS AND ABBREVIATIONS

Ac	Alternating Current
AM	Asynchronous Machine
c	Weibull Scale Parameter
Cp	Coefficient of Power
C_D	Drag Coefficient
CL	Lift Coefficient
CM	Compter Machine
Cq	Coefficeint of Torque
DC	Direct Current
E	Energy
et al.	and others
etc.	et cetera
fig,	Figure
f(v)	Probablity Density Function
F(v)	Cumulative Distribution Function
ie	That is
Kg	Kilogram
Kg/M3	Kilogram Per Cubic Metre
m	Metre
m2	Square metre
No	Number
p	Power
k	Weibull Shape Factor
PO	Power Output
R	Radius of Blade
R_1	Radius of Brake Drum
rpm	Revolutions Per Minute
S	Slip
V	Average Monthly Velocity
V'	Average Wind Velocity

Vi	Initial Wind Velocity
Vo	Final Wind Velocity
Vm	Mean Average Wind Velocity
Viz	Namely
Ws	Speed of the stator field
Wm	roror speed
π	Pie (22/7)
λ	tip speed ratio
0	degree
ρ	Mass density
Ω	Angular Velocity
β	Number of Blades

CHAPTER 1
INTRODUCTION

In the present day's world, the economic well being and the quality of life are closely related to the availability of energy. Owing to the pressure from the ever escalating rate of population and per capita energy consumption level, global energy demand has increased drastically in the recent years. On the other hand, by now, it is evident that our fossil fuel reserve will completely be drained out in the coming 50 to 60 years. Over and above, as the fossil fuel reserves are concentrated at some parts of the world, changes in political equation in these areas will also tamper the dynamics of energy demand and supply. All these factors acted as a catalyst in propelling nations towards long term energy solutions through conservation and exploitation of new and Renewable sources.

We are confronted today with the environmental consequences of the aggregation of CO_2 in the atmosphere through the combustion of fossil fuels. Each EJ conventional fossil fuel (taking average combination pattern), releases through the combustion 19.7 million tons of carbon dioxide to the atmosphere. It should be noted that by the year 2060 , the total accumulative consumption of fossil fuels , would reach a total of 50,000 EJ. Worldwide studies reported so far indicate that 60% of the carbon dioxide thus released is retained in the atmosphere. Working on this assumption , if all liquid and gas fossil fuel resources were to be burnt , 520 giga tons of carbon dioxide would be released in the atmosphere. This would raise the present level of CO_2 by about 40%. If the coal resources were also consumed, it raises the level of CO_2 to three times the present.

It is also estimated that the doubling of CO_2 is about the threshold we dare not cross. But at this rate we would have reached that point already by the middle of the next century. Therefore we have to plan our energy strategies in a manner so that we do not cross the possibly irreversible doubling threshold. Or in other words the process of substitution of fossil fuels with other non-polluting sources of energy must be commenced in the shortest possible time.

Most of the developing countries are poor in conventional fossil fuel resources and have to import them at the expense of their foreign exchange reserves. Such countries are confronted with a multitude of complex problems involving population growth, economics, energy and development. All these problems are interrelated and they have been seriously aggreviated by the unprecedented increase in the oil prices of the recent past. All reasonable solutions to alleviate these problems involve sharp increases both in the amount of energy consumed and in the efficiency of their use. Hence, owing to present days energy crisis, growing environmental concern and constantly escalating most of fossil fuels, scientists, engineers and policy makers all over the world are making every effort to supplement our energy base by renewable sources.

Renewable energy is obtained from the continuous or repetitive currents of energy occurring in the natural environment. Wide varieties of renewable energy sources are available for exploitation. The technologies to tap these energy sources in relation with end users are at different stages of commercialization.

The energy associated with wind is enormous. Wind energy has been exploited even from ancient times for various purposes. The wind derives the energy from the solar radiation that reaches the earth's surface. Uneven heating of the earth from the equator to the poles and over the oceans and the continents drives the motions of the atmosphere. Large quantities of energy are constantly transferred to wind from the sun. It has been estimated that the total power capacity of the wind surroundings the earth is of the order of 10 giga watts.

In India, systematic efforts for wind energy utilization began as far back as 1952 with the formation of a Wind Power Subcommittee under the Council of Scientific and Industrial Research. Wind Power Subcommittee endorsed the manufacture of 200 windmills and their installations by the end of Second

FiveYear Plan. Although as a whole large scale power generation from wind in the state is not economically viable except in few potential sites, it is felt that there is tremendous scope for small scale aerogeneration in the power range of 0.25 to 1 kW. Development of wide spread adoption of such systems are expected to bridge the gap between todays power availability and demand in the state.

In 1959, National Aeronautical Laboratory, Bangalore, designed the windmill model WP-2 which became available to interested users. A number of experiments were carried out on WP-2 windmill and several modifications were made. After many years, the work on wind mills were revised when a panel constituted by NCST in 1973 recommended setting up of 30 WP-2 wind mills in two clusters of 10 numbers each in Gujarat, Rajasthan and Pondicherry. During the last few years several experimental prototypes have been developed at different parts of the country. Presently , the national wind energy program is being administered by the Ministry of Non Conventional Energy Sources(M.N.E.S). A national level agency-IREDA-has also been constituted under the ministry. It is due to all these efforts that, now, India is proudly recognised as the second largest producer of wind generated electricity in the world.

Viewing the above facts, following objectives are formulated for the study.

- To analyse the wind regimes of some selected sites in Kerala.
- To design a wind rotor matching to these wind regimes using CAD technique.
- To evaluate the performance characteristics of a suitable generator for the rotor.
- To match the rotor and generator and to predict the performance of the combined system.

CHAPTER - 2

ANALYSIS OF WIND REGIMES

2.1. INTRODUCTION

Owing to present days energy crisis, growing environmental concern and constantly escalating cost of fossil fuels, scientists, engineers and policy makers, all over the world, are making every effort to supplement our energy base by renewable sources like wind. It is estimated that 30% of our land area experiences moderate wind, which can be efficiently utilised for various end uses like water lifting and power generation (Neogi,1994). Economic analysis at selected sites showed high Internal Rate of Return (in the tune of 30-35%) and benefit cost ratio 2.5-3. (Mathew , 1994).

A thorough understanding of wind regime prevailing in potential sites is a prerequisite for the formulation and implementation of any project for harnessing this abundant and free source of energy. Data from sites should be collected and analysed also to identify the characteristics of the machine, which will work in harmony with the site conditions. The present investigation is a step in this direction in which wind data from five sites of Kerala State are collected, analysed and interpreted.

Exbote et. al. (1962) studied the wind profile characteristics of India and concluded that for large parts of the country , the optimum working speed of the wind mill must be at 7 km./ hr. Beurskens (1974) had traced the history of windmills in north-west of Tanzania as well as in India and wind energy potential of Ganga region. Assuming 50 per cent efficiency of windmill run pump, he had developed the following relationships for the power of the windmill.

Assuming an efficiency of 50 per cent, he had derived the formula as given below:

$$P = 1/10\ AV^3 \quad \text{..................(2.1.2.)}$$

Prastogi (1982) categorised the resource availability based on the review of literature and pointed out the need to undertake the inventory of wind resources in the country based on time, location, wind availability and topography

2.2. THEORETICAL METHODS

The sites selected for the study are Trivandrum, Alleppey, Cochin, Palghat and Calicut. Wind velocities at 10 m mast height were collected from these stations. Average monthly wind velocities are taken from which, monthly variation is observed and annual average is computed.

It is widely agreed (Lysen-1982) that Weibull distribution, characterised by the scale factor c and shape factor k can well define characteristic of a wind regime. Weibull distribution is given by the probability density function

$$f(v) = \frac{dF}{dV} = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^k\right] \quad \text{.......................(2.2.1)}$$

Hence the cumulative distribution function will be

$$F(V) = \int f(V) = 1 - \exp\left[-\left(\frac{V}{c}\right)^k\right] \quad \text{...........................(2.2.2.)}$$

Where,

V	=	Wind velocity (m/s)
$\overline{V}$	=	Average wind velocity
$F(V)$	=	Cumulative density function
$f(V)$	=	Probability density function

c = weibull scale parameter

k = weibull shape factor

A simplified form of weibull distribution assuming the shape factor 2 and termed as Reyleigh distribution can efficiently be used for seasonal wind regimes analysis. In the present investigation Reyleigh distribution is being used to establish the site characteristics.

Releigh distribution is given by the probability density function

$$f(v) = \frac{\pi}{2}\frac{V}{\overline{V}^2}\exp\left[-\frac{\pi}{4}\left(\frac{V}{\overline{V}}\right)^2\right] \text{.............................(2.2.3.)}$$

Hence the cumulative distribution function will be

$$\int f(v) = F(v) = 1 - \exp\left[-\frac{\pi}{4}\left(\frac{V}{\overline{V}}\right)^2\right] \text{..............................(2.2.4.)}$$

It is the most energy intensive velocity - not the most frequent wind speed- that has to be considered while deciding the design and rated wind speeds of a machine. Energy intensity per unit area expected from a machine can be calculated by

$$E = \frac{1}{2}\rho V^3 f(V) \text{.......................(2.2.5.)}$$

It is also interesting to observe the fraction of time for which machine will work at particular site. Hence time period for which a windmill will be functioned at these sites are also calculated taking the cut-in velocity as 2 m/s and cut-out velocity as 10 m/s (these values are selected based up on the informations available from the manufactures of some popular wind machines in India)

Consider a rotor with velocity-power characteristics as shown in fig.(1).
The energy produced by a wind rotor in time 'T' can be given by :

$$E = \int_{V_i}^{V_o} P(v) f(v) d(v). \text{.........................(2.2.6.)}$$

If 'V_m' is the average wind velocity, 'P' the rotor power at velocity 'v' and 'P(o)' the rotor power at cut out point then 'P(v)' and 'f(v)' are given by :

$$P(v) = P_O\left[\frac{V^2 - V_i^2}{V_O^2 - V_i^2}\right] \quad \text{................(2.2.7.)}$$

and
$$f(v) = \frac{\pi}{2}\frac{V}{V_m^2}\exp[-\frac{\pi}{4}[\frac{V}{V_m}]^2] \text{....................(2.2.8.)}$$

Substituting the values of 'P(v)' and 'f(v)' and integrating with the limits V_i and V_o, we will get the expression for E as:

$$E = \frac{TP(o)}{V_0^2 - V_i^2}\left[\left\{\frac{4V_m^2}{\pi}\left[e^{-\frac{\pi}{4}\left(\frac{V_i}{V_m}\right)^2} - e^{\frac{-\pi}{4}\left(\frac{V_O}{V_m}\right)^2}\right]\right\} - \left\{e^{-\frac{\pi}{4}\left(\frac{V_O}{V_m}\right)^2}\left(V_o^2 - V_i^2\right)\right\}\right] \text{.(2.2.9.)}$$

2.3. MONTHLY AVERAGE WIND VELOCITY

Monthly average wind velocities at the sites under study are shown in fig 2,3,4,5 and 6. Wind velocity at Trivandrum registered a maximum value of 3.0 m/s when averaged in a monthly basis. Corresponding velocities for Alleppey, Cochin, Palghat, and Calicut where 3.4m/s, 2.8m/s, 3.35m/s and 3.25m/s respectively.

In Trivandrum average monthly wind velocity is above the so called cut in value of 2m/s in the month of May, June, July, August and September. In the rest of the stations it is higher then 2m/s through the year. In general (except for Trivandrum) wind velocity is high in the month March, April, May and June. This indicates the feasibility of wind power irrigation. The average velocity indicates that large scale electricity generation will not be economically viable due to the relatively low values observed. However it could be seen that small scale aero generator could be successfully employed in these regimes for Stand alone applications like battery charging.

The probability density function for all the five stations were estimated using Reyleigh distribution and displayed in fig. 7,8,9,10 and 11. From the probability density function it could be seen that the most frequent wind speed at Trivandrum was 1.8 m/s. The corresponding values for Alleppey, Cochin, Palghat and Calicut were 2.2, 2.0, 2.15, 2.0 m/s respectively. Similarly, the cumulative distribution function for the sites are shown in figures 12, 13, 14, 15 and 16. From this figures the time period for which wind velocity is below a particular value and between two velocities of interest (example cut-in velocity and cut-out velocity) can be estimated.

2.4. THE UTILISATION FACTOR

Fraction of time in which a wind machine will be functional at a site will depend on the machine characteristics as well as the wind regime characteristics. Once the wind regime is characterised as discussed in the earlier sections, one could easily determine the utilisation factor for a particular machine. Here a unit suitable for low wind regime regions-like the sites under study-had been selected. The machine was cut in at 2m/s wind speed and cut out at 10m/s.

The utilisation factor of a wind mill with 2m/s cut-in-velocity and 10m/s cut-out-velocity where computed which in turn gives the time period for which the wind turbine will be working. The number of hours for which wind turbine will work in a day is obtained by multiplying the utilisation factor by 24 and from it the expected yearly hours of use is found out.

At Trivandrum the expected yearly hours of use of wind turbine is 4409.82 hours. It is found to be 6271.76, 5179.43, 5300.44, 5416.188 hours per year for Alleppey, Cochin, Palghat and Calicut respectively.

The energy intensity Vs velocity graphs corresponding to the five different station-Trivandrum, Alleppey, Cochin, Palghat and Calicut are given in figures 17, 18, 19, 20 and 21 respectively. This can be taken as a good indication in deciding the design wind speed of machine expected to work efficiently at these sites. For Trivanadrum, the peak value is 3.75. Corresponding values for the other sites are 7.739 for Alleppey, 5.06 for Cochin, 5.301 for Palghat and 5.5312

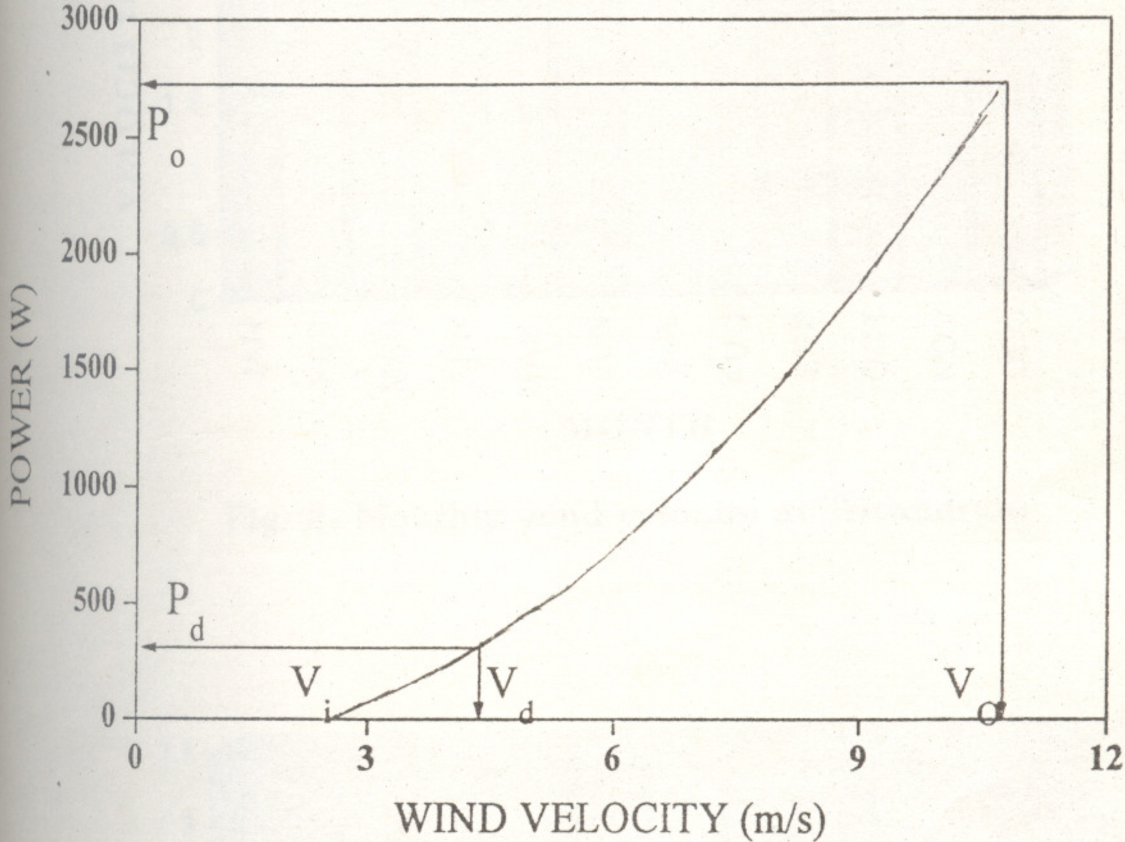


Fig. 1 Typical velocity - power curve of a wind pump rotor

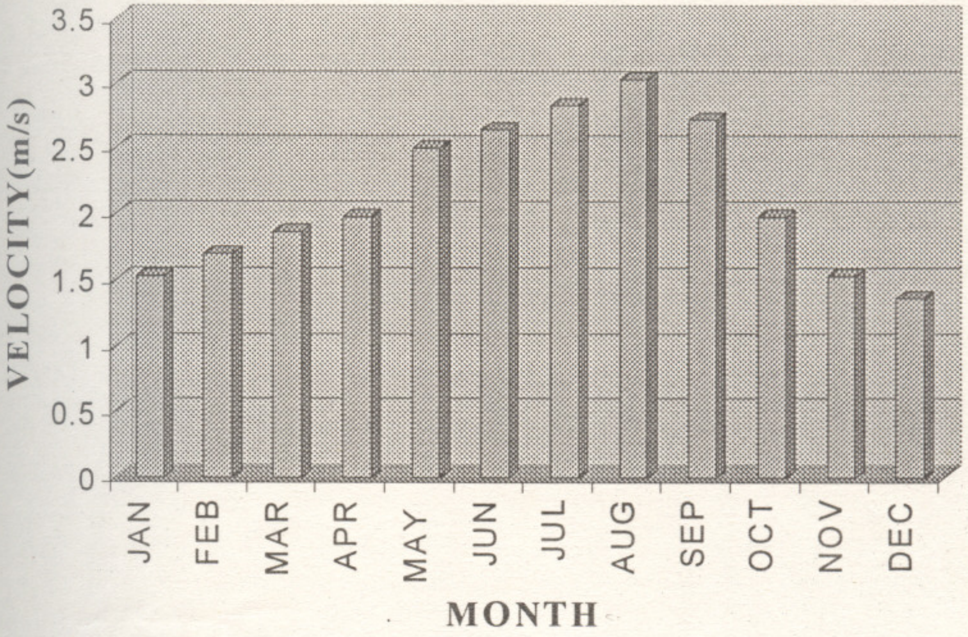


Fig. 2. Monthly wind velocity at Trivandrum

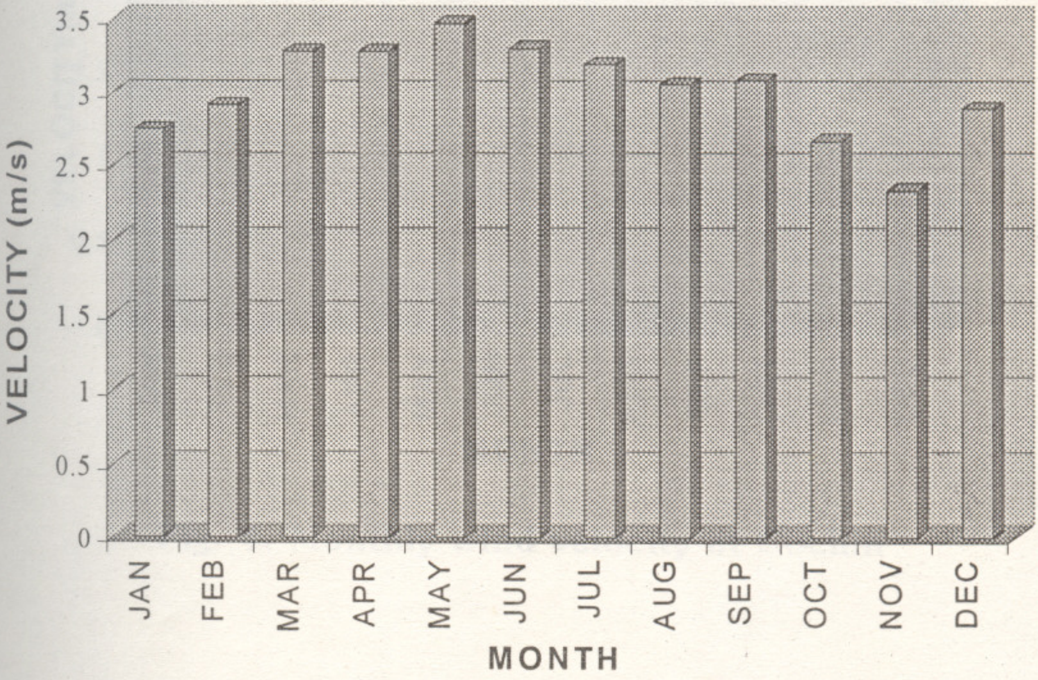


Fig. 3. Monthly wind velocity at Alleppey

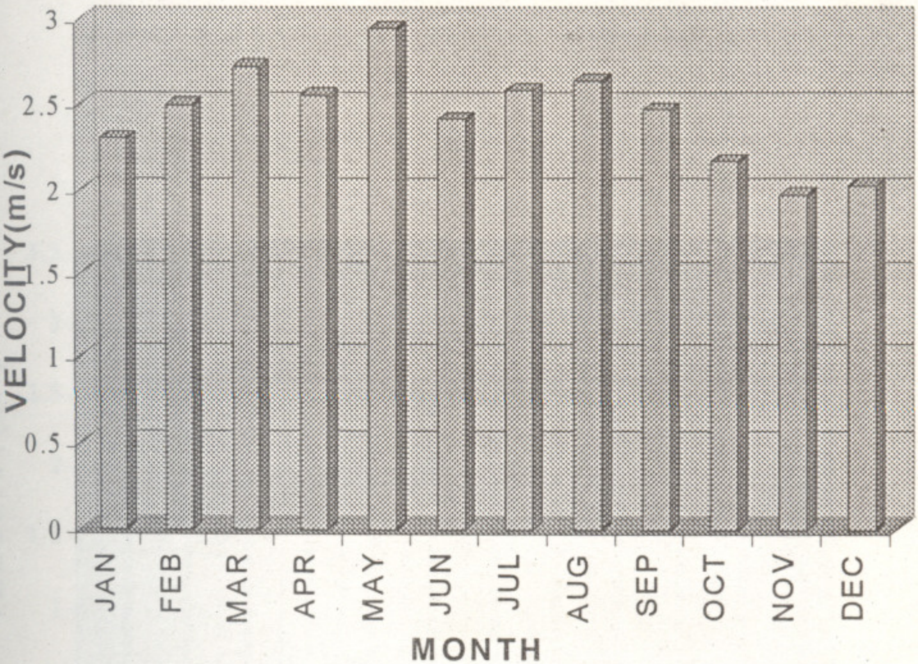


Fig. 4. Monthly wind velocity at Cochin

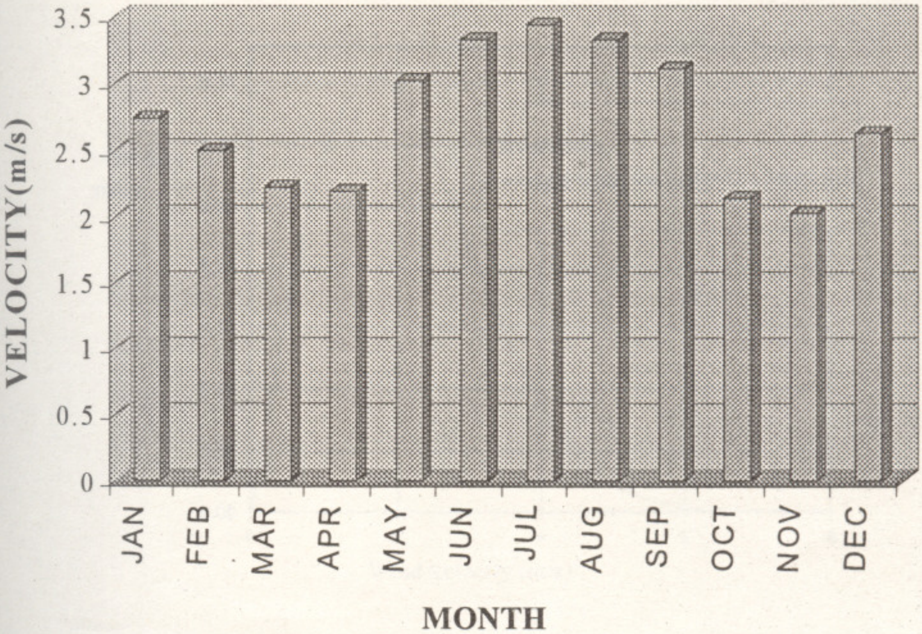


Fig. 5. Monthly wind velocity at Palghat

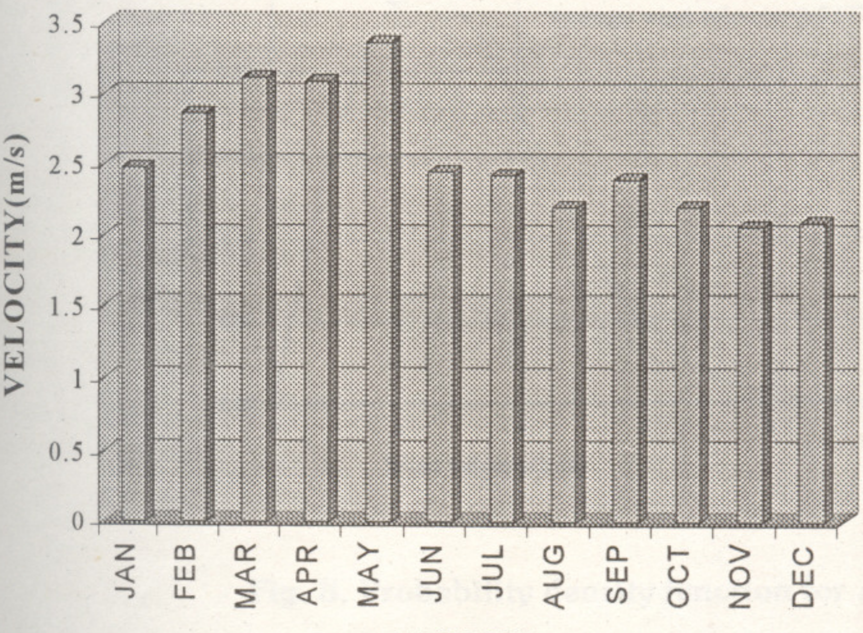


Fig. 6. Monthly wind velocity at Calicut

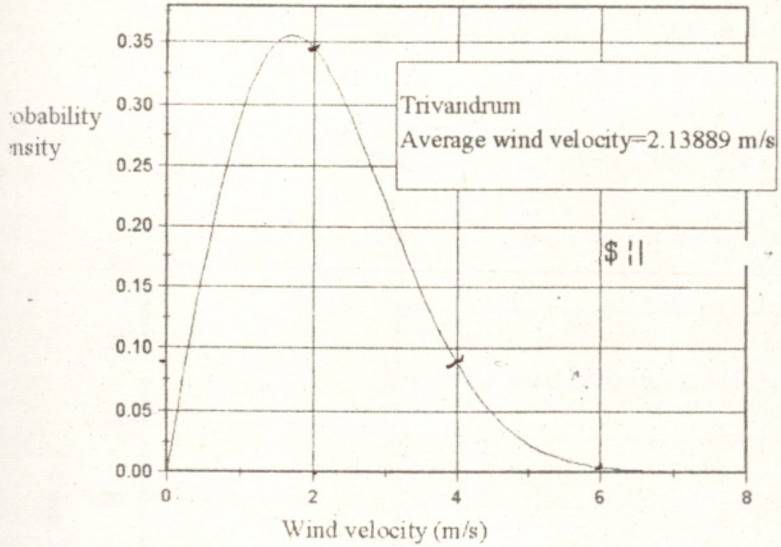


Fig. 7. Probability density function for Trivandrum

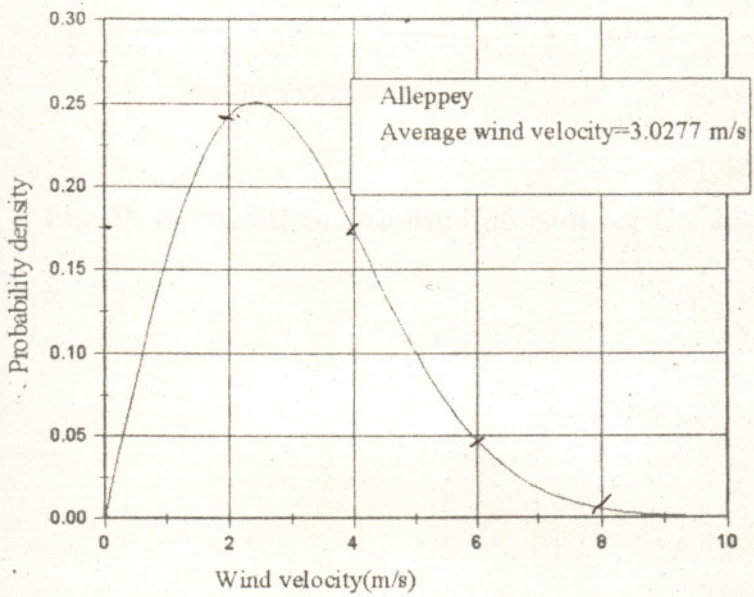


Fig. 8. Probability density function for Alleppey

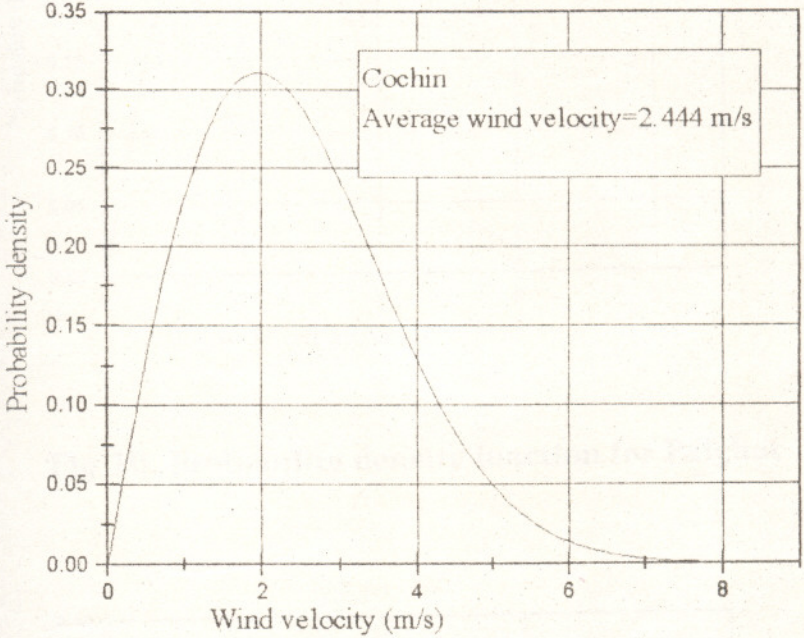


Fig. 9. Probability density function for Cochin

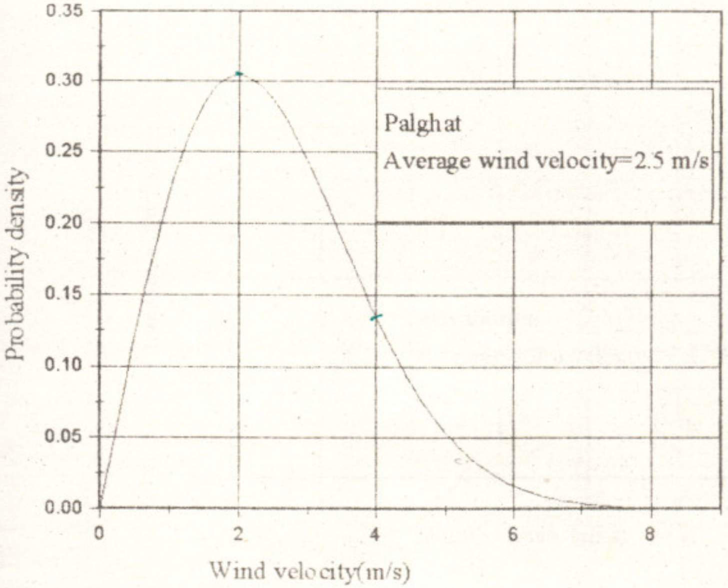


Fig 10. Probability density function for Palghat

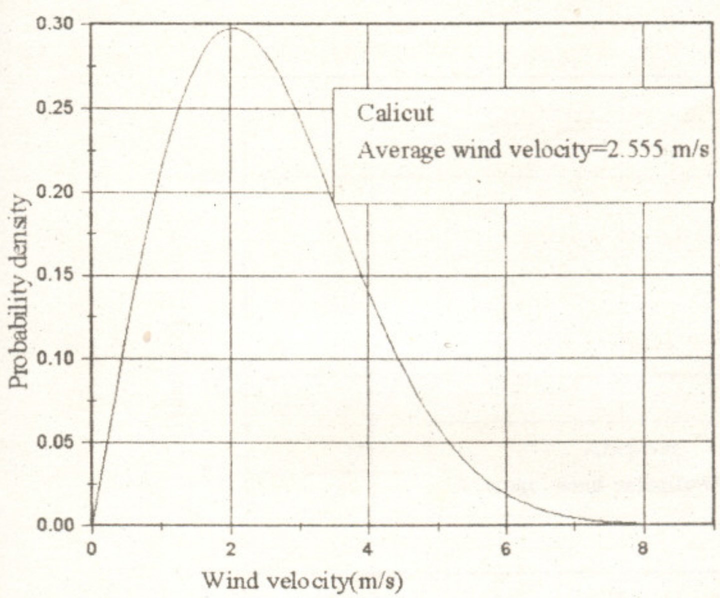


Fig 11. Probability density function for Calicut

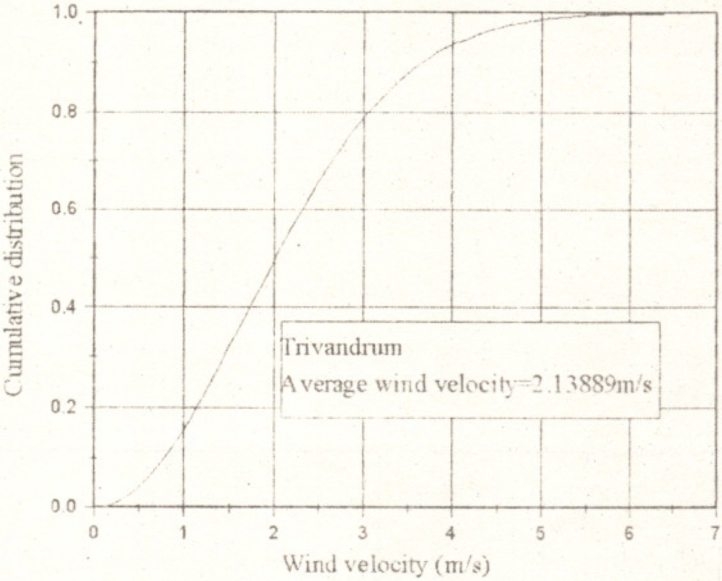


Fig 12. Cumulative distribution function for Trivandrum

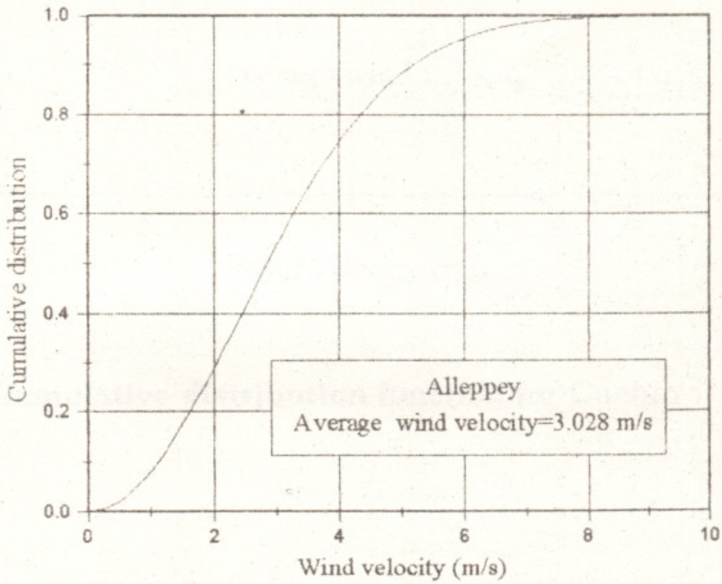


Fig 13. Cumulative distribution function for Alleppey

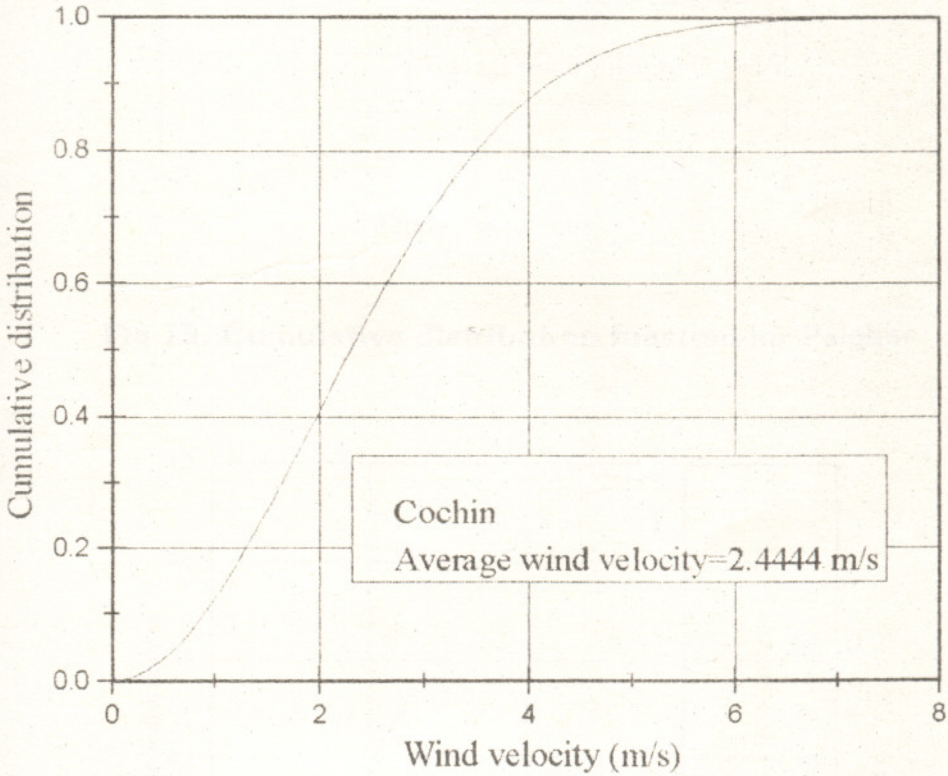


Fig 14.Cumulative distribution function for Cochin

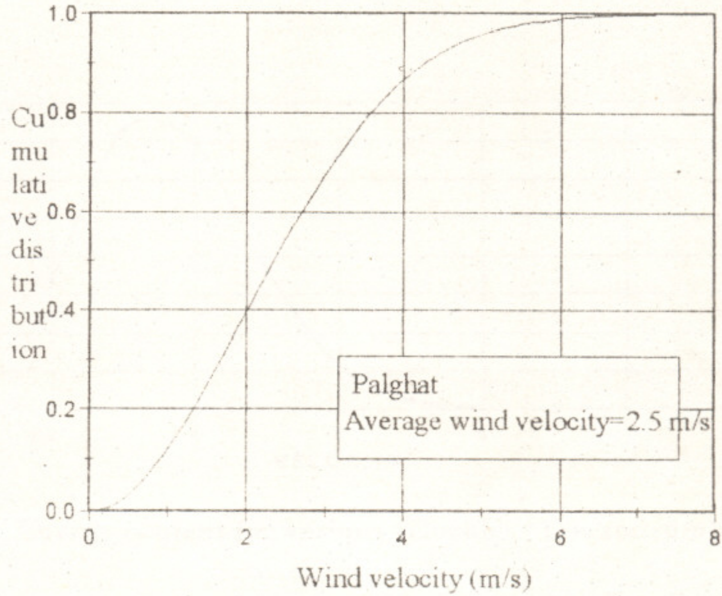


Fig 15. Cumulative distribution function for Palghat

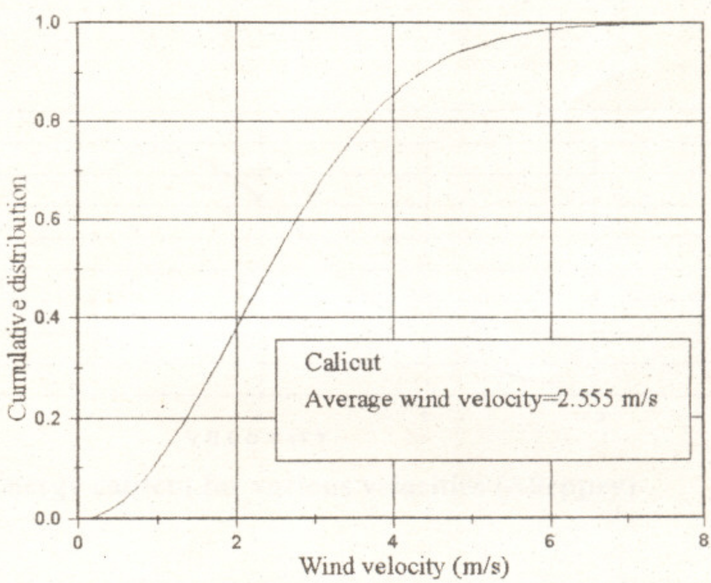


Fig 16. Cumulative distribution function for Caicut

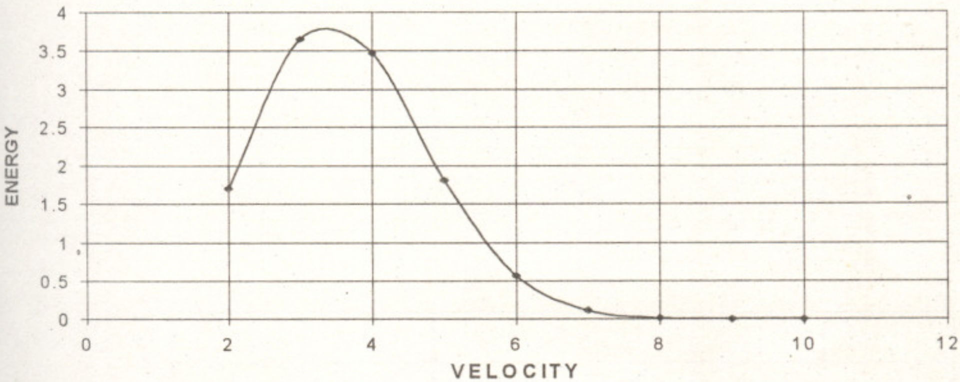


Figure.17. Energy content for various velocities (Trivandrum)

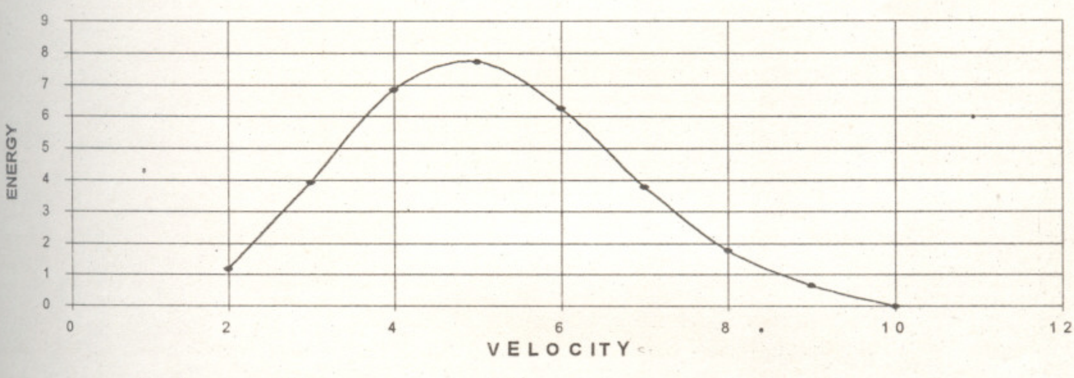


Figure. 18. Energy content for various velocities (Alleppey)

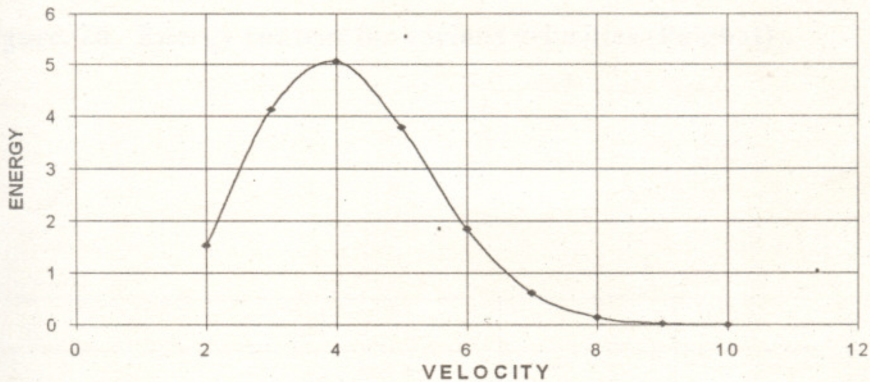


Figure.19. Energy content for various velocities (Cochin)

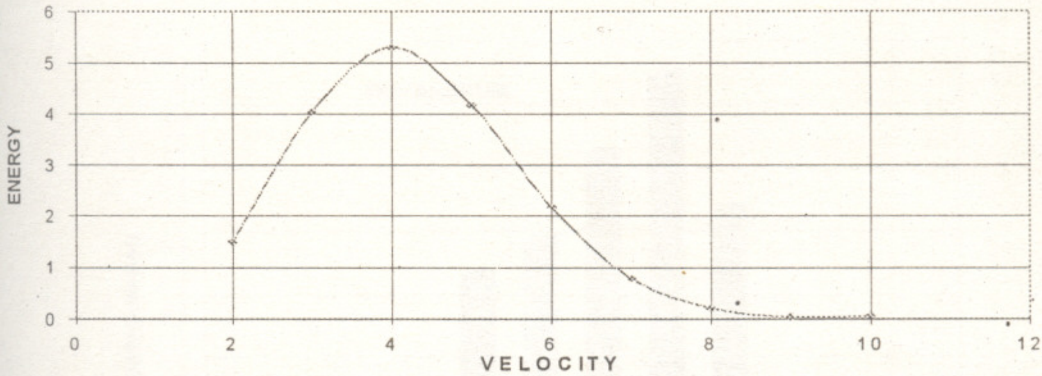


Figure. 20. Energy content for various velocities (Palghat)

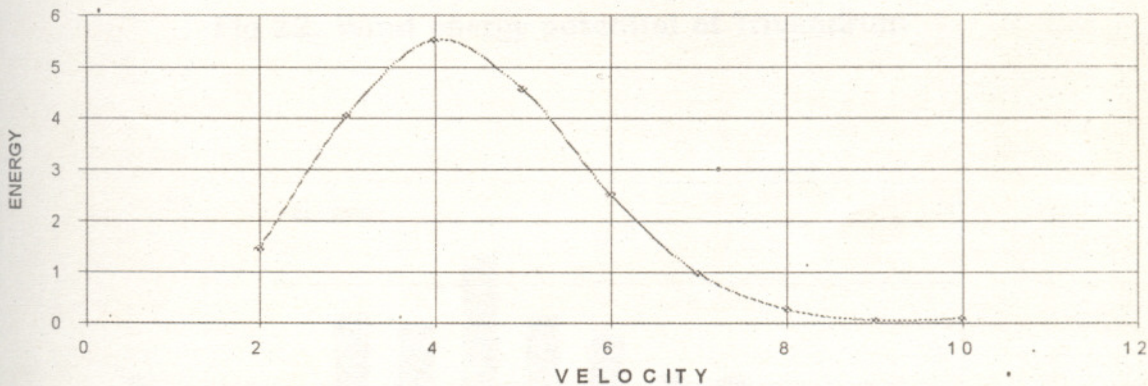


Figure.21. Energy content for various velocities (Calicut)

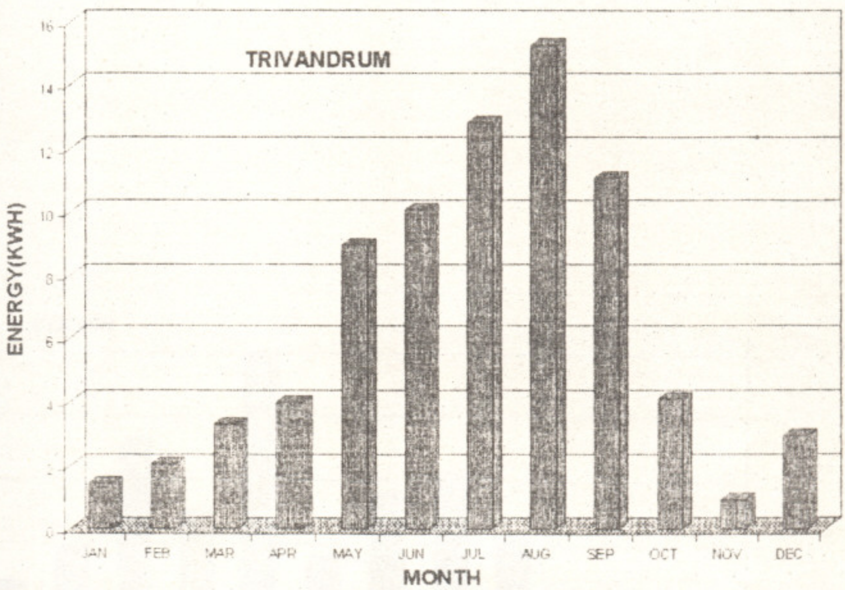


Fig 22. Wind energy potential of Trivandrum

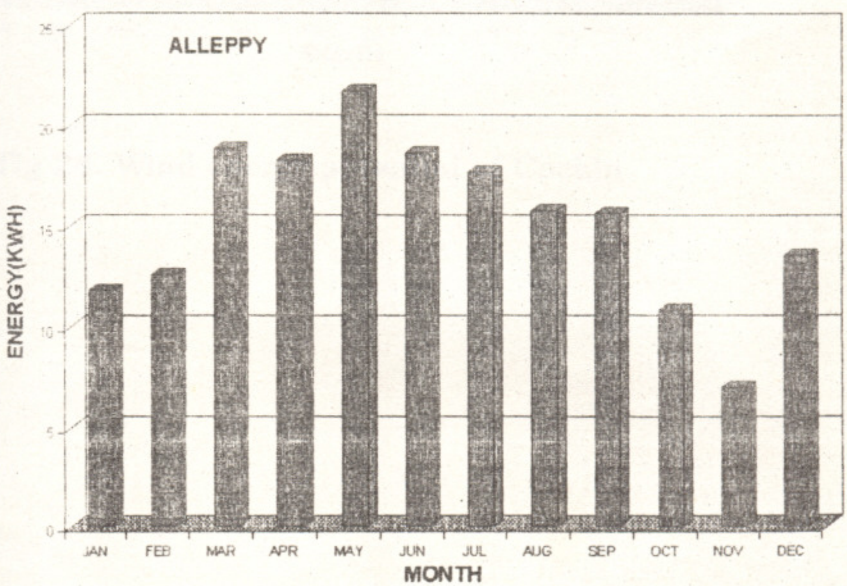


Fig 23. Wind energy potential of Alleppey

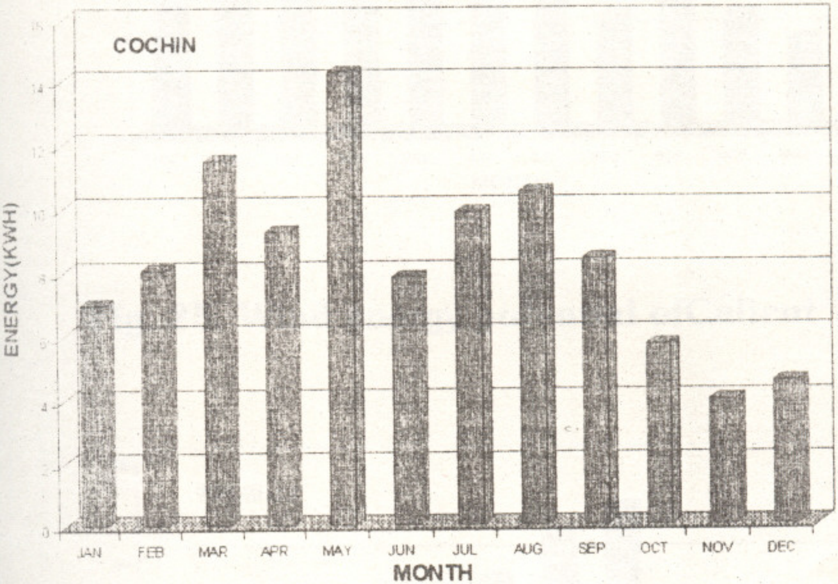


Fig 24. Wind energy potential of Cochin

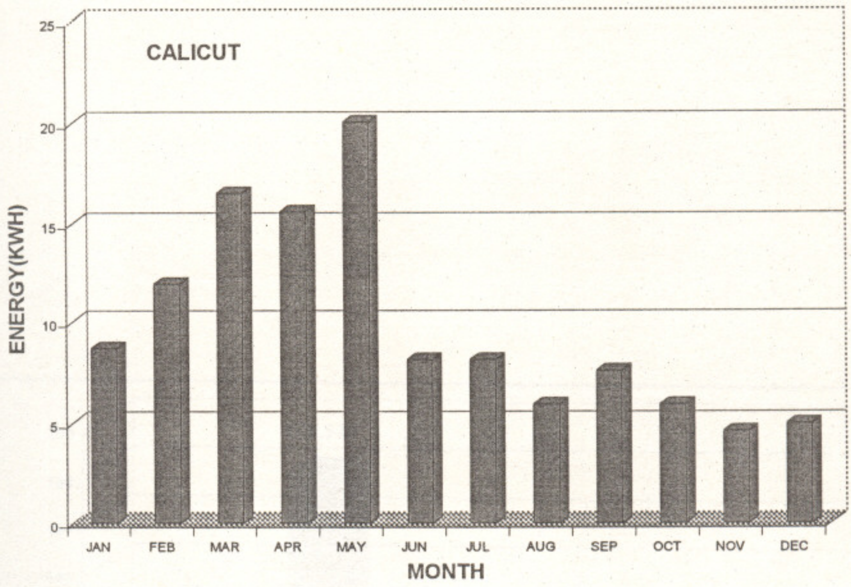


Fig. 25. Wind energy potential ofCalicut

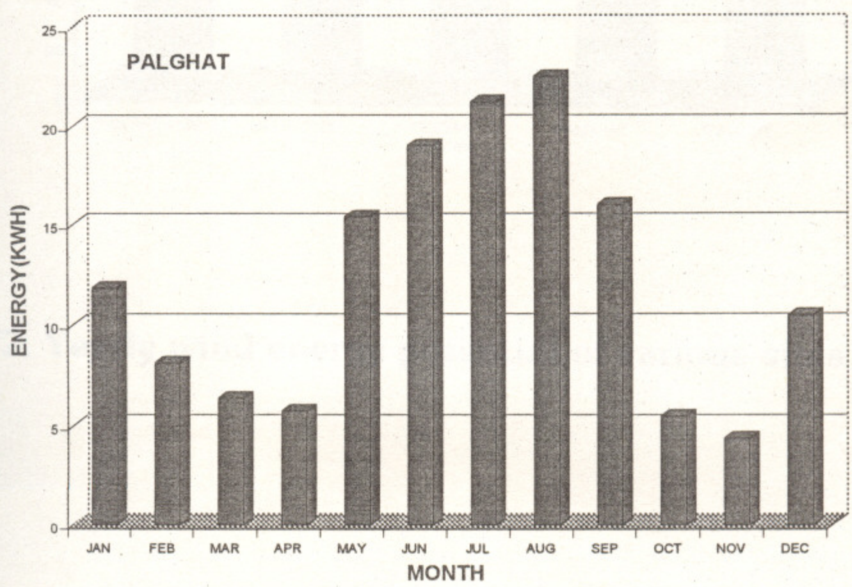


Fig. 26. Wind energy potential of Palghat

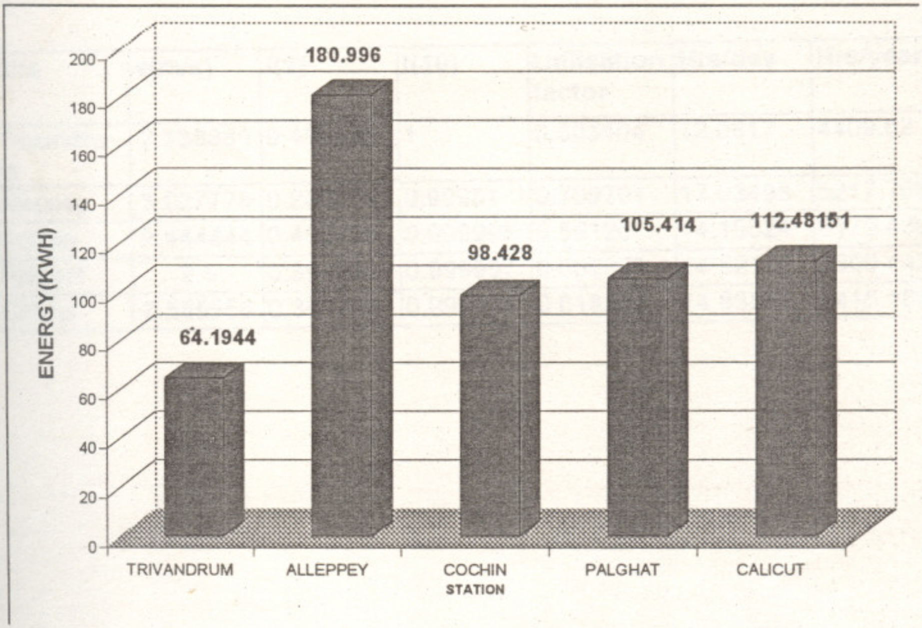


Fig. 27. Yearly wind energy potential of various sites

Table I. Utilisation factors of a wind mill with 2m/s cut-in and 10m/s cut-out at different sites

Site	v(m/s)	f(2)	f(10)	Utilisation factor	Hrs/day	Hrs/year
Trivandrum	2.138889	0.496596	1	0.503404	12.0817	4409.82
Aleppey	3.027778	0.290019	0.99981	0.709791	17.03498	6217.769
Cochin	2.444444	0.408738	0.999998	0.59126	14.19024	5179.439
Palghat	2.5	0.394923	0.999997	0.605073	14.52176	5300.442
Calicut	2.555556	0.381708	0.999994	0.618286	14.83887	5416.188

for Calicut. In general, it would be logical to choose a design wind speed between 5 and 6m/s for the sites under study.

The monthly wind energy potentials of various sites were computed and displayed in. Figures 22, 23, 24,25 and 26. Figure (27) shows a comparison between the annual wind energy potential of the five stations.

The yearly wind energy potential for Trivandrum, Alleppey, Cochin, Palghat and Calicut are found to be 64.194, 180.996, 98.428, 105.414 and 112.481 kwh respectively. The maximum value (180.996) is observed at Alleppey. In general, it is observed that energy intensity is high during the months of May, June , July and August.

Based on the mathematical modern discussed in 2.2.9, a computer programme was developed in C^{++} to estimate the yearly wind energy potential of the sites.

2.4. CONCLUSIONS

- Monthly variations in wind velocity at different sites are studied and feasibility of wind powered irrigation and small-scale power generation is being established.
- Cumulative distribution function and probability distribution function assuming reyleigh distribution for the data is being displayed.
- Expected working hours of a commercial windmill with 2m/s cut-in and 10m/s cut-out are computed.
- Wind energy potentials of various sites are calculated and compared.

CHAPTER- 3

THE ROTOR

3.1. INTRODUCTION

Conversion of wind energy to other forms requires a complex interaction between the source (wind), the ground, a means to capture , a mechanism to convert, a method of transferring the energy into a useful form and then transmitting it to the place where it is to be utilized. The total process is the Wind Energy Conversion System (WECS). A wind energy system consists basically of a turbine which extracts energy from the wind and a load which converts this energy to do useful work. The engineering of wind energy systems naturally involves a multitude of structural, aerodynamics, mechanical and electrical problems associated with the individual system components. The complexity of the input/output characteristics of typical wind turbines and load suggests that careful matching of components is required to ensure adequate system performance.

The capture function in WECS is universally accomplished by means of rotating blades attached either to a hub(HAWT) or a central rotating tower(VAWT). The amount of wind useful to the WECS is limited to the swept area of the rotor which the wind passes through. Shape, size and number of blades is generally based on a combination of aerodynamic efficiency , structural capability and cost. The rotor can spin at constant speed or at multiple or variable speeds. All these variables combine to define the amount of available wind captured in the form of rotating shaft torque. The rotor captures the kinetic energy of wind and converts it for doing useful work.

3.2. CLASSIFICATION OF ROTORS

Many types of wind machines were designed and constructed during the course of wind mill history. Wind mills are classified according to their axis of rotation, relative to the direction of wind. The major categories are:

(a) Horizontal axis rotors

(b) Vertical axis rotors

(c) Cross-wind horizontal - axis rotors

3.2.1. Horizontal axis rotors:

Horizontal axis machines are those devices in which the axis of rotation is parallel to the direction of wind. These devices can either be lift or drag systems. Designs have been varied with number of blades - systems can range from one bladed units to multi- bladed systems having fifty or more blades. Horizontal axis rotors can be upward rotors or downward rotors. In upward rotor, blades rotate in front of the tower with respect to wind direction , and in downward rotor , blades rotate at the back of the tower.

3.2.2. Vertical axis rotors :

Vertical axis rotors are those which have their axis of rotation at right angles to both the earth surface and the direction of the wind. Their major advantage is that they do not have to be repositioned to the direction of oncoming wind as the wind stream direction changes.

Vertical axis rotors can be classified as :

(1) Savonius rotor

(2) Darriens rotor

(3) Cup anemometer

(4) Musgrove rotor

(5) Evans rotor

3.2.3. Cross-wind horizontal axis rotors:

They are machines whose axis of rotation is horizontal with respect to the ground and at right angles to the direction of the wind. The most common type of designs are cross-wind paddle rotor and cross-wind Savonius design. They are primarily complicated systems having no marked advantages over the other designs.

3.3. Aerodynamic characteristics of rotor profile:

Rankine . W. and Froude (1878) originated axial momentum theory, considering the flow past a wind turbine. They found that the wind velocity at the disc of the wind mill is the average of initial and final velocities.

$$U = \frac{V_i + V_0}{2} \quad \text{.........................(3.3.1.)}$$

where U = Wind velocity at the disc.

V_i = Initial wind velocity.

V_0= Final wind velocity.

Power developed , P is given by

$$P = \rho A U\left(\frac{V_i^2}{2} - \frac{V_0^2}{2}\right) \quad \text{.........................(3.3.2.)}$$

OR

$$\frac{P}{\frac{1}{2}\rho A V_0^3} = 4a(1-a)^2 \quad \text{.....................(3.3.3.)}$$

Where P = Power developed (W)

ρ = Mass density of air (kg/m^3)

A = Area of the rotor (m^2)

$$a = \frac{V_i - U}{V_i} \quad \text{.....................(3.3.4.)}$$

The above expression will have a maximum value when a = 1/3

$$\frac{P_{max}}{\frac{1}{2}\rho A V_i^3} = 0.593 \quad \text{..................... (3.3.5.)}$$

Thus , the maximum power coefficient that can be attained by a rotor is 0.593, which is termed us the Betz limit.

For a drag machine , the maximum driving drag force is given by

$$F_D = \frac{C_D \rho A(V_i - U)^2}{2} \text{ ....(3.3.6.)}$$

where F_D = Maximum drag force

C_D = coefficient of drag

The power transmitted is

$$P_D = \frac{C_a \rho A(V_i - U)^2}{2}.U \text{ ....(3.3.7.)}$$

Where P_D = Power transmitted due to drag force.

This is maximum with respect to V when $U = V_i/3$

$$P_D \max = \tfrac{1}{27} C_D \frac{\rho A V^3}{2} \text{ ....(3.3.8)}$$

$$P_D = C_P \rho A V^3/2 \text{ .... (3.3.9.)}$$

$$\therefore \quad C_P \max = 4/27\, C_D$$

Islam *et. al.* (1988) studied the application of cascade theory on the aerodynamic performance of horizontal axis wind turbine. In this study , the flow field was considered as rationally systematic and wind turbine would be treated as an open rectilinear cascade. Forces acting on a different element of blade where calculated and integration was carried out along the length of the blade to compute the performance of the rotor. He came to a conclusion that performance of a horizontal axis wind machine at low tip speed ratio cannot be determined accurately by classical theory. For the high solidity multi-blade turbines , design tip speed ratio is generally low for getting high starting torque. For the type of wind turbines cascade theory predicts better result than the momentum theory although the computational time is much higher in case of cascade theory.

Rama Nathan (1986) studied the design features of a low cost wind mill. He found that the drag force increased with the increase in wind velocity and the maximum value being 633.2 N for the design under study. As the wind velocity is doubled , the drag force was found to increase by a factor of four irrespective of the level of wind velocity. The drag force increased at an average rate of 22 N with increase in unit wind velocity . Owing to doubling the wind velocity , the vertical forces increased by four times.

Clark (1991) designed a 500 kW vertical-axis wind turbine and the initial performance of it was studied. The wind turbine was designed and built to examine aero dynamic control and structural dynamics strategies intended to improve the effectiveness of vertical-axis wind turbine systems. The turbine had a 34 m equitorial rotor diameter and was 50m high. The rotor blades were each constructed in 5 sections with 2 different airfoil shapes and 3 sizes. Power from this rotor is transferred through a speed increasing transmission to a variable speed generator rated at 500 kW in a 12.5 m/s wind operating at 37.5 rev/min. Results from aerodynamic testing indicate the turbine's performance was slightly less than predicted but was much better than previous designs.

3.5. ROTOR DESIGN

The designed of a wind rotor consist of two steps :

I. The choice of basic parameters, such as number of blades, the radius of the rotor, the type of air foil, the tip speed ratio, and
II. The calculations of the blade setting angle β and the chord C *at each position* along the blade.

3.5.1. POWER, TORQUE AND SPEED

A wind rotor can extract power from the wind because it slows down the wind- not too much, not too little. At standstill the rotor obviously producers no power and at very high rotational speed the air is more or less blocked by the rotor, and again no power is produced. In between these extremes there is an optimal rotational speed where the power extraction is at a maximum.

The power P, the torque T and the rotational speed Ω are related by a simple law:

$$P = T \times \Omega \text{------------------} (3.5.1.1.)$$

Where P = Power(W)

T = Torque (Nm)

Ω = Angular Velocity (rad/s)

Power coefficient $= C_P = \dfrac{P}{\frac{1}{2}\rho A V^3}$ .... (3.5.1.2.)

Torque coefficient $= C_T = \dfrac{Q}{\frac{1}{2}\rho A V^2 R}$ .... (3.5.1.3.)

Tip speed ratio $\lambda = \dfrac{\Omega \ R}{V}$ .... (3.5.1.4.)

where V = Wind speed (m/s)

R = Radius of the rotor (m)

ρ = Density of the air (kg/m^3)

Substitution of these equation gives $C_P = C_T \times \lambda$ ....(3.5.1.5)

3.5.2. AIRFOILS : LIFT AND DRAG

The behaviour of the blades can be discussed by describing the lift and dry forces on the air foil-shaped blades. In fact, not only on air foils, but on all bodies placed in a uniform flow, a force is exerted, of which the direction is generally not paralleled to the direction of the undisturbed flow. The component of the force in the direction of undisturbed flow is called the drag and the component perpendicular the direction of the undisturbed flow is called the lift.

In physical terms the force on a body (such as an air foil) is caused by the changes in the flow velocities and direction around the airfoil. On the upper side of the airfoil the velocities are higher than on the bottom side. The result is that the pressure on the upper side is lower than the pressure on the bottom side, hence a force (F) is created.

In describing the lift and drag properties of different air foils, reference is usually made to the dimensionless lift and drag coefficient, which are defined as follows:

Lift coefficient, $C_L = \dfrac{L}{\frac{1}{2}\rho A V^2}$ .... 3.5.2.(1)

Drag coefficient, $C_D = \frac{D}{\frac{1}{2} \rho A V^2}$ 3.5.2. (2)

where ρ = Density of air (Kg/m^3)

V = Undisturbed wind speed (m/s)

A = Projected blade area (Chord x Length) (m^2)

The values C_p and C_d of a given air foil vary with the wind speed or, better, with the Reynolds number R_e. The Reynolds numebr is a vital dimensionless parameter in fluid dynamics and in case of an airfoil,
it is defined as

$R_e = VC/\upsilon$ .... (3.5.2.3)

with V the undisturbed wind speed, C the characterstic length of the body (Hence the chord of the airfoil) and υ the kinematics viscosity of the fluid.
The value of α and C_L at minimum C_D/C_L ratio are important parameters in the design process. The value for some air foils are given in appendix III.

3.5.3. THE MAXIMUM POWER COEFFICIENT

It has been shown by Betz (1926) with a simple axial momentum analysis, that the maximum power coefficient for a horizontal axis type wind rotor is equal to 16/27 or 59.3%. This however, power coefficient of an ideal wind rotor with an infinite number of (zero-drag) blades. In practice there are three effects which cause a further reduction in the maximum attainable power coefficient, namely:

1. The rotation of the wake behind the rotor.
2. The finite number of the blades.
3. C_D/C_L ratio is not zero.

The creation of a rotating wake behind the rotor can be understood by imagining oneself a moving with the wind towards a multibladed wind rotor at standstill. The passage of the air between the rotor blades causes the blades to start moving to the left. (in this example), but the air flow itself is deflected to the right (infact this deflection causes the lift). The result is a rotation of the wake, implying extra kinetic energy losses and lower power coefficient.

For wind rotors with higher tip speed ratios, i.e. with smaller blades and a smaller flow angle, the effect of wake rotation is much smaller. For infinite tip speed ratios the Betz coefficient could be reached.

A finite number of blades, instead of the ideal infinite blade number, causes an extra reduction power, particularly at low tip of the blade. To design a rotor with a given tip speed ratio, one can choose between many blades with a small chord width or less blades with a larger chord. For a given tip speed ratio a rotor with less blades will have larger tip losses. Since the chords become smaller for high tip speed ratios this effect is smaller for higher tip speed ratios.

Another effect is the drag of the profile, characterized by the C_D/C_L ratio of the air foil. This causes a reduction of the maximum power coefficient which is proportional to the tip speed ratio and to the C_D/C_L ratio.

3.5.4. DESIGN PROCEDURE

Lysen,1982 put forth a systematic procedure to design a blade profile of a wind rotor. This consisted of finding both values of the chord C and the setting angle β of the blades at a number of positions along the blade. The angle of attack α and the setting angle β of the blade of an wind rotor is shown in fig. 28. The values for the following parameters must be chosen before hand

R	=	The Radius
λ_d	=	The design tip speed ratio
β	=	The number of blades
C_{ld}	=	Design lift coefficient
α_d	=	Corresponding angle of attack

The radius of the rotor must be calculated with the required energy output E in a year (or in a critical month), given the average local wind speed V and its distribution.

The choices of λ_d and β are more or less related, as the following the guide lines suggested in Appendix III (b)

The type of load will determine the λ_d.: The electricity generating wind turbines usually have $4<\lambda_d<10$. A suitable air foil can be selected from the airfoil data displayed in Appendix III(a)

The following formulae can describe the required information about β and C:

Chord : $C = \dfrac{8\pi r}{BCl_d}(1-\cos\phi)$ 3.5.3. (1)

Blade setting angle : $\beta = \phi - \alpha$ .... 3.5.3.(2)

Flow angle : $\phi = \dfrac{2}{3}\arctan\dfrac{1}{\lambda_r}$ .... 3.5.3.(3)

Local design speed : $\lambda_r = \lambda_d \times \dfrac{r}{R}$ .... 3.5.3.(4)

3.5.5. THE COMPUTER PROGRAM

A computer program in C^{++} was developed based on this model put forth by Lysen. The program requires the power requirement, velocity, power coefficient, design tip speed ratio and number of blades as the input. Rotor blade will be split into ten sections along its length and corresponding chord length, blade setting angle, flow angle and local design speed (output) would be computed using the above said model. Ultimately the complete blade profile will be graphically represented. The complete program is listed in Appendix V. The program was run for rotors with different air foil sections and configurations. The results are shown in Table 2.

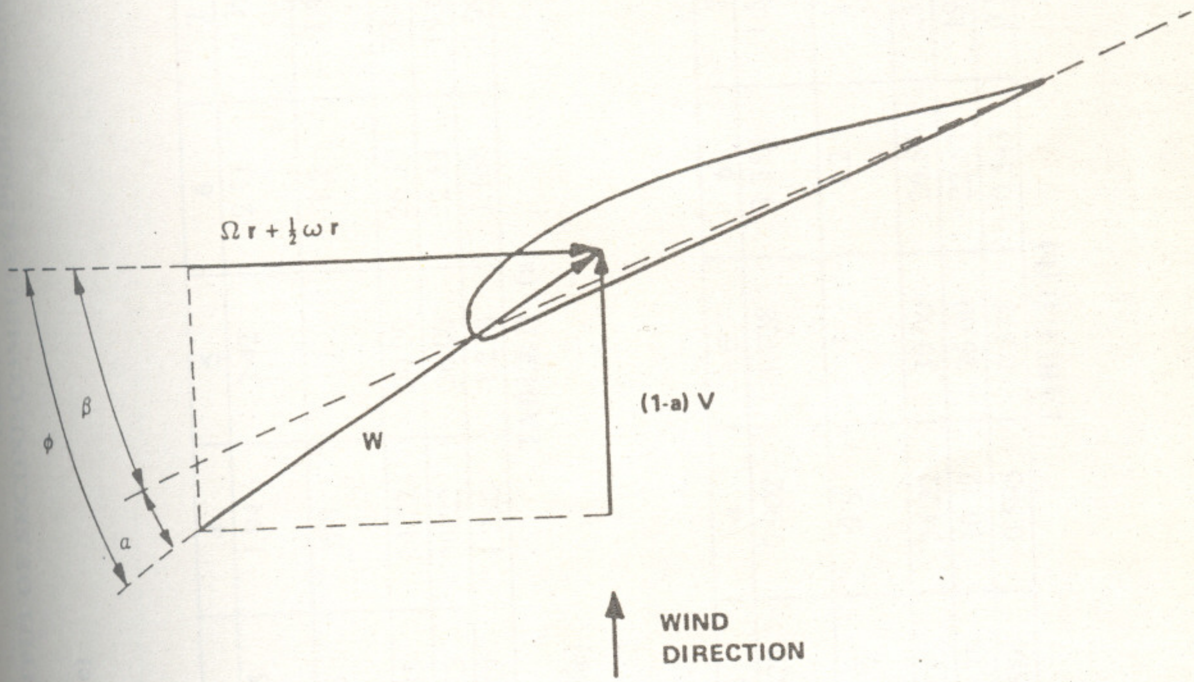


Fig 28. Rotor Blade (Angle of attack)

TABLE - II
OUTPUT OF SECOND COMPUTER PROGRAMME

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 2$

$V = 3$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.48	0.97	1.45	1.94	2.42	2.91	3.39	3.88	4.37	4.87
local tip speed ratio	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
ϕ	52.46	45.46	39.35	34.22	30.00	26.57	23.69	21.33	19.37	17.71
β	48.46	41.46	35.35	30.22	26.00	22.53	19.69	17.33	15.35	13.71
C	0.722	1.104	1.257	1.280	1.238	1.168	1.090	1.013	0.941	0.876

TABLE II - (a)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 2$

$V = 5$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.225	0.451	0.677	0.902	1.128	1.353	1.580	1.805	2.031	2.25733
local tip speed ratio	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
ϕ	52.46	45.46	39.35	34.22	30.00	26.57	23.69	21.33	19.37	17.71
β	48.46	41.46	35.35	30.22	26.00	22.53	19.69	17.33	15.35	13.71
C	0.335	0.513	0.584	0.595	0.575	0.543	0.506	0.471	0.437	0.407

TABLE II (b)

Blade : Type 3 (Curved plate with tube inside)

Power : 480 W

$\lambda = 2$

$V = 7$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.136	0.272	0.408	0.545	0.681	0.817	0.953	1.090	1.226	1.362
local tip speed ratio	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
ϕ	52.46	45.46	39.35	34.22	30.00	26.57	23.69	21.33	19.37	17.71
β	48.46	41.46	35.35	30.22	26.00	22.53	19.69	17.33	15.35	13.71
C	0.202	0.309	0.352	0.359	0.357	0.327	0.306	0.284	0.262	0.245

TABLE - II (c)

Blade : Type 3 (Curved plate with tube inside)

Power : 480 W

$\lambda = 2$

$V = 9$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.093	0.186	0.280	0.373	0.467	0.560	0654	0.747	0.841	0.934
local tip speed ratio	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
ϕ	52.46	45.46	39.35	34.22	30.00	26.57	23.69	21.33	19.37	17.71
β	48.46	41.46	35.35	30.22	26.00	22.53	19.69	17.33	15.35	13.71
C	0.138	0.212	0.242	0.246	0.238	0.220	0.209	0.195	0.181	0.168

TABLE - II (d)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 4$

$V = 3$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.485	0.971	1.457	1.942	2.428	2.914	3.399	3.885	4.371	4.857
local tip speed ratio	0.4	0.6	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
ϕ	45.46	34.22	26.53	21.33	17.71	15.08	13.10	11.56	10.34	9.35
β	41.46	30.22	22.53	17.33	13.71	11.08	9.10	7.56	6.34	5.35
C	0.552	0.640	0.584	0.506	0.438	0.381	0.336	0.300	0.270	0.246

TABLE - II (e)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 4$

$V = 5$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.225	0.451	0.677	0.902	1.128	1.354	1.580	1.805	2.031	2.257
local tip speed ratio	0.4	0.6	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
ϕ	45.46	34.22	26.53	21.33	17.71	15.08	13.10	11.56	10.34	9.35
β	41.46	30.22	22.53	17.33	13.71	11.08	9.10	7.56	6.34	5.35
C	0.256	0.297	0.271	0.235	0.203	0.122	0.156	0.139	0.125	0.114

TABLE - II (f)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 4$

$V = 7$

Sections	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	9	10
Local tip raidus	0.136	0.272	0.408	0.545	0.681	0.817	0.953	1.090	1.226	1.362
local tip speed ratio	0.4	0.6	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
ϕ	45.46	34.22	26.53	21.33	17.71	15.08	13.10	11.56	10.34	9.35
β	41.46	30.22	22.53	17.33	13.71	11.08	9.10	7.56	6.34	5.35
C	0.154	0.179	0.163	0.142	0.122	0.107	0.094	0.084	0.075	0.069

TABLE - II (g)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 4$

$V = 9$

Sections	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	9	10
Local tip raidus	0.093	0.186	0.280	0.373	0.467	0.560	0.654	0.747	0.841	0.934
local tip speed ratio	0.4	0.6	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
ϕ	45.46	34.22	26.53	21.33	17.71	15.08	13.10	11.56	10.34	9.35
β	41.46	30.22	22.53	17.33	13.71	11.08	9.10	7.56	6.34	5.35
C	0.106	0.123	0.112	0.097	0.084	0.073	0.064	0.057	0.052	0.047

TABLE - II (h)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 6$

$V = 3$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.485	0.971	1.457	1.942	2.428	2.914	3.399	3.885	4.371	4.857
local tip speed ratio	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0
ϕ	39.35	26.53	19.37	15.09	12.29	10.34	8.920	7.84	6.99	6.33
β	35.35	22.53	15.37	11.08	8.29	6.34	4.92	3.84	2.99	2.30
C	0.419	0.389	0.313	0.254	0.219	0.180	0.156	0.308	0.125	0.111

TABLE - II (i)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 6$

$V = 5$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.225	0.451	0.677	0.902	1.128	1.354	1.580	1.805	2.031	2.257
local tip speed ratio	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0
ϕ	39.35	26.53	19.37	15.09	12.29	10.34	8.920	7.84	6.99	6.33
β	35.35	22.53	15.37	11.08	8.29	6.34	4.92	3.84	2.99	2.30
C	0.194	0.181	0.145	0.118	0.098	0.083	0.072	0.064	0.057	0.052

TABLE - II (j)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 6$

$V = 7$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.136	0.272	0.408	0.545	0.681	0.817	0.953	1.090	1.226	1.362
local tip speed ratio	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0
ϕ	39.35	36.53	19.37	15.09	12.29	10.34	8.920	7.84	6.99	6.33
β	35.35	22.53	15.37	11.08	8.29	6.34	4.92	3.84	2.99	2.30
C	0.117	0.109	0.088	0.071	0.059	0.050	0.043	0.038	0.034	0.0314

TABLE - II (k)

Blade : Type 3 (Curved plate with tube inside)
Power : 480 W

$\lambda = 6$

$V = 9$

Sections	1	2	3	4	5	6	7	8	9	10
Local tip raidus	0.093	0.186	0.128	0.363	0.467	0.560	0.654	0.747	0.841	0.934
local tip speed ratio	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0
ϕ	39.35	36.53	19.37	15.09	12.29	10.34	8.920	7.84	6.99	6.33
β	35.35	22.53	15.37	11.08	8.29	6.34	4.92	3.84	2.99	2.30
C	0.086	0.074	0.060	0.049	0.0407	0.034	0.030	0.026	0.023	0.02

TABLE - II (l)

CHAPTER. 4

GENERATOR

An electrical generator is a machine which converts mechanical energy in electrical into electrical energy. The energy conversion is based on the principle of the production of dynamically induced emf. According to Faraday's laws of electro- magnetic induction, when conductor cuts magnetic flux an emf is dynamically induced in it. This emf causes a current to flow if the conduction circuit is closed. Hence, two basic essential parts of electrical generator are :
(i) a magnetic field and (ii) a conductor or conductors which can move so as to cut the flux.

The three main types of electrical machines which could be coupled to a wind machine are

1. The synchronous machine
2. The asynchronous machine
3. The commutator machine

4.1. THE SYNCHRONOUS MACHINE (SM)

A synchronous machine is usually constructed in the following way :
The rotor consists of a number of poles, around which coils are wound. When a DC current (the field current or excitation current) is flowing through the coils magnetic poles are excited. The number poles is even (each pair consists of a south pole and north pole) and usually have a value between 2 and 24. When the number of poles is 'P' and rotor rotates with rpm 'N_a' then a fixed point on the stator will see a magnetic field periodically chaining with a frequency as given below:

$$F = P \times Na' \quad \ldots\ldots\ldots\ldots (4.1.1.)$$

On the stator, normally three coils are wound in such a way that, when a three phase current system flows through these coils (with a certain frequency, f), a rotating magnetic field is generated. When the stator of a synchronous machine is connected to a voltage system with a fixed frequency, f, the shaft (after synchronism) will rotate at a fixed speed of 60 x f/p revolutions per minute. Vice versa applies that, when the rotor rotate at a fixed speed, the synchronous machine supplies a voltage of a fixed frequency. As a result, a wind motor coupled to a synchronous machine has to rotate at a constant speed(the synchronous speed) if the machine is directly connected to the public grid. If the machine operates independently, then speed variation is possible, but the output charge will have a variable frequency. For electric heating this will present no difficulties, for other applications rectification and subsequent DC/AC conversion might be necessary.

In general, the rotor of the synchronous machine has two slip rings to which the field current (DC) can be fed. The generated voltage and current is taken from a number of stator coils (depending on the no of phases) .The slip ringless types of synchronous generators also exist.

4.2. THE ASYNCHRONOUS MACHINE:

Basically, the stator of the asynchronous machine is the same as that of the synchronous machine. The stator coils are normally connected to an AC-voltage system eg: grid -These coils, one for a single-phase asynchronous machine and three for the three-phase asynchronous machine, will supply the rotating magnetic field.

The rotor windings are generally not connected to a power source but are short-circuited. Either a squirrel cage rotor is used or the rotor windings are short-circuited outside the machine. The terminals are led outwards by means of slip rings.

The rotating stator field induces currents in the rotor. *These currents are only* limited by impedance of the rotor windings. The magnetic field in the stator exerts a torque on the current conducting windings of the rotor and the rotor will have to rotate, forced by this torque. When the rotor rotates at the same speed as the rotating stator field(this speed is called the synchronous speed), no current is induced in the rotor and no torque is exerted on the rotor by the stator field. This means that, if the stator has to exert a force on the rotor, the mechanical rotor speed W_m has to differ from the speed of the stator field W_s: the rotor rotates at an asynchronous speed with respect to the speed of the stator field.

This speed difference is expressed in the relative "slip" (s) of the machine.

$$S=\frac{W_s-W_m}{W_s} \qquad \text{.......................(4.2.1.)}$$

A practical value of s is 4 %

When an asynchronous machine, rotating at synchronous speed is connected to a load requiring a torque, the rotor speed will decelerate to a value where the difference in the speed of rotor field and stator field causes enough rotor current to produce the required torque. Now the machine acts as a motor.

On the contrary, when the asynchronous machine is driven by a prime mover at a speed higher than the synchronous speed, currents will be generated in the rotor. These currents excite a magnetic field which generates a voltage and subsequently a current in the stator windings. Then the machine acts as a generator with electric power leaving the stator connections. The function of the stator windings are :

- To produce a rotating magnetic field.
- To conduct a generating power.

If no three-phase voltage system is available, the machine will not easily operate as a generator, because it cannot generate its own field current in the rotor.

4.3. THE COMMUTATOR MACHINE

Generally the commutator machine is constructed as follows :

◊ The stator is equipped with one or more pairs of poles to generate the magnetic field. The field can be obtained by electric magnets on the permanent magnets.

◊ On the rotor a number of coils are distributed in slots. The coils are connected to the segments of a commutator. Brushes resting on the commutator conduct the current to the outside world. The voltage generated is a DC voltage with a small ripple caused by the commutation.

The commutator machine is one of the oldest types of electrical machines and has been used extensively. For generating purposes, the commutator machine has been superseded by the synchronous machine. Although, with the advent of the DC/AC converter these still remains a roll for the commutator machine. For constant speed driving applications the asynchronous machine has taken over, but for variable speed drives the commutator machine is still used. Eg: Most electric trains have commutator machine drive.

The torque-speed curves strongly depend on the voltage and field current, as shown in figure(29)

4.4. APPLICATION FOR WIND ENERGY

Nearly every type of generator has been utilized for wind energy applications. There is no “best type” of generator to be used up till now.

For direct connection to the public grid the asynchronous machine is quite favorite, because of the relatively simple synchronization procedure and the low cost & low maintenance requirements. Most small to medium scale wind turbines(10-100KW) in Denmark and Netherlands are equipped with asynchronous machine. The more or less constant speed, however, causes large variations and consequently large current variations. The first are not appreciated by the mechanical construction, the second not by electrical utility. Synchronous generators are used as well, but they show even more torque and current fluctuations. Damping these fluctuations is possible via mechanical means, such as flexible couplings, or by allowing the rotor to run at variable speeds. This can be accomplished with variable speed gear boxes or electrically with the use AC or DC/AC converters.

The latter method receives strong support in the Netherlands and is being tested on several machines, both with synchronous machines and DC commutator machines. Variable speed operation, but nevertheless, a constant frequency and voltage output, can also be accomplished with special electrical machines. For battery charging the DC commutator machine is still used extensively on the small wind turbines but the synchronous machine with rectifiers is used more and more.

In view of the relative merits and demerits of generators commonly used with wind energy systems, it is proposed that a commutator type generator may be used for the present wind powered stand - alone generator.

4.5. TESTING OF THE MOTOR

A universal motor of 1HP (230V) was used to simulate the working conditions of the wind rotor under this study. A universal motor is defined as the motor which may be operated either on direct or single phase AC supply at approximately the same speed and output. The speed of a universal motor varies such that it is low at full load and high on no-load. On no-load the speed is limited only by its own friction and windage load. Inorder to bringout the characteristics of the generator used for this study, it was essential that the characteristics of the driving motor should be brought out. Hence the One HP universal motor (230V) is tested for its power, torque and efficiency characteristics. The experimental set up used for testing is shown in the Fig. 30.

A brakedrum is attached to the universal motor. The power is taken from the main supply through the control device. By turning the adjustable screws, the tension T_1 and T_2 in the belts ($T_1 > T_2$) in contact with the brake drum could be varied. As the brake load increased, the motor draws more power. The tension

T_1& T_2 could be read from the respective spring balances (each of rating 10Kg) connected to the belts. The input current (I) (Ampere) voltage V(Volts) were noted from the ammeter and voltmeter in the control unit. The input power P (Watts) could be calculated as : P= VI. The radius (R) of the brakedrum is 0.075m. The torque T (Nm) can be calculated as :

$$T = (T_1 - T_2)\, R \times 9.81 \quad \text{.................... (4.5.1.)}$$

The rpm of the motor (N) is measured using a contact type tachometer. The universal motor was operated at different speeds and for each speed of operation load was set at different level by changing the belt tension.

The output power P' (watts) is calculated as

$$P' = 2\pi NT/60 \quad \text{............................(4.5.2.)}$$

The efficiency is calculated as ;

Efficiency = output power/ input power = $P'/V \times I$

The motor efficiencies calculated for various speed and load as presented in the fig. 31 & 32 respectively.

From this experiment efficiency of the motor at different speed at low levels could be established. A second degree polynomial equation were fitted to the experimental data and the relationship. fig. 31.

From the experimental results a regression model has been developed relating Torque, Speed and Load of the motor which is given as

$$T = 3.415\,(P^{0.225}/N^{0.12}) - 4.3405 \quad \text{.........................(4.5.3)}$$

Where T = Torque

P = Power

N= rpm (Speed)

and r = 0.9045

Once the relationship between efficiency, speed and load could be established, the torque speed characteristics of the machine could be determine as displayed in the fig. 32.

4.6. TESTING OF THE COMBINED SYSTEM

The experimental setup is as shown in the Figure 33. The alternator is directly coupled to the motor through a dogclutch assembly. The motor rpm is varied and the power input and output of the alternator are measured. The current and voltage are read from the ammeter and voltmeter respectively. A Rheostat is connected to the circuit for offering the required resistance. A 12 V storage battery is connected across the alternator terminals to energise the electronic circuit . Once the circuit is energised by the battery the alternator starts generating power. The power input to the motor is calculated from the current and voltage drawn by the motor. From the rpm V/s efficiency graph and knowing the power input to the motor, the power output of the motor can be found out. This will be the power input to the alternator. Knowing the power input to the alternator, Its torque input can be calculated. Hence torque speed characteristics of the generator is established.

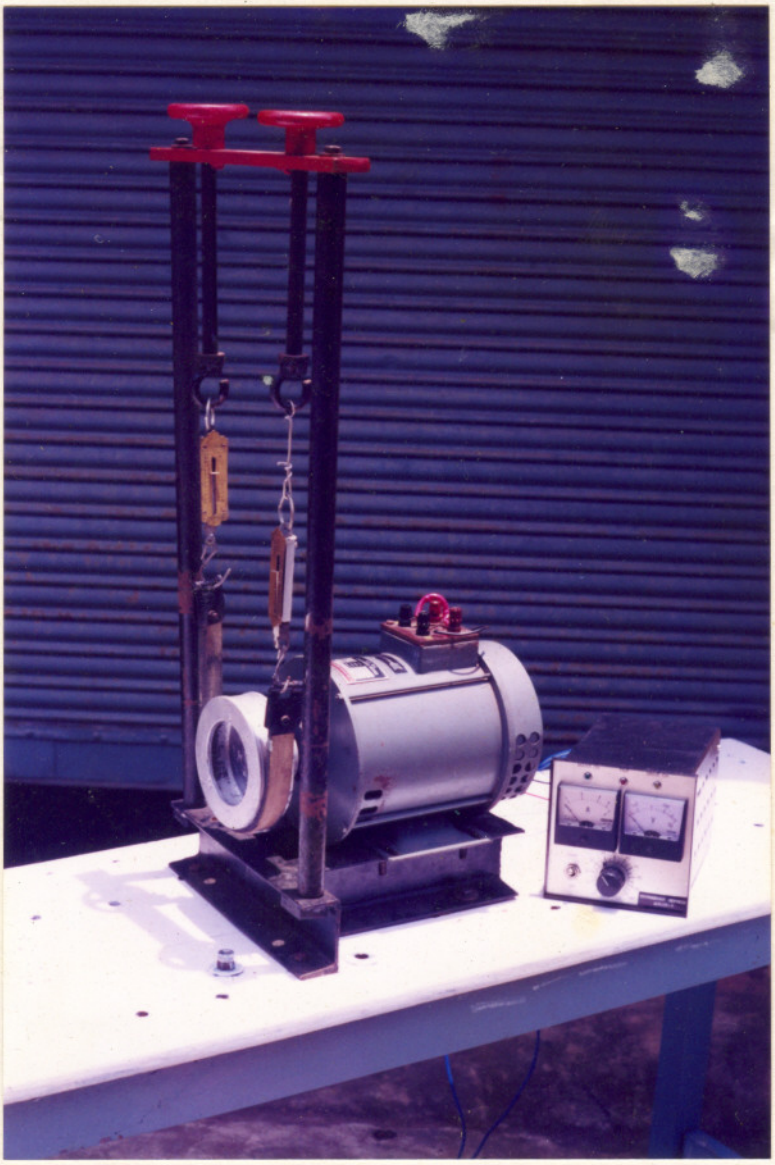


PLATE 1 CALIBRATION SETUP FOR THE MOTOR

PLATE 2 TESTING OF THE COMBINED SYSTEM

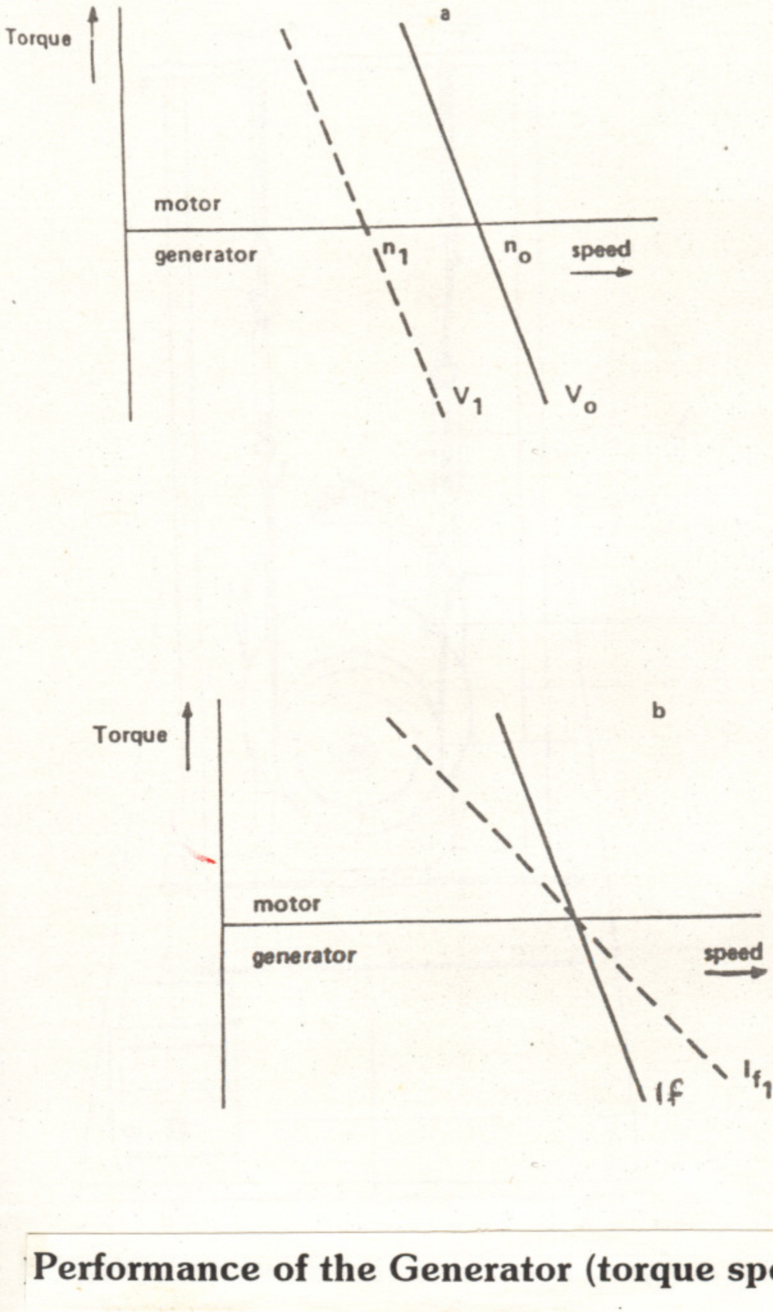


FIG. 29 **Performance of the Generator (torque speed curves)**

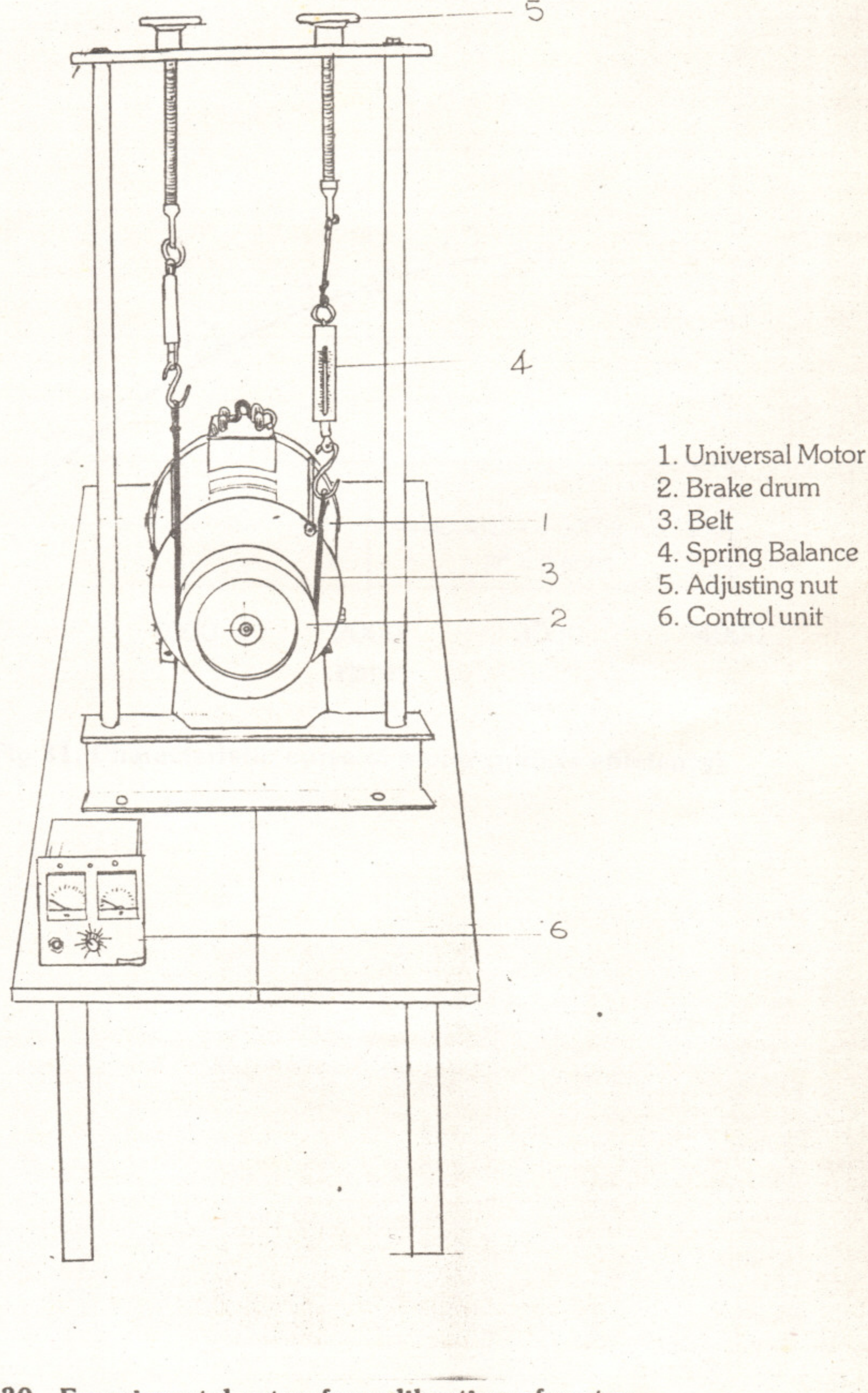


Fig 30. Experimental setup for calibration of motor

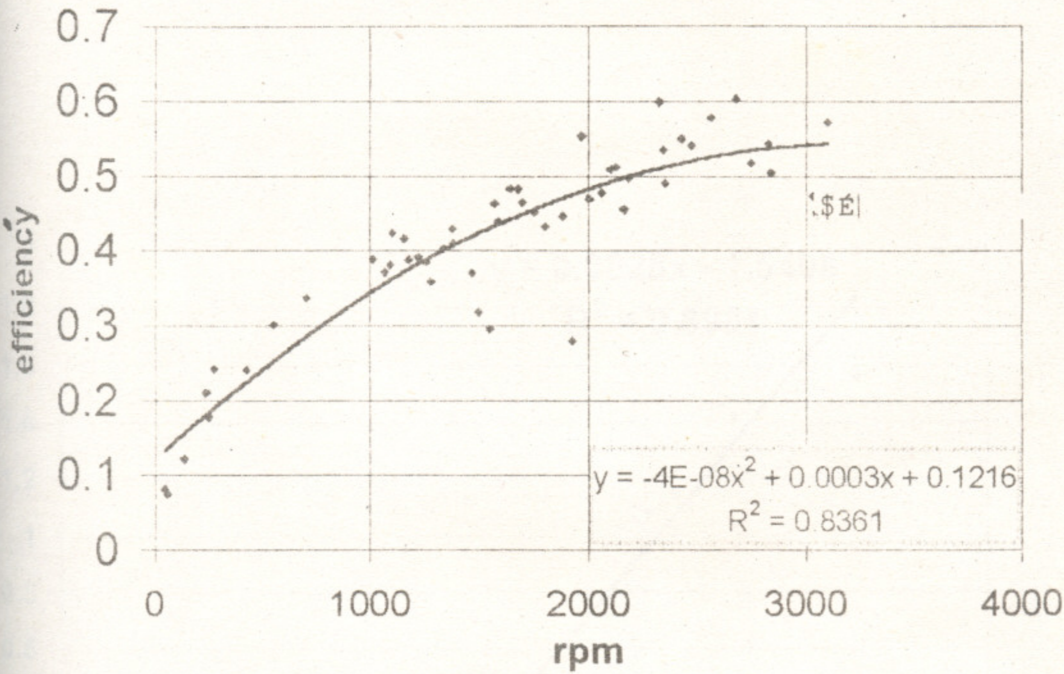


Fig 31. Characteristic curve of motor (rpm vs efficiency)

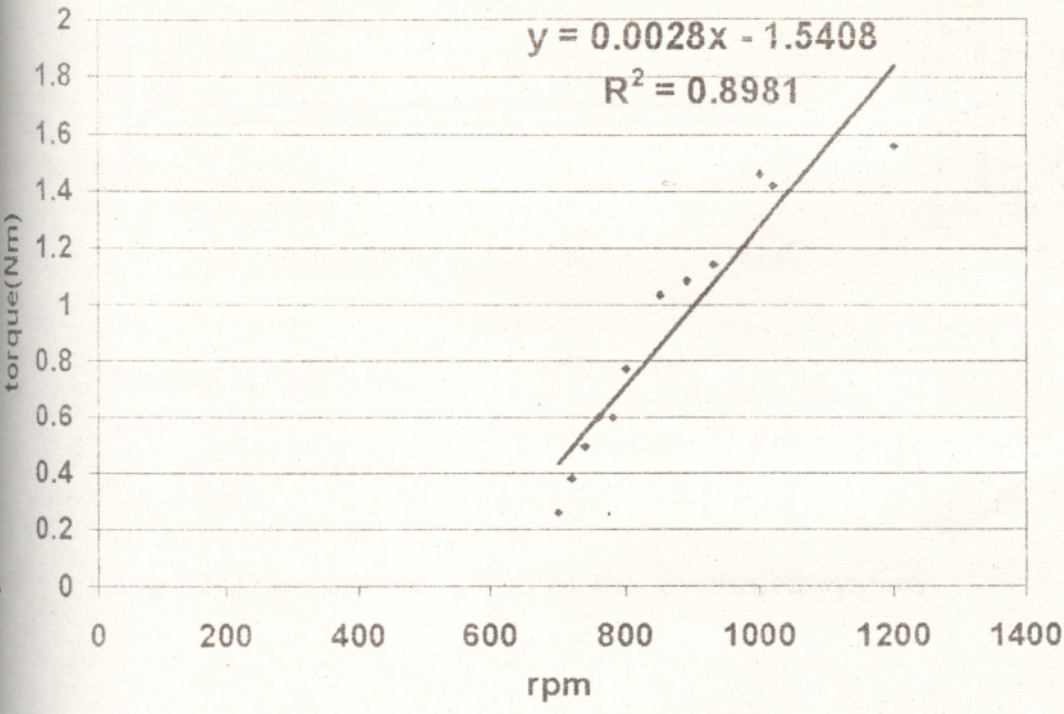
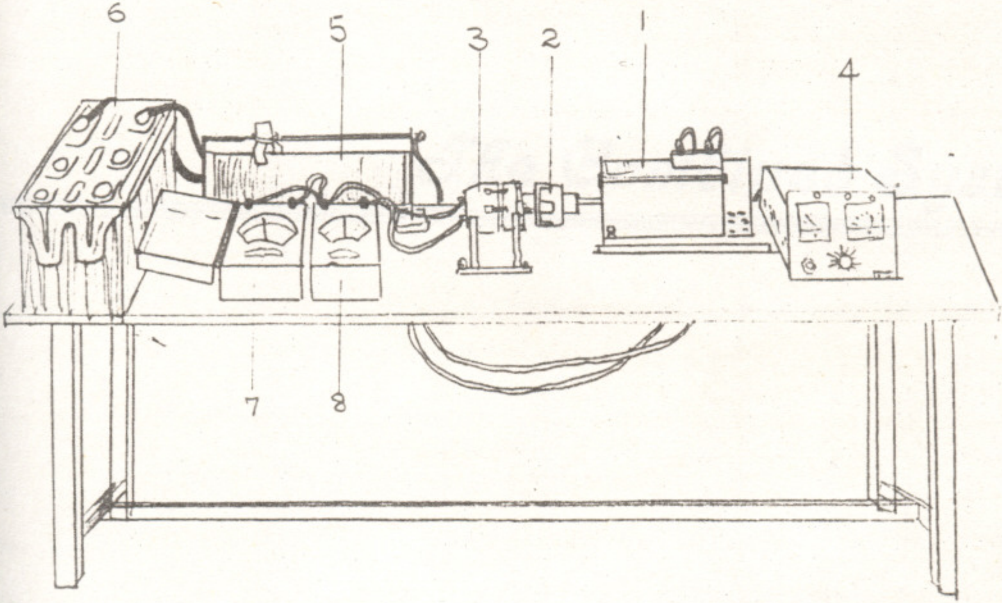


Fig 32. Characteristic curve of the motor (torque vs rpm)



1. Universal Motor (1HP)
2. Coupling Unit
3. Alternator (12 V, 30 A)
4. Control Unit
5. Rheostat
6. Storage Battery (12V)
7. Ammeter (0-20A)
8. Voltmeter (0-30V)

Fig 33. Experimental setup of the combined system

CHAPTER. 5

THE COMBINED SYSTEM

5.1. INTRODUCTION

Once the characteristics of the generator used in the proposed aerogenerator is established in terms of its torque-speed relationship, now the task is to select a suitable rotor to drive the generator and match the two to derive maximum system efficiency. For this, the torque-speed characteristics of the rotor should be determined and the working points of the combine system at different wind speed are to be identified.

If the power-speed characteristics of both the wind rotor and the generator are known, then the coupling procedure is rather straight forward and nearly identical to the coupling of a pump and wind rotor. The only exception being that, because of the high speed required for most generators, a gearbox is usually necessary, of which the optimum gearing ratio has to be determined.

The problem is more complex than it seems however, because the power-speed relation depends upon the type of generator, the power factor, the magnitude of the load, the field current, and upon the fact whether the speed of the machine is kept constant by a grid or is allowed to vary. An extra complication is that most generators are designed to operate at one optimum speed only, and it is often difficult to find their characteristics at lower speeds.

5.2. STUDIES ON AEROGENERATOR

The research works carried out on development of aerogenerator are being briefly revised in the section with a view to derive useful information on the selection and matching the generators with the rotor.

5.3. STUDIES ON AERO GENERATOR

Clark (1982) studied the possibility of electricity generation using a vertical-axis wind turbine of 100 kW capacity. The turbine had two air foil-shaped blades that produce power to drive an induction generator. Electrical power was produced when the wind speed is >5.5m/s. A peak efficiency of 48% had been achieved for the wind turbine.

Vosper *et al* (1982) conducted an investigation on the utilization of variable electric power from a wind turbine. A generator for a wind energy conversion system , producing variable voltage and frequency electric power , was tested in the laboratory. An AC system was selected. A permanent magnet alternator provided power to resistive and to induction motor loads. Testing includes a 5.6 kW-motor powering a centrifugal pump. With an alternator rotor speed between 70 and 150 r/min , frequency of the output varied from 30-65 Hz , while voltage varied from 85 to 250 V with various loads. Transformers were used to increase the voltage to the motors to improve the motor efficiency. The operation , performance , and efficiency of the system were presented and life expectancy of the motor was described. The permanent magnet alternator was found to give a wind turbine the capability of performing multiple tasks without connection to the utility grid.

Abarikwu (1983) conducted a study on the wind energy system for dairy farms. Equations were presented for optimizing the design parameters of a wind generator and the cost of installation and running were calculated for dairy farm with 50 to 500 cows , at different wind speeds and levels of energy conservation. Wind generators are regarded as an attractive part of an overall energy conversion system which includes tubular precooling of milk and energy conservation in refrigerating milk. Calculated costs of wind energy were in the range 3-5 cents/kwh for herd size 200-500 and wind speed 8m/s , and 5-9 cents/kwh for similar herds and wind speed 6m/s.

Clarks (1984) has conducted an investigation on the electrical generation using a vertical axis wind turbine. The major advantage of the vertical axis wind turbine over the conventional propeller and multi-blade types is that no orientation is required to keep the rotor in the wind stream. This simplifies design by eliminating a yaw control and reduces the gyroforce on the rotor. Other advantages are that gearboxes, brakes, generators and others components could be placed at ground level, enabling fabrication and maintenance costs to be reduced by the easy accessibly to heavy items requiring high maintenance. Also, the vertical-axis design used a simple low-cost tower. Several operational problems were encountered, however, during initial testing of a 100 kW Darriens-type wind turbine used to provide electricity for an irrigation system, and these were discussed. The vertical axis turbine tested had an induction generator operated as an electric motor to overcome the starting problem of the system starting at long rotational speeds. The turbine began to produce electric power at a wind speed of 5.5 m/s and reached its peak at 18 m/s; rated output of 100KW is produced at 14 m/s. The unit had obtained a peak efficiency of 43.8 at a wind speed of 7 m/s or 73% of theoretical maximum. Annual energy output was estimated at 200000 kwh.

Vosper and Clark (1985) conducted a study on the energy production and performance of a wind-driver induction generator. The reliability and performance of a wind machine for agricultural applications were examined. It had a 25KW induction generator which provided 240V, 60Hz, single-phase electric power. The horizontal axis wind turbine had a 13.4 m dia, three-bladed fixed-pitch rotor and was mounted on a 24.4m tower. The blades were of laminated epoxywood attached to a steel hub. The wind turbine operated 64% of the time and was available for operation over 95% of the time. Agricultural technicians who had been trained to maintain the machine were able to handle most of the service needs. The unit had a net energy production of over 100,000 KWH for a 20 month period in an average wind speed of 5.9m/s at a height of 10m. Power curves were established for the wind turbine at two different pitch settings and with two different sets of blade-tip brakes.

According to Pazral, (1996) before constructing agricultural windmills to utilise wind power, it is necessary to know the range of wind velocities at the height of the generator axis so that the correct dimensions and gearing could be used. For the appropriate calculations to be made, the efficiency wind speed, average wind speed and coefficient of unevenness (wind fluctuation) must be known. Equations for these values were given and one of the most common methods of calculating them was presented along with five examples in the form of mathematical models. The examples range from relatively low wind speeds (5.49 m/s) to very high ones (9.23 m/s).

Vieskh (1997) has conducted a study on the wind/diesel installation for farms. The use of wind/diesel installation in the USA and UK were briefly reviewed, and the layout of an installation appropriate for use in Russian farms was proposed. It comprises a windmill, synchronous generator, diesel engine, storage battery, rectifier, inverter and switch-gear. It was suitable for use in regions where average wind speeds in autumn, winter and spring were greater than or equal to 5m/s. It could provide a farmhouse and farm with electricity, heat and water at less cost than a diesel-electric generating station.

6.4. LOAD MATCHING

Load Matching should be done in a way such that the combine system will work at the peak efficiency point of rotor. To achieve these objectives, we will have to establish a relationship between speed and torque of the rotor as well as the generator at different wind velocities. It should be made sure that the maximum torque points of the rotor or torque points of the generator should as far as possible, coincide with the peak torque points of the rotor.

As the fabrication of the wind rotor and it testing for aerodynamic characteristic in field or windtunnel, is beyond the scope of this study, it has been decided to adopt the torque speed characteristic of the rotor reported by Lysen (1982).

Care was taken to see that the design wind speed, design tip speed ratio, design Cp and air-foil profile characteristics of the reported rotor and the present rotor match properly.

We have

$$P = \frac{1}{2}\rho A V^3 Cp \qquad \text{...(6. 4.1)}$$

Hence Torque

$$T = \frac{\rho A V^3 C_p}{2} \bigg/ \frac{2\pi N}{60} \qquad \text{...(6. 4.2)}$$

A three bladed rotor with design wind speed and tip speed the ratio 5m/sec and 4 respectively, is selected for the study C_p-λ characteristics of the rotor, as reported by Ragie and Summan is being reproduced and given in fig 34. A Third degree polynomial equation has been fitted to this curve which yielded the regression equation.

$$C_p' = -0.01\lambda^3 + 0.0645\lambda 2 + 0.0199\lambda - 0.0819 \qquad \text{...................(6.4.3.)}$$

substituting C_p in the equation for T and $\lambda = \frac{\pi D N}{60 V}$ and expanding

we get $T = 0.331\ VN - 0.012\ N^2 + 0.432\ V^3/N$ ....(6. 4.5.)

The deduced relationship between torque and speed is demonstrated graphically in figure (35). From the above relationships torque speed characteristics of the rotor was established. Torque speed characteristics of the generator established under the experimental investigation was super imposed over the rotor curves, as given in Fig.(36)

From the figure, it could be clearly seen that the generator demanded higher speed than that of the rotor as evidenced by the absence of any coinciding point. Hence the rotor speed should be stepped up to the tune to that of the generator working speed. This indicated that working speed should be manipulated introducing gears in the system. The problem of determining the desired gear ratio was addressed through graphical method. In the load matching curve, different combinations of gear ratios were tried and it could be found that for a gear ratio of 1:22, the peak torque points of the rotor and torque-speed curve of the generator would coincide at the maximum possible level and the combined system will work in harmony. Now , the working points of the system at 1:22 is also indicated in figure(37) . From the figure, one could easily locate the speed and torque at which the system is settled down at a particular wind velocity. Hence now it is possible to find out the power developed by the combined system at different wind speed. This has been displayed in fig 38 . A Polynomial equation of degree 2 was fitted to the operating points as shown in fig 38, which yielded the velocity power relationship of the combined system as

$$y = 79.164\, x^2 - 560.75\, x + 1022.7 \quad \text{.......................................(6. 4.6.)}$$

Power of the combined system at different velocities were computed using this relationship and displayed in the table III.

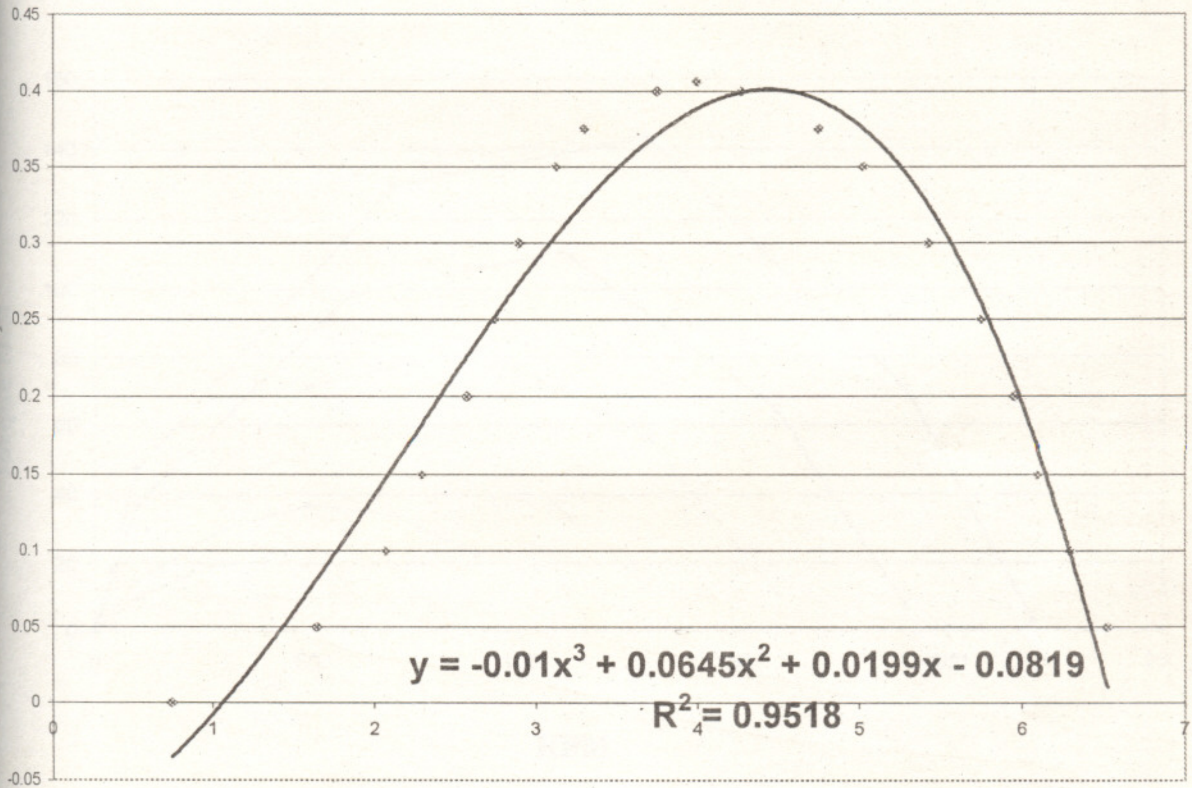


Fig. 34. C_P-λ Curve of the adopted rotor

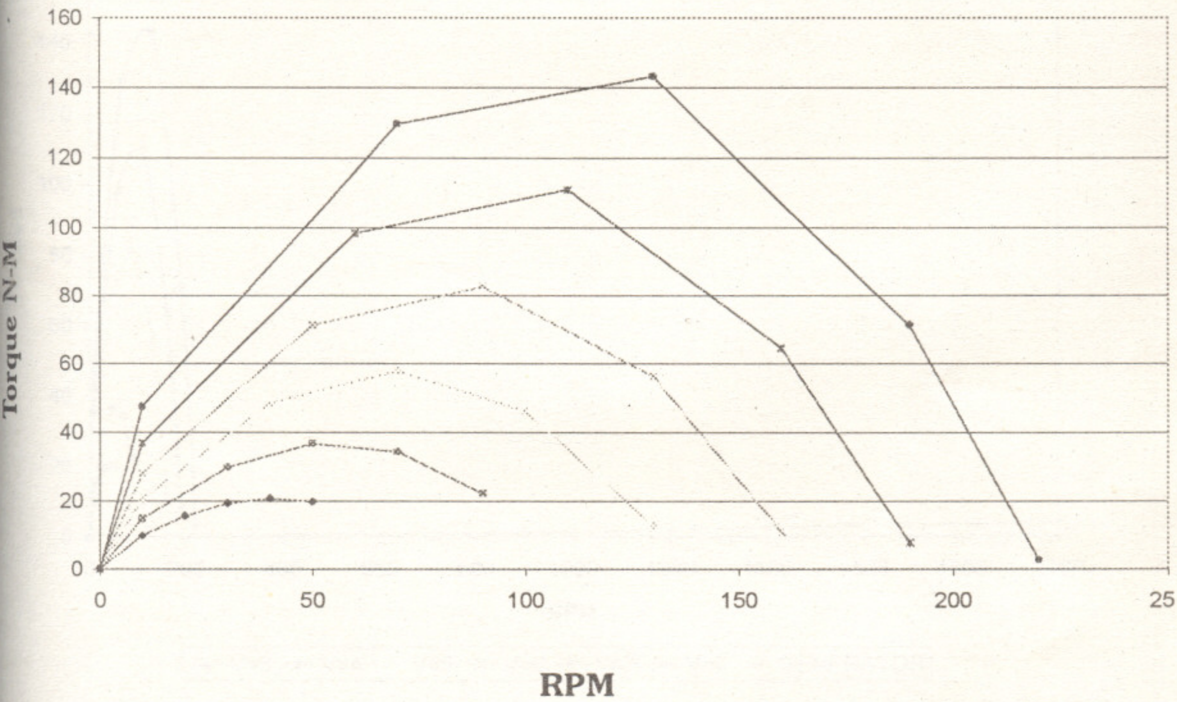


Fig. 35. Torque-speed-velocity curve

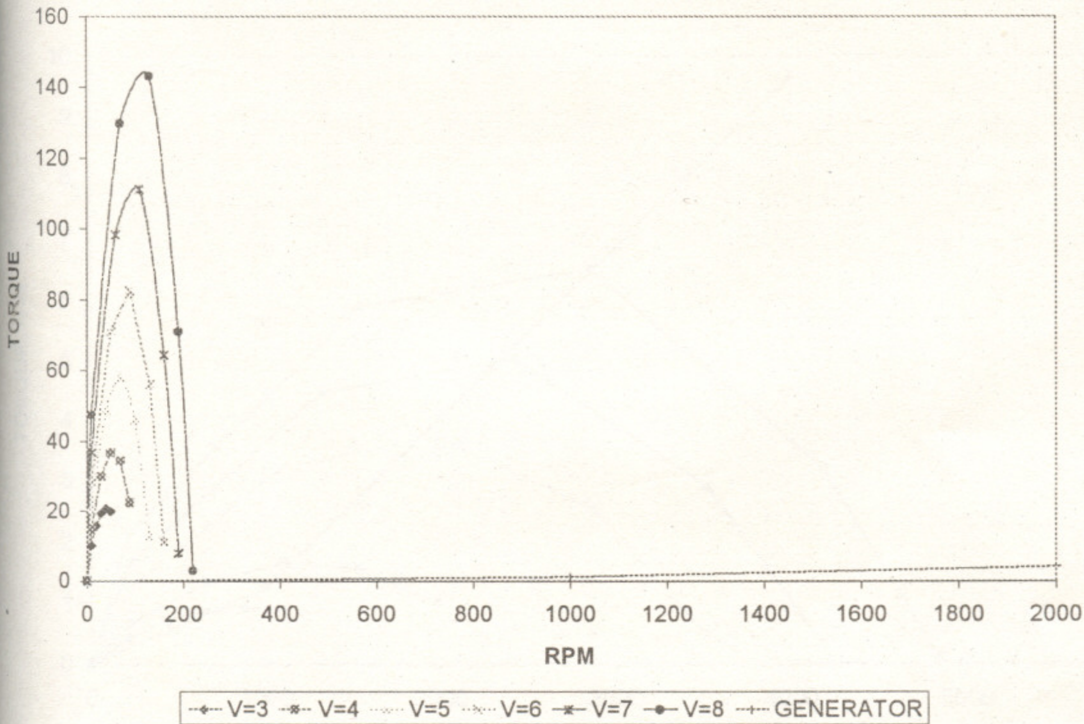


Fig. 36. Matching of rotor and the generator without gear

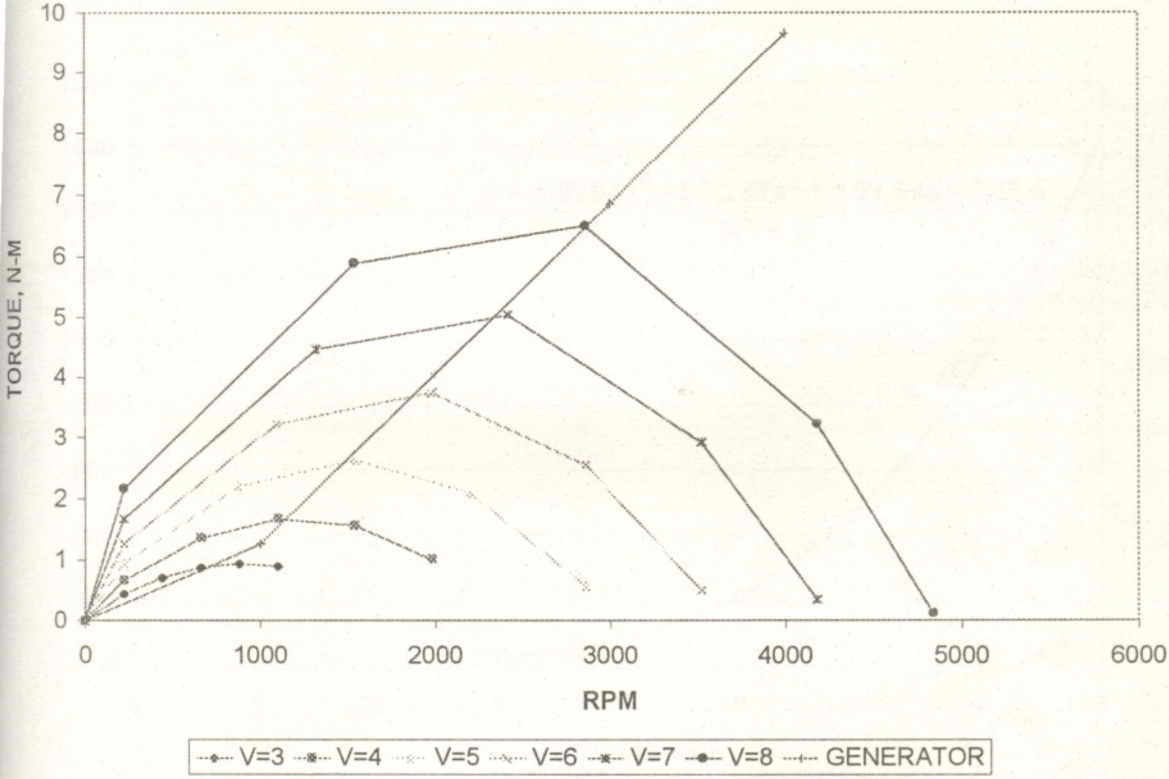


Fig. 37. Matching of rotor and generator with gear ratio 1:22

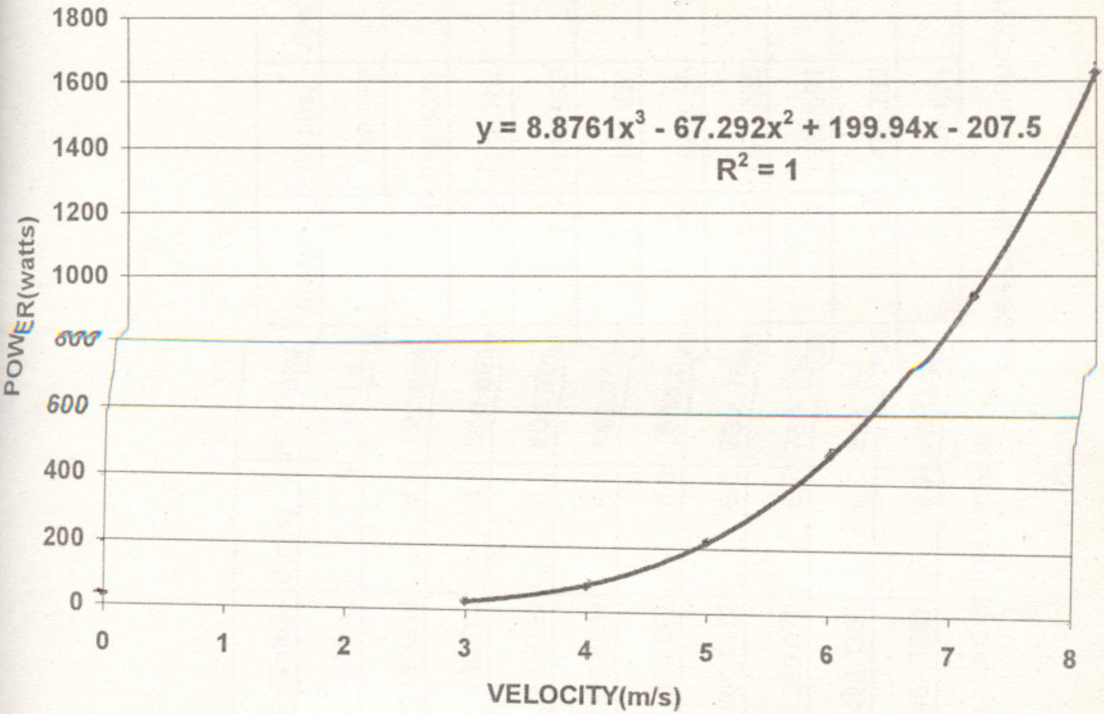


Fig. 38. Power vs Velocity

V(m/s)	P(Watts)	V(m/s)	P(Watts)	V(m/s)	P(Watts)	V(m/s)	P(Watts)	V(m/s)	P(Watts)	V(m/s)	P(Watts)	V(m/s)	P(Watts)
3	26.362	4	83.684	5	219.45	6	486.916	7	939.338	8	1629.972	9	2612.074
3.1	30.08202	4.1	92.8519	5.1	239.3914	6.1	522.9565	7.1	996.8031	8.1	1714.187	9.1	2728.365
3.2	34.10717	4.2	102.8575	5.2	260.703	6.2	560.8997	7.2	1056.704	8.2	1801.371	9.2	2848.157
3.3	38.49071	4.3	113.754	5.3	283.4382	6.3	600.7991	7.3	1119.093	8.3	1891.575	9.3	2971.503
3.4	43.2859	4.4	125.5948	5.4	307.6501	6.4	642.7077	7.4	1184.024	8.4	1984.854	9.4	3098.455
3.5	48.546	4.5	138.433	5.5	333.392	6.5	686.679	7.5	1251.55	8.5	2081.261	9.5	3229.068
3.6	54.32426	4.6	152.3219	5.6	360.7172	6.6	732.7661	7.6	1321.725	8.6	2180.849	9.6	3363.394
3.7	60.67393	4.7	167.3148	5.7	389.679	6.7	781.0223	7.7	1394.601	8.7	2283.671	9.7	3501.487
3.8	67.64827	4.8	183.465	5.8	420.3305	6.8	831.5008	7.8	1470.232	8.8	2389.78	9.8	3643.401
3.9	75.30054	4.9	200.8256	5.9	452.7251	6.9	884.255	7.9	1548.671	8.9	2499.23	9.9	3789.187

Table III Power Produced at the various velocities by the combined system

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Appendix I

Monthly Wind Datas of various Stations					m/s
	TRIVANDRUM	ALLEPPEY	COCHIN	PALGHAT	CALICUT
JAN	5.50	9.90	8.30	9.90	8.90
FEB	6.10	10.50	9.00	9.00	10.30
MAR	6.70	11.80	9.80	8.00	11.20
APR	7.10	11.80	9.20	7.90	11.10
MAY	9.00	12.50	10.60	10.90	12.10
JUN	9.50	11.90	8.70	12.00	8.80
JUL	10.20	11.50	9.80	12.40	8.70
AUG	10.90	11.00	9.50	12.00	7.90
SEP	9.80	11.10	8.90	11.20	8.60
OCT	7.10	10.60	7.80	10.70	7.90
NOV	5.10	8.40	7.10	7.30	7.40
DEC	4.90	10.40	7.30	9.50	7.50
AVERAGE	7.70	10.90	8.80	9.00	9.20

Appendix II
Computer Programme for Predicting the Seasonal Energy Available from a Site

```
# include <stdio.h>
# include <math.h>
# define PI 3.14159
main( )
{
float a,b,c,d,E,VM,PO,T,VI,VO,CPO;
printf ("\n\n\n\n");
printf("_____________________________________________________\n\n");
printf("  ENERGY - A PROGRAMME FOR PREDICTING THE \n");
printf("  SEASONAL ENERGY AVIALABLE FROM A SITE\n\n");
printf("\a\a\a\a\a\a\a\a\a\a\a\a\a\a\a\a\a\a\a\a\a\a");
printf("________________________________________________________\n\n\n\
n");
printf(" LET US START\n\n\n");
printf("WHAT IS THE VALUE OF VM=?            ");
scanf("%f",&VM);
printf("           WHAT IS THE VALUE OF T= ?              ");
scanf("%f",&T);
printf("WHAT IS THE VALUE OF VI=?            ");
scanf("%f",&VI);
printf("WHAT IS THE VALUE OF VO=?                          ");
scanf("%f",&VO);
PO=.5*1.2*.4*(VO*VO*VO);
a=(4*VM*VM/PI);
b=exp((-PI/4)*pow((VI/VM),2))-exp((-PI/4)*pow((VO/VM),2));
c=(exp((-PI/4)*pow((VO/VM),2)))*(VO*VO-VI*VI);
d=T*PO/(VO*VO-VI*VI);
E=d*(a*b-c);
printf("\n\n\n                        NOW LET US HAVE THE RESULTS\n\n\a\a\a\a\a");

printf("
      ________________________________________________________\n\n\n")
;
printf("                        ENERGY   =  %f\n\n\n",E);
printf("
_____________________________________________________________");
printf("\n\n\n THANK YOU FOR USING ME !!!!!");
getche();
}
```

Type of Airfoil	C_d/C_l	α	C_l
Flat plate	0.1	5°	0.8
Curved plate (10% curvature)	0.02	3°	1.25
Curved plate with tube on concave side	0.03	4°	1.1
Curved plate with tube on convex side	0.2	14°	1.25
Airfoil NACA 4412	0.01	4°	0.8

Appendix III (a) The value of α Cl, Cd/Cl for some air foils

λd	B
1	6 - 20
2	4 - 12
3	3 - 6
4	2 - 4
5 - 8	2 - 3
8 - 15	1 - 2

Appendix III (b) The value of λd and β

Appendix IV

Determination of Rotor Blade Parameters

We have designed the rotor with the following parameter and the design is given below:

$P = 480W$

$\rho = 1.2\ kg/m^3$

$V = 5m/s$

$CP = 0.5$

A curved plate with tube on concave side is selected:

$\therefore \quad C_l = 1.1$

$\alpha = 4°$

Take $\beta = 3$

$\lambda_d = 4$

$$E = \tfrac{1}{2} \rho A V^3 C_p$$

$$480 = \tfrac{1}{2} \times 1.2 \times A \times 5^3 \times 0.4$$

$$A = 16$$

$$\pi R^2 = 16$$

$$R = 2.25\ m$$

Dividing this radius into 10 equal sections each with a length of 0.225m.

For the first section:

$$\lambda_r = \lambda_d \times \frac{r}{R} = 4 \times \frac{0.225}{2.25} = 0.4$$

$$\phi = \frac{2}{3} \arctan \frac{1}{\lambda_r} = \frac{2}{3} \times \arctan \frac{1}{0.4} = 45.467$$

$$\beta = \phi - \alpha = 45.467 - 4 = 41.467$$

$$c = \frac{8\pi r}{BC_l}(1-\cos\phi) = \frac{8\pi \times 0.225}{3 \times 1.1} \times (1-\cos 45.467) = 0.2566$$

For the second section:

$$\lambda_r = 4 \times \frac{0.45}{2.25} = 0.8$$

$$\phi = \frac{2}{3} Tan^{-1}\left(\frac{1}{0.8}\right) = 34.2278$$

$$\beta = 34.2278 - 4 = 30.2278$$

$$C = \frac{8\pi \times 0.45(1-\cos 34.2278)}{3 \times 1.1} = 0.2976$$

For the third section:

$$\lambda_r = \frac{4 \times 0.765}{2.25} = 1.2$$

$$\phi = \frac{2}{3} \tan^{-1}\left(\frac{1}{1.2}\right) = 26.54$$

$$\beta = 26.54 - 4 = 22.54$$

$$c = \frac{8 \times \pi \times 0.903}{3 \times 1.1}(1-\cos 26.5378) = 0.2726$$

For the fourth section:

$$\lambda_r = \frac{4 \times 0.903}{2.25} = 1.6$$

$$\phi = \frac{2}{3} \tan^{-1}\left(\frac{1}{1.6}\right) = 21.34$$

$$\beta = 21.34 - 4 = 17.34$$

$$c = \frac{8\pi \times 0.903}{3 \times 1.1}(1-\cos 21.34) = 0.236$$

For fifth section :

$$\lambda_r = \frac{4 \times 1.129}{2.25} = 2$$

$$\phi = \frac{2}{3} \tan^{-1}\left(\frac{1}{2}\right) = 17.71$$

$$\beta = 17.71 - 4 = 13.71$$

$$c = \frac{8 \times \pi \times 1.129}{3 \times 1.1}(1-\cos 17.71) = 0.204$$

For sixth section :

$$\lambda_r = \frac{4 \times 1.359}{2.25} = 2.4$$

$$\phi = \tfrac{2}{3}\tan^{-1}\left(\frac{1}{2.4}\right) = 15.08$$

$$\beta = 15.08 - 4 = 11.08$$

$$c = \frac{8\pi \times 1.359}{3 \times 1.1}(1 - \cos 15.08) = 0.178$$

for the seventh section :

$$\lambda_r = \frac{4 \times 1.580}{2.25} = 2.8$$

$$\phi = \tfrac{2}{3}\tan^{-1}\left(\tfrac{1}{2.8}\right) = 13.17$$

$$\beta = 13.10 - 4 = 9.10$$

$$C = \frac{8\pi \times 1.580}{3 \times 1.1}(1 - \cos 13.10) = 0.157$$

For the eighth section :

$$\lambda_r = \frac{4 \times 1.806}{2.25} = 3.2$$

$$\phi = \tfrac{2}{3}\tan^{-1}\left(\tfrac{1}{3.2}\right) = 11.57$$

$$\beta = 11.57 - 4 = 7.57$$

$$C = \frac{8\pi \times 1.806}{3 \times 1.1}(1 - \cos 11.57) = 0.134$$

For ninth Section:

$$\lambda_r = \frac{4 \times 2.032}{2.25} = 3.6$$

$$\phi = \tfrac{2}{3}\tan^{-1}\left(\tfrac{1}{3.6}\right) = 10.35$$

$$\beta = 10.35 - 4 = 6.35$$

$$C = \frac{8\pi \times 2.032}{3 \times 1.1}(1 - \cos 10.35) = 0.126$$

For tenth Section :

$$\lambda_r = \frac{4 \times 2.25}{2.2.5} = 4$$

$$\phi = \frac{2}{3} \tan^{-1}\left(\frac{1}{4}\right) = 9.36$$

$$\beta = 9.36 - 4 = 5.36$$

$$C = \frac{8\pi \times 2.25}{3 \times 1.1}\left(1 - \cos 9.36\right) = 0.114$$

APPENDIX V

COMPUTER PROGRAM FOR THE DESIGN OF ROTOR

```
#include <iostream.h>
#include <conio.h>
#include <graphics.h>
#include<math.h>
#include<process.h>
float a,b,c,d,e,ld,lr,tr,alpha,r,B,cd;
int sect,typeno;
void main()
{ int gd=DETECT,gm;
float x2,y2,px=100,py=200;
float arr[10];float be[10],cdl;
int i=0,typeno,ld;
initgraph(&gd,&gm,"");
clrscr();
cout<<"                    M A I N   P R O G R A M M E   M E N U
               "                    << "\n";

setcolor(YELLOW);
line(0,15,800,15);
cout<<"\n";
setcolor(RED);
line(0,20,800,20);
cout<<"\n";
setcolor(GREEN);
line(0,25,800,25);
cout<<"\n";
setcolor(BLUE);
line(0,30,800,30);

cout<<""<<"\n";
cout<<"SHAPE OF THE BLADE \n\n\n";
setcolor(RED);
line(0,110,150,110);
cout<<"\n";
setcolor(RED);
line(0,130,150,130);
setcolor(GREEN);
line(0,105,150,105);
cout<<"\n";
setcolor(GREEN);
line(0,135,150,135);

cout<<"\n";
cout<<"                    FLAT PLATE          1\n\n";
cout<<"                    CURVED PLATE                 2\n\n";
```

```
cout<<"                    CURVED PLATE WITH        \n";
cout<<"                    TUBE INSIDE          3\n\n";
cout<<"                    CURVED PLATE WITH        \n";
cout<<"                    TUBE OUTSIDE              4\n\n";
cout<<"                    NACA 4412            5\n\n\n\n";
cout<<" Enter the type number                        ";
cin>>typeno;
switch (typeno)
{
case 1: {cdl=.1;alpha=5;cd =.8;}
case 2:{ cdl=.02;alpha=3;cd=1.25;}
case 3: { cdl=.03;cd=1.1;alpha=4;}
case 4:{ cdl=.2;alpha=14;cd=1.25;}
case 5:{ cdl=.01;alpha=4;cd=.8;}
};

cout<<"\n\n\n";
cout<<"enter the tip speed ratio                  ";
cin>>ld;
cout<<"\n\n";
switch (ld)
{ case 1: {cout<<"enter the no: of blades between 6--20            \n";
          cin>>B;
          if((B<6)||(B>20)) {cout<<"Error input"; exit(0);}
          break;
          }
  case 2: {cout<<"enter the no: of blades between 4--12            ";
          cin>>B;
          if ((B<4)||(B>12)) {cout<<"Error input"; exit(0);}
          break;
          }
 case 3: {cout<<"enter the no: of blades between 3--6              ";
          cin>>B;
          if ((B<3)||(B>6)) {cout<<"Error input"; exit(0);}
          break;
          }
 case 4: {cout<<"enter the no: of blades between 2--4              ";
          cin>>B;
          if ((B<2)||(B>4)) {cout<<"Error input"; exit(0);}
          break;
          }
 case 10: {cout<<"enter the no: of blades between 1--2";
          cin>>B;
          if ((B<1)||(B>2)) {cout<<"Error input"; exit(0);}
          break;
          }
};
cout<<"\n\n";
cout<<"Enter the rotor radius                       ";
```

```
cin>>tr;
do{
cout<<"\n\n";
cout<<" Enter the section number                    ";
cin>>sect;
cout<<"\n\n\n";
switch (sect)
{

    case 1:      r=0.1*tr;
                 break;
    case 2:      r=r+0.1*tr;
    break;
    case 3:     r=r+0.1*tr;
    break;
    case 4:     r=r+0.1*tr;
    break;
    case 5:     r=r+0.1*tr;
    break;
    case 6:     r=r+0.1*tr;
    break;
    case 7:     r=r+0.1*tr;
    break;
    case 8:     r=r+0.1*tr;
    break;
    case 9:     r=r+0.1*tr;
    break;
    case 10:    r=r+0.1*tr;
    break;
    ;
          default:  {    cout<<"Error input";
                              getch();
                            exit(0);
                    }
}
float lr=(ld*r)/tr;
// cout<<ld<<" "<<r<<" "<<tr<<" "<<lr<<" ";
 float x1= atan(1/lr);
float phi=(2*x1*180)/(3.1415*3);
float beta=phi-alpha;
float c=(8*3.14*r*(1-cos((phi*3.14159)/180)))/(B*cd);
arr[i]=c; be[i]=beta;
//cout<<"arr[i]"<<arr[i]<<"\n\n\n";
i=i+1;
cout<<"\n\n";
setcolor(YELLOW);
line(0,400,800,400);
float x=x2;
float y=y2;
```

```
cout<<"\n";
setcolor(BLUE);
line(0,400,800,400);
cout<<"\n";
setcolor(YELLOW);
line(0,400,800,400);

cout<<"                local tip radius                "<<r<<"            \n";
cout<<"                local tip speed ratio           "<<lr<<"\n";
cout<<"                phi                             "<<phi<<"\n";
cout<<"                beta                            "<<beta<<"\n";
cout<<"                c                               "<<c<<"\n\n";
cout<<"\n\n\n\n\n";
setcolor(YELLOW);
line(0,400,800,400);
cout<<"\n";
setcolor(BLUE);
line(0,400,800,400);
cout<<"\n";
setcolor(YELLOW);
line(0,400,800,400);
getch();
 }while(sect<10);
initgraph(&gd,&gm," ");
setcolor(GREEN);
line(0,450,800,450);
cout<<"\n";
setcolor(GREEN);
line(0,455,800,455);
cout<<"\n";
setcolor(GREEN);
line(0,460,800,460);
cout<<"\n";
setcolor(GREEN);
line(0,465,800,465);
cout<<"\n";
setcolor(GREEN);
line(0,470,800,470);
cout<<"\n";
setcolor(GREEN);
line(0,475,800,475);

setcolor(GREEN);
line(0,20,800,20);
cout<<"\n";
setcolor(GREEN);
line(0,25,800,25);
cout<<"\n";
setcolor(GREEN);
```

```
line(0,30,800,30);
cout<<"\n";
setcolor(GREEN);
line(0,35,800,35);
cout<<"\n";
setcolor(GREEN);
line(0,40,800,40);
cout<<"\n";
setcolor(GREEN);
line(0,45,800,45);

cout<<"\n";
i=0;float x=px;float y=py,ry=py;
int opp,n1=100,n2=400;
/*do {
cout<<arr[i]<<"\n";
cout<<be[i]<<"\n";
i=i+1;}
while(i<10);
getch(); */
i=0;
do{
x2=x+40;
y2=py-arr[i]*100;
float y3=py+arr[i]*100;
//cout<<"arr[i]"<<arr[i]<<"\n";
//cout<<"y2"<<y2<<"\n";
setcolor(WHITE);
line(x,y,x2,y2);
line(x,ry,x2,y3);
setcolor(YELLOW);
circle(x2,y2,3);
circle(x2,y3,3);
getch();
setcolor(WHITE);
line(100,400,500,400);
x=x2;
y=y2;
ry=y3;
float m2=n2-80*tan(be[i]*3.1415/180);
float m1=n1+40;
setcolor(RED);
line(n1,n2,m1,m2);
n1=n1+40;
i=i+1;
}while(i<10);
getch();
closegraph();
}
```

Appendix VI
Observations of Motor Testing

	Tensions in springs		Current	Voltage	Power	Torque	Power	efficiency
RPM	T_1(Kg)	T_2(Kg)	I(Ampere)	V(Volt)	P='VI(Watt)	$T=(T_1-T_2)xRx9.81)$N.m	$P^1=2 \times 3.14$ NT	('P/P^1)
215	1.8	0.6	2.6	50	130	0.882	19.84794	0.152676
240	2	0.4	2.8	50	140	1.176	29.54112	0.211008
276	2	0.4	2.8	50	140	1.176	33.972288	0.242659
1015	3.5	1.2	4.2	110	462	1.69	179.5399667	0.388615
1070	3.1	1.1	4	110	440	1.47	164.6302	0.37416
1095	2.9	1	3.8	110	418	1.39	159.3079	0.381119
1160	2.7	0.9	3.5	110	385	1.323	160.62984	0.41722
1180	2.5	0.9	3.4	110	374	1.176	145.24384	0.388353
1125	2.4	0.9	3.3	110	363	1.107	130.34925	0.359089
1260	2.2	0.8	3.2	110	352	1.029	135.70452	0.385524
1285	2	0.8	3	110	330	0.882	118.62606	0.359473
1345	1.9	0.7	2.8	110	308	0.882	124.16502	0.403133
1385	1.8	0.7	2.6	110	286	0.809	117.2753367	0.410054
1470	1.5	0.6	2.5	110	275	0.662	101.85532	0.370383
1500	1.3	0.6	2.3	110	253	0.515	80.855	0.319585
1550	1.1	0.5	2.2	110	242	0.441	71.5449	0.29564
1570	2	0.2	3.6	130	468	1.323	217.40418	0.464539
1640	2	0.4	3.2	130	416	1.176	201.86432	0.485251
1800	2	0.6	3.2	140	448	1.029	193.8636	0.432731

Appendix VII

Observations of Combined (Motor, Alternator) System

V_1(Volt)	I_1 (Amp)	P_1(W)	V_O(volt)	I_O(Amp)	P_O(W)	RPM	EFFICIENCY
70	2.4	168	6.2	2.2	13.64	780	8.11
90	3.25	292.5	9	3	27	850	9.23
95	3.6	342	10	3.8	38	930	11.11
105	4	420	12	4.5	54	1020	12.85
93	3.4	316.2	9.5	3.8	36.1	890	11.42
80	2.8	224	7.75	2.5	19.375	800	8.64
80	2.7	216	7.3	3	21.9	800	10.13
90	3.3	297	9.7	2.4	23.28	880	7.83
100	3.6	360	11	3	33	950	9.16
105	3.98	408.45	12.5	3.8	47.5	1050	11.64

COMPUTER AIDED DESIGN OF A STAND ALONE AERO GENERATOR

By

Gawas Narayan Dasharath
Mayarani. N
Vijaya Gandheevam . V

ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree

BACHELOR OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering & Technology
KERALA AGRICULTURAL UNIVERSITY

Department of Farm Power Machinery and Energy
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING & TECHNOLOGY
TAVANUR - 679 573
MALAPPURAM

1999

ABSTRACT

Wind data from five different stations in Kerala were collected and analysed. Average monthly wind velocities were taken from these stations and the annual average and yearly wind energy potentials were found out. Expected working hours of a commercial wind mill with 2m/s cut in velocity and 10m/s cut-out velocity at these sites were also computed. A computer program in 'C' was developed for predicting the seasonal energy available from the sites. A wind rotor, was designed using computer aided techniques and blade profile at different sections were determined. It is essential that for the economical and smooth functioning of the system, the characterstics of both the rotor and the generator should match properly. A 1 HP universal motor which could simulate the fluctating wind regime characteristics was tested and coupled to a generator (30V, 5A). The torque speed characteristic of a rotor suitable for these sites was established and the torque speed characteristic of a generater established under the experimental investigation was super imposed over the rotor curves. Different gear ratios were tried and it could be found that for a gear ratio of 1:22, the peak torque points of the rotor and generator would coinside at the maximum possible level and combined system will work in harmony. Power of the combined system at different velcoities were computed and displayed.