Wind turbine model and control

Wind turbines are becoming more prevalent and their potential as a primary or simply as a complementary source of electric energy is becoming increasingly desirable. Wind turbines can also be designed to aid in network stabilization, further increasing their use. This article will present the modeling and control of a Fully Rated Converter Wind Turbine to achieve those goals.

Rapports of depleting oil resources cause instability on the energy market which at the consumer end usually ends up in increasing costs. Apart from the financial benefits of alternative sources of energy like solar-, hydro- and wind-power there's also the environmental encouragement. Wind power is one of the alternative energy sources experiencing impressive yearly growth and the trends show continuing investments being made in wind power.

Wind energy can be harnessed using several different principles, however the most commercially prevalent way of converting the kinetic energy in wind to electric energy is using a horizontal-axis wind turbine. This means that the blades are rotating on an axis which is mounted in parallel to the horizon.

The highest amount of kinetic energy from the wind that the wind turbine can convert is limited by Betz limit. The limit determines a theoretical power coefficient for maximum extracted power from the wind. The limit is 59.3% of the wind energy. Due to the non-ideal wind flow and wind turbine material and construction, modern wind turbines have power coefficients ranging from 0.25 to 0.45.

The power coefficient is at its maximum at a certain velocity of the wind turbine blade-tips relative to the velocity of the surrounding wind. This indicates that if the wind turbine is designed to operate at a single speed, it will have inherently lower power conversion rates as the wind velocity is in its nature non-constant. The ability to control the turbine blade-tips will facile keeping a high power coefficient.

There are several designs for wind turbines, however the most common one is the three bladed turbines designed to face the wind direction. Thereafter they are constructed depending on whether they will be operating at varying-speeds or fixed-speeds. As the wind turbines operating during variable speeds is the most favorable from an energy extraction point of view this is the design that will be modeled.

A common variable speed wind turbine is the Fully Rated Converter (FRC) Wind Turbine. The name indicates that the entire electric energy generated from the rotating blades will be converted and fed out to the network. The FRC architecture is oriented as follows; rotor blades, Synchronous Generator (SG), AC/DC rectifier (C1), DC link and DC/AC inverter (C2). Depending on the design, there can also be a gearbox connecting the rotor blades and the SG.

The control strategy for the FRC strives to extract as much power as possible from the wind using data comparing generated power per wind speed per generator speed. The curve is expressed as optimal torque per generator speed and results in a current reference for the regulator controlling the converter which controls generator torque; C1. The control strategy for C2 is to keep a stable value on the DC link via feeding active power to the network and to feed or draw reactive power from the network to control the grid voltage in order to keep it stable on its nominal value.

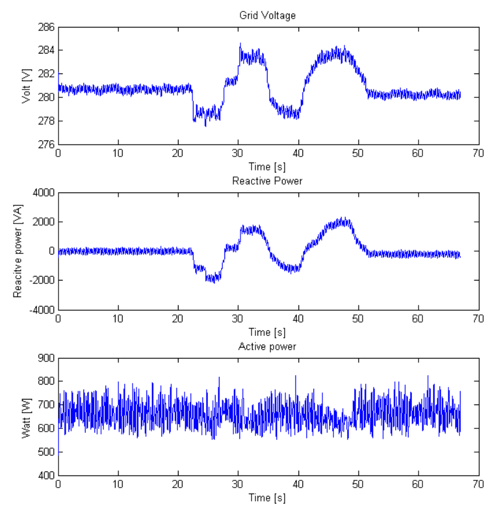
The project described in this article does however use a manually set generator torque value as the intention of the project was firstly to construct a working model running from a Digital Signal Processor (DSP).

The DSP controls converter C1 and C2 using regulators in order to comply with the control strategy. This is done using a custom algorithm written in C-code and assembly. The algorithm is set to run from the flash memory of the DSP making it run independently of both external processors and memory.

The principle for the embedded system is that at each sample instance there is an interrupt routine in which the AD converter on the DSP is calibrated, its values are used for calculations and setting of new reference values and these values are fed to the regulators controlling the converters.

The model is tested using a DC motor to rotate the axis of the SG in the wind turbine model; acting as the turbine blades propelled by wind. The network is simulated using a SG connected to C2 to be able to simulate variations from the nominal voltage.

The experiment is conducted so that the wind turbine model has to generate active power to the grid while trying to stabilize the voltage variations.



Graph 1. Results with disturbance stabilization.

The graph (Graph 1) shows that the wind turbine model is able to generate reactive power proportional to the voltage variation while maintaining active power generation. Without the regulator controlling the reactive power from wind turbine the reactive power will be inversely proportional to the voltage variations.

Complete rapport: Development of Wind Power Laboratory Setup.

Caspar Ralvenius 2011