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Vertical Axis Wind Turbine Power Generation & It's Generator Losses

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Abstract- Wind energy is one of the major forms of renewable energy resources found abundantly which widely used as an alternative energy. Due to lack of fossils fuels, world is looking on renewable energy sources like solar, wind, tidal etc., coming to wind the machine used to convert the wind energy into electrical energy is wind turbine. In this, we see the types of wind turbine performance parameters of VAWT and their influence on VAWT, electricity generation by VAWT, losses and costs associated with different speeds and torques on VAWT. The generator of a VAWT is consist of different losses where we can reduce the losses with different material in which we can adjusts the cost of VAWT.

Indexed Terms- VAWT, wind turbine, wind speed, torque, generator

I. INTRODUCTION

The exhaust of fossil fuels leaving a question mark, what if there are no fossil fuels? how we can survive? as so many things coming in to our mind, we use renewable energy sources wind, solar, hydropower, geo thermal, hydrogen etc., in these renewable energy sources are ecofriendly, don't release pollutants like CO_2, SO_2, NO_2 and other harmful things like radiation. As the most promising, renewable, clean and mostly available energy source wind power, is highly expected to play major role in power generation in the coming decades. Wind energy is converted from solar energy by nuclear fusion of Hydrogen (H) and Helium (He) in its core. The fusion of Hydrogen-Helium creates heat and electromagnetic radiation streams out from the sun to space in all directions. The small part of its strikes the earth's where it fulfills the earth's energy needs.

coming to wind generation, wind generated from the movement of air due to change in pressure. As we all know wind flows from high pressure areas to low pressure areas. And also due to solar uneven radiation on earth surface leads to wind generation due to change of temperature gradient differs from equator to poles. The earth self-rotation is another important factor to affect the wind direction and speed i.e., coriolis force. In large scale atmospheric movements, the all the factors of solar radiation, earth geometry, pressure gradient, earth rotation leads to wind generation. As the wind is used from ancient period for major applications like sailing, smelting process, windmills, wind turbines etc., We can measure the wind speed by using different instruments like cup anemometers, propellers, anemometers, sonic anemometers, doppler sensors etc.,

II. LITERATURE SURVEY

WIND TURBINE CLASSIFICATION

Wind turbine operates on simple process. The wind turbine consists blades connected to a rotor, the rotor/shaft is coupled to generator with help of gears. According to rotor/shaft placement, the wind turbine broadly classified into the two types they are

1. Horizontal Axis Wind Turbine (HAWT)
2. Vertical Axis Wind Turbine (VAWT)

In HAWT, rotor is coupled Parallel to ground. The rotor, generator and all the equipment placed at top of wind turbine. The HAWT generally contains sensor coupled with servo-meter, gearbox to maintain the design requirement without respect to wind speed. The tower produce turbulence behind it, the turbine is usually positioned upwind of its supporting tower. Turbine blades are stiff to prevent blades from being pushed into the tower by high winds.

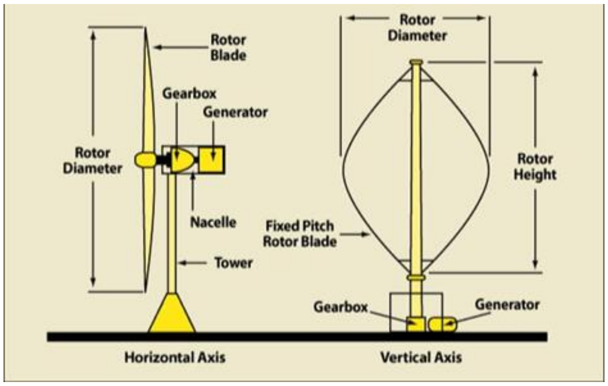

Fig: HAWT & VAWT

In VAWT, the rotor is vertical i.e., perpendicular to the ground. These machines are of simple design and require only short tower bases the gearbox and generator are placed at the ground level where maintenance is easy. It does not require any type of sensors to predict the wind as the VAWT grabs wind from 360 degrees. It has many advantages over HAWT, as it is suitable for small scale industries domestic purposes. Again, the VAWT is subclassified into two types according to blades shapes they are Darrieus wind turbine and Savonious wind turbine.

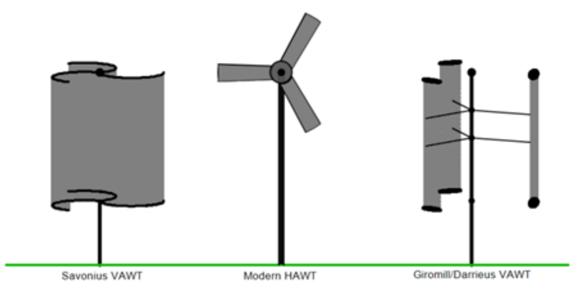

Fig: Horizontal Axis Wind Turbine Vs Vertical Axis wind turbine

George, J.M., Peterson, R.E., Lee, J.A. & Wilson, G.R., Modeling wind and relative humidity effects on air quality. Int. Specialty Conf. on Aerosols and Atmospheric Optics: Radiative Balance and Visual Air Quality, Snowbird, Utah, 1994.

The kinetic energy of wind at blades is converted into mechanical energy as it is given by

$K.E = \frac{1}{2}\rho A V^3$

Where, ρ= air density (kg/m$^{3)}$

A= swept area (m^2)

V= wind speed (m/s)

The wind energy conversion primarily depends upon the air density, swept area of wind speed. The air density does not change until there is change in temperature. Swept area of blades is a constant value. Assuming the ρ, a are constants, then the varying thing is wind speed. The wind speed is directly proportional to the kinetic energy. So, the output will increase, if the wind speed increases & vice-versa.[1]

POWER GENERATION BY VAWT

Wind energy conversion takes two stages, as the 100% wind energy is not converted in to the electricity. There are some parameters effects the efficiency in each stage. First, the conversation of wind kinetic energy to mechanical energy to drive the rotor the power coefficient (C_p) deals with the efficiency in first stage, defined as the ratio of captured mechanical power by blades to the available power in wind.

$$C_p = \frac{P_{mech.\ out}}{P_w} = \frac{P_{mech.\ out}}{1/2(\rho A \bar{u}^3)}$$

Due to some aerodynamic losses, the kinetic energy doesn't convert into 100% mechanical energy. C_p ranges from 30 to 45%.

In the second stage, mechanical energy gained at blades is converted into electrical energy via wind generators. In this stage there are different efficiencies, they are

Gearbox efficiency (η_{gear})- Power loses in gearbox like friction loses, bearing loses, churring, sealing loses,

Generator efficiency (η_{gen}) -All mechanical and electrical generator losses, they are copper, iron, load, windage friction and other miscellaneous losses.

Electrical efficiency (η_{ele}) - Power losses in AC to DC converter, switches, controls, and cables.

Therefore, the total power conversion efficiency from wind energy to electricity η_t is the product of all efficiencies.

$\eta_t = C_P .\ \eta_{gear} .\ \eta_{gen} .\ \eta_{elec}$

The effective power output is given by

$$P_{eff} = \eta_t P_w = \eta_t . \frac{1}{2}(\rho A \bar{u}^3)$$

According to Lanchester and Betz are the limit for efficiency of wind turbine called as lanchester-betz limit is about 59.26%. No wind turbine converts kinetic energy into mechanical energy more than

59.26% and if we derivate the effective output power equation w.r.t wind speed and substituting equation we get efficiency as 59.26% at maximum of 1/3 axial indication factor i.e., change in speed to the initial velocity.[2]

Also, if we draw a graph between C_p and axial indication factor(a) we get a power curve where the peak point is Lanchester-Betz limit i.e., 0.5926. Initially the conversation rate is high, when it crosses maximum value of C_p i.e., 0.5926 it starts decreasing as it crosses the rated power. Due to power control, we didn't get more power.

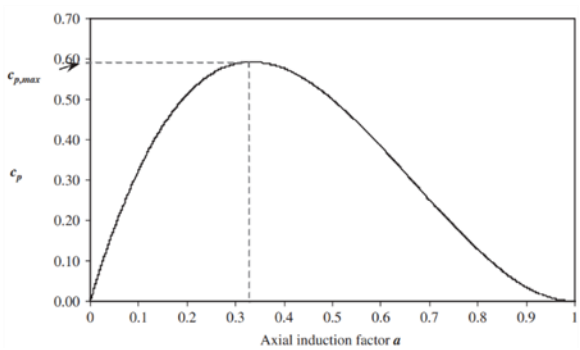

Fig:Power Coefficient as a function of Axial Induction Factor

The tip speed ratio is an extremely important factor in wind turbine design which is defined as the ratio of tangential speed at blade tip to actual wind speed (ranges from 5.24 to 5.45). Due to intermittent nature of wind turbines do not make power all time. The ratio of wind turbine actually power output per year to the total power output in wind turbine life is called as wind turbine capacity that ranges from 0.25 to 0.40

The wind turbine faces some challenges in power generation. First, environment imparts in which the wind turbines in large size as the birds die if they strike turbine blades with high speed it has to be considered. Second, turbine produces noise, so wind turbines are installed far to the residentials. Third, as the wind turbine connected to wind-grid we should protect the wind grid due to intermittent power loses. Fourth, wind energy storage, we have to store the electricity for future purpose of excess loads. Also cost of electricity from wind power, it decreases for continuous usage. So, it shouldn't be minimized.

Integration of wind energy with other renewable energy source leads to fulfill the needs effectively. We can see some of the integrations like wind-solar hybrid system, wind-hydro system, wind-hydrogen system, wind diesel power generation systems etc.[3]

III. METHODOLOGIES:(GENERATOR LOSSES DUE TO DIFFERENT SPEEDS AND STRATEGIES)

Here are some of the losses & costs associated with different torques & speeds of VAWT.

CYCLIC MECHANIC TORQUE

Due to cyclic loads on generator is caused by the variation in wind speed (aerodynamic loading) and change in wind direction leads the effect on the rotor blades. As it is represented by fourier-series of sine wave form and given by

$T=\overline{T}+T_{\Delta}\sin(b\theta)$

For each wind speed, the mechanical torque T contain mean torque $\overline{T}$ (torque load of HAWT having same blades & radius) and peak variation T_{Δ} (assumed to be 50% of $\overline{T}$)

ELECTRICAL TORQUE RESPONSE

Due to cyclic loads, there will imbalance in both the mechanical torque and electric torque. From newton's second law of rotating systems, the difference between mechanical and electrical torque is given by

$T_{mech} - T_{elec} = J\alpha$

Where, J= moment of inertia

α =angular acceleration

The electrical torque response of generator can be controlled by limiting parameter 'q' defined as ration of electrical torque variation to mechanical torque variation.

$$q = \frac{T_{\Delta elec}}{T_{\Delta mech}}$$

There are two strategies to control the torque, they are fixed torque operation & fixed speed operation. Fixed torque operation(q=0); electrical torque is kept constant and mechanical torque varies throughout the cycle. This leads constant electrical output. Second, fixed speed operation(q=1); when electrical torque is equal to mechanical torque where rotor speed kept constant. It leads to largest peak torque where we get maximum output the q value lies between 0 to 1 variation as shown in fig.[4]

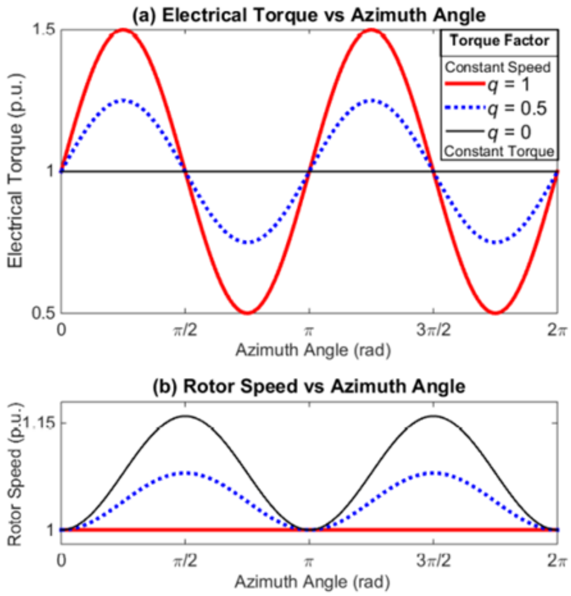

Fig: Cyclic variation of (a) Electrical Torque and (b) Rotor Speed for different Torque Factors q

GENRATOR MODEL

The generator dimensions like magnet size, stator size, coil diameter also takes part in losses which are not negotiable. We have to calculate the losses due to dimensions in FEM analysis & MAT lab where we get equivalent circuit and generator segment models as shown in fig.

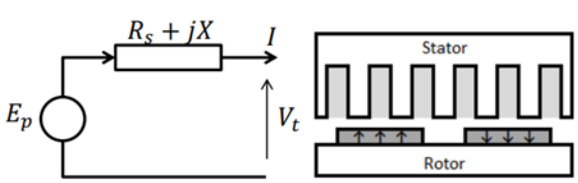

Fig: Equivalent Circuit and Generator Segment Models

GENRATOR LOSSES

These are focused on losses from the copper and iron the copper losses are directly proportional to the electrical torques where they depend upon the current through stator coil. The copper losses are given by.

$$P_{Cu} = R\left(\bar{I}^2 + \frac{(qI_\Delta)^2}{2}\right)$$

Where,

R= revolutions

I= mean r.m.s current

I_Δ= max. r.m.s current

The iron losses depend on the electrical frequency and flux density in the stator. The losses given by

$$P_{Fe} = \sum_i \left(A_h \overline{f_e} + A_e \overline{f_e^{\,2}}\right) \hat{B}_{Fei}{}^2 m_i$$

Where,

$\overline{f_e}$ - mean electrical frequency

$\overline{f_e^{\,2}}$-mean square electrical frequency

A_h, A_e- constants

$\hat{B}_{Fei}$ -flux density

m_i- mass of Iron

GENRATOR SPECIFICATIONS

The power output, designed specification also have some losses. Same specifications VAWT and HAWT doesn't give same output. For this study we are considering some specifications are on follows in generator data.[4]

Table: Generator data(q_{max}=1)

Rated Power	5MW
Rated Speed	12m/s (@5rpm)
Turbine System Moment of Inertia	1.05 × 10^8 kg m^2
Stator Radius	5.6m
Stack Length	2.6m
Pole Pairs / Pole Pitch	160 / 110mm
Stator Tooth (Width × Height)	18mm × 80mm
Stator Slot (Width × Height)	18.6mm × 80mm
Stator Yoke (Height)	40mm
Rotor Yoke (Height)	40mm
Rotor Magnet (Width × Height)	79mm × 15mm
Air Gap	5mm

IV. RESULTS

The following results after different tests for a fixed generator segment.

GENRATOR LOSSES FOR A FIXED WIND SPEED

The first results demonstrable how the copper & iron losses vary for different torque factor as shown in fig. as the copper losses increases with wind speed.[5]

Where iron losses decrease. But both the losses have same magnitude at q=0.4.

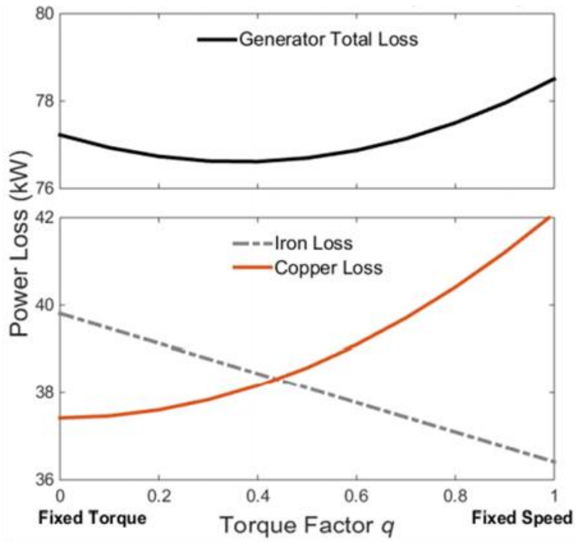

Fig: Generator Power Loss (at 9m/s wind speed)

STRATEGIES TO MINIMIZE GENRATOR LOSSES

Second focus on reducing losses at different wind speeds with different torques (q=0 to 1).

The minimum value in each speed gives the optimal q, where the losses will be optimum.[5]

i.e., q= 0.2. The fig below represents the losses at different speeds

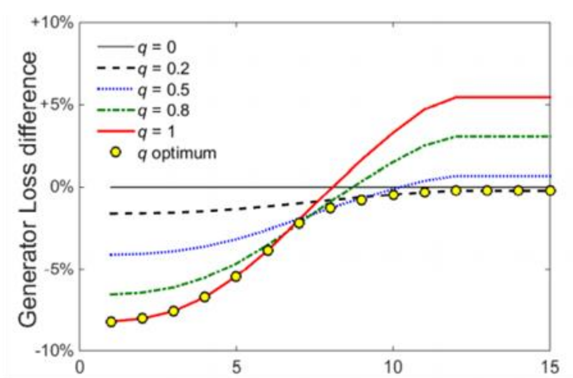

Fig: Generator Loss Difference relative to q=0 baseline

ANNUAL ENERGYLOSSES

Annual energy losses given by the product of total working hours of VAWT per year and losses per each hour. The following table shows the annule losses per base line if we follow the strategies, we get 0.78% decrease in losses.[4]

Table: Annual Energy Losses for different q strategies

Torque Factor q	*Annual Losses (MWh)*	*% Loss (vs q=0)*
0	508.0	0.0%
0.2	504.8	-0.6%
0.4	504.1	-0.8%
0.6	505.9	-0.4%
0.8	510.1	+0.4%
1	516.9	+1.8%
Optimum-*q*	500.4	-1.5%

GENERATOR TORQUE LOADING

If the generator is carrying peak electrical torque it has to be designed for q=1, the q_{opt} carries the lowest peak torque. So we have to design peak torque load as less than (q=1), as if we follows the q_{opt} . The below graph shows the peak electrical torque for different q strategies.[6]

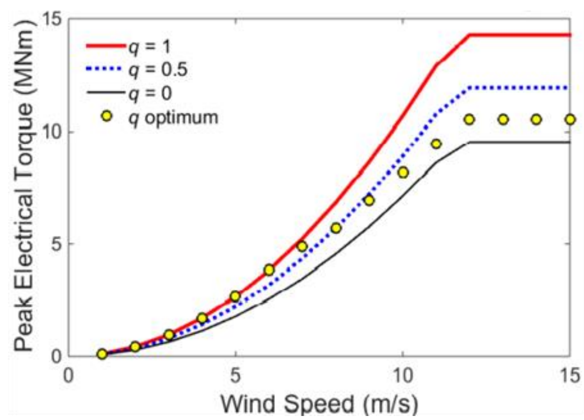

Fig: Peak Electrical Torque at different wind speeds for different q strategies

GENERATOR COSTS

One of the parameters that determines the sizing of the generator is the peak torque that it is expected to deal with in the spirit parameter q_{max} as setting for q. The relationship between q_{max} and T_{rating} is given by

$$T_{rating} = \bar{T}(v_{rated}) + q_{MAX}T_{\Delta}(v_{rated})$$

The following table given cost of active materials in the generator. [7]

Table: Cost of Active Materials for different q_{MAX} designs

Max Torque Factor q_{MAX}	*Pole Pairs*	*Generator Active Cost (kEuro)*	*% Cost (vs q_{MAX} =1)*
1	160	765.3	0.0%
0.8	155	739.1	-3.4%
0.6	149	712.4	-6.9%
0.4	144	684.0	-10.6%
0.2	138	654.8	-14.4%
0	131	624.6	-18.4%

CONCLUSIONS

Energy plays a key role in our daily life where we use coal, petrol as resources here the problem is they are exhaust in future. The non-renewable energy sources like solar, wind, geothermal, hydrogen solve the problem coming to wind energy, the machines used to convert wind energy into electrical energy are wind turbines. They are classified as two types namely HAWT and VAWT

Vertical axis wind turbine produces less power comparing to HAWT. Here we saw some losses due to different speeds and different torques. we can minimize the losses by using a gearbox and maintaining speed constant by using different strategies where we can increase the life of VAWT and decrease the cost by using VAWT at optimum range.

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