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Comparison of various Wind Turbine Generators

Abstract

This paper analyzes and compares various wind turbine generator connections and its control using various power electronic circuits. This paper deals with the current status of generator and power electronics in wind turbine concepts. It shows that doubly fed induction generator driving variable speed wind turbine controlled by back to back converter is most effective as compared to others.

1. INTRODUCTION

Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Wind passes over the blades, generating lift and exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotational speed to that which is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy. The power output goes to a transformer, which converts the electricity from the generator at around 700 to the appropriate voltage for the power collection system, typically 33 kV. Wind turbine is having two types. One is fixed speed wind turbine and another one is variable wind turbine. The most common type of wind turbine is the fixed-speed wind turbine with the induction generator directly connected to the grid. This system has a number of drawbacks, however. The reactive power and, therefore, the grid voltage level cannot be controlled. Most of the drawbacks of fixed wind turbine are avoided when variable-speed wind turbines are used. These turbines improve the dynamic behavior of the turbine and reduce the noise at low wind speeds. But in variable speed wind turbine power electronics converter is needed which makes the variable speed operation possible. Basically, a wind turbine can be equipped with any type of three-phase generator, such as synchronous generator and asynchronous generator. Out of these, doubly fed induction generator which is type of asynchronous generator is more preferable because of its several advantages. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator. Some researchers believe that the DFIG should be used only for the purpose for which it has been installed, i.e., supplying active power only. The paper describes the current status regarding generators and power electronics for wind turbine.

2. TYPES OF WIND TURBINES

It is characteristic of fixed-speed wind turbines that they are equipped with an induction generator that is directly connected to the grid, with a soft-starter and a capacitor bank for reducing reactive power compensation. They are designed to achieve maximum efficiency at one particular wind speed. In order to increase power production, the generator of some fixed-speed wind turbines has two winding sets. The fixed-speed wind turbine has the advantage of being simple, robust and reliable and well-proven. And the cost of its electrical parts is low. Its disadvantages are an uncontrollable reactive power consumption, mechanical stress and limited power quality control. Owing to its fixed-speed operation, all fluctuations in the wind speed are further transmitted as fluctuations in the mechanical torque and then as fluctuations in the electrical power on the grid.

Variable-speed wind turbines are designed to achieve maximum aerodynamic efficiency over a wide range of wind speeds. It has more complicated electrical system than that of a fixed-speed wind turbine. It is typically equipped with an induction or synchronous generator and connected to the grid through a power converter. The power converter controls the generator speed. The advantages of variable-speed wind turbines are an increased energy capture, improved power quality and reduced mechanical stress on the wind turbine. The disadvantages are losses in power electronics, the use of more components and the increased cost of equipment because of the power electronics. The introduction of variable-speed wind-turbine types increases the number of applicable generator types and also introduces several degrees of freedom in the combination of generator type and power converter type.

3. TYPES OF GENERATORS

Basically, a wind turbine can be equipped with any type of three-phase generator. Today, the demand for grid-compatible electric current can be met by connecting frequency converters, even if the generator supplies alternating current (AC) of variable frequency or direct current (DC). Several generic types of generators may be used in wind turbines:

- Asynchronous (induction) generator:
- – squirrel cage induction generator (SCIG)
- – wound rotor induction generator (WRIG)
    - o OptiSlip induction generator (OSIG)
    - o Doubly-fed induction generator (DFIG)
- Synchronous generator:
- – wound rotor generator (WRSG)
- – permanent magnet generator (PMSG)

3.1 Synchronous generator

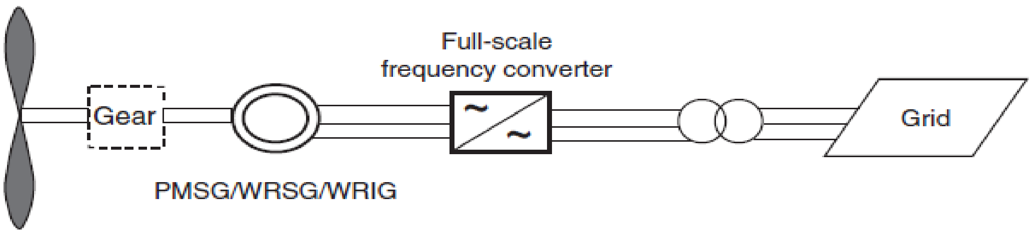

Fig. (c)

Synchronous generator has two types:

3.1.1 Wound rotor generator

The stator windings of WRSGs are connected directly to the grid and hence the rotational speed is strictly fixed by the frequency of the supply grid. The rotor winding is excited with direct current using slip rings and brushes or with a brushless exciter with a rotating rectifier. Unlike the induction generator, the synchronous generator does not need any further reactive power compensation system. The rotor winding, through which direct current flows, generates the exciter field, which rotates with synchronous speed. The speed of the synchronous generator is determined by the frequency of the rotating field and by the number of pole pairs of the rotor. It has the advantage that it does not need a gearbox. But the price that has to be paid for such gearless design is a large and heavy generator and a full-scale power converter that has to handle the full power of the system.

3.1.2 Permanent magnet generator

In the permanent magnet machine, the efficiency is higher than in the induction machine, as the excitation is provided without any energy supply. However, the materials used for producing permanent magnets are expensive, and they are difficult to work during manufacturing. Additionally, the use of PM excitation requires the use of a full scale power converter in order to adjust the voltage and frequency of generation to the voltage and the frequency of transmission, respectively. This is an added expense. However, the benefit is that power can be generated at any speed so as to fit the current conditions. The stator of PMSGs is wound, and the rotor is provided with a permanent magnet pole system. The synchronous nature of the PMSG may cause problems during startup, synchronization and voltage regulation. It does not readily provide a constant voltage. Another disadvantage of PMSGs is that the magnetic materials are sensitive to temperature. Therefore, the rotor temperature of a PMSG must be supervised and a cooling system is required

3.2. Asynchronous (induction) generator

Asynchronous generator has two types:

3.2.1 Squirrel cage induction generator

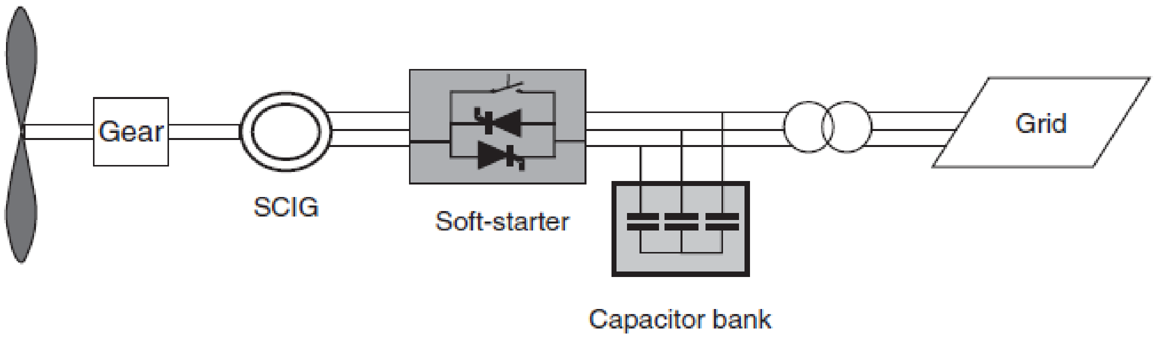

Fig. (a)

As illustrated in Figure (a) the SCIG is directly grid coupled. The SCIG speed changes by only a few percent because of the generator slip caused by changes in wind speed. Therefore, this generator is used for constant-speed wind turbines. The generator and the wind turbine rotor are coupled through a gearbox. Wind turbines based on a SCIG are typically equipped with a soft-starter mechanism and an installation for reactive power compensation, as SCIGs consume reactive power. SCIGs have a steep torque speed characteristic and therefore fluctuations in wind power are transmitted directly to the grid. These transients are especially critical during the grid connection of the wind turbine, where the in-rush current can be up to 7–8 times the rated current. Therefore, the connection of the SCIG to the grid should be made

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gradually in order to limit the in-rush current. The major problem is because of the magnetizing current the full load power factor is relatively low. Too low a power factor is compensated by connecting capacitors in parallel to the generator. In the case of a fault, SCIGs without any reactive power compensation system can lead to voltage instability on the grid. The wind turbine rotor may speed up, for instance, when a fault occurs, owing to the imbalance between the electrical and mechanical torque. Thus, when the fault is cleared, SCIGs draw a large amount of reactive power from the grid, which leads to a further decrease in voltage.

3.2.2 Wound rotor induction generator

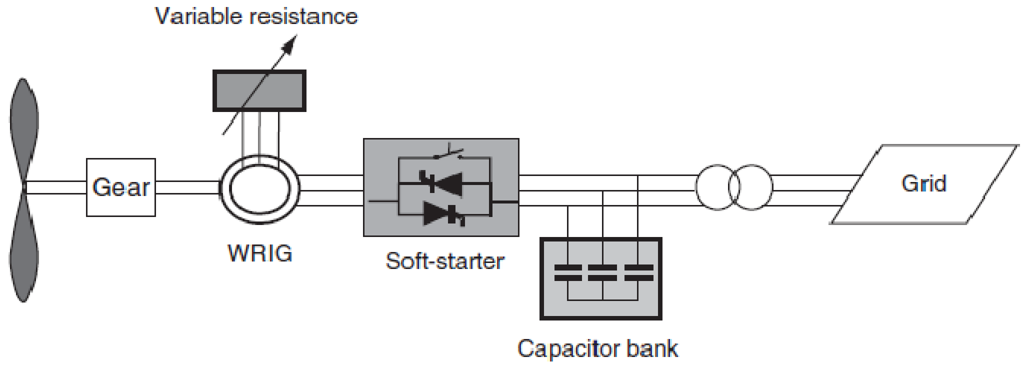

Fig. (b)

Wound rotor induction has two subtypes:

3.2.2.1 Optislip induction generator

The Optislip feature allows generator to have a variable slip and to choose the optimum slip, resulting in smaller fluctuations in torque and power output. The variable slip is a very simple, reliable and cost-effective way to achieve load reductions. WRIG includes a variable external rotor resistance by means of which slip can be controlled. The converter is optically controlled, which means that no slip rings are necessary. The stator of the generator is connected directly to the grid. The advantages of this generator concept are a simple circuit topology, no need for slip rings and an improved operating speed range compared with the SCIG. To a certain extend, this concept can reduce the mechanical loads and power fluctuations caused gusts. However, it still requires a reactive power compensation system. The disadvantages include the speed range is typically limited to 0–10 %, poor control of active and reactive power is achieved and the slip power is dissipated in the variable resistance as losses.

3.2.2.2 Doubly fed induction generator

The term ‘doubly fed’ refers to the fact that the voltage on the stator is applied from the grid and the voltage on the rotor is induced by the power converter. This system allows a variable-speed operation over a large, but restricted, range. The converter compensates the difference between the mechanical and electrical frequency by injecting a rotor current with a variable frequency. Both during normal operation and faults the behaviour of the generator is thus governed by the power converter and its controllers. The power converter consists of two converters, the rotor-side converter and grid-side converter, which are controlled independently of each other. The rotor-side converter controls the active and reactive power by controlling the rotor current components, while the line-side converter controls the DC-link voltage and ensures a converter operation at unity power factor. In both cases – sub synchronous and over synchronous – the stator feeds energy into the grid. The DFIG has several advantages. It has the ability to control reactive power and to decouple active and reactive power control by independently controlling the rotor excitation current. The DFIG has not necessarily to be magnetized from the power grid, it can be magnetized from the rotor circuit, too. It is also capable of generating reactive power that can be delivered to the stator by the grid-side converter. In the case of a weak grid, where the voltage may fluctuate, the DFIG may be ordered to produce or absorb an amount of reactive power to or from the grid, with the purpose of voltage control. The converter used in DFIG is back to back converter

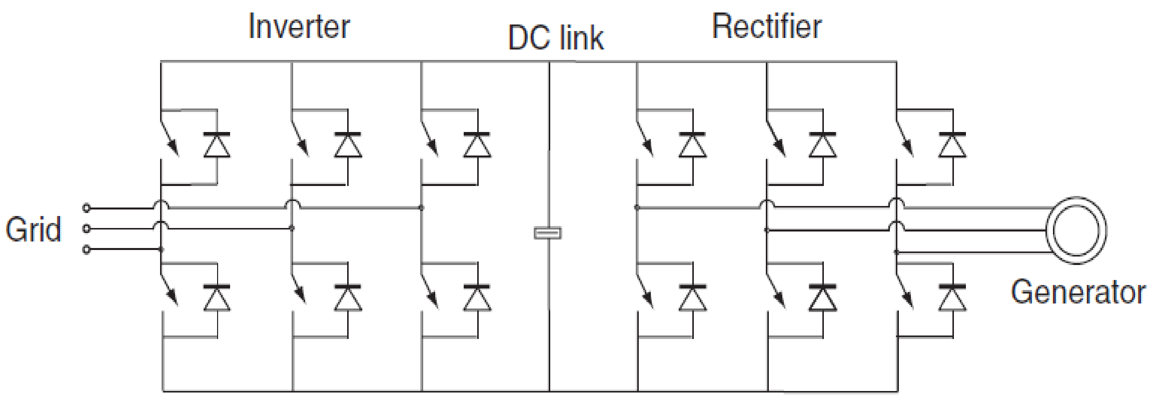

Fig. (d)

the back-to-back converter is highly relevant to wind turbines today. The back-to-back converter is a bidirectional power converter consisting of two conventional pulse-width modulated converters. The DC link voltage is boosted to a level higher than the amplitude of the grid line-to-line voltage in order to achieve full control of the grid current. The capacitor between the inverter and rectifier makes it possible to decouple the control of the two inverters without affecting the other side of the converter. The power flow at the grid-side converter is controlled to keep the DC link voltage constant, and the control of the generator-side converter is set to suit the magnetization demand and the desired rotor speed.. it is concluded that the back to back converter is the ones recommended for further studies in different generator topologies.

4. CONCLUSION

This paper provides a brief and comprehensive survey of the generator and power electronic concepts used by the modern wind turbine industry. A short introduction, presenting the basic wind turbine topologies and control strategies, was followed by the state of the art of wind turbines, from an electrical point of view. Old and new potentially promising concepts of generators and power electronics based on technical aspects and market trends were presented. It is obvious that the introduction of variable-speed options in wind turbines increases the number of applicable generator types and further introduces several degrees of freedom in the combination of generator type and power converter type. A very significant trend for wind turbines is that large wind farms will have to behave as integral parts of the electrical power system and develop power plant characteristics. Power electronic devices are promising technical solutions to provide wind power installations with power system control capabilities and to improve their effect on power system stability.

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