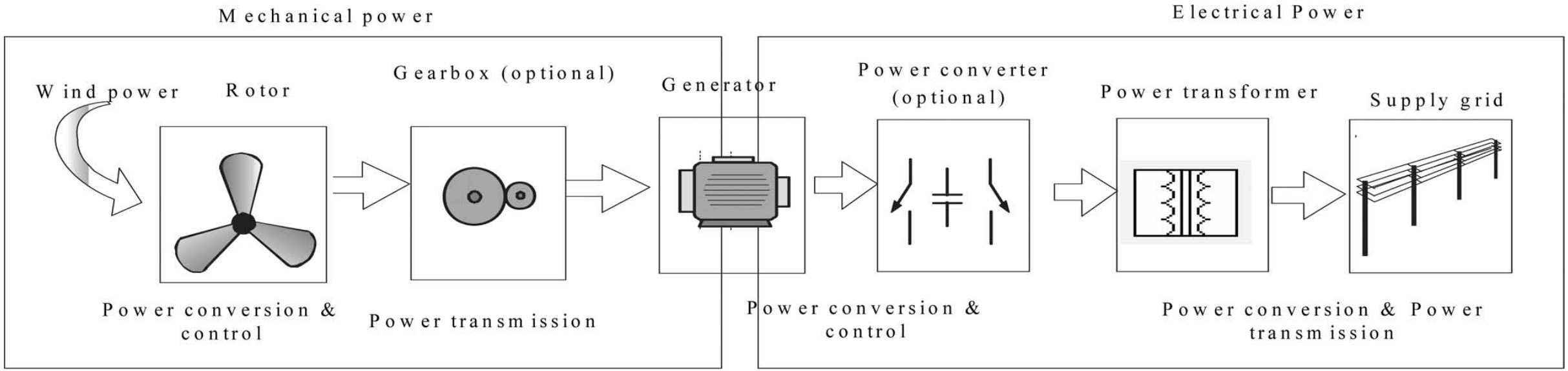
Wind generators

Components of wind turbine system



- Wind turbines capture the power from wind by means of turbine blades and convert it to mechanical power.
- It is important to be able to control and limit the converted mechanical power during higher wind speeds.
- The common way to convert the low-speed, high-torque mechanical power to electrical power is using a gearbox and a generator with standard speed.
- The gearbox adapts the low speed of the turbine rotor to the high speed of the generator.
- The generator converts the mechanical power into electrical power, which being fed into a grid possibly through power electronic converters, and a transformer with circuit breakers and electricity meters.

Wind turbine concepts and generator types

- Referring to the rotation speed, wind turbine concepts can be classified into:

➢ fixed speed

➢ limited variable speed

➢ variable speed

- For variable speed wind turbines, based on the rating of power converter related to the generator capacity, they can be further classified into wind generator systems with:

➢ Partial scale and a full-scale power electronic converter

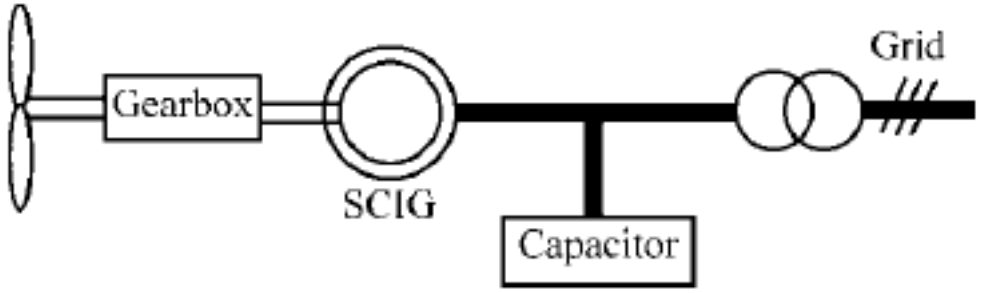
- In addition, considering the drive train components, the wind turbine concepts can be classified into:

➢ Geared drive and Direct-drive wind turbines

- In geared-drive wind turbines, one conventional configuration is :
- A multiple-stage gear with a high-speed generator
- A single-stage gear and a low-speed generator

Fixed speed systems

- The fixed speed wind generator systems have been used with a multiple-stage gearbox and a SCIG directly connected to the grid through a transformer.
- Because the SCIG operates only in a narrow range around the synchronous speed, the wind turbine equipped with this type of generator is often called the fixed-speed wind generator system.



- Since the SCIG always draws reactive power from the grid, during the 1980s this concept was extended with a capacitor bank for reactive power compensation.
- Smoother grid connection was also achieved by incorporating a soft-starter.
- Furthermore, a pole-changeable SCIG has been used, which leads two rotation speeds.

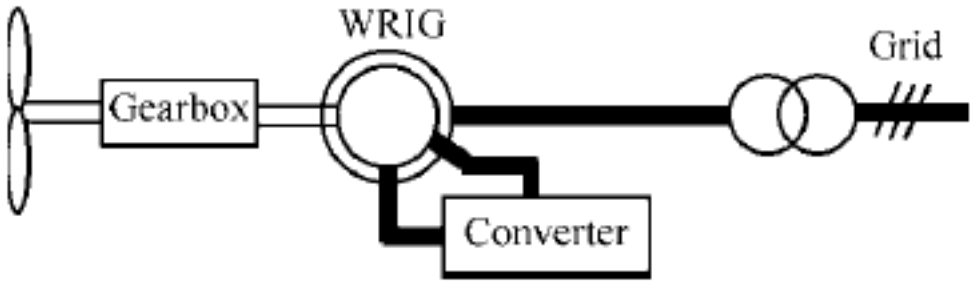
- The well-known advantages of SCIG are it is robust, easy and relatively cheap for mass production.
- In addition, it enables stall-regulated machines to operate at a constant speed when it is connected to a large grid, which provides a stable control frequency.
- Although the stall control method is usually used in combination with the fixed speed SCIG for power control, the active stall control or pitch control have also been applied.

- The disadvantages of SCIG for the fixed speed wind turbine concept are as follows:
- The speed is not controllable and variable only over a very narrow range, in which only speeds higher than the synchronous speed are possible for generator operation.
- Additionally, the fixed speed concept means that wind speed fluctuations are directly translated into electromechanical torque variations, this causes high mechanical and fatigue stresses on the system (turbine blades, gearbox and generator) and may result in swing oscillations between turbine and generator shaft.

- A three-stage gearbox in the drive train is necessary for this wind turbine concept.
- Gearboxes represent a large mass, and also a large fraction of the investment costs.
- It is necessary to obtain the excitation current from the stator terminal of SCIG. This makes it impossible to support grid voltage control.
- In most cases, capacitors are connected in parallel to the generator to compensate for the reactive power consumption.

Limited variable speed concept

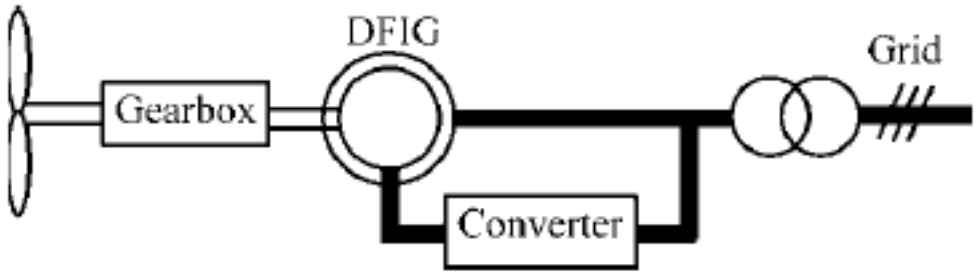
- The limited variable speed concept with a multiple-stage gearbox is uses a wound rotor induction generator (WRIG) with variable rotor resistance by means of a power electronic converter and the pitch control method.



- The stator of WRIG is directly connected to the grid, whereas the rotor winding is connected in series with a controlled resistor.
- Variable-speed operation can be achieved by controlling the energy extracted from the WRIG rotor; however, this power must be dissipated in the external resistor.
- With the increase in variable speed range, a higher slip means a high power extracted by the rotor, and the lower generator efficiency, so that the rating of the resistor must also be higher.
- Therefore the dynamic speed control range depends on the size of the variable rotor resistance , and the energy extracted from the external resistor is also dumped as heat loss in the controllable rotor resistance.
- A typical limited variable speed range is less than 10% above the synchronous speed

Variable speed concept with a partial-scale power converter

- This configuration is known as the DFIG concept, which corresponds to a variable speed wind turbine with a WRIG and a partial-scale power converter on the rotor circuit.



- The stator is directly connected to the grid, whereas the rotor is connected through a power electronic converter.
- The power converter controls the rotor frequency and thus the rotor speed.
- This concept supports a wide speed range operation, depending on the size of the frequency converter.
- Typically, the variable speed range is ± 30% around the synchronous speed.
- The rating of the power electronic converter is only 25–30% of the generator capacity, which makes this concept attractive and popular from an economic point of view.

Advantages

- Compared with the limited variable speed concept, the rotor energy, instead of being dissipated, can be fed into the grid by the power electronic converter.
- Moreover, the power converter system can perform reactive power compensation and smooth grid connection.

Disadvantages

- Multi-stage gearbox is still necessary in the drive train because the speed range for DFIG is far from a common turbine speed of 10–25 rpm.
- A gearbox is inevitable to have some drawbacks, such as heat dissipation from friction, regular maintenance and audible noise.
- The slip ring is used to transfer the rotor power by means of a partial-scale converter, which requires a regular maintenance, and maybe result in machine failures and electrical losses.
- Under grid fault conditions, on the one hand, large stator currents result in large rotor currents, so that the power electronic converter needs to be protected from destruction.

Variable speed direct-drive concept with a full-scale power converter

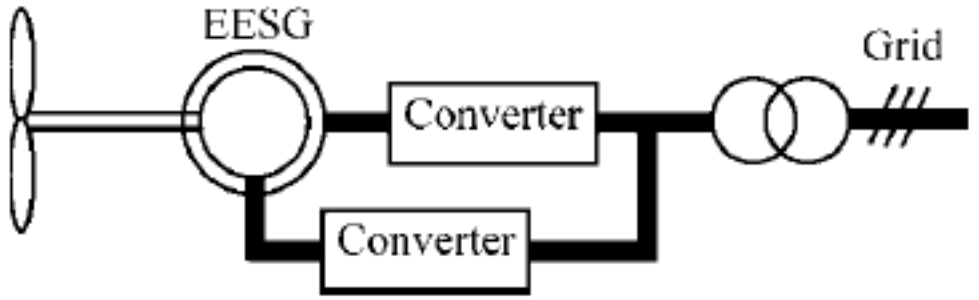
- This configuration may correspond to a variable speed wind turbine with a direct-drive generator connected to the grid through a full-scale power converter.
- The most important difference between geared drive wind turbines and direct-drive types is the generator rotor speed.
- The direct-drive generator rotates at a low speed, because the generator rotor is directly connected on the hub of the turbine rotor.

- To deliver a certain power, the lower speed makes it necessary to produce a higher torque.
- A higher torque means a larger size of the generator.
- Therefore for direct-drive generators, the low speed and high torque operation require larger size of the generators.
- At the same time, the advantages of direct-drive wind turbines are the simplified drive train, the high overall efficiency, the high reliability and availability by omitting the gearbox.
- Compared with the variable speed concept with a partial-scale power converter, the full-scale power converter can perform smooth grid connection over the entire speed range.
- However, it has a higher cost and a higher power loss in the power electronics, since all the generated power has to pass through the power converter.

- Basically, types of direct-drive generators used in the market can be classified into:
- Electrically excited synchronous generator (EESG)
- Permanent Magnet synchronous generator (PMSG).

Electrically excited synchronous generator (EESG)

- The EESG is usually built with a rotor carrying the field system provided with a DC excitation.
- The stator carries a three-phase winding quite similar to that of the induction machine. The rotor may have salient poles or may be cylindrical. Salient poles are more usual in low-speed machines and may be the most useful version for application to direct-drive wind turbines.



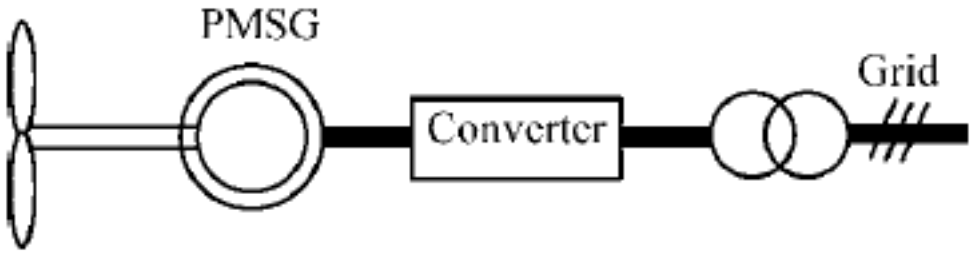
- The amplitude and frequency of the voltage can be fully controlled by the power electronic at the generator side, so that the generator speed is fully controllable over a wide range, even to very low speeds.
- In addition, the EESG has the opportunities of controlling the flux because the excitation current can be controlled by means of the power converter in the rotor side.

Drawbacks

- In order to arrange space for excitation windings and pole shoes, the pole pitch has to be large enough for the large diameter-specific design, so a larger number of parts and windings probably make it a heavy weight and expensive solution.
- It is necessary to excite the rotor winding with DC, using slip rings and brushes, or brushless exciter, employing a rotating rectifier, and the field losses are inevitable.

PM synchronous generator

- The advantages of PM machines over electrically excited machines:
- Higher efficiency and energy yield.
- No additional power supply for the magnet field excitation.
- Improvement in the thermal characteristics of the PM machine due to the absence of the field losses, higher reliability due to the absence of mechanical components such as slip rings.
- Lighter and therefore higher power to weight ratio.

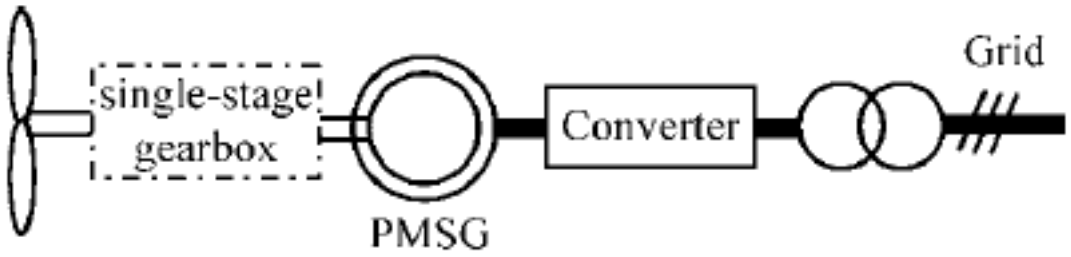


Drawbacks

- High cost of PM material
- Difficulties to handle in manufacture
- Demagnetisation of PM at high temperature

Variable speed single-stage geared concept with a full-scale power converter

- In this scheme, a variable speed wind turbine is connected to a single-stage gearbox that increases the speed by a factor of roughly 10 and a low-speed permanent-magnet generator.
- This concept, has gained the attention because it has the advantages of a higher speed than the direct-drive concept and a lower mechanical component than the multiple-stage gearbox concept.



Variable speed multiple-stage geared concept with a full-scale power converter

- A PMSG system with a multiple gearbox is used in order to reduce the generator's volume and improve the generator efficiency in variable speed wind turbine concepts with a full-scale power converter.
- Compared with the DFIG system, this wind generator system has the following advantages:

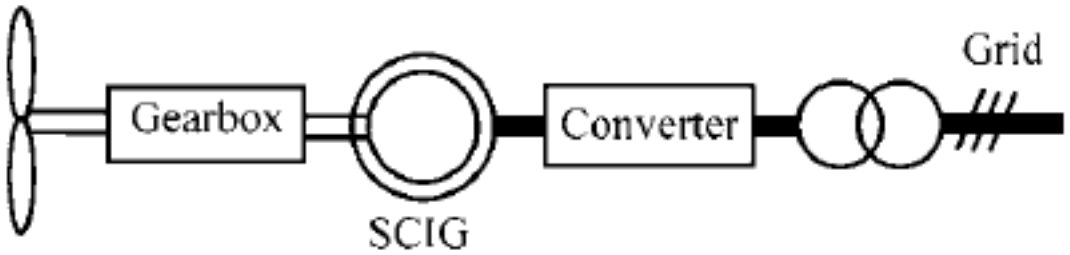
➢The generator has a better efficiency.

➢The generator can be brushless.

Drawbacks

- Larger, more expensive converter (100% of rated power instead of 30%).
- The losses in the converter are higher because all powers are processed by the power electronic converter.

- In order to fulfil the variable speed operation with an SCIG, an alternative generator system that might replace the capacitor bank and soft-starter is a variable speed multiple-stage geared SCIG with a full-scale converter.



- Compared with conventional scheme, this concept has advantages of the flexible control with a full-scale power, such as variable speed operation, better performances of reactive power compensation and smooth grid connection.
- However, its disadvantage is the high cost and losses of the full-scale converter, the efficiency of the total system (gearbox induction generator and converter) may be low.
- ***The decreasing cost of power electronics and the absence of brushes makes variable speed multiple-stage geared concepts (both PMSG and SCIG) more attractive.***