

Review of Doubly Fed Induction Generator Used in Wind Power Generation

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ABSTRACT

Wind is a renewable and non-polluting energy source. This source of energy has gained popularity in the last few years and is mainly used for supplying power for distribution systems. It uses various kinds of generators for its use. Nowadays, the most widely used generator type for units above 1MW is the doubly-fed induction machine. Doubly fed induction machines allow active and reactive power control through a rotor-side converter, while the stator is directly connected to the grid. Hence a review of the suitability of Doubly Fed Induction generator and its characteristics which make it stand alone from other generators are presented. The rotor protection schemes are also included for DFIG.

Keywords – Wind power generation, doubly fed induction generator (DFIG)

1. INTRODUCTION

Wind is an alternative source of energy for electricity production. Because of the conventional sources of energy harming the environment, these alternative sources are gaining importance. Wind is the most available and exploitable sources of energy. Wind blows due to change in atmospheric pressure and is a by-product of solar energy. Hence it has emerged as the most viable source of electrical power and is economically competitive with the conventional sources.

In the 1990s, wind power turbines were characterized by a fixed-speed operation. Basically, they consisted of the coupling of a wind turbine, a gearbox and an induction machine directly connected to the grid. Additionally, they used a soft starter to energize the machine and a bank of capacitors to compensate the machine power reactive absorption. Although being simple, reliable and robust, the fixed-speed wind turbines were inefficient and power fluctuations were transmitted to the network due to wind speed fluctuations [1].

In the mid-1990s, variable-speed wind power turbines gave an impulse to the wind power industry. A better turbine control reduces power fluctuations. In addition, optimal power extraction from wind was possible by operating the turbine at optimal speed. Among the different configurations of variable-speed wind power turbines, the doubly-fed induction generator, at present, is the most used in the development of wind farm projects [2].

2. WIND POWER GENERATION

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 700V to the appropriate voltage for the power collection system, typically 33 kV. A wind turbine extracts kinetic energy from the swept area of the blades [3].

Wind turbines convert the kinetic energy present in the wind into mechanical energy. Since the energy contained by the wind is in the form of kinetic energy, its magnitude depends on the air density and the wind velocity. The wind power developed by the turbine is given by the equation

$$P = 0.5 C_p A \rho V^3$$

Where C_p is the Power Co-efficient, ρ is the air density in kg/m^3 , A is the area of the turbine blades in m^2 and V is the wind velocity in m/sec .

In 1920, Albert Betz, a German pioneer of wind power technology, studied the best utilization of wind energy in wind mills establishing a theoretical limit for the power extraction. Basically, it said that independently of the

turbine design, at most 59% of the wind kinetic energy can be converted into mechanical energy. This is known as Betz's limit. Also at every wind speed there is an optimum turbine speed at which the power extraction from the wind is maximized. This is shown in fig. 1.

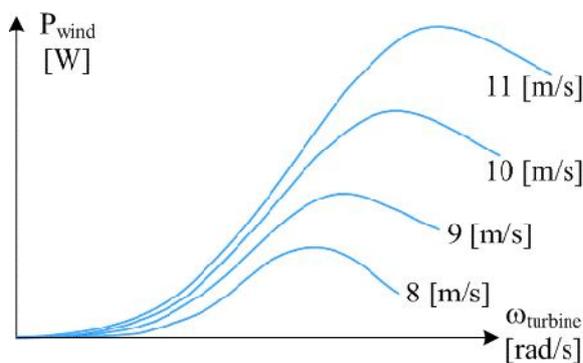


Fig. 1. Extracted power from the wind [1]

3. DOUBLY-FED INDUCTION GENERATOR

During the last years, the most used configuration in wind power projects has been the doubly-fed induction generator shown in figure 2. The main advantage of this configuration is that it allows variable-speed operation. Therefore, the power extraction from the wind can be optimized.

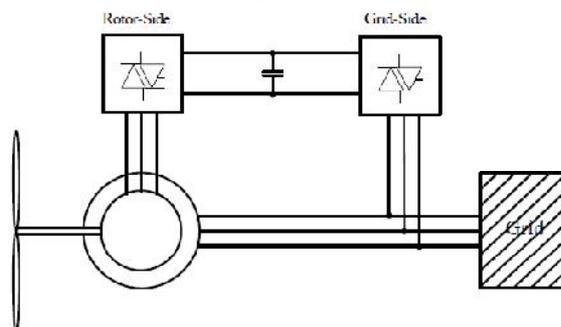


Fig. 2. Doubly Fed induction generator system [4]

The mechanical power generated by the wind turbine is transformed into electrical power by an induction generator and is fed into the main grid through the stator and the rotor windings. Back to back converters consist of two voltage source converters (ac-dc-ac) having a dc link capacitor connecting them. The rotor side converter takes the variable frequency voltage and converts it into dc voltage. The grid side converter has the ac voltage from the dc link as input and voltage at grid parameters as output.

With the rotor-side converter it is possible to control the torque or the speed of the DFIG and also the power factor at the stator terminals, while the main objective for the grid-side converter is to keep the dc-link voltage constant regardless of the magnitude and direction of the rotor power. Between the two converters a dc-link capacitor is placed, as energy storage, in order to keep the voltage variations (or ripple) in the dc-link voltage small.

The stator is connected directly to the grid. The rotor on the other hand needs a step down transformer in order to connect to the grid. For a normal generation regime, the energy obtained by processing the wind speed as an input is fed into the network by both the stator and the rotor.

4. CHARACTERISTICS OF DFIG

Figure 3 shows how the rotor and stator power vary as the rotor slip changes from sub- to super-synchronous modes. The speed of the rotor has to change as wind speed changes in order to track the maximum power point of the aerodynamic system. Slip, s , therefore is related to incident wind speed. In this case, a slip of -0.2 occurs with

rated wind speed (12 ms⁻¹). As wind speed drops, slip has to increase and in this case has a maximum value of 0.35[2].

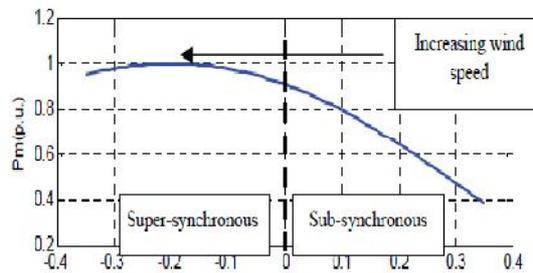


Fig. 3. DFIG power flows [2]

When rotating at the synchronous speed ($s = 0$), the DFIG supplies all the power via the stator winding, with no active power flow in the rotor windings and their associated converters. Note that at $s=0$, the stator power is maximum as shown in figure 4.

As the wind speed increases, the rotational speed must also increase to maintain optimum tip-speed ratios. In such circumstances, the machine operates at super synchronous speeds ($s < 0$). The mechanical power flows to the grid through both the stator windings and the rotor windings and their converter. At lower wind speeds, the blades rotate at a sub-synchronous speed ($s > 0$). In such circumstances, the rotor converter system will absorb power from the grid connection to provide excitation for rotor winding. With such a control scheme it is possible to control the power extracted from the aerodynamic system such that the blade operates at the optimum aerodynamic efficiency (thereby extracting as much energy is as possible) by adjusting the speed of rotation according to the incident wind speed.

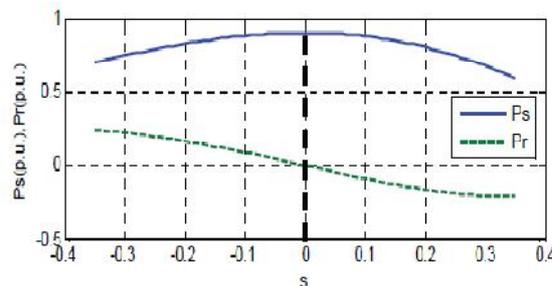


Fig. 4. DFIG power flows showing stator power (P_s) and rotor power (P_r) [2]

5. CONVERTER PROTECTION SYSTEMS

The prevalent DFIG converter protection scheme is crowbar protection. A crowbar is a set of resistors that are connected in parallel with the rotor winding on occurrence of an interruption. The crowbar circuit bypasses the rotor-side converter. The active crowbar control scheme connects the crowbar resistance when necessary and disables it to resume DFIG control.[2]

A braking resistor (DC-chopper) can be connected in parallel with the DC-link capacitor to limit the overcharge during low grid voltage. This protects the IGBTs from overvoltage and can dissipate energy, but this has no effect on the rotor current. In a similar way to the series dynamic braking resistor, which has been used in the stator side of generators, a dynamic resistor is proposed to be put in series with the rotor (series dynamic resistor) and this limits the rotor over-current. In normal operation, the switch is on and during fault conditions, the switch is off and the resistor is connected in series to the rotor winding. The rotor equivalent circuit is shown with all the above protection schemes in Fig. 5.

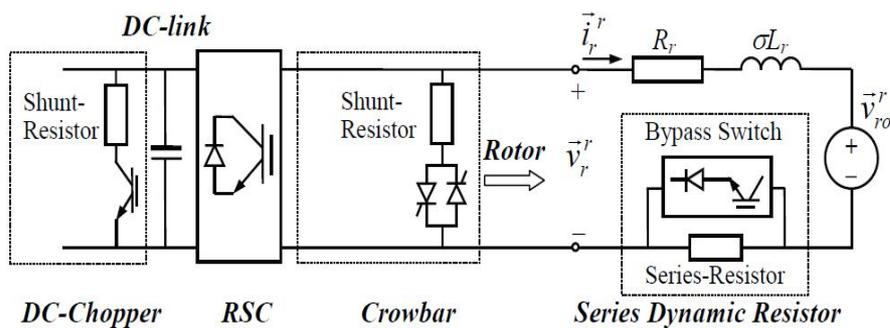


Fig. 5. DFIG rotor equivalent circuit with all protection schemes shown [2]

6. CONCLUSION

The DFIG system costs more than fixed-speed induction generators without converters. However, the performance and controllability are excellent in comparison with fixed speed induction generator systems; they capture more wind energy, they exhibit a higher reliability gear system, and high-quality power supplied to the grid. It saves investment on full-rated power converters, and soft-starter or reactive power compensation devices (fixed-speed systems). 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. Also because of its ability to control reactive power and to decouple active and reactive power control by independently controlling the rotor excitation current, DFIG is preferred in wind power generation.

7. REFERENCES

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