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Wind Turbine Using Doubly Fed Induction Generator Systems for Wind Turbines

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***Abstract*— In order to fully study the electrical , mechanical and aerodynamic aspects of a wind turbine with doubly fed induction generator , a detailed model, or vice versa. Hence, the effects of interactions between electrical and mechanical components are not accurately taken into account. In this paper, three simulation programs- Turbsim, FAST and Simulink—are used to model the wind, mechanical and electrical parts of a wind turbine.**

***Index Terms*— FAST, doubly fed induction generator (DFIG), Simulink, Turbsim, Voltage Sag, and Wind Energy**

I. INTRODUCTION

Wind energy has been used for thousands of years by humans. Ancient Persians used wind energy to pump water before the birth of Christ. Recently, there has been a growing interest in the use of wind energy as environmental advancements are needed to make wind energy competitive with many other energy supply methods. The doubly fed induction generator (DFIG) is an induction generator with both stator and rotor windings. The DFIG is now days widely used in variable-speed wind energy applications with a static converter connected between the stator and rotor.

This paper is intended to provide a comprehensive study about the DFIG which includes the aerodynamic, mechanical and electrical aspects of WECS, it is intended to cover the operation from variable speed turbine, power converter is used, its integration into the utility system and thereafter also study the factors which are affected from its integration with the grid.

II. WIND ENERGY CONVERSION SYSTEM (WECS)

The wind energy is now one of the fastest growing and attractive renewable energies. This has drawn increasing attention to renewable energies including wind energy The increasing price-competitiveness of wind energy against other conventional fossil fuel energy sources such as coal and natural gas is another positive.

WECS consists of three major aspects; aerodynamic, mechanical and electrical as shown in figure 1. The electrical aspect of WECS can further be divided into three main components, which are wind turbine generators (WTGs), power electronic converters (PECs) and the utility grid.

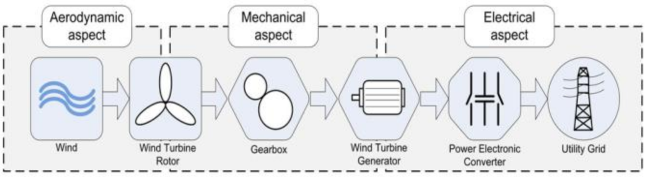

Fig.1 Wind Energy Conversion System (WECS)

III. MODEL OF DOUBLY FED INDUCTION GENERATOR WIND TURBINE

The doubly fed induction generator is widely used in wind power generation due to its high energy efficiency and controllability. This generator converts the wind energy into useful electrical power through wound rotor induction machine, wind turbine with drive train system, rotor side converter (RSC), grid side converter (GSC), DC-link capacitor and coupling transformer. The wound rotor induction machine stator winding is connected to the grid via AC/DC/AC IGBT power convertor and a three phase power transformer by slip rings and brushes, hence the term 'doubly-fed' . The stator of the DFIG is connected to grid with fixed frequency (fs) and voltage, whereas the rotor side supplies a variable frequency which is controlled by the power converter before connecting to the grid. Because only part of the real power flows through the rotor circuit, these converters are used to handle a fraction (25-30%) of the total power to accomplish independently full control of the real and reactive power of generator.

Thus, the losses in the power converter can be reduced because these converter handle less than 30% of the generator rated power. The control system controls the real and reactive power by changing the current flowing in the rotor winding to extract the maximum possible power from the wind. Therefore, the power of the rotor can be connected to the grid at the rated frequency by interposing the converters.

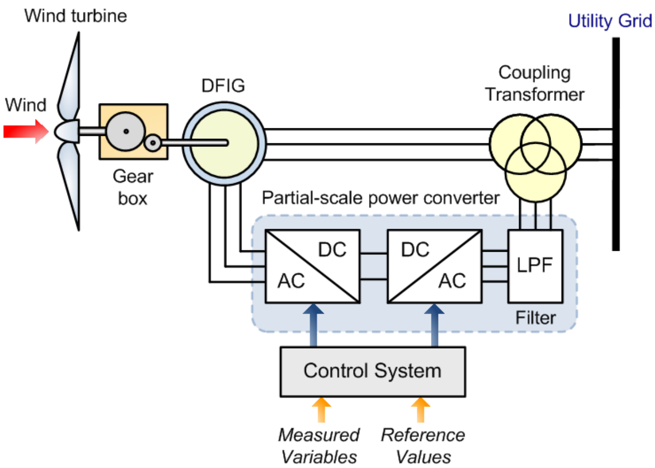

Fig.2 Doubly Fed Induction Generator (DFIG)

The active power of the stator is always flowing to the grid, independently of the operation state, whereas the machine operates as motor (sub-synchronism operation) when observing power, while the machine operates as a generator (super-synchronism operation) when supplying power. By neglecting the power loss, the relation between the rotor power (Pr) and stator power (Ps) through the slip (s) is given by :

$$Pr = -s.Ps$$

Where the (s) is defined as the slip of the machine which is given by:

$$S = \frac{\text{Sychronous Speed(Ws)-Rotor speed(Wr)}}{\text{Synchronous Speed (Ws)}}$$

Therefore, the net power (Pnet) that is generated from both stator and rotor side can be expressed as:

$$P\ net = Ps + Pr = (1-S).Ps$$

When the slip is negative, the machine will operate in (super-synchronous) operation state (as a generator),while the machine will operate in sub-synchronous operation state(as a motor) when the slip is positive, i.e. the rotor speed is slower than the synchronous speed. By the configuration, the wound rotor induction generator delivers directly the 2/3 of its rated power to the grid through the stator windings, while it delivers 1/3 of its rated power through the rotor winding via the converters.

IV. POWER CONVERTOR TOPOLOGY FOR DFIG

The doubly fed induction generator (DFIG) has received much attention in the wind energy conversion. If the wound rotor induction generator (DFIG) is used, it is possible to control the generator by accessing rotor circuits. A significant advantage in using doubly fed induction generator is the ability to output more than its rated power without becoming overheated. It is able to transform maximum power over a wide speed range in both sub and super-synchronous modes. The DFIG along with induction generators are excellent for high power applications in the MW range. More importantly, converter power rating is reduced since it is connected to the rotor, whilst the majority of the power flows through the stator.

- ***Back-to-Back PWM Converters***

A technologically advanced method using back-to-back converters has been developed. Much work has been presented using this type of converter. Although the converter used in these works are extremely similar, great differences lie within the control strategy and complexity.

One option is to apply vector control to the supply side converter, with a reference frame oriented with the d-axis along the stator voltage vector. The supply side converter is controlled to keep the DC-link voltage through regulation of the d-axis current. It is also responsible for reactive power control through alternation of q-axis current. As for the rotor side, the choice of decoupled control of the electrical torque and the rotor excitation current is presented. The machine is control in the synchronously rotating reference frame with the d-axis oriented along the stator flux vector, providing maximum energy transfer. Conversely, the rotor current was decomposed in d-q components, where the d-axis current is used to control the electromagnetic torque and the q-axis current controls the power factor. Both types of rotor-side converter control employ the use of PI-controllers. PWM switching techniques can be used, or alternatively space vector modulation (SVM) used in order to achieve a better modulation index.

Often control schemes aided by a rotor speed encoder obtain excellent tracking results. However these encoders are expensive and the cost due to lost accuracy without the encoder may not as large. To accompany the capacitor in the DC-link, a battery may be used as storage device. With the extra storage device, the supply side converter now controls the transfer of real power between the grid and the battery, as the DC voltage now fixed. The supply-side controller made up of three PI controllers, one for outer loop power control, and other two for the d-q axis inner current control loop. Energy is stored during high winds and is exported to the grid during calm conditions to compensate for the drop in the stator power. During long periods of high and low wind speeds, the control algorithm is modified to regulate the bus voltage until the conditions change. In this case the rotor-side converter is gated in order to control real and reactive power of the machine. The algorithm searches for the peak power by varying the rotor speed, and the peak power points are recognized as zero slopes on the power speed curves. The control works continuously, as a significant shift in power causes the controller to shift the speed which in turn causes the power to shift again, d-q axis control is used to control the real and reactive power of the machine.

A typical control objectives described above can be attained through control theory based on voltage space vectors(VSV). The application of certain voltage vectors may accelerate the rotor flux, and increase the active power generated by the stator. Other voltage vectors may also increase or decrease the rotor flux magnitude, resulting in a reduction in the reactive power drawn by the stator and on improved power factor. This direct power control method requires a series of tables to determine which of the six sectors the controller is operating in. From the choice of the applied voltage vectors can be determined from another table.

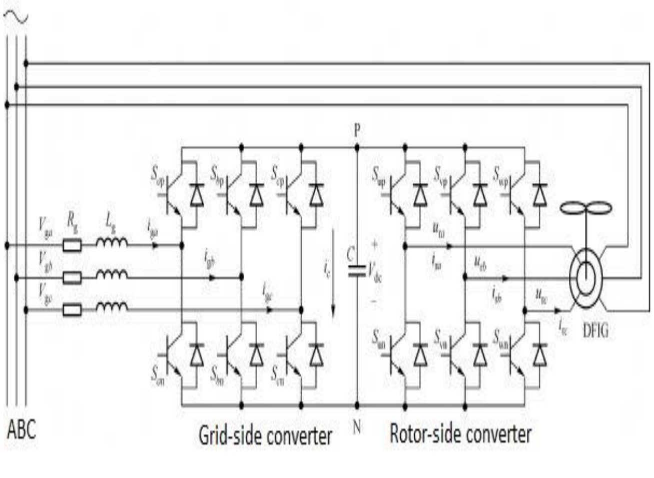

Fig.3 Back-to-Back PWM Converter

A final control scheme, for the back-to-back PWM converter scheme, uses information on shaft speed and turbine output power to estimate the wind speed. The turbine output power is described as a function of TSR. The roots of the equation are solved generator output power and shaft speed is obtained. The system is commanded to the desired shaft speed and the output power is again measured, regurgitating the control.

This control is applied to a brushless DFIG, which gives reduced cost in comparison to machines with brushes and slip-ring.

The design of DFIG using back-to-back PWM converter is given in fig.1. the analysis of decoupled d-q vector control scheme is implemented for the control of active, reactive power and to provide wide speed operation by using back-to-back PWM converter connected between the rotor-side and the utility grid-side. The converter performance of grid connected wind energy conversion system for DFIG with back-to-back PWM. Since PWM generate harmonics, so to overcome this harmonics filters are required.

V. CONTROL SYSTEM FOR DFIG

A. Maximum Power Point Tracking(MPPT) Control

The control of a variable speed wind turbine below the rated wind speed is achieved by controlling the generator. The main goal is to maximize the wind power capture at different wind speed, which can achieved by adjusting the turbine speed in such a way that the optimal tip speed ratio maintained.

For a given wind speed, each power curve has a maximum power point at which the optimal tip speed ratio is achieved. To obtain the maximum available power from the wind at different wind speeds, the turbine speed must be adjusted to ensure its operation at all the maximum power points.

The relations between the mechanical power, speed and torque of a wind turbine can be used to determine the optimal speed or torque reference to control the generator and achieve the maximum power point.

Generator-control mode: When the wind speed is between the cut in and rated speed, the blades are pitched into the wind with its optimal angle of attack. The turbine operates with variable rotational speeds in order to track the maximum power point at different wind speeds. This is achieved by proper control of generator.

Pitch-control mode: For higher than rated wind speed but below the cut-out limit, the captured power is kept constant by the pitch mechanism to protect the turbine from damage while the system generates and delivers the rated power to the grid. The blades are pitched out of the wind gradually with the wind speed, and the generator speed is controlled accordingly. When the wind speed reaches or exceeds the cut-out speed, the blades are pitched completely out of the wind. No power is captured, and turbine speed is reduced to zero. The turbine will be blocked into the parking mode to prevent damage from the strong wind.

B. Rotor –Side Converter Control

The rotor-side converter provides the excitation for the induction machine rotor. With this PWM converter it is possible to control the torque hence the speed of the DFIG and also the power factor at the stator terminals. The rotor-side converter provides a varying excitation frequency depending upon the wind speed condition. The function of the receiving end converter is to feed the active power transmitted by the sending end converter while maintaining the DC voltage at the desired level. Additionally, the reactive power channel can be used to support the grid voltage during faults and also in steady-state. The PI-controllers maintains DC voltage through active converter current under consideration of a feed forward term representing the power transfer through the DC link. AC voltage control is performed by two PI controllers. The controller in the upper branch is slow and only responsible for set-point tracing in steady state operation. The second controller is very fast and is activated during grid faults. The magnitude of the current outputs is limited. In steady state operation the DC voltage has higher priority.

C. Grid-Side Converter Control

The grid –side converter controls the flow of real and reactive power to the grid interfacing inductance. The objective of the grid –side converter is to keep the DC-link voltage constant regardless of the magnitude and direction of the rotor power. The sending end converter is responsible for transmitting the active power produced by the wind farm, while maintaining the AC voltage in the wind farm grid. Furthermore, it can be used for frequency which in turn controls the changes in the generator slip of the connected DFIG wind turbines. Thus, active power transfer through the low rated converter in the rotor circuit of the DFIG can be limited without the reduction of the total power.

As the power control is performed by the wind turbines, a simple voltage magnitude controller can be used for the sending end converter, thus fulfilling the aforementioned requirements. The frequency can be directly regulated without the need for a closed loop structure.

VI. CONCLUSION

In this paper, the detailed study of DFIG along with its topology, grid configuration, relevant power converter devices, appropriate control parameters, integration with the utility grid and its effect on the various system conditions are presented. The operation of both slip-ring and brushless arrangement of DFIG has been summarized. The influence of DFIG on the performance, system stability, system reliability, power quality and power transmission has been received. This comprehensive review will be helpful for researchers working in area of DFIG.

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