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A Variable Speed Wind Generation System Based on Doubly Fed Induction Generator

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Abstract

Wind energy has become one of the most important and promising sources of renewable energy, which demands additional transmission capacity and better means of maintaining system reliability. The evolution of technology related to wind systems industry leaded to the development of a generation of variable speed wind turbines that present many advantages compared to the fixed speed wind turbines. These wind energy conversion systems are connected to the grid through Voltage Source Converters (VSC) to make variable speed operation possible. The studied system here is a variable speed wind generation system based on Doubly Fed Induction Generator (DFIG). The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid-side converter (GSC) keeps the voltage of the DC-link constant. The additional freedom of reactive power generation by the GSC is usually not used due to the fact that it is more preferable to do so using the RSC. However, within the available current capacity the GSC can be controlled to participate in reactive power generation in steady state as well as during low voltage periods. The GSC can supply the required reactive current very quickly while the RSC passes the current through the machine resulting in a delay. Both converters can be temporarily overloaded, so the DFIG is able to provide a considerable contribution to grid voltage support during short circuit periods. This report deals with the introduction of DFIG, AC/DC/AC converter control and finally the SIMULINK/MATLAB simulation for isolated Induction generator as well as for grid connected Doubly Fed Induction Generator and corresponding results and waveforms are displayed.

1. Introduction

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter, as Figure 1 [1]. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. 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. Where V_r is the rotor voltage and V_{gc} is grid side voltage. The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system [2].

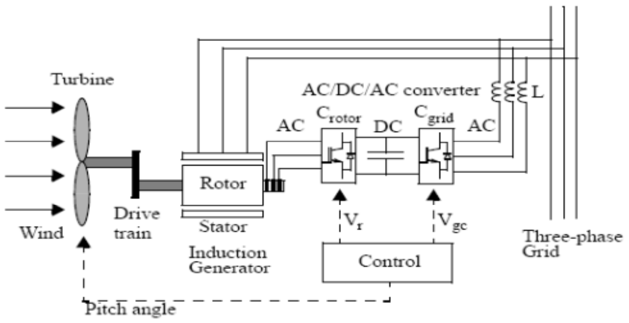

Figure 1. Schematic of Doubly Fed Induction Generator with Converters [1]

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Here Crotor is rotor side converter and C grid is grid side converter. To control the speed of wind turbine gear boxes or electronic control can be used.

2. Operating Principle of DFIG

The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator and rotor-side converters allows the storage of power from induction generator for further generation as Figure 2. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage. The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes. Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter, where slip power is returned to the stator. Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and statorside converter as a rectifier, where slip power is supplied to the rotor. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine [3-5].

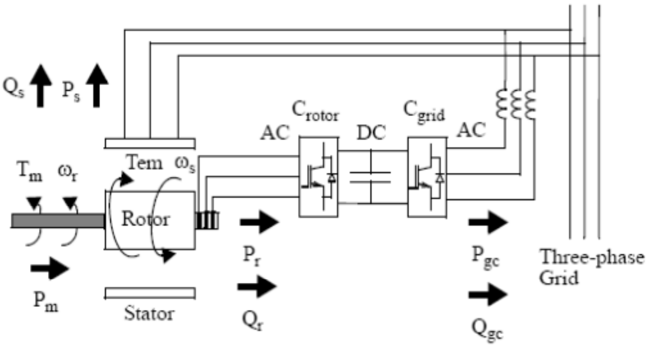

Figure 2. Power Flow Diagram

3. Back-to-Back AC/DC/AC Converter Modeling

Mathematical modeling of converter system is realized by using various types of models, which can be broadly divided into two groups: mathematical functional models and Mathematical physical models (either equation-oriented or graphic-oriented, where graphic-oriented approach is actually based on the same differential equations) as Figure 3. Functional model describes the relationship between the input and output signal of the system in form of mathematical function(s) and hence constituting elements of the system are not modeled separately [3]. Simplicity and fast time-domain simulation are the main advantages of this kind of modeling with the penalty of losing accuracy. This has been a popular approach with regard to DFIG modeling, where simulation of converters has been done based on expected response of controllers rather than actual modeling of Power Electronics devices. In fact, it is assumed that the converters are ideal and the DC-link voltage between them is constant. Consequently, depending on the converter control, a controllable voltage (current) source can be implemented to represent the operation of the rotor-side of the converter in the model. Physical model, on the other hand, models constituting elements of the system separately and also considers interrelationship among different elements within the system, where type and structure of the model is normally dictated by the particular requirements of the analysis, e.g. steady-state, fault studies, etc. Indeed, due to the importance of more realistic production of the behavior of DFIG, it is intended to adopt physical model rather than functional model in order to accurately assess performance of DFIG in the event of fault particularly in determining whether or not the generator will trip following a fault. This paper proposes a graphic-oriented switch-by-switch representation of the back-to-back PWM converters with their modulators for both rotor- and stator-side converters, where both IGBT and reverse diode devices are represented as a two-state resistive switch. The two-state switch can take on two values, RON (close to zero) and ROFF (very high) [6-8].

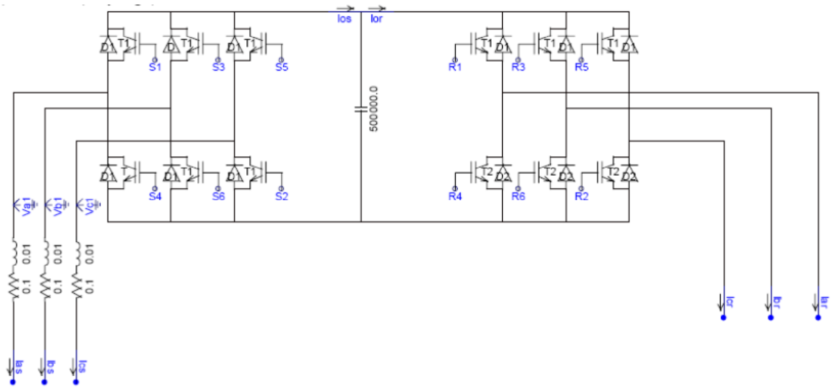

Figure 3. Converter

4. Converter Control System

The back to back PWM converter has two converters, one is connected to rotor side and another is connected to grid side. Control by both converters has been discussed here.

4.1. Rotor Side Converter Control System

The rotor-side converter is used to control the wind turbine output power and the voltage measured at the grid terminals. The power is controlled in order to follow a pre-defined power-speed characteristic, named tracking characteristic, as Figure 4.

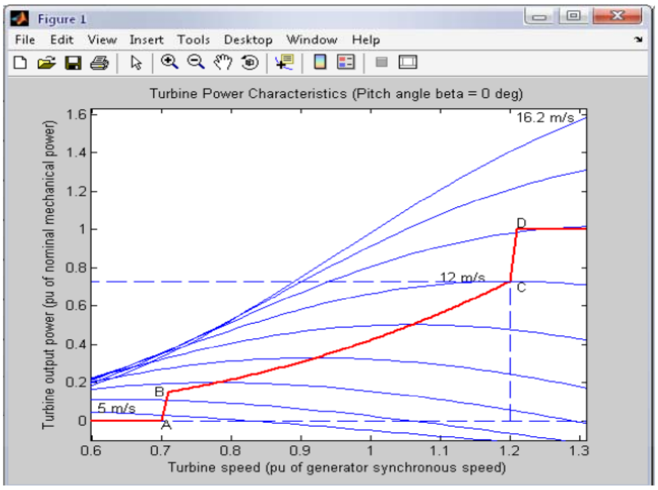

Figure 4. Turbin Power Characteristics

This characteristic is illustrated by the ABCD curve superimposed to the mechanical power characteristics of the turbine obtained at different wind speeds. The actual speed of the turbine ωr is measured and the corresponding mechanical power of the tracking characteristic is used as the reference power for the power control loop. The tracking characteristic is defined by four points: A, B, C and D. From zero speed to speed of point A the reference power is zero. Between point A and point B the tracking characteristic is a straight line. Between point B and point C the tracking characteristic is the locus of the maximum power of the turbine (maxima of the turbine power vs turbine speed curves), as Figure 5. The tracking characteristic is a straight line from point C and point D. The power at point D is one per unit. Beyond point D the reference power is a constant equal to one per unit.

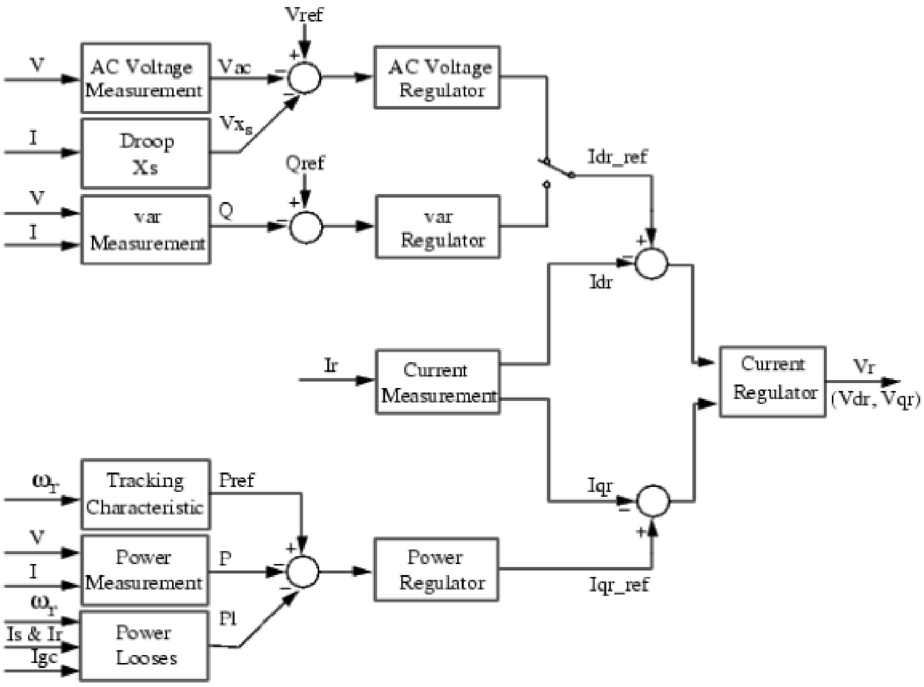

Figure 5. Grid Side Converter Control

4.2. Wind Turbine Driven Isolated Induction Generator Model Simulation in SIMULINK

Operation of Induction Generators (IG) Driven by Variable-Pitch Wind Turbines. A wind farm consisting of six 1.5-MW wind turbines is connected to a 25-kV distribution system exports power to a 120-kV grid through a 25-km 25-kV feeder. The 9-MW wind farm is simulated by three pairs of 1.5MW wind-turbines. Wind turbines use squirrel-cage induction generators (IG).

The stator winding is connected directly to the 60 Hz grid and the rotor is driven by a variable pitch wind turbine. The pitch angle is controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed (9 m/s). In order to generate power the IG speed must be slightly above the synchronous speed. Speed varies approximately between 1pu at no load and 1.005 pu at full load. Each wind turbine has a protection system monitoring voltage, current and machine speed. This simulation is shown as Figure 6, and the detailed Simulink block diagram of the wind turbine is shown in Figure 7.

4.3. Output Characteristics

Turbine response to a change in wind speed. We Started simulation and observed the signals on the "Wind Turbines" scope monitoring active and reactive power, generator speed, wind speed and pitch angle for each turbine.

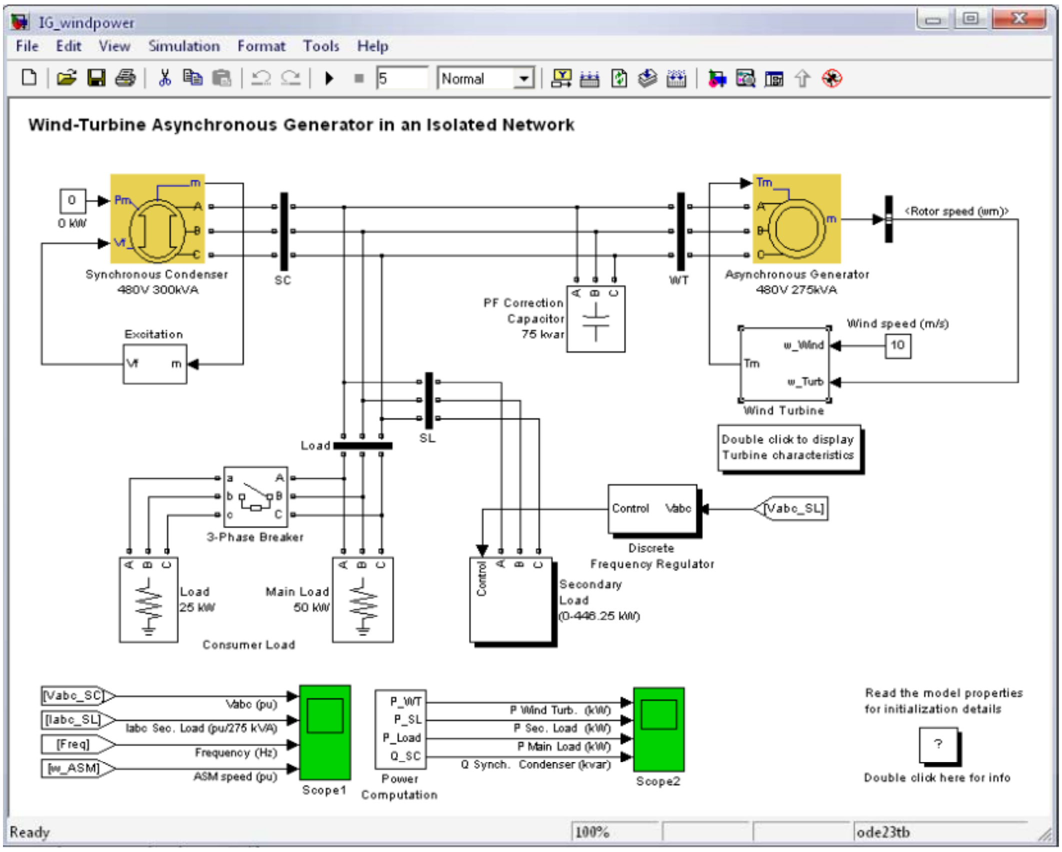

Figure 6. Simulink Power Block diagram

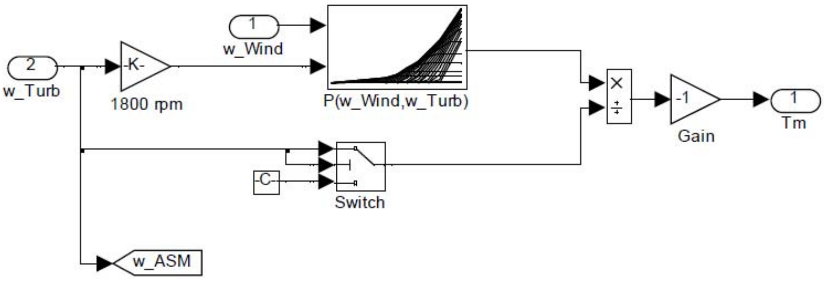

Figure 7. Wind Turbine Simulink Block Diagram

For each pair of turbine the generated active power starts increasing smoothly (together with the wind speed) to reach its rated value of 3MW in approximately 8s. Over that time frame the turbine speed will have increased from 1.0028pu to 1.0047pu. Initially, the pitch angle of the turbine blades is zero degree. When the output power exceeds 3MW, the pitch angle is increased from 0 deg to 8 deg in order to bring output power back to its nominal value. Observe that the absorbed reactive power increases as the generated active power increases. At nominal power, each pair of wind turbine absorbs 1.47Mvar. For a 11m/s wind speed, the total exported power measured at the B25 bus is 9 MW and the statcom maintains voltage at 0.984pu by generating var. The characteristics of the voltage and current are shown in Figure 8, and the active power of wind turbine, loads and reactive power of synchronous condenser is shown in Figure 9.

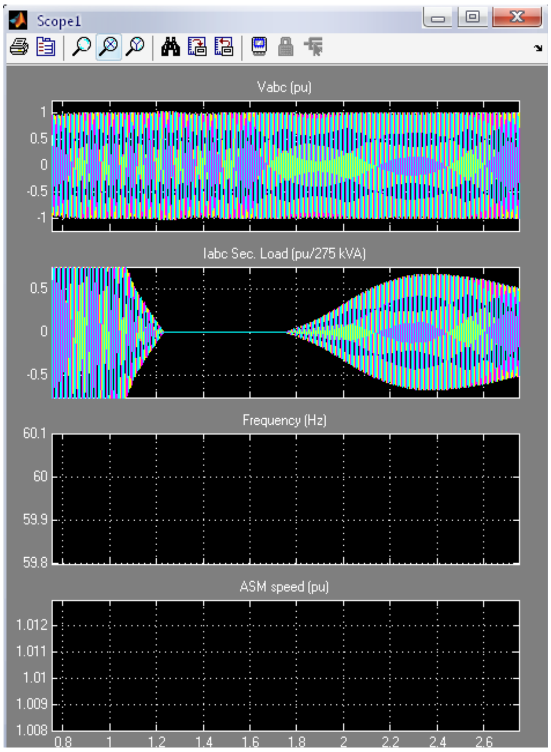

Figure 8. Voltage and Current Characteristic

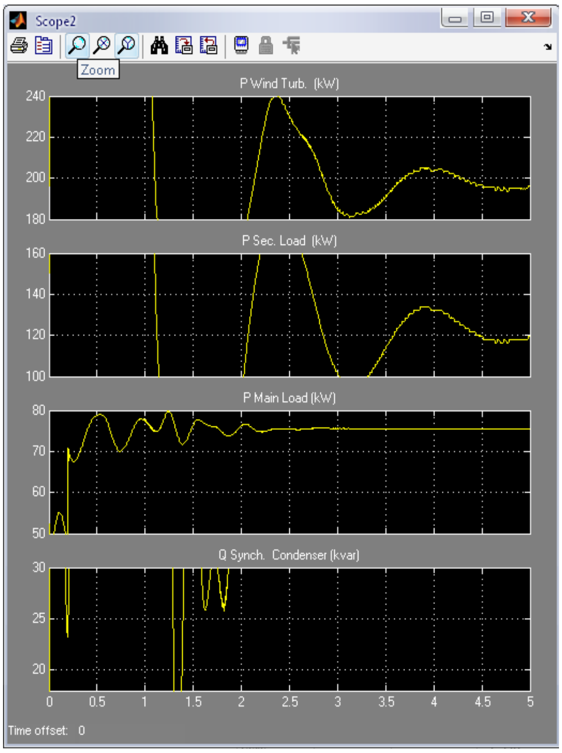

Figure 9. Active Power of Wind Turbine, Loads and Reactive Power of Synchronous Condenser

5. Conclusion

Simulation of a wind turbine driven isolated induction Generator is used which connected to grid side and has better control. The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid-side converter (GSC) keeps the voltage of the DC-link constant. The model is a discrete-time version of the wind turbine doubly-fed induction generator (phasor type) of Matlab/SimPowerSystems. When there is a fault (single phase to ground fault) on the system, the protection system in consideration gives a trip signal to the system. The faults can occur when wind speed decreases to a low value or it has persistent fluctuations.

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