LAB # 11

To Study and Understand Wind Turbine Power Characteristics

Objectives:

- To analyze effect on wind turbine output parameters by changing wind speed and pitch angle
- To observe and understand the behavior of wind turbine output power & wind speed curve

Related Theory:

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electrical power, windmills for mechanical power, wind pumps for water pumping or drainage, or sails to propel ships.

Large wind farms consist of hundreds of individual wind turbines which are connected to the electric power transmission network. For new constructions, onshore wind is an inexpensive source of electricity, competitive with or in many places cheaper than fossil fuel plants. Small onshore wind farms provide electricity to isolated locations. Utility companies increasingly buy surplus electricity produced by small domestic wind turbines. Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher.

Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land. The effects on the environment are generally less problematic than those from other power sources. As of 2011, Denmark is generating more than a quarter of its electricity from wind and 83 countries around the world are using wind power to supply the electricity grid. In 2014 wind energy production was over 3.4% of total worldwide electricity usage and growing rapidly at more than 25% per annum.

Wind energy is the kinetic energy of air in motion, also called **wind**. Total wind energy flowing through an imaginary area A during the time t is:

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}\rho A v^3 t C_p$$

Where ρ is the density of air and v is the wind speed, Av is the volume of air passing through A (which is considered perpendicular to the direction of the wind); $Av\rho$ is therefore the mass m passing per unit time. C_P the fraction of the wind's power that is extracted by the blades; that is, it is the efficiency of the rotor. *Note that ½ ρv^2 is the kinetic energy of the moving air per unit volume.*

Wind power in an open-air stream is thus ***proportional*** to the ***third power*** of the ***wind speed***; the available power increases eightfold when the wind speed doubles. Wind turbines for grid electricity therefore need to be especially efficient at greater wind speeds.

Wind is the movement of air across the surface of the Earth, affected by areas of high pressure and of low pressure. The surface of the Earth is heated unevenly by the Sun, depending on factors such as the angle of incidence of the sun's rays at the surface (which differs with latitude and time of day) and whether the land is open or covered with vegetation. Also, large bodies of water, such as the oceans, heat up and cool down slower than the land. The heat energy absorbed at the Earth's surface is transferred to the air directly above it and, as warmer air is less dense than cooler air, it rises above the cool air to form areas of high pressure and thus pressure differentials. The rotation of the Earth drags the atmosphere around with-it causing turbulence. These effects combine to cause a constantly varying pattern of winds across the surface of the Earth.

Wind turbine:

A **wind turbine** is a device that converts kinetic energy from the wind into electrical power. A wind turbine used for charging batteries may be referred to as a **wind charger**.

The result of over a millennium of windmill development and modern engineering, today's wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making small contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

When a turbine is mounted on a rooftop the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the ***height*** of a rooftop mounted turbine tower is approximately 50% of the building height it is near the optimum for maximum wind energy and minimum wind turbulence. Wind speeds within the built environment are generally much lower than at exposed rural sites, noise may be a concern and an existing structure may not adequately resist the additional stress.

Controls:

The control system for a wind turbine is important with respect to both machine operation and power production. A wind turbine control system includes the following components:

- sensors – speed, position, flow, temperature, current, voltage, etc.
- controllers – mechanical mechanisms, electrical circuits
- power amplifiers – switches, electrical amplifiers, hydraulic pumps, and valves
- actuators – motors, pistons, magnets, and solenoids
- Intelligence – computers, microprocessors

Wind turbine Mechanical Power Equation:

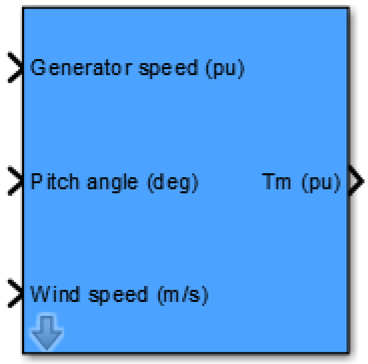
$$P = \frac{1}{2}\rho A v^3 C_p(\lambda, \beta)$$

Where,

- P = Mechanical output power of the turbine (W)

- CP = Performance coefficient of the turbine
- ρ = Air density (kg/m^3)
- A = Turbine swept area (m^2)
- V = Wind speed (m/s)
- λ = Tip speed ratio of the rotor blade tip speed to wind speed
- β = Blade pitch angle (deg)

Wind Turbine Module:



Wind Turbine

Pin description:

Inputs:

Input 1: The first input is the generator speed in per unit of the generator base speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load.

Input 2: the second input is the blade pitch angle (beta) in degrees. ***Blade pitch*** or simply pitch refers to turning the angle of attack of the blades of a rotor into or out of the wind to control the production or absorption of power. Wind turbines use this to adjust the rotation speed and the generated power.

Input 3: the third input is the wind speed in m/s.

Outputs:

Tm: The output is the torque applied to the generator shaft in per unit of the generator ratings.

Block Parameters, Wind Turbine:

Nominal mechanical output power:

The nominal output power in watts (W).

Base power of the electrical generator:

The nominal power of the electrical generator coupled to the wind turbine, in VA. This parameter is used to compute the output torque in pu of the nominal torque of the generator.

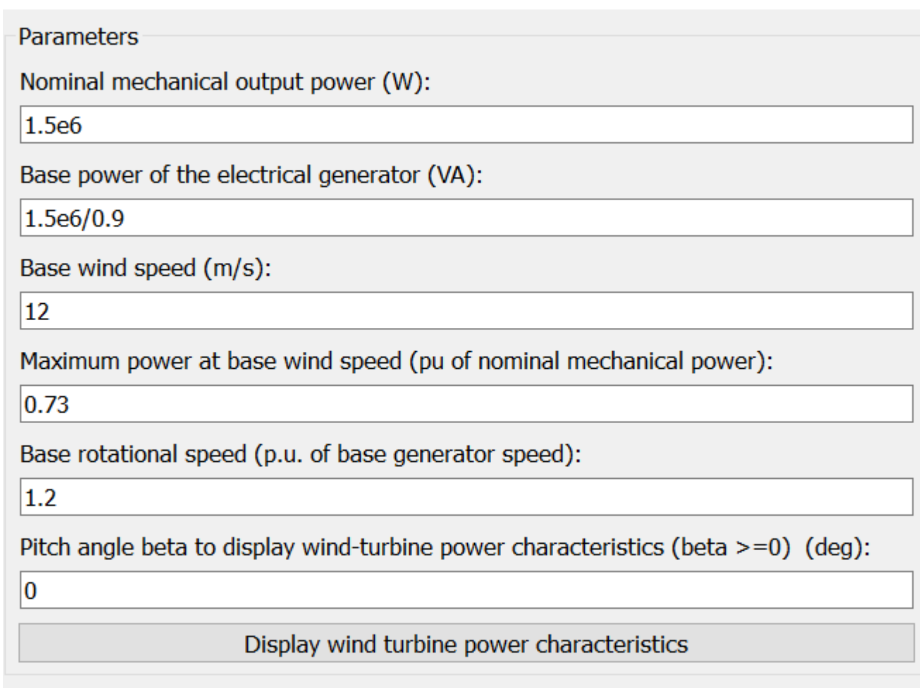
Base wind speed:
The base value of the wind speed, in m/s, used in the per unit system. The base wind speed is the mean value of the expected wind speed. This base wind speed produces a mechanical power which is usually lower than the turbine nominal power.

Maximum power at base wind speed:
The maximum power at base wind speed in pu of the nominal mechanical power. This parameter is the power gain C_P already defined.

Base rotational speed:
The rotational speed at maximum power for the base wind speed. The base rotational speed is in pu of the base generator speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load.

Pitch angle beta to display wind turbine power characteristics:
The pitch angle beta, in degrees, used to display the power characteristics. Beta must be greater than or equal to zero.

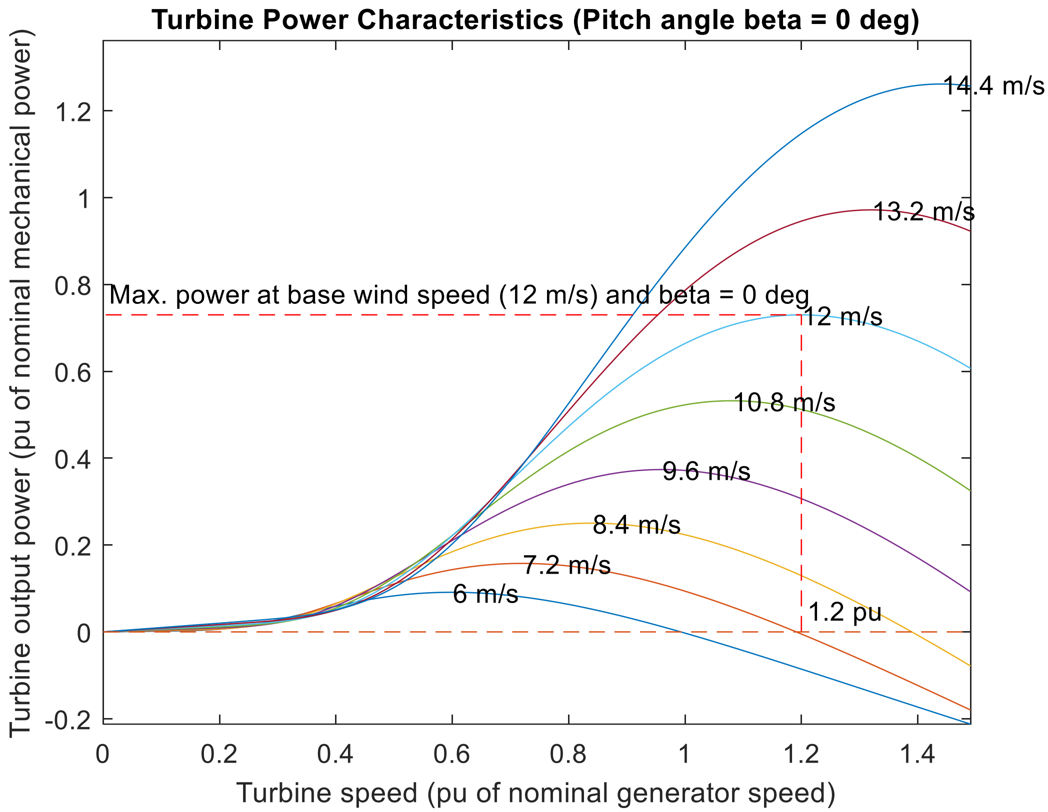
Display wind turbine power characteristics:
Click to plot the turbine power characteristics for different wind speeds and for the specified pitch angle beta.



CHARACTERISTICS CURVE:

The mechanical power *P* as a function of generator speed, for different wind speeds and for blade pitch angle β = 0 degree, is illustrated below. This figure is obtained with the default parameters (base wind speed = 12 m/s, maximum power at base wind speed = 0.73 pu (k_p = 0.73) and base rotational speed = 1.2 pu).

We see that as the value of wind speed is increase, the wind output power is increase relatively at 12 m/s of wind speed & 1.2 turbine speed, the power will be 0.7, while the pitch angle is 0 degree.



Lab Task:

Check the Turbine Power Characteristics at different base speeds and Pitch angles Listed below:

i. Base wind speed=8m/s
Pitch angle=1

ii. Base wind speed=12m/s
Pitch angle=10

iii. Base wind speed=12m/s
Pitch angle=45

Conclusion and Comments: