

Mathematical Modelling of Small Wind Power Plant with Asynchronous Generator in Simulink

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Abstract--- This paper deals with mathematical modelling of wind power plant with induction generator. The modelling is briefly explained, mathematical description and Simulink model of wind plant basic parts shown and the model of whole system is presented.

Keywords: Induction generator, Wind turbine, R-L and R-C loads, Balance excitation, Balanced/unbalanced loads, MATLAB/ SIMULINK

I. INTRODUCTION

The connection and the operation of wind power plants create some inconvenience that are rising partly as a result of 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.

II. MODELS OF BASIC PARTS OF WIND POWER PLANT

To do proper calculations, it is required 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.

A. 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:

$$P_m = \frac{1}{2} \rho * \pi * R^3 * \omega^2 * C_p \dots \dots \dots (2.1)$$

Where ρ is the air density, R is the radius of the turbine; ω 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:

$$T_m = \frac{P_m}{\omega_t} = \frac{1}{2} \rho * \pi * R^3 * \omega^2 * C_M \dots \dots (2.2)$$

Where ω_t 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 1, of the wind turbine in Simulink platform.

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 violations lead to the simulated shutdown. 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 to the generator.

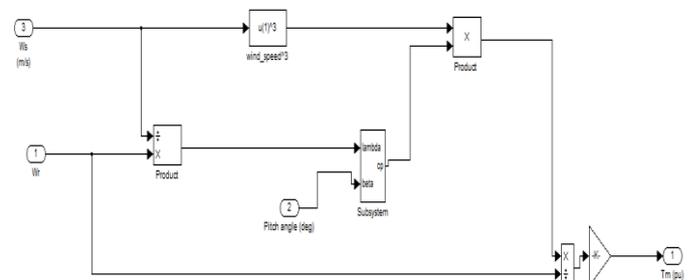


Fig. 1: Model of Wind Turbine in Simulink

B. Model of asynchronous generator

The second 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 phases. Appropriate components of electromagnetic quantities are actually their components for the symmetrical two phases 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:

$$\frac{dF_{qs}}{dt} = \omega_b \left[v_{qs} - \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{x_{ls}} \left(\frac{\dot{x}_{ml}}{x_{lr}} F_{qr} + \left(\frac{x_{ml}}{x_{ls}} - 1 \right) F_{qs} \right) \right] \quad \dots (2.3)$$

$$\frac{dF_{ds}}{dt} = \omega_b \left[v_{ds} + \frac{\omega_e}{\omega_b} F_{qs} + \frac{R_s}{x_{ls}} \left(\frac{\dot{x}_{ml}}{x_{lr}} F_{dr} + \left(\frac{x_{ml}}{x_{ls}} - 1 \right) F_{ds} \right) \right] \quad \dots (2.4)$$

$$\frac{dF_{qr}}{dt} = \omega_b \left[-\frac{(\omega_e - \omega_r)}{\omega_b} F_{dr} + \frac{R_r}{x_{lr}} \left(\frac{\dot{x}_{ml}}{x_{ls}} F_{qs} + \left(\frac{x_{ml}}{x_{lr}} - 1 \right) F_{qr} \right) \right] \quad \dots (2.5)$$

$$\frac{dF_{dr}}{dt} = \omega_b \left[-\frac{(\omega_e - \omega_r)}{\omega_b} F_{qr} + \frac{R_r}{x_{lr}} \left(\frac{\dot{x}_{ml}}{x_{ls}} F_{ds} + \left(\frac{x_{ml}}{x_{lr}} - 1 \right) F_{dr} \right) \right] \quad \dots (2.6)$$

$$\frac{d\omega_r}{dt} = \left(\frac{p}{2J} \right) (T_e - T_L) \quad \dots (2.7)$$

$$T_e = \frac{3}{2} \left(\frac{p}{2} \right) \frac{1}{\omega_b} (F_{ds} i_{qs} - F_{qs} i_{ds}) \quad \dots (2.8)$$

Where,

- d : direct axis
- q : quadrature axis
- s : Stator Variable
- r : Rotor Variable
- F_{ij} is Flux linkage ($i = q$ or d and $j = s$ or r)

- V_{qs}, V_{ds} : D and q axis stator voltages
- V_{qr}, V_{dr} : D and q axis rotor voltages
- F_{mds}, F_{mq} : D and q axes magnetizing flux linkages
- R_r : Rotor resistance
- R_s : Stator resistance
- X_{ls} : Stator leakage reactance
- X_{lr} : Rotor leakage reactance
- p : Number of poles
- J : Moment of inertia
- T_e : Electrical output torque
- T_L : Load torque
- ω_e : Stator angular electrical frequency
- ω_b : Based electrical frequency
- ω_r : Rotor angular frequency

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.

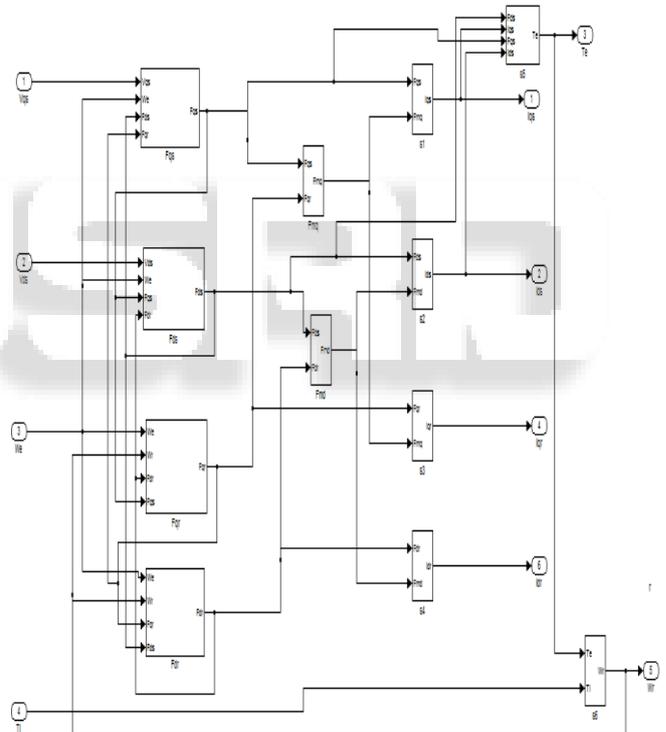


Fig. 2: dynamic Model of Asynchronous Generator in Simulink

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 2, 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.

C. Load and capacitor modelling

LOAD: Here the modelling of load has been developed in terms of d-q reference frame under balanced conditions. The load currents in terms of their respective voltages have been discussed below:

Balanced RL-Load:

$$i_{ld} = \int \left(\frac{1}{L} \right) V_{ld} - \left(\frac{R}{L} \right) i_{ld} \quad \dots (2.9)$$

$$i_{lq} = \int \left(\frac{1}{L} \right) V_{lq} - \left(\frac{R}{L} \right) i_{lq} \quad \dots (2.10)$$

Balanced R-C load:

$$I_{ld} = C_L * \rho(V_{ds} - R i_{ld}) \quad \dots (2.11)$$

$$I_{lq} = C_L * \rho(V_{ds} - R i_{lq}) \quad \dots (2.12)$$

Figure 3 and 4 show the SIMLINK model of the balanced loads.

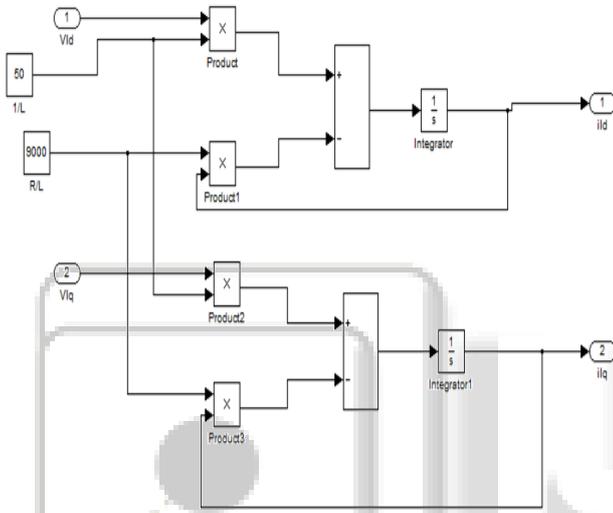


Fig. 3: Block Model of Balanced R-L Load in Simulink

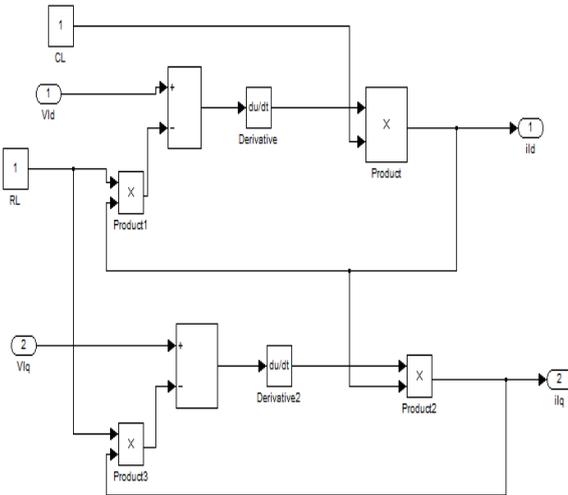


Fig. 4: Block Model of Balanced R-C Load in Simulink

Capacitor model:

The capacitor has been modelled using equations (2.13), (2.14), (2.15) and (2.16) that represent the self excitation capacitor currents and voltages in d-q axes representation as:

$$i_{ds} = i_{cd} + i_{ld} \quad \dots (2.13)$$

$$i_{qs} = i_{cq} + i_{lq} \quad \dots (2.14)$$

$$pV_{ld} = \left(\frac{3}{2K_3} \right) \left(\frac{1}{C_b} + \frac{1}{C_c} \right) i_{ds} + \left(\frac{\sqrt{3}}{2K_3} \right) \left(\frac{1}{C_b} - \frac{1}{C_c} \right) i_{qs} - \left(\frac{3}{2K_3} \right) \left(\frac{1}{C_b} + \frac{1}{C_c} \right) i_{ld} - \left(\frac{\sqrt{3}}{2K_3} \right) \left(\frac{1}{C_b} - \frac{1}{C_c} \right) i_{lq} \quad \dots (2.15)$$

$$pV_{lq} = \left(\frac{\sqrt{3}}{C_b} \right) \left\{ \left(\frac{K_1}{K_3} \right) \left(\frac{1}{C_b} + \frac{1}{C_c} \right) - 1 \right\} i_{ds} - \left(\frac{\sqrt{3}}{C_b} \right) \left\{ \left(\frac{K_1}{K_3} \right) \left(\frac{1}{C_b} + \frac{1}{C_c} \right) - 1 \right\} i_{qs} - \left(\frac{\sqrt{3}}{C_b} \right) \left\{ \left(\frac{K_1}{K_3} \right) \left(\frac{1}{C_b} + \frac{1}{C_c} \right) - 1 \right\} i_{ld} + \left(\frac{\sqrt{3}}{C_b} \right) \left\{ \left(\frac{K_1}{K_3} \right) \left(\frac{1}{C_b} + \frac{1}{C_c} \right) - 1 \right\} i_{lq} \quad \dots (2.16)$$

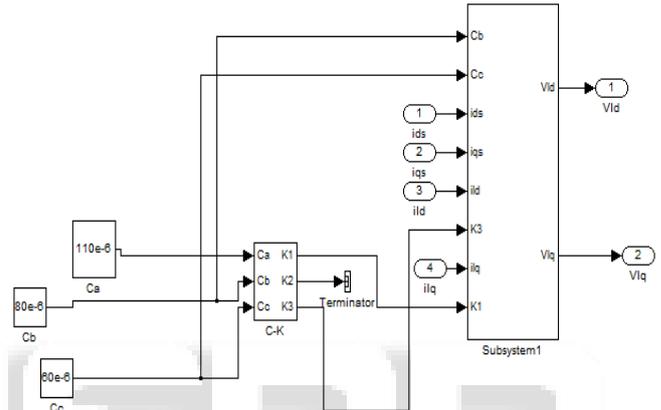


Fig. 5: Block Model Capacitive in Simulink

III. 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 wound rotor asynchronous generator, the system with constant speed, which has the gearbox 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.

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.

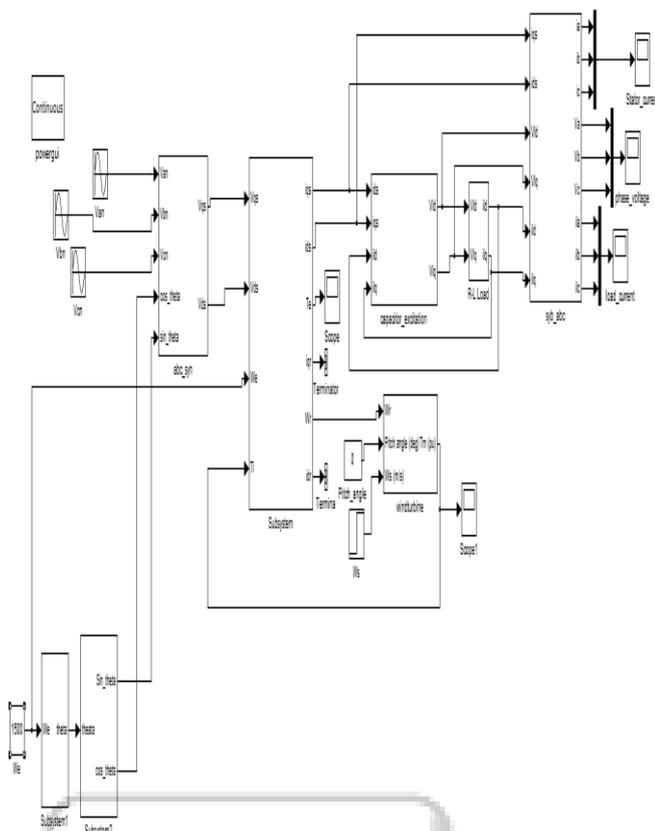


Fig. 6: Model of Wind Power Plant in Simulink

IV. CONCLUSION

In this paper, 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 the doubly-fed asynchronous generator, which is one of the most using systems for large wind power plants.

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