Design procedure for Lenz type vertical axis wind turbine for urban domestic application

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Abstract—This paper presents an approach for the optimization of Lenz type vertical axis wind turbine (vawt) design. The main objective of this paper is to design the Lenz type VAWT for domestic applications which can generate electricity on diminutive scale in order to make urban areas of Gujarat state self sustainable and energy secure in the area of energy requirements. From this paper one can learn a design procedure for latest invented Lenz VAWT. From the design calculation and based on previous research data in related domain, basic design parameters of Lenz type VAWT is derived which are tip speed ratio, wing dimensions etc.

I. INTRODUCTION

The current energy system still relies mainly on fossil fuels. This intensive consumption of coal and oil had and still has a massive impact on the environment. The IPCC report indicates that the 20th century saw a considerable and sudden increase in global temperature when compared to the last thousand years [1]. The measured temperature rise is partly attributed to CO2 emissions. If cheap fossil energy is available word-wide and no measures are taken to reduce its burning for electricity generation, we can expect a further substantial increase in atmospheric carbon dioxide in the 21st century.

In many industrialized countries programs have been carried out to reduce the consumption of fossil energy by energy conservation or by improvement in energy efficiency. Simple substitution of coal and oil by renewable energy sources has also contributed to a certain decrease in CO2 emissions.

Renewable energy technologies such as hydro, solar, wind, biomass and geothermal energy are already being used in many countries. Renewable energy is clean, affordable, domestic, and effectively infinite. It produces no emissions and results in cleaner air and water for all. Renewable power creates jobs and generates revenue for local communities. Revenue from wind farms helps stimulate local economies that need new roads, schools, libraries, and hospitals.

II. INTRODUCTION TO LENZ TYPE VAWT

There are so many modifications are researched and still day by day it is continuous in Savonius type VAWT. In this channel of modifications Edward Lenz has found one Design of wind turbine which uses the principal of venture meter in construction of wind mill which was thought by one patent email to him and he had construct the turbine which named as Lenz VAWT[2].

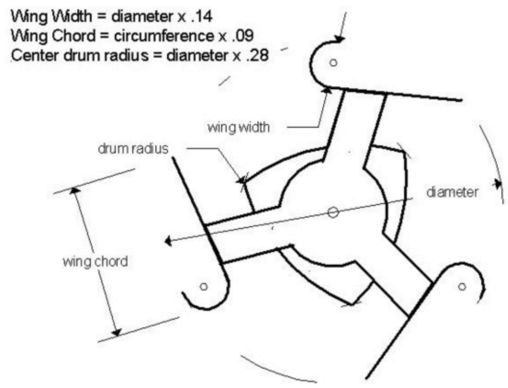

Fig. 1: First Lenz VAWT which works on venture-meter principal.

Another update to the fascinating world of VAWT's, the Lenz 2 is a larger wing version of the first and the centre drum was removed. Although it's only been run in low winds to date the performance is quite impressive for a small machine.

Figure 2 shows the beginning of the second version. Using parts from the first one and some quickie fabrication for the wings began testing the unit. The alternator is a 12 pole 3 phase machine made up just for that project.

Fig. 2: Second version of Lenz VAWT

Yet there was not much research work available on it or there were not any patents found on this type of vertical axis wind turbine. So in this paper all work is focused on Lenz version 2 type of wind turbine.

III. DESIGN PROCEDURE

Wind machine design is a process of continuous evaluation by trial and retrial. To begin with, the wind analysis data at different height of Gujarat is brought up from Center for

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Wind Energy Technology, Chennai with the co-ordinates 23.2167° N, 72.6833° E.

Initially the type of wind mill will be selected, overall system efficiency will estimate and based on that data available rotor size will calculated and all the required components of machine will designed. In the next step proper analysis of whole system is to be done and if it found satisfactory then it brings to practical realization. The wind machine design process consists of two major tasks, aerodynamic design and structural design. If the load is a mechanical device (i.e. water pump) then high starting torque-from the rotor will be needed and if the load is an electrical generator then low starting torque but high rpm will be required.

The generalize wind machine design procedure is as shown in figure 3. The whole wind mill design procedure is given in subsequent topics.

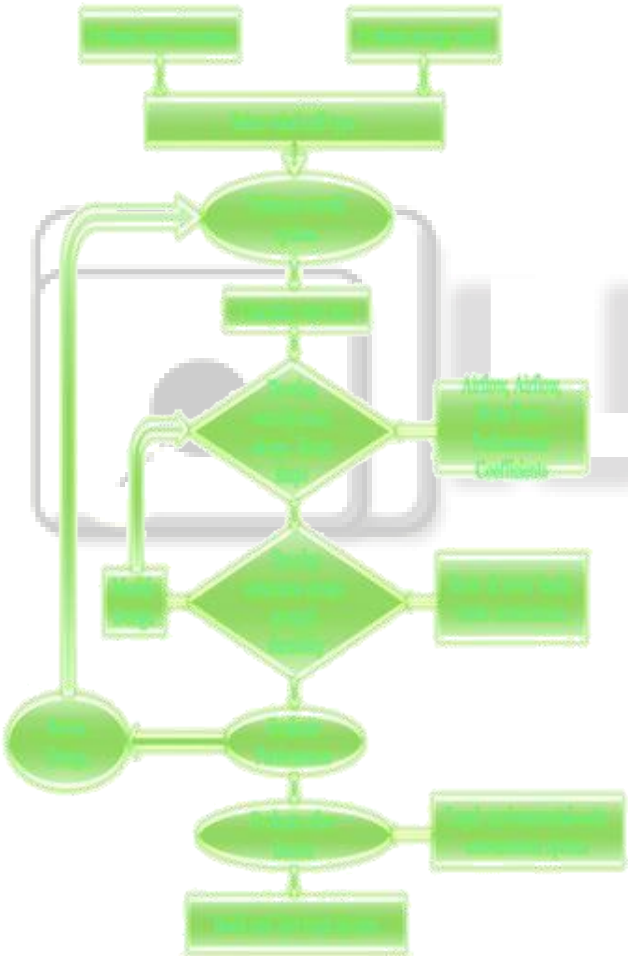

Fig. 3: The wind machine design process

A. Evaluation of Wind Resource

The wind map of India is shown in Figure. This wind maps is published by C-WET (Center for Wind Energy Technology) in February 2010.

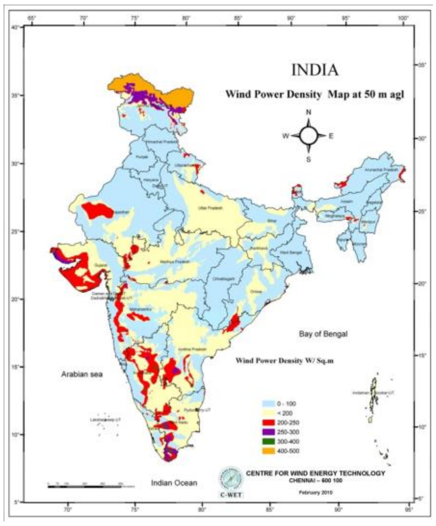

Fig. 4: wind map of India by CWET on February 2010

This map shows wind zones of different region in India. The magnitude of wind zone is given in term of power density (W/m^2). Very large portion of India is having wind power density less than 100 w/m^2. Gujarat, Maharashtra, Karnataka, A.P. & small portion of Rajasthan are having very good area wind power density nearly 200-250 w/m^2. Gujarat is having very good wind power density because of its very large coastal area. Red portion in Gujarat is showing 200-250 w/m^2 of wind of density which is very good for producing wind power generation.

B. Wind Mill Type Selection

Lenz VAWT is selected in this paper as it has following advantages which are well suited for low cost & low speed power producing rotor.

- Very less number of parts and bearings, so that the vane rotor costs only a fraction of that of a wind wheel of equal capacity.
- This turbine is more efficient than a pure Savonius in that it provided both drag and lift.
- Simple in Design so Simplicity of construction.
- Towers are not necessity & even at ground level it can operate.
- Longer life because less number of moving part are use.
- Self started.

C. Rotor Size Calculation

There are two principal ways to determine frontal area of wind turbine: either approximate size of rotor has to be decided and power generation to be calculated or first power requirements are identified & then frontal area is to be calculated.

The swept area of VAWT can be calculated from following equation.

$$A = 2R \times H \qquad [Eq - 1]$$

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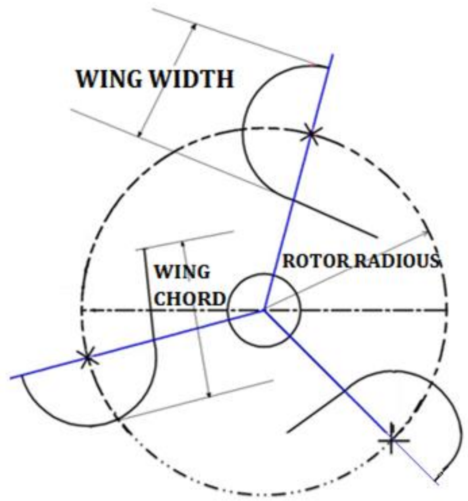

Fig. 5: schematic diagram for Lenz rotor

Windmill blades are designed to move in response to wind force, and it can extract a substantial portion of the energy and power available. The wind energy available in a unit volume of air depends only upon the air density ρ and the instantaneous wind speed U.

This "kinetic energy" of the air in motion is given by the following formula.

$$\frac{Kinetic\ energy}{unit\ volume} = \frac{1}{2}\ \rho U^2 \qquad [Eq-2]$$

The volume of air that passes through an imaginary surface-say the disk swept out by a horizontal-axis windmill-oriented at right angles to the wind direction is equal to:

$$Volume = \ A \times V \times t \qquad [Eq-3]$$

Thus, the wind energy that flows through the surface during time t is just,

$$Available\ energy = \frac{1}{2}\ \rho AU^3\ t \qquad [Eq-4]$$

Wind power is the amount of energy which flows through the surface per unit time, and is calculated the wind energy by the elapsed time (t),

$$Power = \frac{1}{2}\ \rho AU^3 \qquad [Eq-5]$$

By putting value of area from Equation [ ]

$$Power = \ \rho RHU^3 \qquad [Eq-6]$$

Both energy and power are proportional to the cube of wind speed.

D. Geometrical parameters

This project is limited to Single Stage Lenz VAWT rotor. Selection & calculations of other parameters are discussed in following topics. As there are no any research work as well as any experimental work done on this type of turbine most parameters are estimated or consider the Lenz rotor as Savonius VAWT rotor and values will be adopted.

E. Shape of blade

This project has been done for Lenz vertical axis turbine, so the shape of blade is selected as per Ed. Lenz has suggested which is shown over here in below figure.

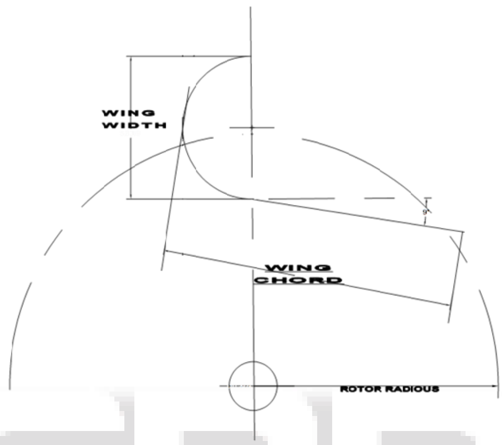

Fig. 6: shape of Lenz rotor blade.

F. Wing Width

The founder of Lenz VAWT has suggested the empirical relation for wing width calculation and it is given as

Wing width = turbine rotor Diameter x 0.14

G. Chord length

The empirical relations for calculate chord length of Lenz type VAWT is given by Ed. Lenz as:

Wing Chord = turbine rotor Diameter x 0.09

H. No. of Blade

3 blades is most preferred and most often used for wind turbine rotor because 2 blades produces noise, rattle, imbalance, harder to start in low winds and other problems, And higher number of blades increases weight of wind mill.

I. Tip Speed Ratio (TSR)

Tip Speed Ratio= (Blade Tip Speed)/(Wind Speed)

The Tip Speed Ratio (TSR) is used by wind turbine designers to properly match and optimize a blade set to a particular generator. If the blades are too slow they are not capturing all the wind they could and if they are too fast, then the blades are spinning through used/turbulent wind.

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For this reason, TSR's are employed when designing wind turbines so that the maximum amount of energy can be extracted from the wind using a particular generator. It will optimized from cfd analysis.

J. Frontal area

It is the multiplication of the diameter of wind turbine rotor and height of turbine rotor. In this paper, value of Frontal area is taken as 3,60,000 mm^2.

K. Pitch Angle

The pitch angle is the angle at which the blade surface contacts the wind. It is often variable to ensure optimum operation of the turbine in varying wind conditions and to prevent electrical overload and over speed in high winds. Ed. Lenz has suggested the optimum value of pitch angle as 9°.

L. No. of stages

Researchers have investigate on this parameter but there were not any optimum value for no. of stages were established for Savonius VAWT rotor. The two stage rotor gives higher specific power than single stage rotor.[3]

M. Aspect ratio

The aspect ratio (AR) plays an important role in the aerodynamic performances of a Lenz rotor. Aspect ratio can be defined as following equation.

$$AR = 2R/H \qquad [Eq-7]$$

Performance increases slightly with increasing height-to-diameter ratio.[4]

N. Torque and Power coefficients

Calculations of torque and power coefficient of n-blade rotor are as following:

$$T_\theta = \sum_{N=1}^{n} F_N \left(\frac{C-e}{2}\right) \qquad [Eq-8]$$

For n-blade rotor,

$$T_\theta = [F_{N_1} + F_{N_2} + F_{N_3} + \cdots + F_{N_n}]\left(\frac{C-e}{2}\right) [Eq-9]$$

Here FN_1, FN_2, FN_n can be found out by following equation,

$$F_{N_1} = x_1 \cos\theta - y_1 \sin\theta$$
$$F_{N_2} = -x_2 \cos\theta + y_2 \sin\theta$$
.
.

$$F_{N_n} = \pm x_n \cos\theta \pm y_n \sin\theta \qquad [Eq-10]$$

Torque produced on rotor is,

$$\text{Torque} = z \times F_{N_1} + z \times F_{N_2} + z \times F_{N_3} + \cdots + z \times F_{N_n}$$
$$\text{Torque} = z \times [F_{N_1} + F_{N_2} + \cdots + F_{N_n}] \qquad [Eq-11]$$

Mean torque for n-bladed rotor,

$$T_m = \frac{\sum_{\theta_i=0}^{360} T_{\theta_i}}{i} \qquad [Eq-12]$$

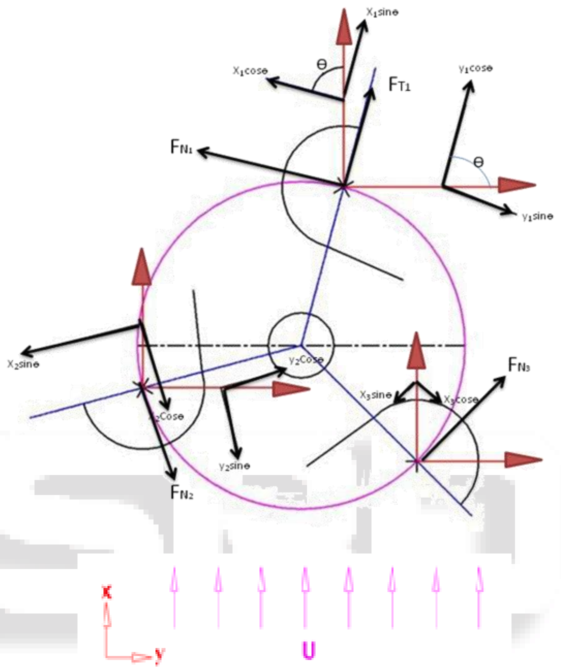

Fig. 7: Forces on rotor blades

Torque co-efficient,

$$C_m = \frac{T_m}{\rho R^2 H U^2} \qquad [Eq-13]$$

Power co-efficient,

$$C_p = \frac{P_m}{\rho R H U^3} \qquad [Eq-14]$$

O. Preliminary Design Parameters

Parameter	Value Suggested By Ed. Lenz
Aspect ratio	1
Diameter	610 mm
Height	610 mm
No. of stages	1
Shape of blade	Lenz type
Wing Width	0.0937 x Diameter
Chord length	diameter x 0.4

No. of blade	3
Tip Speed Ratio	1 to 0.4
Frontal area	372100 mm^2
Pitch Angle	9°

Table. 6: Preliminary Design Parameters

For the Lenz wind model, Number of stages has been chosen as 1, frontal area has been chosen as 36000 mm^2. All other data as tabulated above can be optimized with CFD analysis of Lenz turbine.

P. *Estimation of Power*

Maximum Power of wind energy has been estimated from the equation

$$m = \rho AU \qquad [\mathrm{Eq}-15]$$

$$Available\ power \ = \frac{Kinetic\ energy}{time} = \frac{1}{2}\ \rho\, A\, V_\infty^3$$

$$= \tfrac{1}{2} \times 1.22557 \times 0.3600 \times 4^3$$

$$= 14.1185\, Watt \qquad [\text{Eq-16}]$$

According to the Betz theory, maximum power can be extracted from any kind of wind turbine is 59.29 %[1].

$$Power_{max} \ = \ 14.1185 \ \times 0.5929$$

$$= 8.3708 \ \ Watt \qquad [\mathrm{Eq}-17]$$

As there is no any efficiency of Lenz VAWT is searched out with experimental data, we can take out as in between 30% as efficiency of Savonius VAWT and 40% as efficiency of darrieus type VAWT. So average of it here efficiency estimated as 35%. So considering turbine efficiency we have maximum power available as

$$Power_{max} = \ 8.3708 \ \times 0.3500 \quad Watt$$

$$= \ 2.92978 \quad Watt \qquad [\mathrm{Eq}-18]$$

IV. CONCLUSION

From this paper one can find the design procedure for Lenz type vertical axis wind turbine. Mathematically we can obtain maximum power as 2.92978 watt with 4 m/s wind speed and having 360000 mm^2 areas.

Different Preliminary parameter that should be selected for Design are presented in this paper from which computational fluid dynamic analysis can be possible to do on Lenz second version of turbine with any analytical software and based on that optimum parameter one can fabricate the best performer vertical axis wind turbine for urban domestic application.

REFRENCES

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