Expt 4 :- Wind Energy System

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Objective :

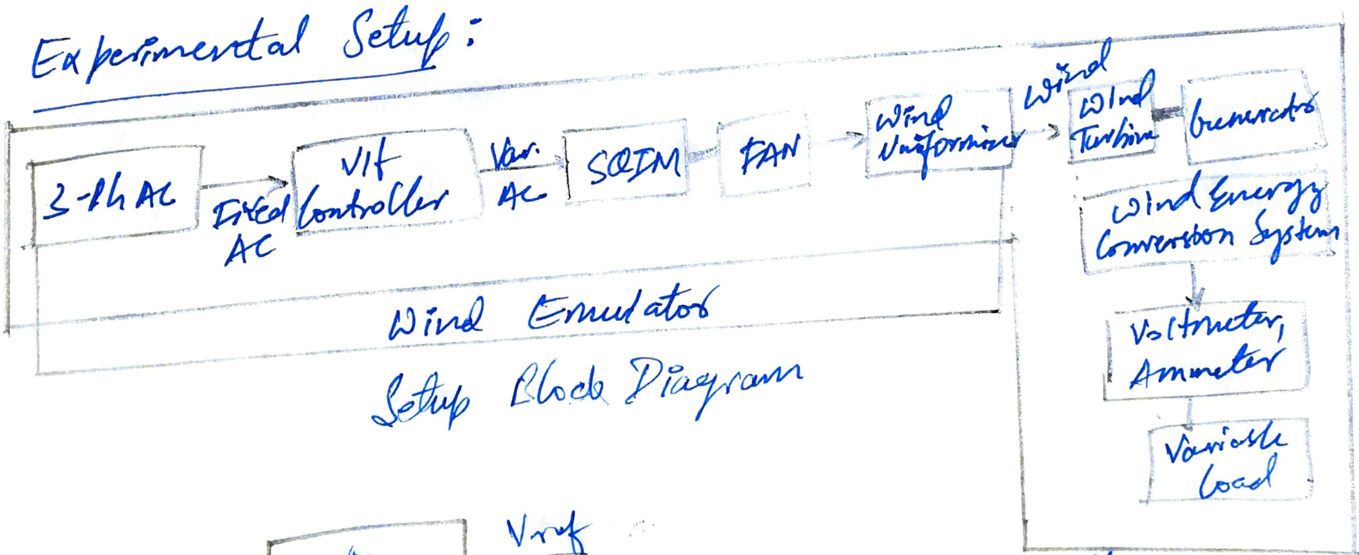
→ Study of Wind Energy Conversion System (WECS) to understand its basic characteristics & working scheme

→ To familiarize with the PMSG based experimental wind energy setup.

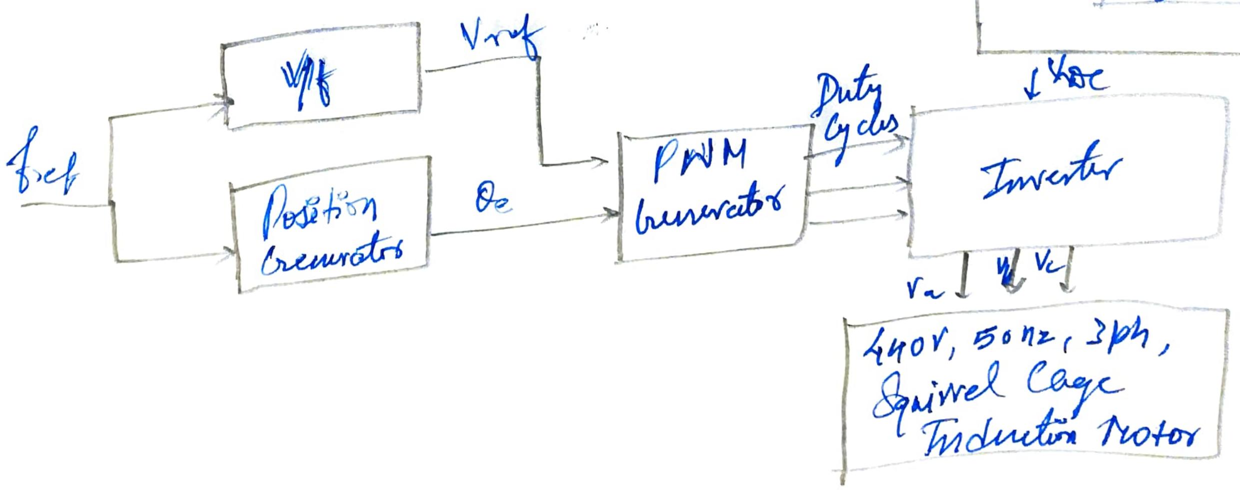
→ To understand the experimental procedure for measurement and observation

→ To realise the experimental setup under 3 conditions:
Variable load, variable wind velocity and variable pitch angle.

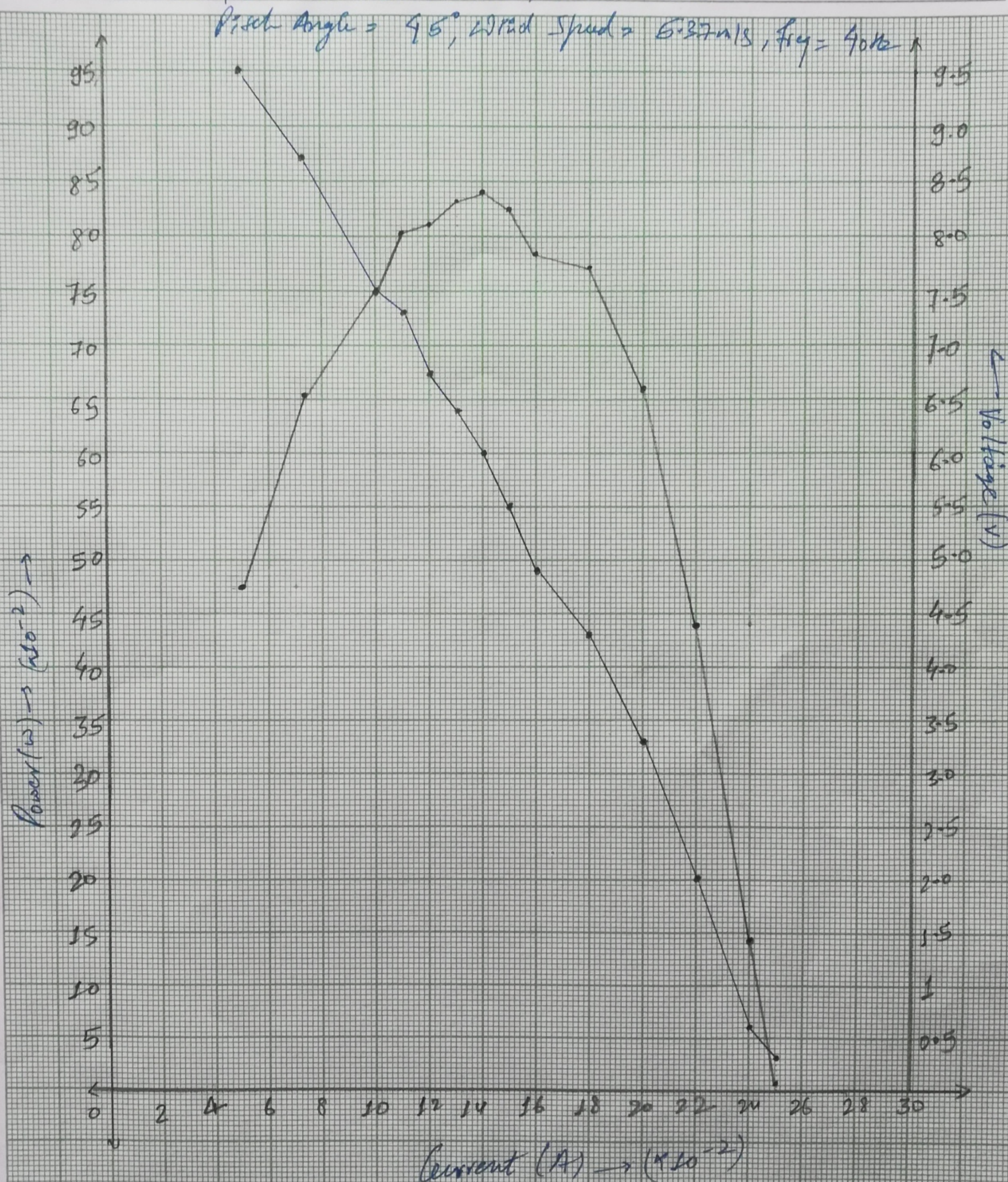
Experimental Setup :



Setup Block Diagram

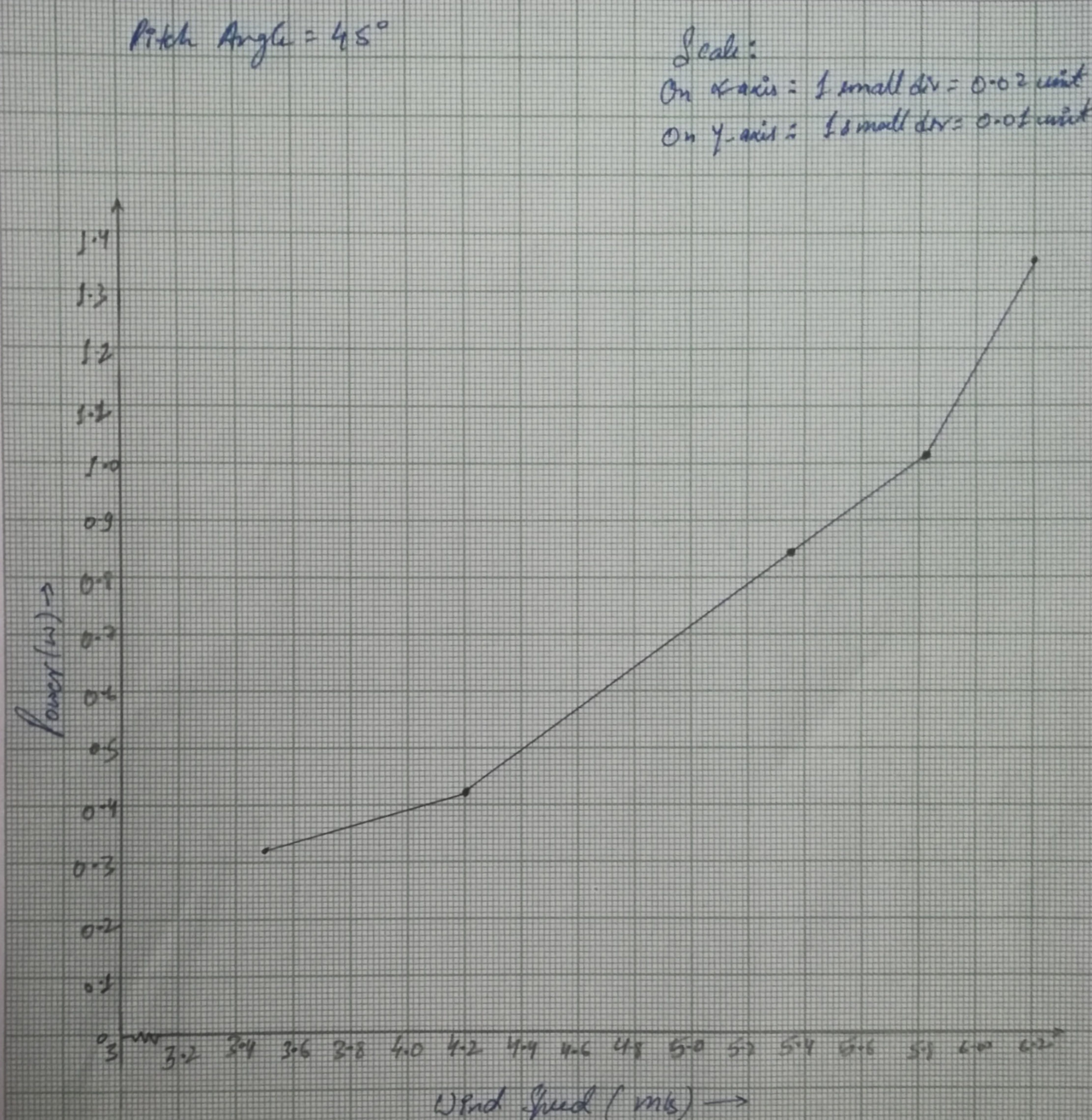


Load Variation, PRATYUSH JAISWAL, 18EE30021

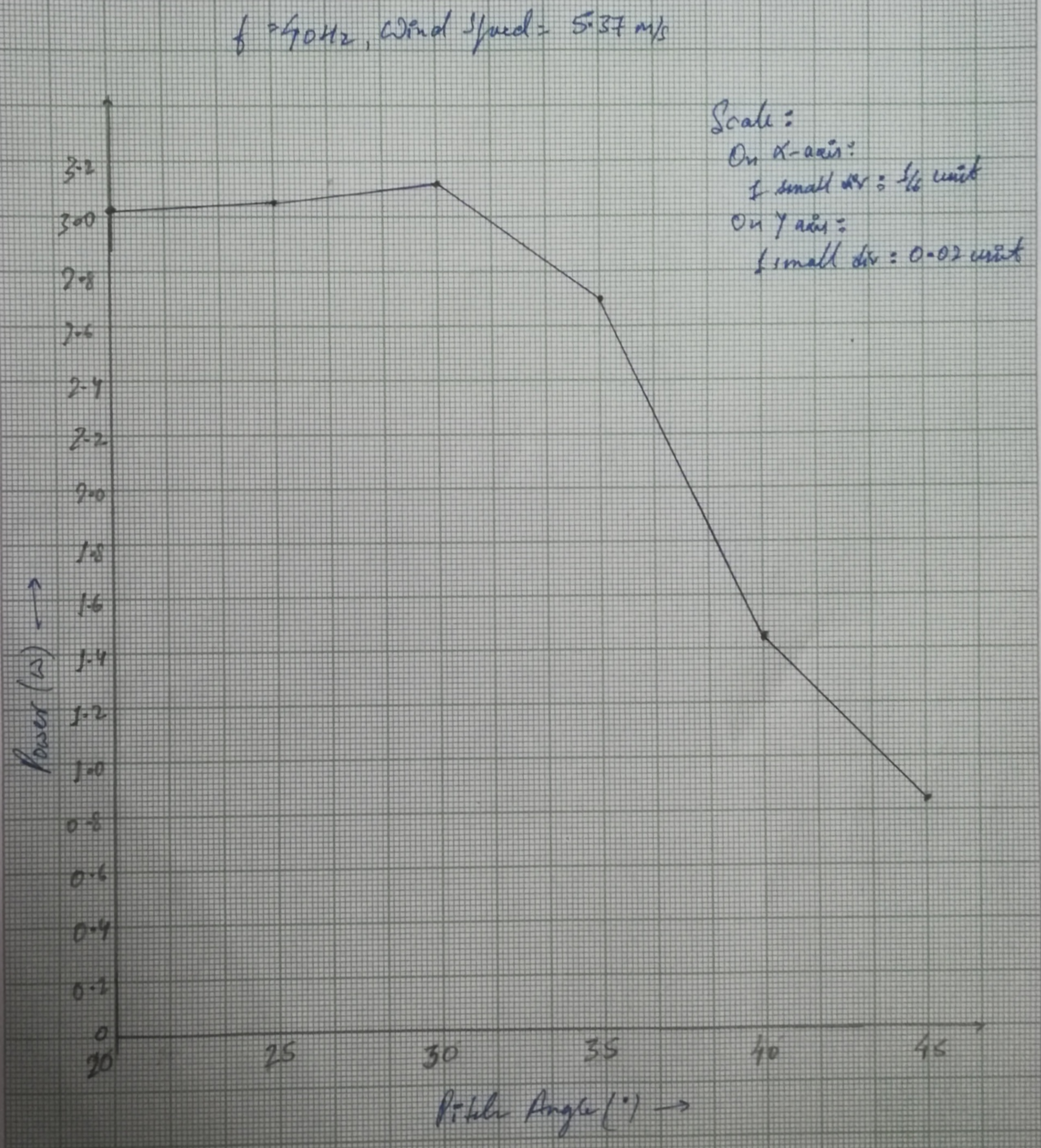


P.R.E.

Wind Speed Variation, PRATYUSH JAISWAL, 18EE30021



PITCH Angle Variation , PRATYUSH JAISWAL , 18EE30021



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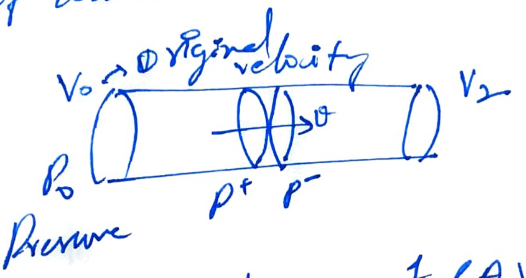
DISCUSSION:

1) What is Betz limit? Derive an expression to find out Betz limit.

→ Betz limit is the theoretical maximum efficiency for a wind turbine. According to it, no wind turbine can capture more than 16/27 (59.3%) of the kinetic energy of wind.



Power in wind $= \frac{1}{2}\rho A V_0^3 = P$

Applying Bernoulli's Principle;

$$\frac{1}{2}\rho V_0^2 + P_0 = \frac{1}{2}\rho v^2 + p^+ \quad \text{— (i)}$$

$$\frac{1}{2}\rho V_2^2 + P_0 = \frac{1}{2}\rho v^2 + p^- \quad \text{— (ii)}$$

then from eq (i) & (ii),

$$p^+ - p^- = \frac{1}{2}\rho(V_0^2 - V_2^2)$$

$$\text{Thrust } (T) = A(p^+ - p^-) = \frac{1}{2}\rho(V_0^2 - V_2^2)$$

$$T = \text{Change of momentum} = m(V_0 - V_2) = \rho A v(V_0 - V_2)$$

$$\frac{1}{2}\rho(V_0^2 - V_2^2) = \rho A v(V_0 - V_2)$$

$$\Rightarrow \boxed{\frac{V_0 + V_2}{2} = v}$$

Let axial interference factor be a.

$$v = V_0(1 - a)$$

$$v_2 = V_0(1 - 2a)$$

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$$\text{Power} = \frac{1}{2}\rho VA(V_0^2 - V_2^2)$$

$$= \frac{1}{2}\rho A(1-a)V_0(V_0^2 - V_2^2)$$

$$P = \frac{1}{2}\rho A(4a - 8a^2 + 4a^3)V_0^3$$

$$\frac{dP}{da} = 0$$

$$4 - 16a + 12a^2 = 0, \quad a = 1 \text{ or } 1/3$$

$a=1$ will give zero, power then
$a = 1/3$.

$$P = \frac{1}{2}\rho A\left(4 \cdot \frac{1}{3} - 8/9 + 4/27\right)V_0^3$$

$$= \frac{1}{2}\rho A V_0^3 \times \frac{16}{27}$$

Max^m Power is $\left(\frac{16}{27}\right)^{th}$ of the wind power.
$\hookrightarrow$ 59.3%

2) Discuss Pitch Angle control and yaw control used in wind energy systems.

→ Pitch Control adjusts the blades in wind turbine by rotating them so that they use the right fraction of the available wind energy to set the most power output, all the while ensuring the turbine doesn't exceed the max rotating speed. It is used to operate and control the angle of blades in a wind turbine. The pitch system is a closed loop drive system. The turbine's main controller calculates the required pitch angle from a set of conditions such as wind speed, generator speed and power production. Then the required pitch angle is transferred to the pitch system as a set point.

→ Yaw refers to the rotation of the entire wind turbine in the horizontal axis. Yaw control ensures the turbine is constantly facing the wind to maximize the effective rotation area and as a result maximise power. Because of variation in the wind direction, the turbine may misalign causing huge power loss.

3) Discuss various types of generators used in the wind energy conversion systems.

→ DC Generators:-

The dc machines, the field is on the stator and the armature is on the rotor. The motor is electrically excited it tends to follow a shunt wound DC generator model. for shunt wound, DC generators, the field current increases with operational speed while the actual speed of the turbine is determined by the turbine drive torque and load torque balance. Electrical power is extracted through brushes connecting the commutator. In general DC machines are not used in turbine applications.

→ Synchronous Generator:-

When the rotor is driven by the wind turbine, a 3ϕ phase power is generated in the stator windings which are connected to the grid through transformer and power connectors. For fixed speed sync generator, the rotor speed must be kept at synchronous speed. The reactive power characteristics of a sync gen can be easily controlled by the field circuit used for electrical excitation. As the speed is fixed, random wind fluctuation and other disturbances along with natural resonance of component is passed into the power grid.

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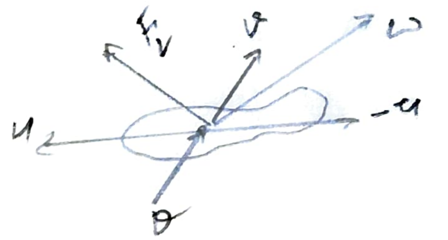
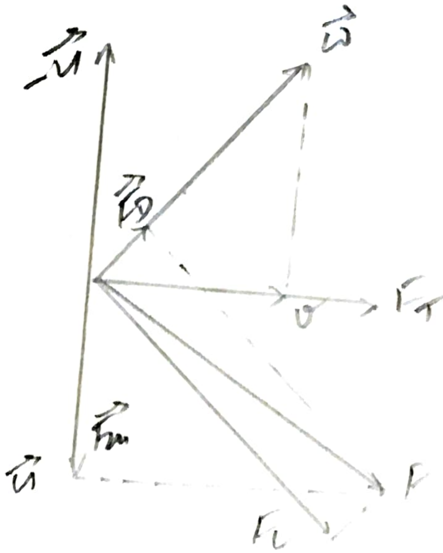
→ Induction Machine :-

Modern industries use IM selectively in wind turbine applications.

Q) What is aerodynamic principle used in the turbine blades. Draw and explain the vector diagram showing wind velocity, blade velocity, relative wind velocity, Lift force, Drag force, Moment & Thrust force.

→ Force is generated by the wind interaction with the blade. The magnitude and distribution of this force is the primary focus of wind turbine aerodynamics. the ~~distraction~~ direction of drag force is parallel to relative wind. To extract power, the turbine must move in direction of net force. The relative wind aspect ~~effect~~ dramatically limits the maximum power that can be extracted by a long drag based wind turbine. Lift based wind turbines typically have lifting surfaces moving perpendicular to the flow.





v → wind speed
w → relative speed
F_D → drag force
F_L = lift force
F_T = torque force
F_M → moment force.

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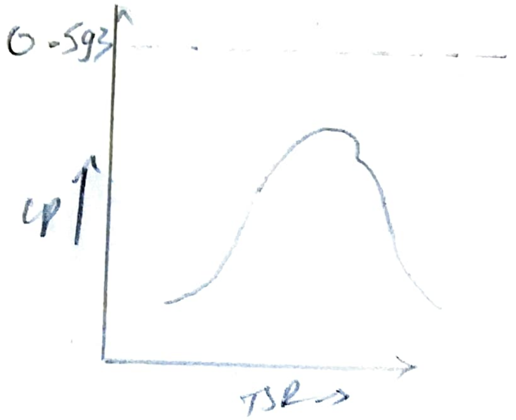
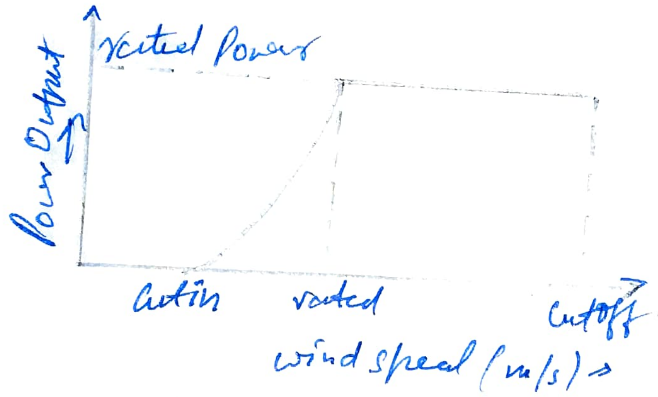
5) Wind turbine coeff vs Tip speed ratio (TSR)
(CP)



Power Output vs Wind Speed



Conclusions:

Case 1: There exists a particular wind speed and pitch angle combination for which WECS supplies max^m power to a particular load

Case 2: The maximum power supply output of the WECS increases with the wind speed.

Case 3: For a particular wind speed, WECS is capable to ~~study~~ supply max^m ~~supply~~ power with a particular value of pitch angle.

Varying the wind speed & the pitch angle of the turbine, the wind energy conversion system behaviour is observed.