MODEL OF WIND POWER PLANT WITH ASYNCHRONOUS GENERATOR IN SIMULINK PLATFORM

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ABSTRACT

This paper deals with mathematical modelling of wind power plant with asynchronous generator. The modelling procedure is briefly explained, mathematical descriptions and Simulink models of the wind power plant basic parts are shown and the model of the whole system is presented.

1. INTRODUCTION

The connection and the operation of wind power plants produce some problems that are rising partly owing to large changeability of environment conditions, influencing the electrical energy supply from these sources, and partly owing to phenomena that are characteristic for their devices. Therefore, the solving of these problems is absolutely fundamental in term of the ensuring of the electricity quality and also in term of the question of the energy security, which plays very important role in all strategic fields of human activities, at the present time.

To be possible to study phenomena that are connected with wind power plants and with impacts of their operation on the operation of distribution and transmission systems, it is necessary to do, such as in other branches, different computer simulations. For this, it is necessary to create models of all individual parts of simulated system, which consists, in this case, of wind, wind turbine, aerodynamic control, drive train, electric generator, elements of power electronics, transformer, part of the grid with connection point and measuring elements.

2. MATHEMATICAL MODELLING PROCEDURE

The procedure during the mathematical modelling is shown in Figure 1. The basis of any simulation is good knowledge of the system under consideration, because each model rises by the abstraction of real object. During this process the real object is necessarily simplified and some physical phenomena that practically haven’t any impact on its characteristics and behaviour are neglected. The real system is replaced by the mathematical description of phenomena and their interactions on the basis of physical laws. This interpretation can be solved by two approaches, the analytical way of calculation and the way with the use of some numerical method.

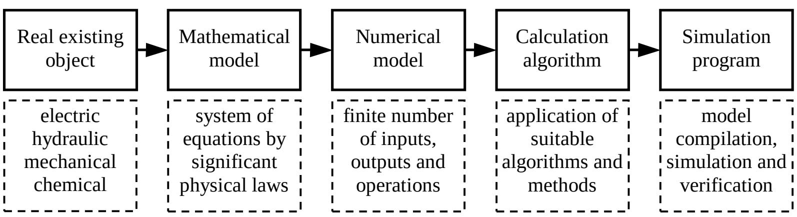

Figure 1 – General procedure of mathematical modelling

Using of the analytical way of solving requires greater range of the equations simplification describing the system and in specific cases, such as some nonlinear equations, it isn’t possible to use this way. On the other hand, this way enables the generalized interpretation of results that may serve to verify the correctness of the numerical way that, in comparison with it, enables the usage of much less simplified mathematical model. Results of this way are always only specific set of solutions for specific values of parameters, initial conditions and input quantities and their accuracy is dependent on the accuracy of these values. The generalized interpretation of these results can be unreliable.

3. MODELS OF BASIC PARTS OF WIND POWER PLANT

To do appropriate calculations, it is necessary to choose suitable algorithms and approximation or integration methods that are consequently use by the simulation software, which must be suitable with respect to requirements of given task. One of tools that are successfully used for the creation of models of different systems in all branches is Simulink tool, which forms an integral part of environment of mathematical program Matlab and which enables to use blocks of basic mathematical functions to creation of practically all more complicated system.

3.1. Model of Wind Turbine

The first part of the studied system is the wind turbine, which is used to conversion of wind kinetic energy to mechanical work. Its description comes from laws of energy and momentum conservation that can be applied in a space, which is limited by flow surfaces. On the basis of relationships for the calculation of these two quantities before and behind the turbine, it is possible to express the value of the axial performance acting on the shaft by this way:

$$P_{tur} = \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot w^3 \cdot c_P , \tag{1}$$

where ρ is the air density, R is the radius of the turbine, w is wind speed and c_P is the performance coefficient, which expresses the relationship between performances of the air flow and of the wind turbine, i.e. the efficiency of the wind turbine, in dependence on the wind speed or on the tip speed ratio of the turbine. From the value of the rotational motion performance, it is possible to determine the value of the torque acting on the shaft like this:

$$M_{tur} = \frac{P_{tur}}{\omega_{tur}} = \frac{1}{2} \cdot \rho \cdot \pi \cdot R^3 \cdot w^2 \cdot c_M , \tag{2}$$

where ω_{tur} is the turbine angular speed, and c_M is the torque coefficient. From these formulas is evident that the instantaneous values of the performance, respectively of the mechanical torque, are dependent on the wind speed very much. On the basis of these equations, it is possible to build the model, which structure is shown in Figure 2, of the wind turbine in Simulink platform.

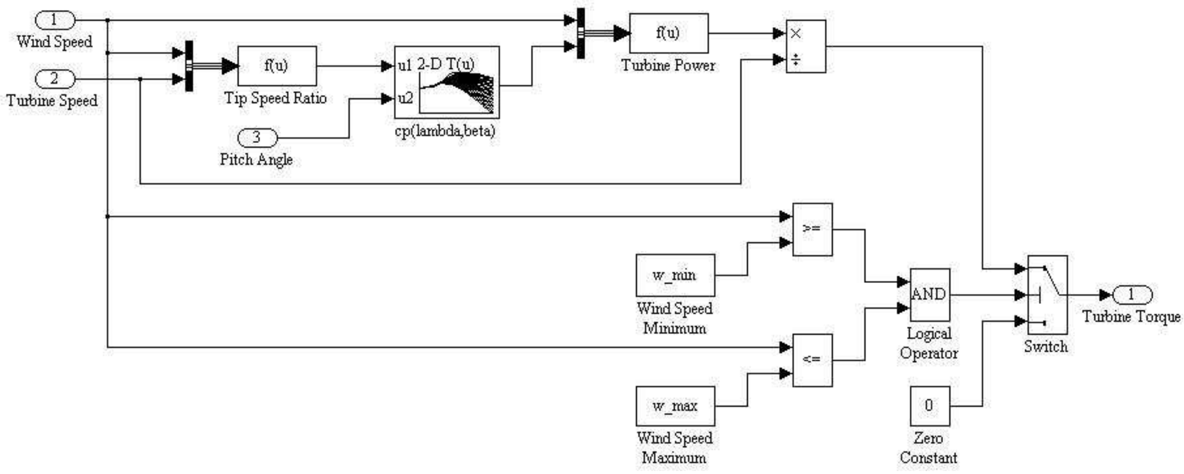

Figure 2 – Model of Wind Turbine in Simulink

The basic parameters of this model that are freely exchangeable in the mask of this block include the rotor radius the air density and wind speed operation limits. Inside this block, curves of performance coefficient are loaded. Before the calculation, the right curve of this coefficient is chosen and the wind speed is compared with operation limits whose violation lead to the simulated shut-down. Inputs of the model are the wind speed, the blades angle and the turbine angular speed. Output quantity is the axial torque, which is transmitted by the drive train to the generator.

3.2. Model of Drive Train

The second part of the wind power plant system is the drive train, which ensures a transmission of the mechanical torque from the turbine to the generator. During its description, it is possible to go from simplified scheme for the attachment of two disks, which is ensured by the flexible shaft. For this mechanical system, supplemented by the value of the gear ratio, it is possible to write, after release of both solids, the next equations that express relationships between end of the shaft:

$$\begin{aligned} M_{tur} &= J_{tur} \cdot \frac{d\omega_{tur}}{dt} + b_e \cdot \left(\omega_{tur} - \frac{\omega_{gen}}{k_p} \right) + k_e \cdot \left(\theta_{tur} - \frac{\theta_{gen}}{k_p} \right) \\ -M_{gen} k_p^2 &= J_{gen} k_p^2 \cdot \frac{d\omega_{gen}}{dt} - b_e \cdot \left(\omega_{tur} k_p - \omega_{gen} \right) - k_e \cdot \left(\theta_{tur} k_p - \theta_{gen} \right) \end{aligned} , \qquad (3)$$

where J_{tur}, J_{gen} are moments of inertia of turbine and generator, k_e is the shaft stiffness, b_e is the shaft damping coefficient and k_p is the gear ratio. From these equations, it is possible to express values of turbine and generator angular speed in dependence of mechanical torques that act on it from the side of the wind turbine and from the side of the electric generator. Then, these formulas form the basis of the model, which is shown in Figure 3, which enables to watching changes in angular speeds caused by changes in mechanical torques from both sides.

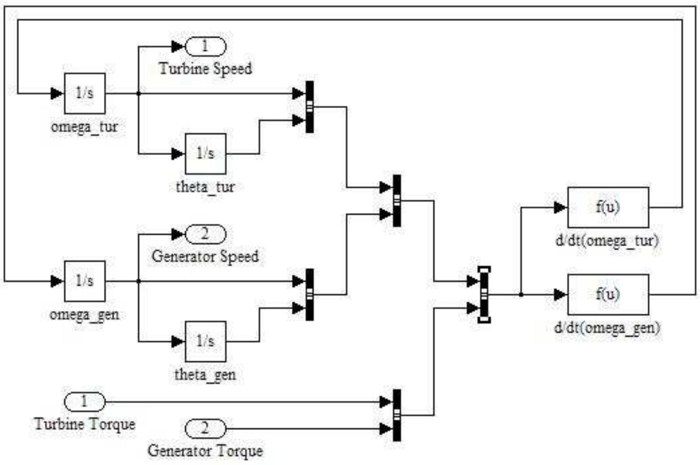

Figure 3 – Model of Drive Train in Simulink

The basic parameters of this model whose values can be freely exchanged in the mask of this created block are the value of shaft stiffness, the damping coefficient, inertia moments of both the turbine and the generator rotor and, of course, also initial conditions. Input quantities are formed by torques acting from both sides and outputs are formed by angular speeds.

3.3. Model of Asynchronous Generator

The third basic part of the studied system is an asynchronous generator with symmetrical three phase stator and rotor winding, which can be depicted as the system of six windings, three stator and three rotor that have mutual inductive coupling among each other. For some simplifications, it is possible to describe this machine by the nonlinear system of differential equations. With using the space phasors method, which works with positions of individual quantities phasors in the complex plane, this system is simplified into two equations, one for stator and one for rotor voltage, whereas all quantities must be expressed in unified coordinates, namely stator or rotor. This mathematical description is consequently simplified also by the division of space phasors into their real and imaginary parts, which causes the conversion of the three phase system to the two phase. Appropriate components of electromagnetic quantities are actually their components for the symmetrical two phase winding, which causes, in the space of the machine, the same working wave as the origin three phase. This conversion can be done using the Park’s transformation, such as for the backward conversion of calculated currents from the two phase to the three phase system. Then, the final form of equations for the calculation of stator and rotor voltages, in the stator coordinates, is the next:

$$\begin{aligned}
u_{S\alpha} &= R_S i_{S\alpha} + L_S \frac{di_{S\alpha}}{dt} + L_m \frac{di_{R\alpha}}{dt} \\
u_{S\beta} &= R_S i_{S\beta} + L_S \frac{di_{S\beta}}{dt} + L_m \frac{di_{R\beta}}{dt} \\
u_{R\alpha} &= R_R i_{R\alpha} + L_R \frac{di_{R\alpha}}{dt} + L_m \frac{di_{S\alpha}}{dt} + p_p \omega_{gen} \left(L_R i_{R\beta} + L_m i_{S\beta} \right) \\
u_{R\beta} &= R_R i_{R\beta} + L_R \frac{di_{R\beta}}{dt} + L_m \frac{di_{S\beta}}{dt} - p_p \omega_{gen} \left(L_R i_{R\alpha} + L_m i_{S\alpha} \right)
\end{aligned}, \qquad (4)$$

where R_S, R_R are stator and rotor resistances, L_S, L_R are stator and rotor inductances, L_m is magnetizing inductance between stator and rotor, p_p is the number of machine poles and ω_{gen} is the angular speed of the generator. From these equations, it is possible to get also the formula for the determination of the inner electromagnetic torque of the machine in the next form:

$$M_{gen} = \frac{3}{2} p_p L_m \left(i_{S\beta} \cdot i_{R\alpha} - i_{S\alpha} \cdot i_{R\beta} \right) \qquad (5)$$

This value is dependent, on the generator angular speed, which is hidden in values of rotor currents components. On the basis of these equations, the simplified model of the asynchronous generator with wound rotor whose Simulink structure is shown in Figure 4, is built. This model enables to watching curves of individual phase currents or the inner electromagnetic torque in dependence on stator supply voltages and on the angular speed of the generator.

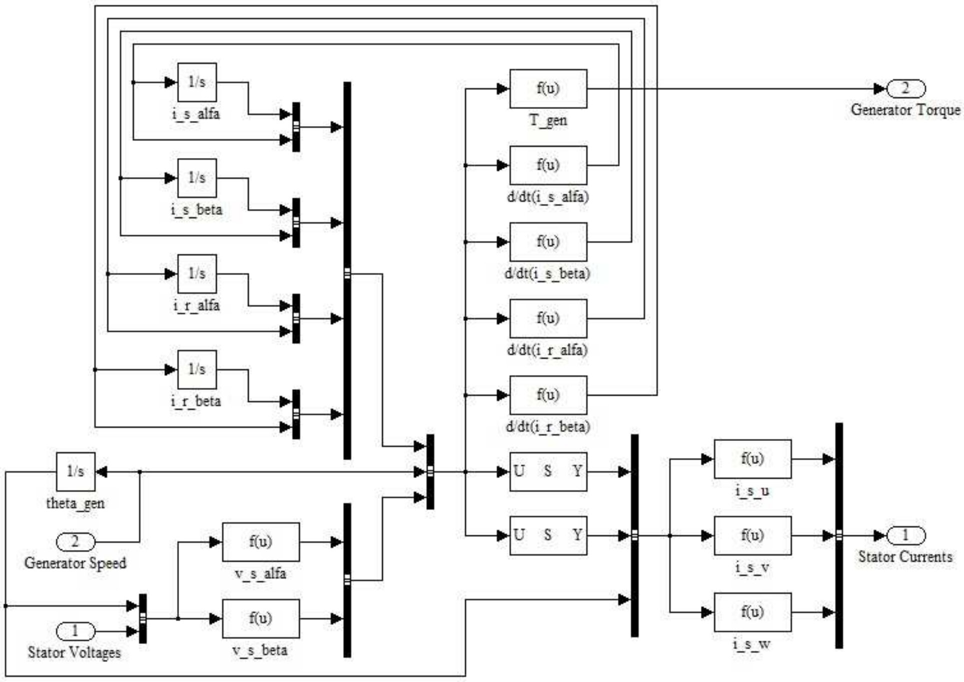

Figure 4 – Model of Asynchronous Generator in Simulink

Its basic parameters that can be set in the mask of this block are values of resistances and inductances of the stator or rotor winding, the magnetizing inductance between the stator and the rotor and also the number of machine poles. The set of input quantities includes individual supply voltages and the speed of the rotor. Outputs are formed by curves of currents in individual stator and rotor phases and also the inner electromagnetic torque of the machine.

3.4. Model of Aerodynamic Control

The important part of the wind power plants is also the system of aerodynamic control, which enables to regulate the mechanical power of the turbine by the nominal electrical output of the generator. This control system works on principle of automatic changing in the blades angle at the revolutions over the maximal generator speed and due to this it also protects the generator before overloading at high wind speeds. The optimal angle for the wind speed below the nominal value is approximately zero and then it increases with the wind speed growing. It have considerable impact on the performance coefficient and on the value of the turbine torque. During the modelling of this controller, it is very important to take into account that changes of the blades angle must be fluent with a finite rate, maximal 10 degrees per second, depending on the size of the wind turbine. The structure of the aerodynamic controller in the Simulink, which is shown in Figure 5, is relatively simple.

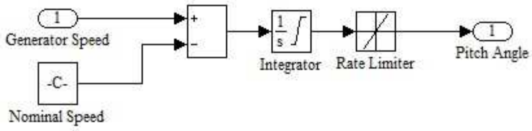

Figure 5 – Model of Aerodynamic Control in Simulink

The basic parameters set is formed by the nominal generator speed, the rate of pitch angle change and by the maximal and minimal value of this angle. The input value is the speed of the generator, which is during the simulation compared with its nominal value and the output is the value of the pitch angle of the blades, which changes the performance coefficient of the turbine.

4. MODEL OF WIND POWER PLANT

The model of the whole system of the wind power plant originates by the interconnection of the blocks of individual system parts, how the Figure 6 shows. In this case, it is the system of wind power plant with the woud rotor asynchronous generator, the system with constant speed, which has the gearbox and which is equipped by the aerodynamic control of the blades angle and which stator is connected to the grid directly. How you can see in this figure, the first element is the wind turbine, which converts the wind energy to the mechanical torque, which is fed to the one side of the gearbox. In this element the mechanical energy is converted to the rotational motion angular speeds of both ends of the shaft are determined. One of them is fed back to the turbine and determines the value of the performance coefficient and the second is fed into the generator and determines the value of the electromagnetic torque, which is fed into the second side of the drive train. The speed of the generator is also fed to the aerodynamic controller, where it serves to the calculation of the blades angle.

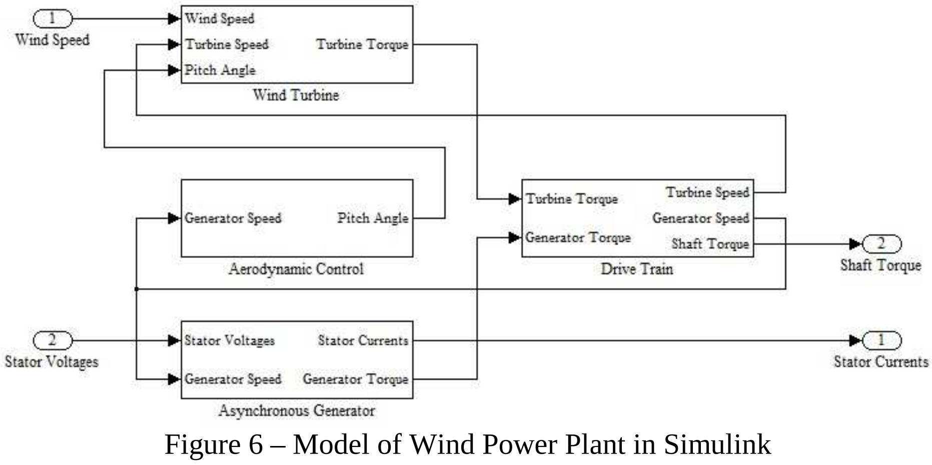

Figure 6 – Model of Wind Power Plant in Simulink

The set of this system parameters is composed of all values that was mentioned in the description of individual system parts. The set of the input values of the whole system is formed by the wind speed, which can be represented by the measured curve of the real wind speed or by the curve from the wind model, and by the stator supply voltages that correspond to the voltage level of the grid. The set of outputs of this wind power plant model is formed by the shaft torque and mainly stator phase currents that are produced by the asynchronous generator and that determine the values of the active power and also of the reactive power in each phase.

5. CONCLUSIONS

The mentioned mathematical description of individual parts of the wind power plant with the wound rotor asynchronous generator contains several simplifications and therefore it can be extended and the model can be improved, mainly in the case of the asynchronous generator, which can be supplemented especially by the inclusion of the skin-effect in wires or losses in the magnetic circuit. The presented model of the whole wind power plant system is designed to be possible to interconnected it with the mathematical model of the power grid and to be possible to simulated some influences of this system, which is used generally for small wind power plants that are connected to the low voltage level, on the operation of the local electrical network. This model is also the basis of the more complicated model of the wind power plant with variable speed with the doubly-fed asynchronous generator, which is one of the most using systems for large wind power plants.

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