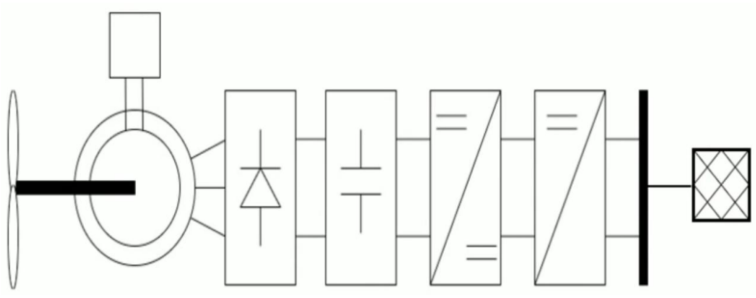
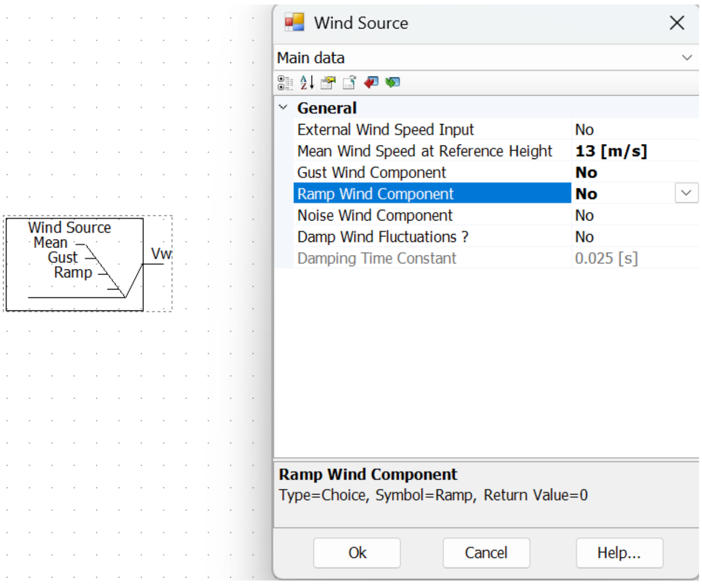
Wind Turbine Power Grid Simulation and Analysis on PSCAD

- **Wind turbine model design**



  - **1st step**: create wind source that used to power the wind turbine. Wind turbine needs to start with at least 5-6 m/s wind speed. The simulated wind source is shown below. To simplify the wind source, the wind gust and ramp components are set to be zeros (Basically, a wind with constant speed is provided).



  - **2nd step**: create wind turbine. For the wind turbine block, the input elements are Vw (wind speed), w (mechanical speed), Beta (angle of the blade), and the output elements are Tm (wind turbine power), P (mechanical torque).
    - Support formulas:

The kinetic energy contained in the moving air hits the rotor blades is shown below. m is the mass of air, w is the wind speed:

$$E = \frac{1}{2} * m * w^2$$

The power from wind turbine is shown below. ρ is the air density, S is the blades rotating surface, and w is the wind speed:

$$P = \frac{1}{2} * \rho * S * w^3$$

Bernoulli principal coefficient β, α is the blade incline angle :

$$\beta = 0.5 * (\lambda - 0.022 * \alpha^2 - 5.6) * e^{-0.17\lambda}$$

$$\lambda = 2.237 * \frac{wind\ speed}{turbine\ shaft\ speed}$$

Rated rotational speed of the generator shaft (turbine shaft or machine rated angular mechanical speed), where p is the number of pole pairs. In this example, f = 50hz, and p=120:

$$n = \frac{2\pi f}{p} = 2.61 rad/s$$

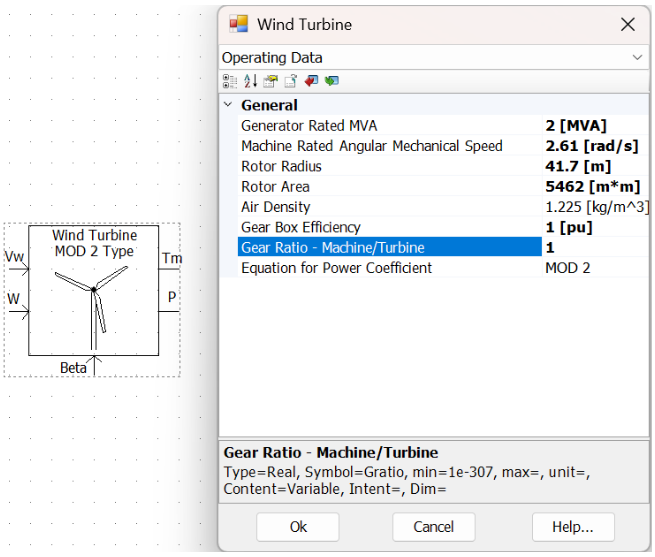
Rated current I_r, where S_r is the rated apparent power from generator and V_r is the rated voltage.

$$I_r = \frac{S_r}{3 * V_r}$$

- Parameters set up for wind turbine model. In this example, the rated power is 2MVA, and rated voltage is 0.4 kV. And it's a low speed wind turbine without gearbox.
  - Based on above formula and information, $\beta = 0.4$
  - To consider the friction and power loss during the wind turbine process, the electrical power generated from wind turbine shall be 1.2 times more than the rated apparent power.

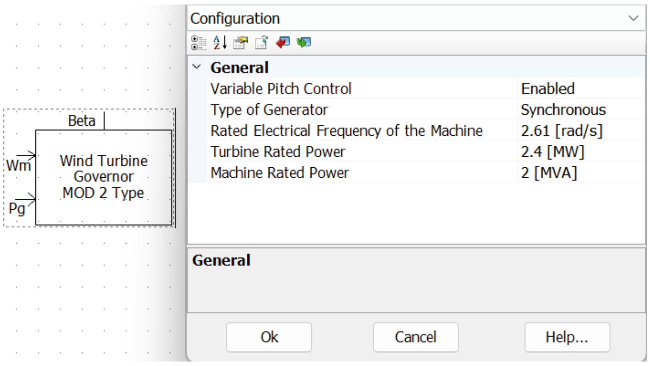
$$2.4MVA = \frac{1}{2} * \rho * S * w^3$$

  - The rotor area is obtained as 5462 square meters.

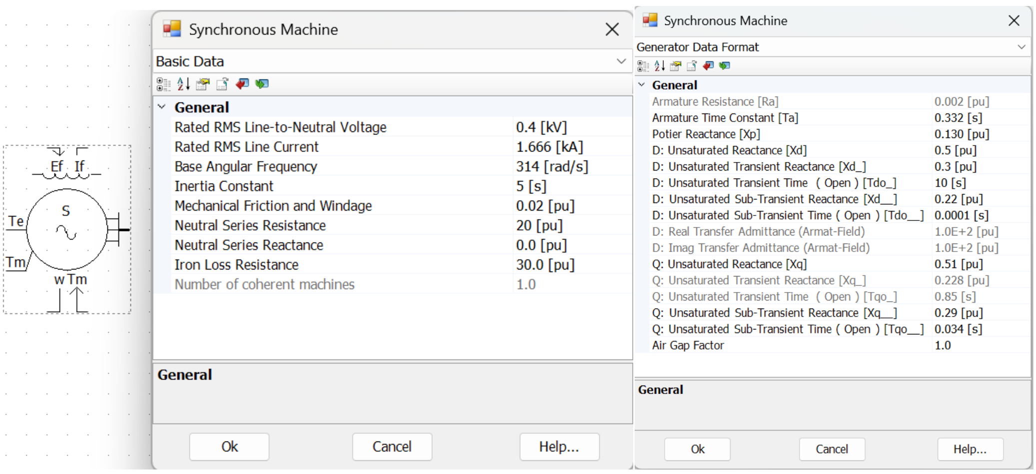


- **3rd step**: Governor set up.

- **Attention**: there has wind kinetic power, turbine rated power, and machine rated power. Turbine rated power is the maximum mechanical power the designed turbine can deliver to the generator, and the machine rated power is the electrical rating of the generator.
- Based on the above info, the governor info is set below:



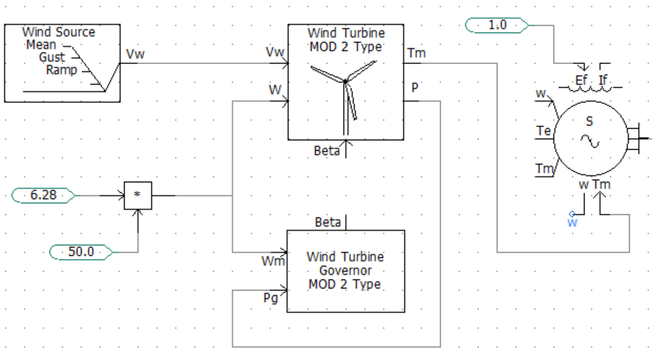
- **4th step**: synchronous machine setup
  - The synchronous machine is used to act as a real generator to convert mechanical power (mechanical torque) to electrical power (AC electricity)
  - The synchronism means the mechanical rotor speed should be same as the grid frequency.
  - Attention: from above, the machine rated angular mechanical speed is 2.61 rad/s, it's per unit speed as per each pair pole, so the actual rotor speed is 2.61 rad/s * 120 = 313.4 rad/s very close to the frequency 50hz (w = 2*pi*f)
  - The requirements of the synchronous machine:
    - Large unsaturated transient time which increases the field leakage in 10s
    - Very small unsaturated time transient to provide a high dumper resistance 0.0001



- For the inputs, the Ef is excitation field voltage (DC voltage), it controls the terminal voltage and reactive power, generator uses this to regulate voltage. ‘If’ is the measured field current (output) that shows the actual current produced by Ef. ‘Tm’ is the mechanical torque input, ‘Te’ is the electromagnetic torque (output) that for control and monitoring.

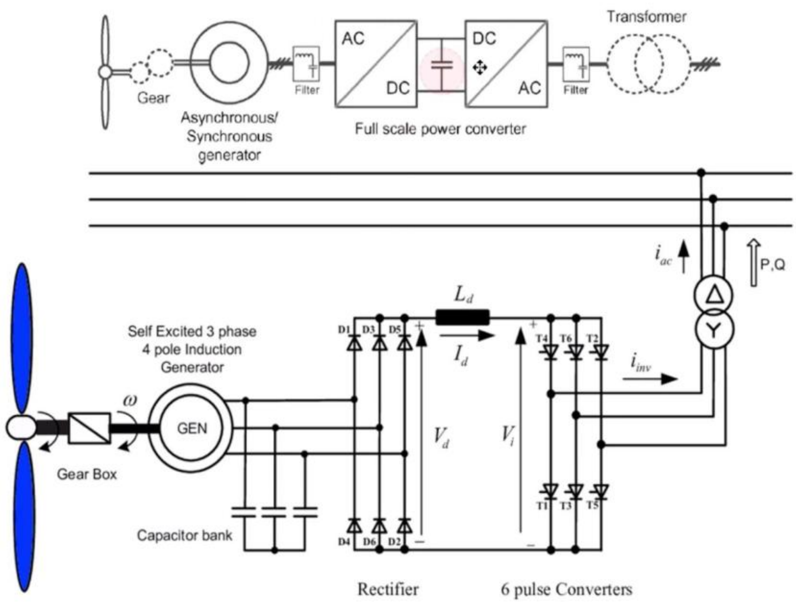
- If Te = Tm, the generator operates under steady speed
- If Te > Tm, the generator slows
- If Te < Tm, the machine speeds up

■ From above, the wind turbine that contains wind, physical wind turbine, governor, and synchronous electrical power generator is shown below:



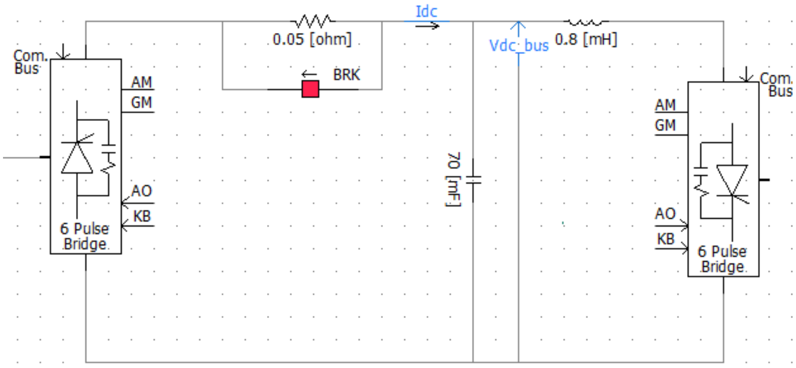
■ **5th step**: power converter design

◆ The diagram of wind turbine connects the converter can be shown below



◆ As the source of the wind does not always have constant speed, the converter is needed to provide the grid AC power with a constant frequency and constant voltage.

◆ The converter that connects the wind turbine is shown below:



- The formulas that will be used to decide the values of RLC are shown below. As mentioned above, the rated line voltage from wind turbine generator is 400V, and the rated current value is 1.6kA.

$$S_{AC} = \sqrt{3}V_{LL}I = 1.11MVA$$

- The DC voltage after the AC-DC rectifier

$$V_{dc} = 1.35V_{LL} = 540V$$

- Ripple frequency from a 6-pulse bridge on 50hz: $f_{ripple} = 6 * f = 300hz$
- Assume the voltage ripple requirement is 5%: $\Delta V_{dc} = 0.05 * 540 = 27V$
- Assume the current ripple requirement is 5%: $\Delta I_{dc} = 0.05 * \frac{P}{V_{dc}} = 185A$
- The left side 6-pulse bridge acts as a rectifier (AC-DC)
- The RLC filter network is confirmed through below method:
  - The resistor limits the current to prevent the big jump oscillation. Here R=0.05 ohm is chosen to keep a small power loss.
  - The capacitor stabilizes the DC voltage by reducing the voltage ripple, where the power P is assumed as 2MW

$$C = \frac{P}{2\pi f_{ripple} V_{dc} \Delta V_{dc}} = 70mF$$

  - The inductor smooths the DC current

$$L = \frac{P}{4\pi f_{ripple} \Delta I_{dc}} = 0.8mH$$

- The right side 6-pulse bridge acts as a DC-AC inverter
- Overvoltage protection design

- **6th step**: grid connection and sizing

  - A voltage source is used to represent the grid with 33kV base voltage and 100 MVA base power. And the load connected on the bus bar has 1MW power consumption and 11kV load voltage.

- From above, the apparent power comes out from the converter is 1.1MVA, and the rated voltage is 400V
- Components sizing
  - Shunt capacitor: it's used to reduce the current ripple and harmonics, assume it supplies 0.1MVAr reactive power:

$$C_{shunt} = \frac{Q}{\omega V_{LL}^2} = \frac{0.1MVAr}{2\pi * 50 * 400^2} \approx 2mF$$

  - The step-up transformer: as the grid has 33kV base voltage, the transformer ratio is set as 400V/33kV=1:82.5
  - series inductor: it helps with the harmonic filtering. To compute the inductance, firstly the base impedance is obtained: $Z_{base} = \frac{V_{base}^2}{S_{base}} = \frac{33kV^2}{1.1*10^6} \approx 990\Omega$. The inductance here is computed based on 0.1pu:

$$L = \frac{X_L}{\omega} = \frac{99}{2\pi 50} \approx 0.3H$$

  - The step-down transformer on the load: 33kV/11kV = 3:1
  - The resistor on the grid source: assume the voltage source internal X/R ratio = 20. The impedance can be computed through:

$$Z_{grid} = \frac{V_{grid}^2}{S_{grid}} = \frac{33kV^2}{100MVA} = 11\Omega, Z^2 = R^2 + X^2, R \approx 3.5\Omega$$

- From above, the detailed wind turbine power grid design in PSCAD is completed, and the power grid diagram can be seen through below diagram.