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Harnessing of wind power in the present era system

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Abstract— This paper deals with the harnessing of the wind power in the present era system with the introduction of DFIG. The studied system here is a variable speed wind generation system based on DFIG which uses the rotor side converter and grid side converter which keeps the dc link voltage constant. Both the converters are overloaded temporarily so that the DFIG provides a considerable contribution to grid voltage during short circuit conditions. This report includes 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.

Index Terms— DFIG, GSC, PWM firing Scheme, RSC, Simulink, Tracking Characteristic, Tolerance band control.

1 Introduction

Penetration of high wind power, in recent years, has made it necessary to introduce new practices. For example, grid codes are being revised to ensure that wind turbines would contribute to the control of voltage and frequency and also to stay connected to the host network following a disturbance.

In response to the new grid code requirements, several DFIG models have been suggested recently, including the full-model which is a 5th order model. These models use quadrature and direct components of rotor voltage in an appropriate reference frame to provide fast regulation of voltage. The 3rd order model of DFIG which uses a rotor current, not a rotor voltage as control parameter can also be applied to provide very fast regulation of instantaneous currents with the penalty of losing accuracy. Apart from that, the 3rd order model can be achieved by neglecting the rate of change of stator flux linkage (transient stability model), given rotor voltage as control parameter. Additionally, in order to model back-to back PWM converters, in the simplest scenario, it is assumed that the converters are ideal and the DC-link voltage between the converters 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. However, in reality DC-link voltage does not keep constant but starts increasing during fault condition. Therefore, based on the above assumption it would not be possible to determine whether or not the DFIG will actually trip following a fault.

In a more detailed approach, actual converter representation with PWM-averaged model has been proposed, where the switch network is replaced by average circuit model, on which all the switching elements are separated from the remainder of network and incorporated into a switch network, containing all the switching elements. However, the proposed model neglects high frequency effects of the PWM firing scheme and therefore it is not possible to accurately determine DC-link voltage in the event of fault. A switch-by-switch representation of the back-to-back PWM converters with their associated modulators for both rotor- and stator-side Converters has also been proposed. Tolerance-band (hysteresis) control has been deployed. However, hysteresis controller has two main disadvantages: firstly, the switching frequency does not remain constant but varies along the AC current waveform and secondly due to the roughness and randomness of the operation, protection of the converter is difficult. The latter will be of more significance when assessing performance of the system under fault condition.

Power quality is actually an important aspect in integrating wind power plants to grids. This is even more relevant since grids are now dealing with a continuous increase of non-linear loads such as switching power supplies and large AC drives directly connected to the network. By now only very few researchers have addressed the issue of making use of the built-in converters to compensate harmonics from non-linear loads and enhance grid power quality. In, the current of a non-linear load connected to the network is measured, and the rotor-side converter is used to cancel the harmonics injected in the grid. Compensating harmonic currents are injected in the generator by the rotor-side converter as well as extra reactive power to support the grid. It is not clear what are the long term consequences of using the DFIG for harmonic and reactive power compensation. some researchers believe that

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the DFIG should be used only for the purpose for which it has been installed, i.e., supplying active power only . This paper extends the concept of grid connected doubly fed induction generator .

The actual implementation of the DFIG using converters raises additional issues of harmonics. The filter is used to eliminate these harmonics.

The above literature does not deal with the modelling of DFIG system using simulink. In this work, an attempt is made to model and simulate the DFIG system using Simulink.

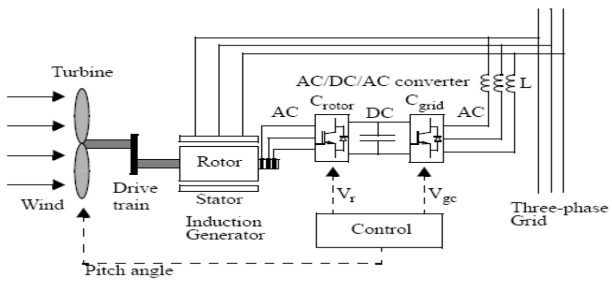

Fig 1: Schematic Diagram of DFIG

2 Problem Formulation

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. 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.
The mechanical power and the stator electric power output are computed as follows:

$$P_r = T_m * \omega_r$$

$$P_s = T_{em} * \omega_s$$

For a loss less generator the mechanical equation is:

$$J \frac{d\omega_r}{dt} = T_m - T_{em}$$

In steady-state at fixed speed for a loss less generator

$T_m = T_{em}$ and $P_m = P_s + P_r$

and It follows that:

$$P_r = P_m - P_s = T_m \omega_r - T_{em} \omega_s = -sP_s$$

Where

$s = (\omega_s - \omega_r)/\omega_s$ is defined as the slip of the generator.

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 stator side 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.

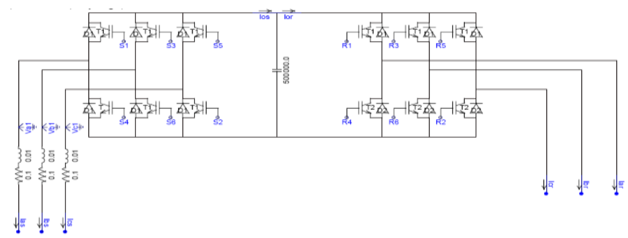
Fig 2: Back to Back AC/DC/AC Converter modeling

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. 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.

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3 Simulation Results

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. 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.

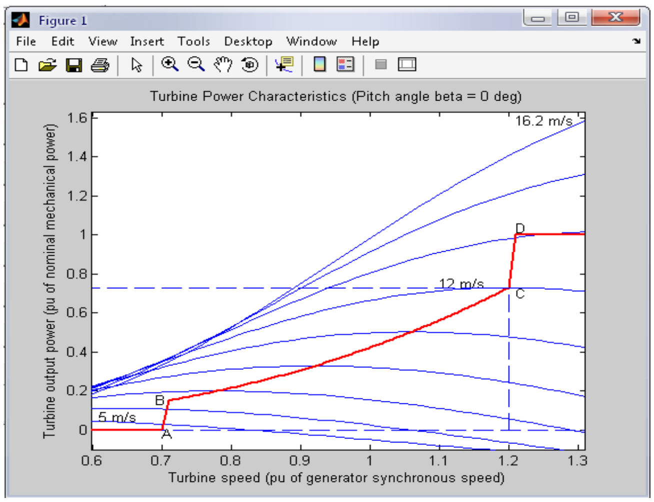

Fig 3a: Tracking Characteristics of a turbine Power

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.

For the rotor-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with air-gap flux. The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristic. A Proportional-Integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is the reference rotor current Iqr_ref that must be injected in the rotor by converter rotor. This is the current component that produces the electromagnetic torque Tem. The actual Iqr component is compared to Iqr_ref and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage Vqr generated by rotor. The current regulator is assisted by feed forward terms which predict Vqr. The voltage at grid terminals is controlled by the reactive power generated or absorbed by the converter rotor. The reactive power is exchanged between rotor and the grid, through the generator. In the exchange process the generator absorbs reactive power to supply its mutual and leakage inductances. The excess of reactive power is sent to the grid or to rotor.

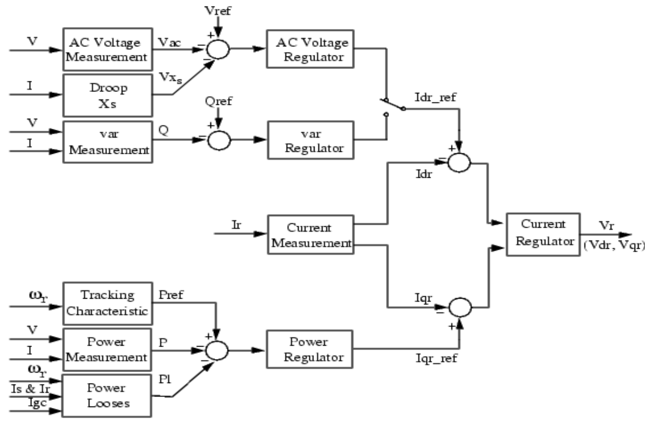

Fig 3b: Modeling of Rotor Side Converter (RSC)

The Grid side converter is used to regulate the voltage of the DC bus capacitor. For the grid-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of grid voltage. This controller consists of:

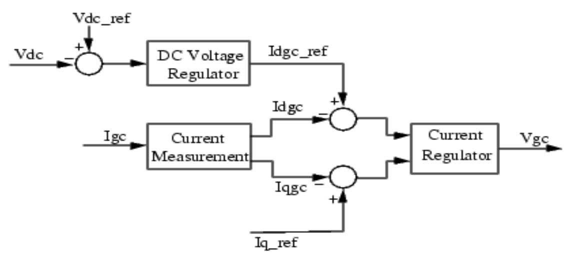

Fig 3c: Modeling of Grid Side Converter (GSC)

1. A measurement system measuring the d and q components of AC currents to be controlled as well as the DC voltage Vdc.
2. An outer regulation loop consisting of a DC voltage Regulator.
3. An inner current regulation loop consisting of a current Regulator.

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 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 1 pu at no load and 1.005 pu at full load. Each wind turbine has a protection system monitoring voltage, current and machine speed.

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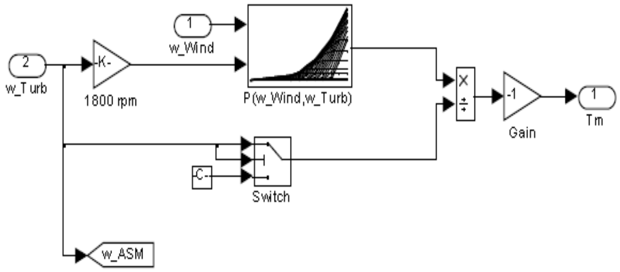

Fig 3d: Modeling of Wind Turbine

This is the Simulink diagram for a doubly fed induction generator connected to grid side with wind turbine protection schemes involved for protection from single phase faults and ground faults. The system is connected to a 120 KV, 3 phase source which is connected to a 9MW wind farm (6 of 1.5 MW each) via. Step down transformers, fault protection and pi-transmission line. The wind-turbine model is a phasor model that allows transient stability type studies with long simulation times. In this demo, the system is observed during 50 s.

The three sequence components are computed as follows.

$$V_1=1/3\,(V_a+aV_b+a^2v_b)$$

$$V_2=1/3(V_a+a^2V_b+aV_c)$$

$$V_0=1/3(V_a+V_b+V_c)$$

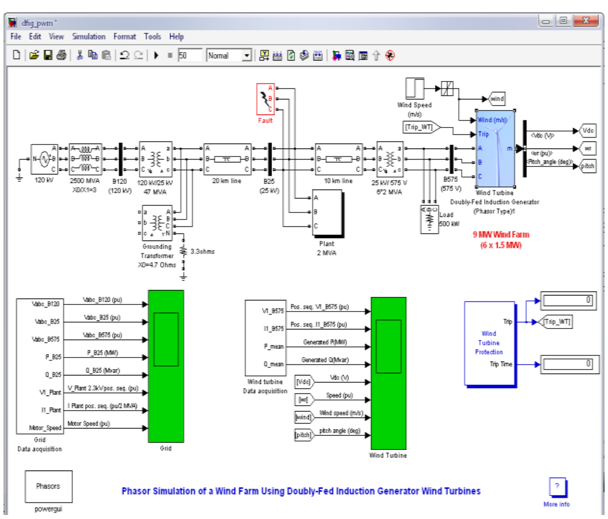

Fig 3e: Wind Turbine driven generator model

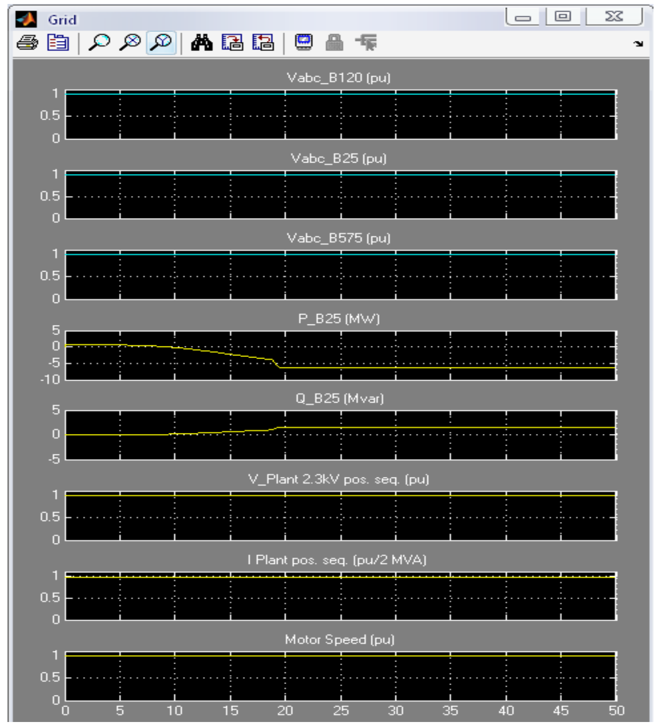

Fig 3f: Change in voltage response to a change in wind speed

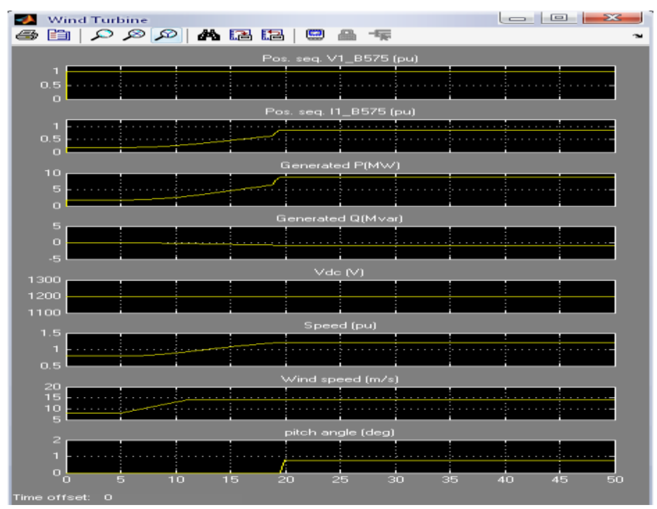

Fig 3g: Turbine response to a change in wind speed

4 Conclusion

The model is a discrete-time version of the Wind Turbine Doubly-Fed Induction Generator (Phasor Type) of Matlab/SimPowerSystems. Here we also took the protection system in consideration which gives a trip signal to the system when there is a fault (single phase to ground fault) on the system. The faults can occur when wind speed decreases to a low value or it has persistent fluctuations. The DFIG is able to provide a considerable contribution to grid voltage support during short circuit periods. Considering the results it can be

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said that doubly fed induction generator proved to be more reliable and stable system when connected to grid side with the proper converter control systems.

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