**UNIVERSITY OF ENGINEERING AND TECHNOLOGY**

**MSC. THESIS TOPIC PROPOSAL**

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**Name of Student:**

**Registration No:**

**Registration Date:**

**PART TIME/ FULL TIME:**

**Supervisor**

**[]**

**Department of Electrical Engineering**

**University of Engineering and Technology**

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**Research Title**

**Problem Statement**

This project investigates the modeling and vector control of the Grid-connected Doubly Fed Induction Generator, and the associated back-to-back converters in dq reference frame. The study encompasses system losses, efficiency, optimum reactive power sourcing and the reduction of harmonics via improved PWM schemes and line filtering.

**Objectives and Aims**

The Induction Machine’s characteristic electrodynamic equations must be used to build the equivalent Induction Machine Simulation model in dq reference frame. Likewise, the mathematical relations of Grid Side Converter Control and Rotor Side Converter control must be modeled using feedback controllers, instead of using discrete circuit components for the back-to-back VSCs. The converter controls regulate real power and reactive power sent to the grid through output voltages of the converters. The magnitude, frequency, and angle of the voltage source converters must be controlled through vector control scheme. This vector control scheme must be tested by monitoring the system transient response during different stimuli; and comparing the steady state output against the mathematical results.

**Literature Survey**

Fan and Miao [1] have presented analytical models of three phase Induction Machines along with demonstrations to simulate their behavior. Expressing the EMFs phase by phase leads to the use of phase-coupled and time varying inductances. They used Park’s transformation to develop analytical models based on a dq rotating reference frame. The resulting space vector models have a much simpler form; and the dq-axis inductances are decoupled and constant. They have also developed vector control plant models for the Grid Side Converter Control and Rotor Side Converter Control.

Pena, Clare and Asher [2] have presented a variable speed doubly fed induction generator driven from a wind turbine and supplying an isolated load. Two back-to-back PWM VSCs allowed sub- and super-synchronous operation with low distortion currents. An auxiliary load was connected in parallel with the main load, and the auxiliary power was controlled to allow the DFIG to track the optimal wind turbine speed. Stator-orientated vector control scheme resulted in constant load voltage and frequency for variations in load and wind speed.

**Methodology**

First, a complex vector-based per unit model will be built to demonstrate the dynamics of the induction machine. The dq0-axis model of the induction generator will be obtained by decomposing the Complex Vectors of ac voltage, current and flux linkage into their corresponding dc d-, q- and 0-axis components. The resulting d-, q- and 0-axis circuits for 3-phase Induction Machine will be used to formulate the corresponding per unit Voltage, Current, Motion and Torque Equations.

Then the control of DFIG converters in the dq-reference frame will be modeled. Rotor Side Converter and Grid Side Converter will be expressed in a reference frame where the stator voltage space vector is aligned with the q-axis. A converter will be considered as a controllable AC voltage source with a controllable frequency, magnitude, and phase angle. For a DFIG, the converter controls regulate real power (or torque) and reactive power (or voltage) sent to the grid through RSC and GSC’s output voltages. Hence, the GSC control and RSC control should be coordinated.

Finally, feedback control blocks will be built, which integrate the converter controls with the DFIG model in the same dq reference frame. The GSC is connected to the Grid via a GSC Filter/ Transformer, whereas the RSC is connected directly to the rotor windings of the DFIG. Moreover, the RSC and GSC are connected through a DC Link Capacitor to keep the DC Link Voltage constant. The dynamics of these interconnections need to be modeled in Matlab/Simulink as well.

**Experimentation**

The input variables of the Induction Machine model include the dq-axis stator voltages, dq-axis rotor voltages and the mechanical torque. The output variables are dq-axis stator currents, dq-axis rotor currents, the electromagnetic torque and the rotor speed of the generator. Since DFIG wind turbines are integrated to the grid, and the grid voltage can be assumed as constant, the stator flux of the DFIG can be assumed as constant. Hence, DFIG control relies on stator flux-oriented reference frame.

The GSC is connected to the grid through a filter and/or a transformer. The converter will be connected to the Point of Common Coupling through an inductor to model this.

If the coupling point voltage is kept constant, real power and reactive power are linearly related to the q-axis and d-axis GSC currents, respectively. The feedback controller will sense these GSC currents, and through feedforward of cross coupling items, the desired converter voltages will be found. The GSC is expected to regulate the AC side voltage/reactive power and to keep the DC-link capacitor voltage constant.

With a constant DC-link voltage, the power through the RSC will be the same as that through the GSC. Therefore, the DC-Link Capacitor realizes power balance of the converters.

Since the RSC is directly connected to the rotor circuit, the rotor currents should be regulated to avoid overcurrents. If the rotor speed varies much slower than the power control, the slip can be assumed constant and only q-axis rotor current must be adjusted to regulate the electromagnetic power. In that sense, the inner current control for a RSC should be the rotor current control, while the outer control should be the real power/ torque and reactive power/ ac voltage control. Assuming that the dynamics of the current control are much faster than the power control, separate control design will be carried out for each.

The output real and reactive power from the stator circuit can be controlled via q-axis rotor current and d-axis rotor current respectively. Hence, from the outer power control, rotor current references will be generated. It is through the inner current control that the rotor current commands will be followed by the rotor currents. Feedback control will be employed to realize the command tracking. After the feedback controllers, feedforward compensation will be added back to generate the desired rotor voltages.

**Experimental Setup**

After the DIG Model is ready, the stator voltage will be impressed to connect the DFIG to the Grid. Since the stator voltage space vector is aligned with the q-axis, the q-axis stator voltage will be constant and the d-axis stator voltage will be zero. To ensure sub-synchronous operation, the rotor speed and slip will be fixed as well.

The DFIG will be operated in steady state by setting the desired power references for RSC/ GSC active and reactive powers. Also the initial DC Link Voltage Reference will be set.

The RSC real power reference will be set according to maximum power point tracking look up table, whereas the RSC reactive power reference will be zero. This ensures that the RSC delivers real power to the DFIG but does not deliver reactive power.

The system transient behavior will be investigated by step changes in the DC-Link Voltage Reference, wind velocity and the main load supplied by the generator.

**Results Expected and Method of Analysis**

After all the parameters have been entered, the simulation will be run to probe the electrodynamic behavior of the DFIG. In steady state, the results must match with the mathematical model results.

GSC control must keep the DC Link Capacitor Voltage constant at the initial reference value. GSC must draw real power but no reactive power, hence iqg must be positive and idg must be zero.

The GSC must not consume or deliver any reactive power because its reference is zero. GSC must draw real power from the Induction Machine and deliver it to the RSC, which delivers it back to the Induction Machine. These power measurements will be compared with mathematical formulae, and their magnitudes must be equal.

If the model is verified by comparing with mathematical formulas, the system transient behavior will be investigated by step changes in the DC-Link Voltage Reference, wind velocity and the main load supplied by the generator. Again, the results will be compared with mathematical equations to verify the system behavior.

**References**

[1] L. Fan and Z. Miao, *Modeling and Analysis of Doubly Fed Induction Generator Wind Energy Systems*. Academic Press, 2015.

[2] R. Pena, J. Clare and G. Asher, *A doubly fed induction generator using back-to-back PWM converters supplying an isolated load from a variable speed wind turbine*.  IEEE Proceedings - Electric Power Applications, October 1996. Available: IEEE Explore.