WIND TURBINE GENERATORS

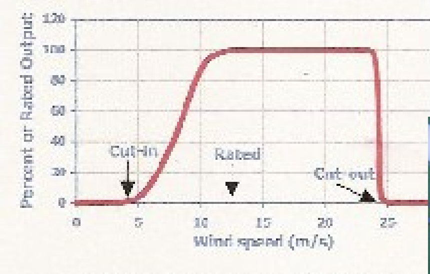


Figure 2-28: Typical WTG power curve.

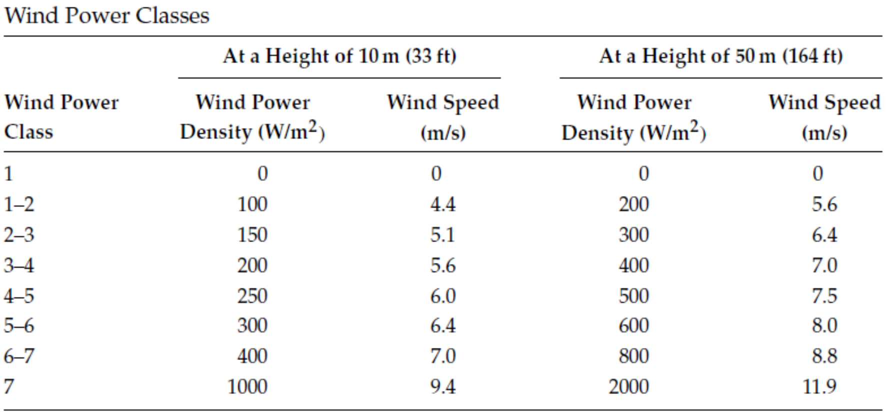
Wind Turbine Siting

- Wind turbines can be grid connected or independently operated from isolated locations.
- The two critical factors in finding the most suitable locations for wind turbines are wind speed and the quality of wind.
- The most suitable sites for wind turbines are turbulence-free locations since turbulence makes wind turbines less efficient and affects overall stability of the turbine.
- Wind turbulence is influenced by the surface of the earth. Depending on the roughness of the terrain, the wind can be more or less turbulent.

Wind Turbine Siting

- It is only at 3000 ft and above ground level that the wind speed is not affected by friction against the earth's surface and therefore there is no turbulence.
- Wind power can be categorized into seven classes according to the wind speed (m/s) and wind power density (W/m^2*)*.
- It should be noted that in this table each wind power class corresponds to two power densities.
- For example, wind power class 4 represents the wind power density range between 200 and 250W/m^2.

Wind Turbine Siting



Wind Power Classes

	At a Height of 10 m (33 ft)		At a Height of 50 m (164 ft)	
Wind Power Class	Wind Power Density (W/m^2)	Wind Speed (m/s)	Wind Power Density (W/m^2)	Wind Speed (m/s)
1	0	0	0	0
1–2	100	4.4	200	5.6
2–3	150	5.1	300	6.4
3–4	200	5.6	400	7.0
4–5	250	6.0	500	7.5
5–6	300	6.4	600	8.0
6–7	400	7.0	800	8.8
7	1000	9.4	2000	11.9

Wind Turbine Siting

- Another important factor for wind turbine siting is **roughness of terrain**. There are roughness classes, which explain the relation between wind speeds and landscape conditions.
- Roughness class varies from 0 to 4, where class 0 represents water surfaces and open terrains with smooth surfaces, and class 4 represents very large cities with tall buildings and skyscrapers.
- Two key parameters regarding the different geographical locations affect the wind turbine siting: the friction coefficient and the roughness classification .
- The friction coefficients are based on different terrain characteristics and were shown previously

Different Electrical Machines in Wind Turbines

- There are various types of electrical machines that are used in wind turbines.
- There is no clear criterion for choosing a particular machine to work as a wind generator.
- The wind generator can be chosen based on the **installed power, site of the turbine, load type, and simplicity of control.**
- BLDC generators, permanent magnet synchronous generators (PMSGs), induction generators, and synchronous generators are the machine types that are used in wind turbine application.

Different Electrical Machines in Wind Turbines

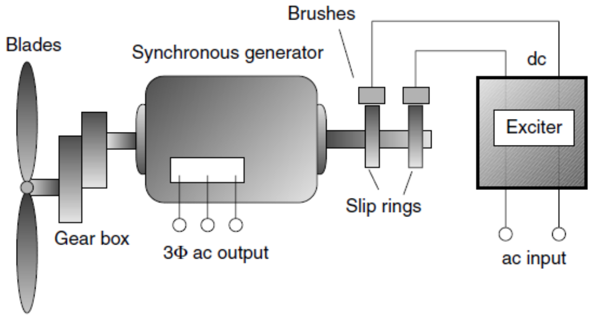
- **Squirrel cage induction or BLDC generators** are generally used for **small wind turbines** in household applications.
- **Doubly fed induction generators (DFIGs**) are usually used for **megawatt size turbines**.
- **Synchronous machines and permanent magnet synchronous machines** (PMSMs) are the other machines that are used for **various wind turbine applications.**

Synchronous Generators

- Synchronous generators are forced to spin at a precise rotational speed determined by the number of poles and the frequency needed for the power lines.
- Their magnetic fields are created on their rotors.
- While very small synchronous generators can create the needed magnetic field with a permanent magnet rotor, almost all wind turbines that use synchronous generators create the field by running direct current through windings around the rotor core.
- The fact that synchronous generator rotors needs dc current for their field windings creates two complications.
- First, dc has to be provided, which usually means that a rectifying circuit, called the *exciter*, is needed to convert ac from the grid into dc for the rotor.
- Second, this dc current needs to make it onto the spinning rotor, which means that slip rings on the rotor shaft are needed, along with brushes that press against them.
- Replacing brushes and cleaning up slip rings adds to the maintenance needed by these synchronous generators.

Synchronous Generators

- Figure below shows the basic system for a wind turbine with a synchronous generator, including a reminder that the generator and blades are connected through a gear box to match the speeds required of each.



BLDC Machines

- ➢ BLDC machines are widely used in small wind turbines (up to 15 kW) due to their control
- ➢ simplicity, compactness, lightness, ease of cooling, low noise levels, and low maintenance.
- ➢ Due to the existence of a magnetic source inside the BLDCs, they are the most efficient electric machines.
- ➢ Recent introduction of high-energy density magnets (rare-earth magnets) has allowed the achievement of very high flux densities in these machines bringing compactness.
- ➢ There is no current circulation in the rotor for the magnetic field; therefore, the rotor of a BLDC generator does not heat up.

BLDC Machines

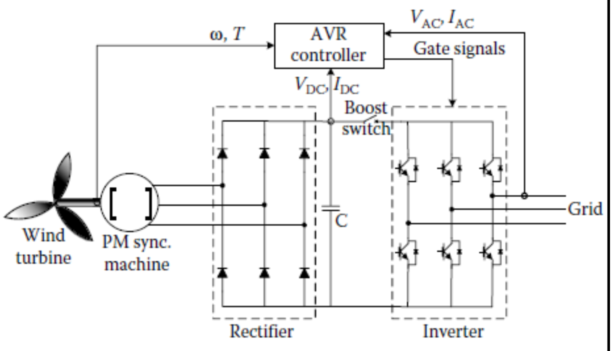
- The absence of brushes, mechanical commutators, and slip rings suppresses the need for regular maintenance and suppresses the risk of failure associated with these elements.
- Moreover, there is no noise associated with the mechanical contact. The switching frequency of the driving converter is high enough so that the harmonics are not audible
- Due to its mechanical performance, the BLDC generator drive system can provide additional increase in power density with the advanced control techniques.

Permanent Magnet Synchronous Machines

- This type of machine can be used in both fixed and variable speed applications.
- The PMSG is very efficient and suitable for wind turbine applications.
- PMSGs allow direct-drive (DD) energy conversion for wind applications.
- DD energy conversion helps eliminate the gearbox between the turbine and generator; thus these systems are less expensive and require less maintenance.
- However, the lower speed determined by the turbine shaft is the operating speed for the generator.

Permanent Magnet Synchronous Machines

- The boost converter controls the electromagnetic torque. The supply side converter regulates the DC link voltage and controls the input power factor.
- The grid side converter (GSC) can be used to control the active and reactive power being fed to the grid.
- The automatic voltage regulator (AVR) collects the information on the turbine's speed, DC link voltage, current, and grid side voltage, and it calculates the pulse width modulation (PWM) pattern (control scheme) for the converter
- This configuration has been considered for small size (<50 kW)

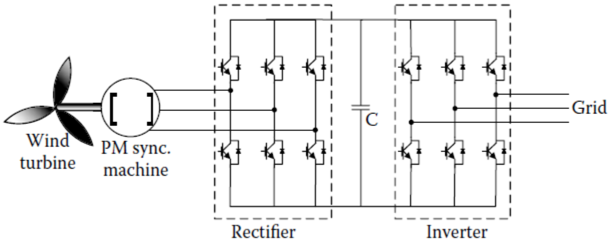


PMSG with a rectifier/inverter.

PMSG

- **The turbine can be operated at its maximum efficiency and the variable speed operation of the PMSG** can be controlled by using a power converter that is able to handle the maximum power flow.
- The stator terminal voltage is controlled, utilizing the field orientation control (FOC) allows the generator to operate near its optimal working point in order to minimize the losses in the generator and power electronic circuit.
- However, the performance depends on the knowledge of the generator parameter that varies with temperature and frequency.
- The main drawbacks are the cost of the PMs that increases the price of the machine, and the demagnetization of the PMs.
- **In addition, it is not possible to control the power factor of the machine**

PMSG with a back-to-back inverter.



Induction Machines

Induction machines used as electric **power generators need an external reactive power source that will excite the induction machine**, which is certainly not required for synchronous machines in similar applications.

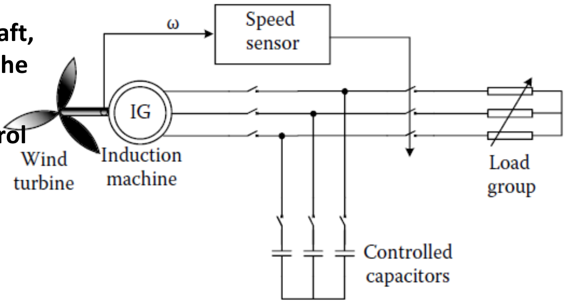
- If the induction machine is connected to the grid, the required reactive power can be provided by the power system .
- The induction machine may be used in cogeneration with other synchronous generators or the excitation can be supplied from capacitor banks (only for stand-alone self-excited generators application)

Induction Machines

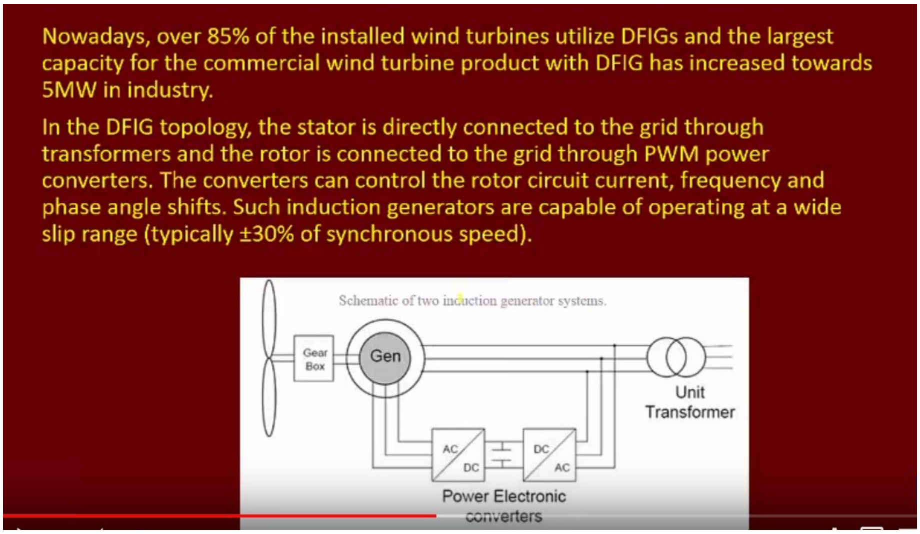
- For stand-alone induction generator applications, the reactive power required for excitation can be supplied using static Volt-Ampere-reactive (VAR) compensators or static compensators (STATCOMs)
- Brushless rotor construction does not need a separate source for excitation; hence its cost can be relatively low.
- Induction generators are often used in wind turbine applications since they require no maintenance and they offer self-protection against severe overloads and short circuits.

IG Conventional Control Scheme

- The conventional scheme for frequency control of an induction generator consists of a speed governor, which regulates the prime mover, and switched capacitor banks, to provide reactive power to the load and excitation of the induction generator,
- The input power for the induction generator has to match the load power demand. The speed of the wind is not controllable; therefore, the induction generator should be controlled according to the load variations .
- Increasing the speed of the shaft, in the case of any increase of the load, is very difficult.
- Therefore, the frequency control technique has a very poor performance.
- Another issue is that voltage regulation requires precise control of the reactive power source.



Doubly-Fed Induction Generator DFIG



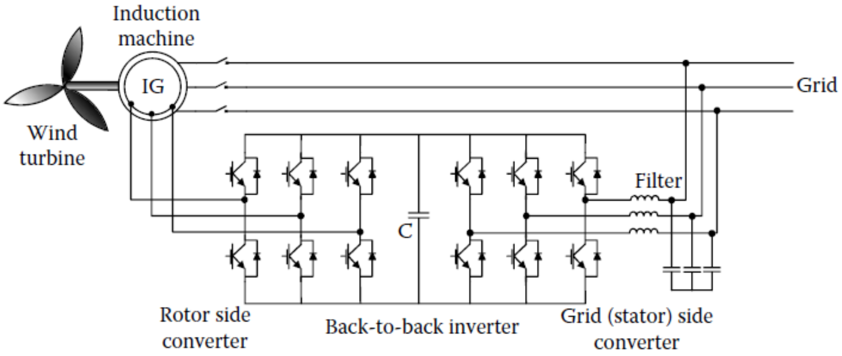
Nowadays, over 85% of the installed wind turbines utilize DFIGs and the largest capacity for the commercial wind turbine product with DFIG has increased towards 5MW in industry.

In the DFIG topology, the stator is directly connected to the grid through transformers and the rotor is connected to the grid through PWM power converters. The converters can control the rotor circuit current, frequency and phase angle shifts. Such induction generators are capable of operating at a wide slip range (typically ±30% of synchronous speed).

Schematic of two induction generator systems.

DFIG

- In the DFIG topology, the induction generator is not a squirrel cage machine and the rotor windings are not short circuited.
- Instead, the rotor windings are used as the secondary terminals of the generator to provide the capability of controlling the machine power, torque, speed, and reactive power.



DFIG

- To control the active and reactive power flow of the DFIG topology, the rotor side converter (RSC) and (GSC) should be controlled separately .
- The speed and the torque of the wound rotor induction machine can be controlled by regulating voltages from both the rotor and the stator sides of the machine.
- In the DFIG, like the synchronous generator, the real power depends on the rotor voltage magnitude and angle.
- In addition, like the induction machine, the slip is also a function of the real power

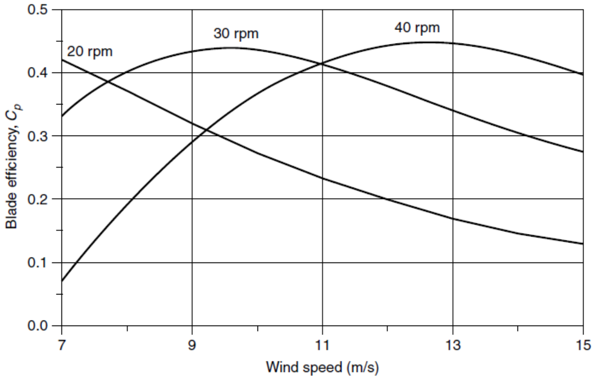
DFIG Advantages

- The inverter cost and size are considerably reduced
- It has an improved effeciency of approximately 2–3% can be obtained.
- DFIG topology offers a decoupled control of generator active and reactive powers .
- The cost and size of the inverter and EMI filters can be reduced since the inverter size is reduced.
- In addition, the inverter harmonics are lowered since the inverter is not connected to the main stator windings.

Importance of Variable Rotor Speeds

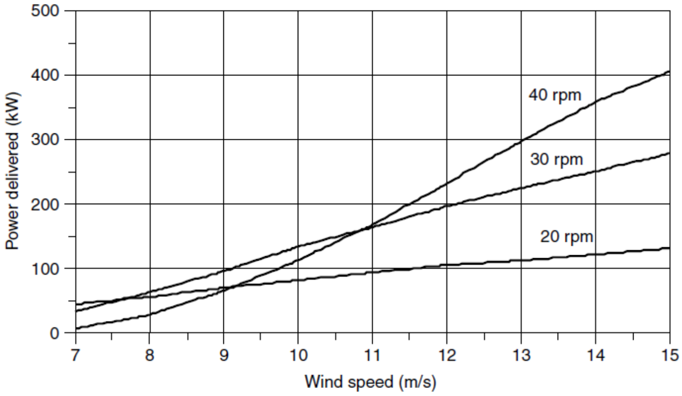
- Figure below shows the impact of rotor speed on blade efficiency,
- what is more important is electric power delivered by the wind turbine.

Blade efficiency is improved if its rotation speed changes with changing wind speed. In this figure, three discrete speeds are shown for a hypothetical rotor.



Importance of Variable Rotor Speeds

- Figure below shows the impact of varying rotor speed from 20 to 30 to 40 rpm for a 30-m rotor with efficiency given in previous Figure , along with an assumed gear and generator efficiency of 70%.



Example of the impact that a three-step rotational speed adjustment has on delivered power.
For winds below 7.5 m/s, 20 rpm is best; between 7.5 and 11 m/s,
30 rpm is best; and above 11 m/s, 40 rpm is best.

Pole changing IG

- Induction generators spin at a frequency that is largely controlled by the number of poles.
- A two-pole, 60-Hz generator rotates at very close to 3600 rpm; with four poles it rotates at close to 1800 rpm; and so on.
- If we could change the number of poles, we could allow the wind turbine to have several operating speeds
- The stator can have external connections that switch the number of poles from one value to another without needing any change in the rotor.
- This approach is common in household appliance motors such as those used in washing machines and exhaust fans to give two- or three-speed operation.

Multiple Gearboxes

- Some wind turbines have two gearboxes with separate generators attached to each, giving a low-wind-speed gear ratio and generator plus a high-wind-speed gear ratio and generator.