Green Future – Simulations models for wind power plant analysis

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Abstract: The paper is proving insights into wind power plants modeling and analyzing, focusing on doubly fed induction generator-DFIG as the best solution for mid power range, providing the best power output over the variety of wind power ranges. Firstly we present the common technologies utilized for wind power plants, focusing on DFIG system. Afterwards Wind data analysis is described with an example for area with ideal wind speeds through year in Lower Carinthia, Austria. The wind data is sorted and extrapolated to needed values using Matlab script. In last part wind models are used to analyze energy production in typical operating cases: wind velocity change, voltage drop and so on. The model used in Simulink is part of Simulink PowerSystems library, but is has been modified to fit into our analysis with parameters of our systems.

Key-Words: Wind Power Plants, Models, Matlab, Simulink, Wind Data Analysis

1 Introduction

1.1 Wind Power Plants overview

Our energy demand is increasing from year to year. The challenge is to provide quality energy, without harming the environment and enabling sustainable development. In order to achieve our goals, renewable energy will have to become important part of our lives.

Today various wind turbines, powering different generators (induction generator with squirrel cage, doubly-fed induction generator, synchronous generator) are present on the market.

The installed capacity of Wind Power Plants is increasing in Europe; therefore this paper is dealing with very hot in the industry. Wind power plants are important part of our energy system and in order to design and implement them, simulation is of the crucial importance, gaining more and more popularity.

Different types of power plants will be analysed, focusing on most widely used ones in popular simulations programs like Simulink and PLECS. Models parameters will be carefully described, afterwards our goal would be to simulate typical operational states each model is enabling us and log the results. The results will be then compared and described.

1.2 Generators

The type of generator, being using in certain type of wind power plant is dependent on various parameters. The most important ones being power, control solutions and price of inverter. In case of smaller wind system, we decide more often than not for induction machine with squirrel cage rotor, mainly due to its simplicity, here the control system is controlling just the angle of blades β. This system is used for smaller rotating speeds, also the power curves for different wind speeds have to be close together, the overall efficiency of the turbine is relatively small.

1.3 Doubly-fed induction generator

The operation of doubly-fed induction machine is possible in all four quadrants and is mainly limited with converter specifications. The operation of DFIG is not limited to constant speed; it is possible in whole torque/speed area diagram. Current and frequency limits of operation are given by the converter, which has to be designed for specific operation of DFIG.

The phase sequence of rotor current is changing and can be above or below synchronism; this is given by rotor frequency, which is dependent on speed of the system. [3].

The rotor voltage in DFIG system can be varied in order to achieve desired slip or torque. The energy flow is being changed, depending on the slip value; rotor is acting as an energy source or a load. If stator is connected directly to the grid, then its flux is dependable on voltage grid and frequency. We have to take into account, that various DFIG configurations are existing on the market.

DFIG is able to operate at optimal point on operation curve, where we have the maximum output power for certain wind speed. It consists of two basic operation modes: sub and super synchronous, in sub synchronous operation the energy is flowing from stator into rotor, rotor is consuming the energy (positive rotor power). Even thought that a fraction of energy is being consumed, the total energy produced is overall still larger, due to increased stator power. In super-synchronous operation also the rotor supplies the energy into the grid, which results in lowering the turbine speed and proves to be especially useful for large wind velocities [4].

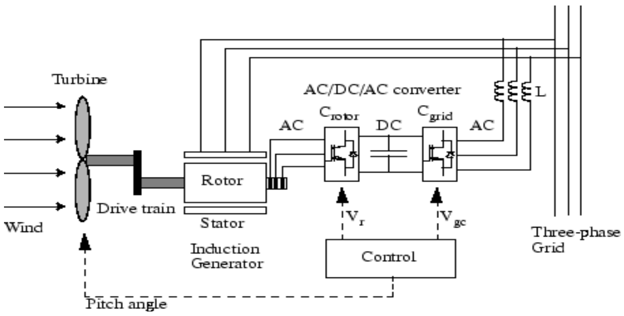

Figure 1: DFIG System

2 Wind Data Analysis

2.1 Wind velocity profile

Firstly we will find areas with suitable wind speed, which have to be constant through year and stable without frequent occurence of wind gusts. Secondly the metrological climate data considering wind will be gathered and analysed with script written in Matlab. It is important to underscore the fact, that wind velocity needs to be calculated at height of wind tower with the following equation:

$$v_2 = v_1 \times (\frac{z_2}{z_2})^{\alpha}$$

- V_1 = Velocity at height Z_1
- V_2 = Velocity at height Z_2
- Z_1 = Height 1 (lower height)
- Z_2 = Height 2 (upper height)
- α = wind shear exponent

- To continue with, wind data needs to be sorted by value from maximum to minimum and converted to rated value, for which the highest speed in our case was taken. This is necessary in order to choose correct wind turbine in aspect of power, keeping in mind that it has to be adapted to average wind speed through year or also very commonly to median speed, which is present at least 70% of the yearly interval. This data is then utilized as a basis to dimension wind power system with other parameters also being considered, as connection to electrical grid (power transfer and conversion), placement into environment and so on.

2.2 Location of analysis: Villach Alps

The wind velocity data for Weather station Villacher Alpe has been analysed. The wind table attached at the end of article is showing the wind velocity for every month.

The graph showing average wind speed per year has been plotted in order to represent data in graphical form. It can be deducted that two periods with higher wind speeds are present, first one from January until April and the second from September until December, which together cover 2/3 of the year. From April until August wind speed tends to be lower, but still exceeds the value of 4 m/s.

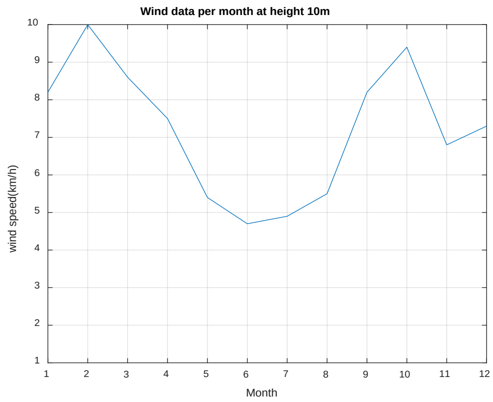

Figure 2: Wind data for observed weather station

The first graph at page above depicts wind speed at weather station “Villacher Alpe” at typical measurement height 10 m eters. Our wind tower will be significantly higher, at height of 65 m; therefore the speed needs to be transformed in order to match with sufficient height.

Using extrapolation the wind speed at measurement point has been calculated to height of the tower using so called power law, which is based on theoretical and empirical background. Other possibility would be to use low law, but we decided for the first one, being the most common in practical research. Both approaches are subject to uncertainty caused by the variable, complex nature of turbulent flows. (Manwell, J. F., Wind Energy Explained, Wiley, 2003).

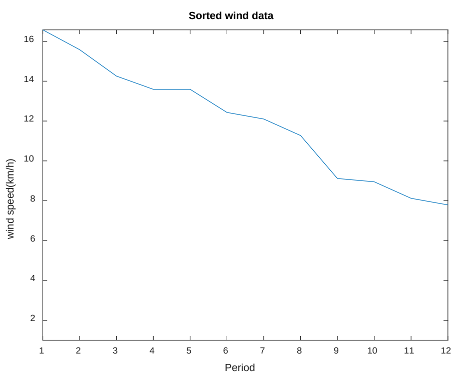

Figure 3: Sorted wind data

Afterwards when power range is chosen, bearing in mind importance of turn on and cut-off wind speed according to wind climate data given, system which meets our requirements is chosen. More often than not turbines and wind power systems as a whole, especially in aspect of controlling parameters need to be adapted for certain geographical area.

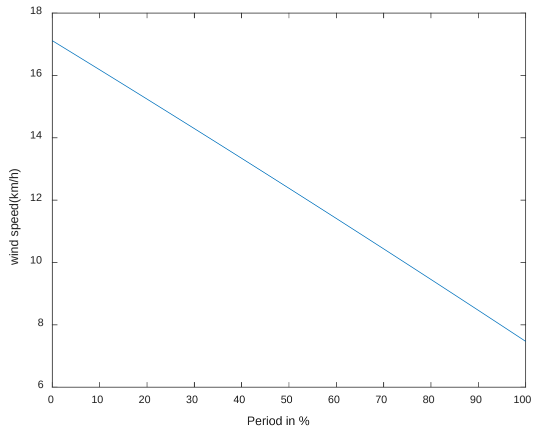

Figure 4: Wind speed per year in %

Analysis in our case has been concluded in parallel to wind power plants models simulation and their verification in order to link them to our applied part of the paper. Therefore it has been found, that for mountain areas in Carinthia, with high wind potential the power range from 1 to 3 MW is suitable.
Systems in this power range supply their rated power at wind velocity from 9 m/s to 13 m/s, which conditions are fulfilled in areas chosen. On the other hand minimum wind speed required for operation is about 3-4 m/s, and cut-off wind speed 25 m /s. Both parameters are suitable for Alpine area around Villach, according to climate data gathered; wind speed rarely exceeds 20 m/s.

Two systems that meet our requirements have been chosen for analysis:

- General Electric 1.5 sled
- Vestas V63

3 Simulink DFIG Model

The model of turbine and DFIG in the form of block schemes is located in Renewable Energy library. Rotor winding are connected to the grid through slip rings, stator on the other hand is directly connected. The converter, using IGBTs is also implemented.

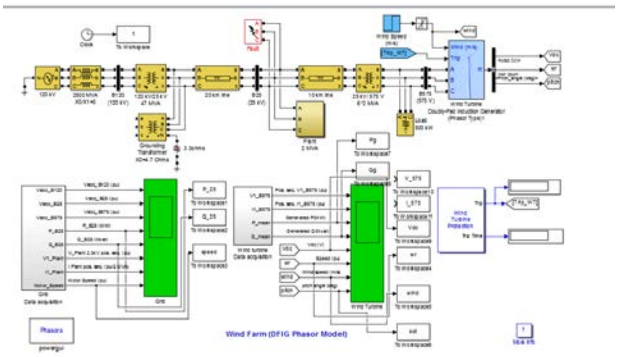

Figure 5: Simulink model of DFIG plant

The topology above presents the power plant system of 9 M W total power, consisting of 6 turbines, each having the nominal power of 1, 5 MW. They are connected to distribution grid, which is then connected with 20 km long transmission line to transmission electrical grid. Also the 2 M VA load is connected to distribution grid. The current model is phasor type model, meant for stability transient studies with longer time intervals [10].

3.2 Simulation results

Turbine response to change of wind speed

The model has been stimulated with change of wind speed, the response of the system has been then observed. At 5 s econds, the wind speed begun increasing, after time interval of 5 seconds it reaches its maximum value of 15 m/s. Consequently due to change of wind speed, the blade angle is being changed, the turbine speed increases from 0, 8 up to 1, 23 up. The blade angle needs to adjust, to prevent the mechanical power to increase to critical value.

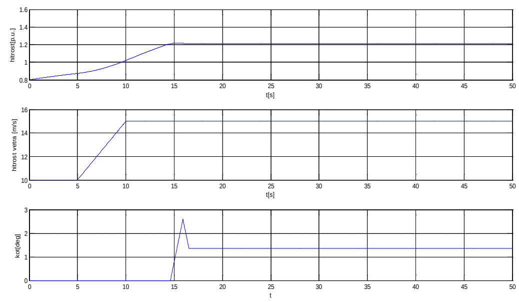

Figure 6: Speed and angle of the turbine

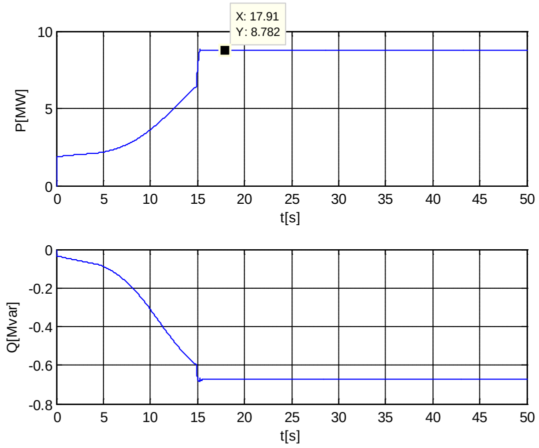

Figure 7: Supplied power to grid

It is seen from the picture above, that when the wind speed has increased, as a results active power produced has become larger. At the time 15 s it becomes close to nominal power and has the value of 8,782 MW. Reactive power has to be supplied from the grid; the bigger quantity is needed when the active power becomes larger. At the rated operational point 0, 68 M var is needed. Voltage is being stable at the whole simulation time at 1 pu.

Results on the one turbine:

The model had the same input with wind velocity change as above, but only one turbine in the system has been observed in order to compare the simulation results later with other simulations performed with different software.

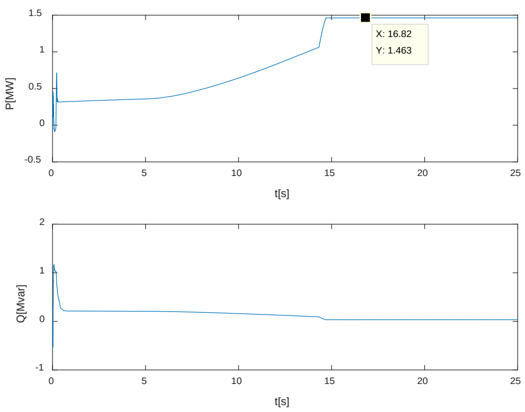

Figure 8: Active and reactive power

3.2.1 Grid Voltage drop

The wind velocity is being constant at 8 m/s, therefore the output power plant power is significantly lower than in case before when it was fixed at rated value. Due to the fact that wind velocity is constant, there is no need for the blade angle to change.

There is a voltage drop in the grid, due to some failure (power plant fails out), this drop is measured at 0, 15 pu and happens at 5 s.

3 PLECS DFIG Model

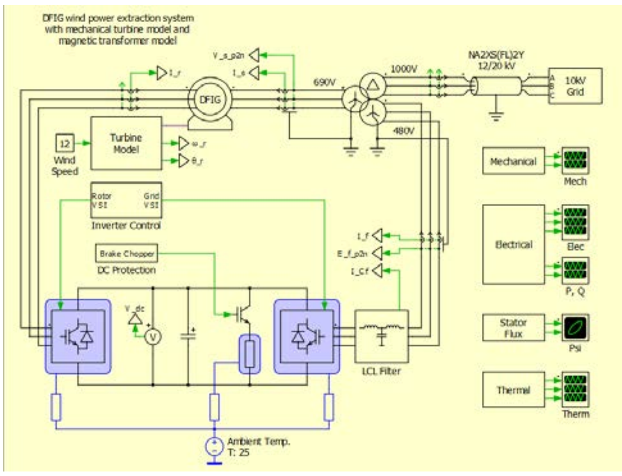

Figure 9: DFIG Model in PLECS

The scheme above shows the DFIG wind power plant model in PLECS simulation program. The stator is directly connected to the grid, rotor needs to be connected through power converter, this supplies the energy to 10 kV voltage grid. In Simulink models, PI representation with concentrated parameters was used to model the transmission line, here it is represented with distributed parameters.

PLECS is highly specialized for power electronics simulation, therefore important part of simulation is Cooling systems of IGBT devices, which is not present in any of Simulink models analysed before. All the electronic devices due to non-ideal switches are impacted with phenomenon called switching losses, power losses due to them will cause high junction temperatures and present potential danger do semiconductor power devices. Our simulation is started at synchronous speed being in synchronism with the grid frequency. At this operational state, the majority of electrical energy will be directly supplied to the grid from the stator side, as it is not necessary to use the converter; therefore no losses on the converter are present. No thermal losses in converter are generated; the only part of energy being lost is resistive losses on the rotor, typical for the induction machine. At t=3 s the turbine speed is increased and we observe the system response to it, system stays stable and continues operating.

As in example done in Simulink, also here grid fault is being simulated. We simulate the short circuit on the 10 kV distribution grid, as in Simulink this is done with controllable voltage source.

The main advantage of this model compared to Simulink models, is its focus on observing damped oscillation between mechanical parts, but on overall Simulink models perform better due to their speed and quality of results.

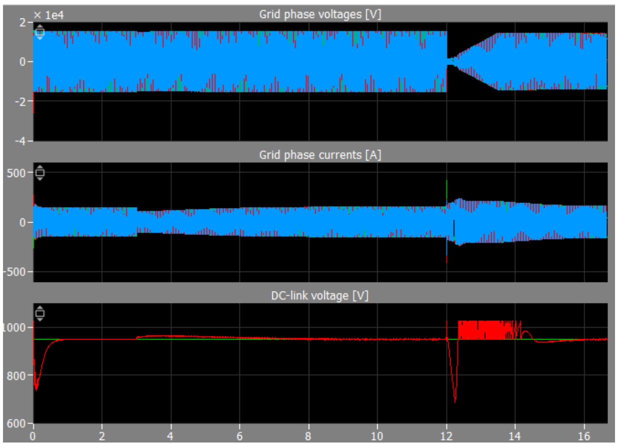

Figure 10: Grid voltage, current and DC-link voltage in PLECS model

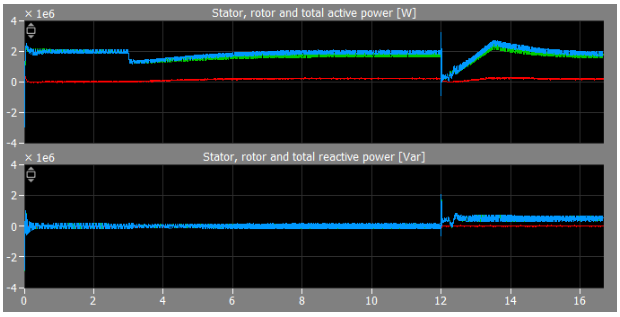

Figure 11: Stator and rotor active and reactive power

4 Conclusion

DFIG system has been analyzed and tested with Simulink and PLECS model. It has been proven, that it is the optimal solution for example location, due to optimal power curves and maximized power output due to various wind velocity range.

Both models represented in this paper are suitable for practical analysis of different DFIG Wind Power systems and should be applied in the phase of constructing wind systems at certain location in order to enable decision makers to better optimize the system, as well as test several operational states before the plant is built.

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