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Dynamic Model of an Asynchronous Generator with Double Supply

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ABSTRACT: In this state, the principles and operating modes of the AGDP wind turbines are discussed. Modeling of the wind power plant using DFIG was provided using MATLAB SiMULINK software, and the supersynchronous and subsynchronous mode of its operation with changing wind speed were also considered. For this purpose, models of all system elements were developed using ready-made and additionally created systems..

KEYWORDS: double-fed asynchronous generator, external wind energy utilization factor, wind turbine, coal wind, wind parameters, Matlab Simulink model.

I. INTRODUCTION

Wind turbines with double-fed asynchronous generators (DFAG) are widely used in the modern energy sector. DFIG is a FRAG in which external devices can be inserted into the generator rotor circuit to achieve variable speed operation. The generator stator is connected to the network through a transformer, and the rotor is connected through power converters, harmonic filters and a transformer. The rated power of AGDS usually ranges from several hundred kilowatts to several megawatts. The generator stator transfers electrical energy from the windmill to the grid, so the electrical current is unidirectional.

However, the power flow in the generator rotor circuit is bidirectional depending on the operating conditions (operating mode). Energy can be transferred from the rotor to the grid or back through a generator side power converter (PCg) and a grid side power converter (PCn). Thus, the maximum rotor power is about 30% of the rated stator power. The power rating of the converter is significantly less than that of a full-scale conversion wind turbine (full power conversion). When operating at variable speed, an DFIG wind turbine can produce more power than a constant speed wind turbine at lower than rated wind speeds.

Depending on the angular frequency (speed) of the generator rotor, two modes of operation of wind turbines with DFIG are distinguished: 1) supersynchronous operation mode, in which the generator operates at a speed exceeding synchronous speed; 2) subsynchronous operation mode, in which the generator operates at a speed below synchronous. The slip is negative in supersynchronous mode and positive in subsynchronous mode. Figure 1 shows the energy flow in an AGGR wind turbine system. Depending on the operating mode (super synchronous or subsynchronous), the rotor circuit of the generator can receive power from the network or transmit it to it. In supersynchronous operating mode, the mechanical power of the wind generator blades is transmitted to the electrical network through two circuits - the stator and the generator rotor.

The power on the generator rotor Pr of the power transformers of the generator rotor winding is transmitted to the network, and the power on the generator stator Pc is transmitted directly to the network. If we neglect the losses of the generator and converter, then the power generated by the wind turbine is transferred to the network, as shown in Figure 1, a.

In operating mode at subsynchronous speed (Fig. 1, b), the generator rotor receives power from the network. The mechanical power of the wind turbine and the power of the generator rotor (Gr) are transmitted to the network through the generator stator circuit. In this case, the generator stator power (Pc) is equal to the sum of the wind turbine power and the rotor power, but does not exceed the nominal value, since the mechanical power of the wind turbine in the subsynchronous high-speed mode is lower. than in super-synchronous high-speed mode. As in the previous case, if losses are not taken into account, the total power transferred to the network is equal to the mechanical power of the wind turbine.

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And we can say that the stator power in supersynchronous speed mode is greater than the stator power in subsynchronous speed mode.

II. METHODS

MATLAB software is an interactive programming environment and high-level programming language developed by MathWorks that allows the use of basic mathematical functional blocks to create all of these systems. MATLAB is a set of practical programs for solving technical computing problems. Using MATLAB Simulink, a model of a wind turbine DFIG can be assembled from basic functional blocks. A model of a wind turbine with an DFIG, created in MATLAB Simulink, is intended to study operating modes when wind speed changes. In this article, a simplified single-mass dynamic model is used to describe rotating masses (wind turbine, gearbox, generator).

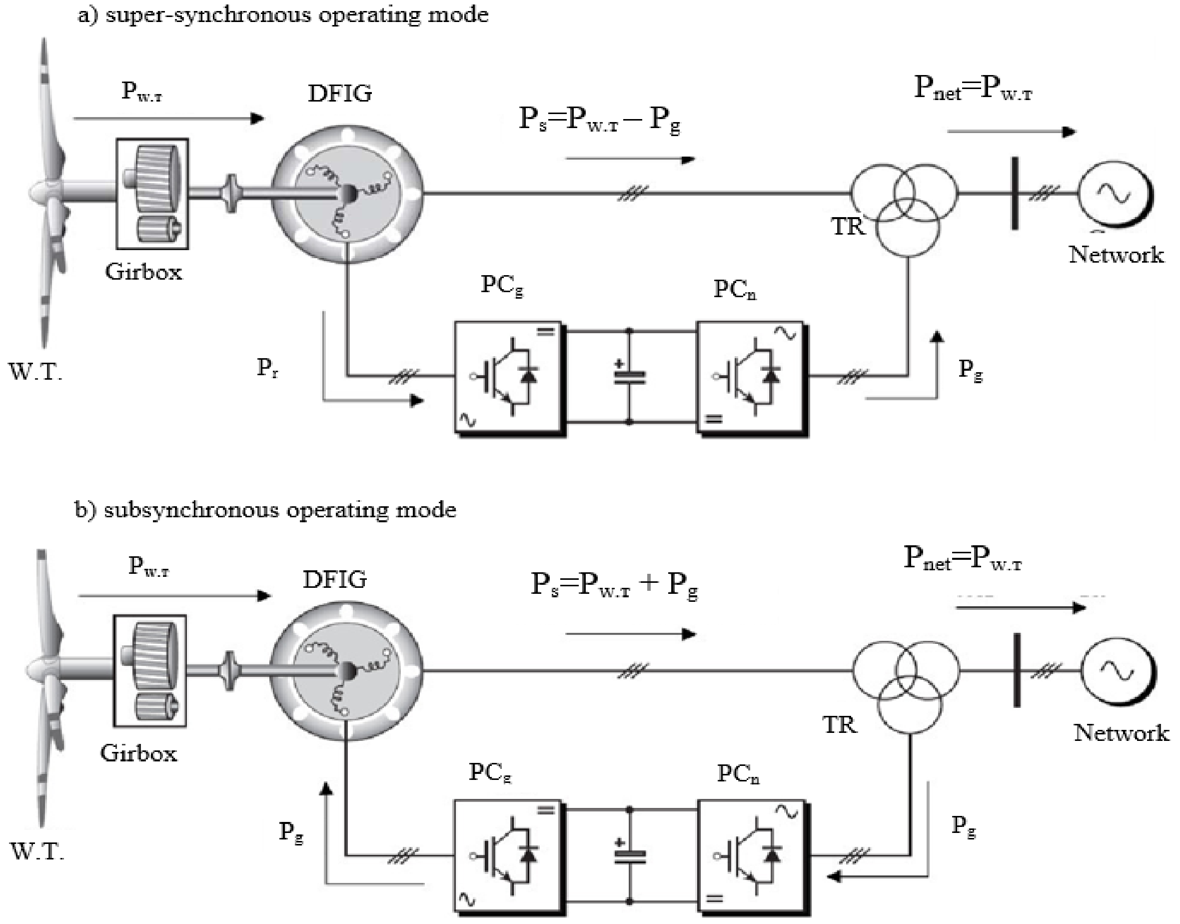

Fig.1. Power flows of the DFIG wind power plant in various operating modes.

The following equation (1) describes the single-mass model in relative units:

$$J_{EK}=\frac{d\omega_{Mg}}{dt}=M_{EM.g}-M_{Mg} \tag{1}$$

where Mmg is the mechanical moment on the generator rotor shaft, n.b., (M_{Mg}<0 in generator mode); Electromagnetic torque generator mem.g pu; $\omega_{M\Gamma}$ - angular velocity of the generator rotor, n.b. ; J_{EK} - equivalent moment of inertia of rotating masses (windmill, suction speed transmission, generator).

The following tolerances are included in the calculations:

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1) The angular frequency of the wind turbine ω_{WT} is the frequency of the generator $\omega_{M\Gamma}$ equal to ($\omega_{Ш\Gamma}$ "=" $\omega_{M\Gamma}$); therefore, the transmission function of the gearbox should not be taken into account;

2) If you do not take into account mechanical losses, then the mechanical moment of the wind turbine can be taken equal to the electromagnetic moment of the generator in relative units.

A general model of a wind turbine DFIG in MATLAB Simulink is presented in Figure 3.2, which uses several ready-made blocks (semi-systems) from the MATLAB Simulink library and additionally generated semi-systems.

Ready-made blocks (nim systems):

1. Asynchronous generator (DFIG) powered by two terminals based on an asynchronous machine with a wound rotor; This is a 690 V FRAG with a power of 1.5 MW.

Rated generator power: P_n=1.5 MW, rated stator network voltage U_N=690 V, rated generator stator phase voltage U_f=398, V, rated frequency f=50 Hz, rated generator rotor speed n_n=1750 rpm, synchronous rotation speed n_s=1500 rpm, rated slip s_N=-0.15, number of pole pairs p=2, stator winding resistance R_c=0.00265 Ohm, rotor winding resistance R_r=0.0263 Ohm, stator winding leakage inductance Ls= 0.1687 mH, leakage inductance of the coil rotor Lr=0.1337 mH, mutual inductance Lm= 5.4749 mH.

The parameters of the generator stator in Figure 2 are indicated in capital letters (A, B, C), and the parameters of the generator rotor are indicated in lowercase letters (a, b, c). The generator is entered as an input parameter using the Tm block , and this parameter is calculated as the mechanical torque of the wind turbine, measured in relative units. The output parameters of the generator are displayed in the AsincMac_sig block : rotor angular velocity (pu), stator and rotor currents (pu) and electromagnetic torque (pu).

According to the above model, a dynamic model of a wind turbine can be created using DFIG. Here, the dynamic characteristics of the wind turbine and the AGGR can be obtained using the DFIG Wind Turbine unit.

The DFIG is represented by the following equations in the d and q coordinate systems:

$$\left.\begin{aligned} U_{qc} &= R_c i_{qc} + \frac{d\omega_{qc}}{dt} + \omega_c \psi_{dc} \\ U_{dc} &= R_c i_{dc} + \frac{d\omega_{dc}}{dt} - \omega_c \psi_{qc} \\ \psi_{qc} &= (L_m + L_{lc}) i_{qc} + L_m i_{qp} = L_c i_{qc} + L_m i_{qp} \\ \psi_{dc} &= (L_m + L_{lc}) i_{dc} + L_m i_{dp} = L_c i_{dc} + L_m i_{dp} \\ M_г &= \psi_{dc} i_{qc} - \psi_{qc} i_{dc} \\ Q_c &= U_{qc} i_{dc} - U_{dc} i_{qc} \end{aligned}\right\} \tag{2}$$

here U_{dc} , U_{qc} , i_{dc} , i_{qc} , ψ_{dc} , ψ_{qc} is the projection of voltage, current and current ratios onto the d and q axes; L_c - specific stator inductance; Q_c - reactive power of the stator circuit; ω_c - synchronous angular velocity of the generator.

$U_{qc} = 0$ and the resistance of the stator circuit $R_c = 0$ if we assume that (the active resistance of the stator circuit of powerful DFIGs is close to zero) at $\psi_{dc} = 0$ will

Thus, the fourth term in the system of equations (2) has the form:

$$i_{dp} = \frac{L_m + L_{lc}}{L_m} i_{dc} = -\frac{L_c}{L_m} i_{dc} \tag{3}$$

Using the system of equations 2 and 5 in the system of equations (2) and equations (2, 3), the electromagnetic torque of the generator is found as follows:

$$M_г = -\psi_{qc} i_{dc} = -\frac{L_m}{L_c} U_{dc} i_{dp} \tag{4}$$

According to equation (4), the electromagnetic torque of the DFIG depends on the projection of the rotor current and stator voltage onto the d axis.

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According to the above equation (2), a dynamic model of the DFIG is constructed in Figure 2.

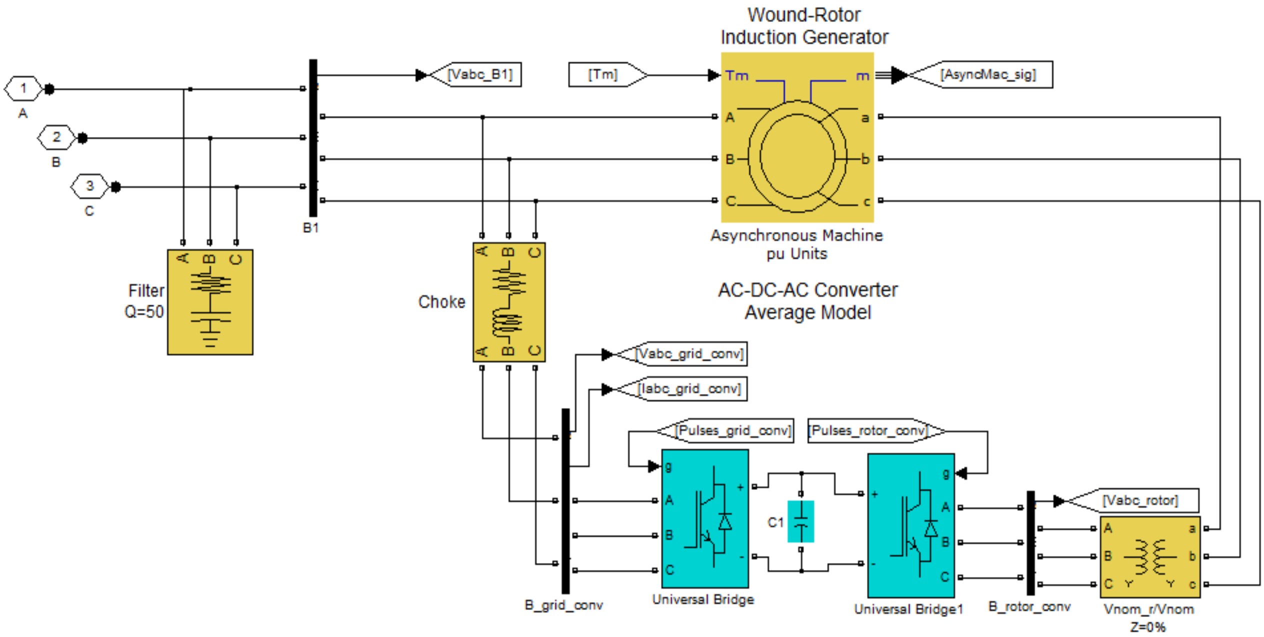

Fig.2. General model of the wind turbine DFIG in MATLAB Simulink General model of the wind turbine DFIG

The asynchronous machine assembly block in Figure 2 consists of two parts according to equation (2), that is, the electrical part and the mechanical part.

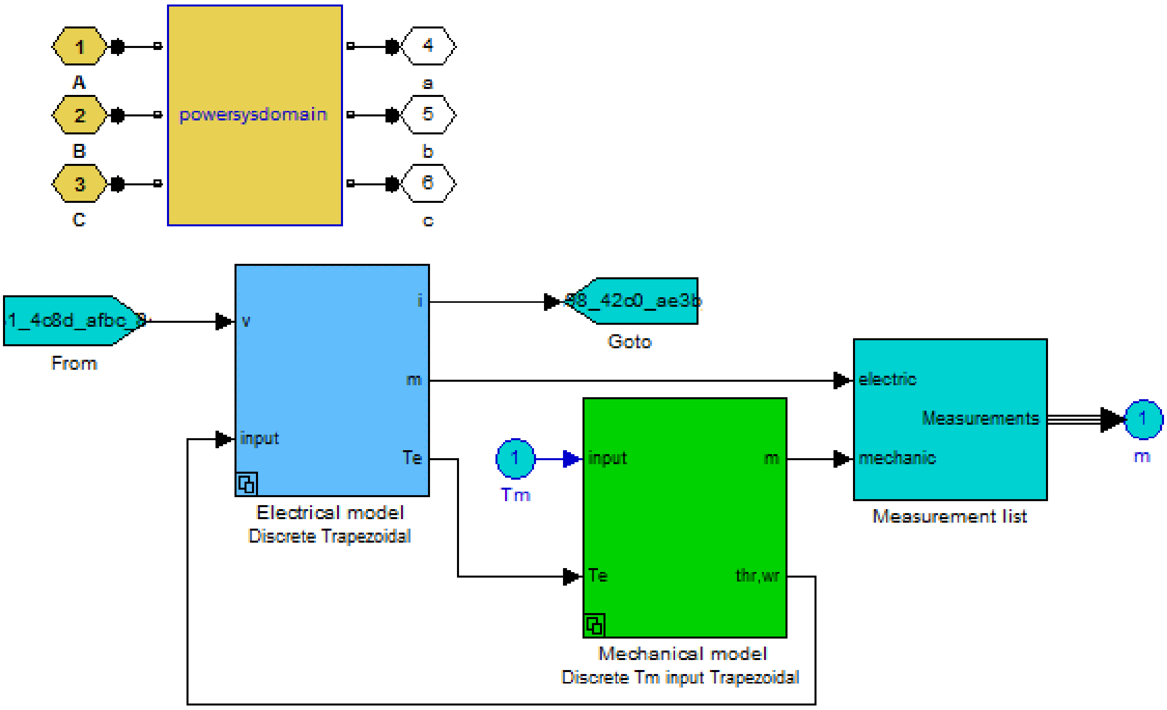

Fig.3. DFIG model, consisting of electrical and mechanical parts.

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According to Figure 3, the parameters of the three-phase ABC network and the speed and output parameters of the wind turbine are stator and rotor currents, rotor speed and electromagnetic torque, and active and reactive power as the input parameters of this model.

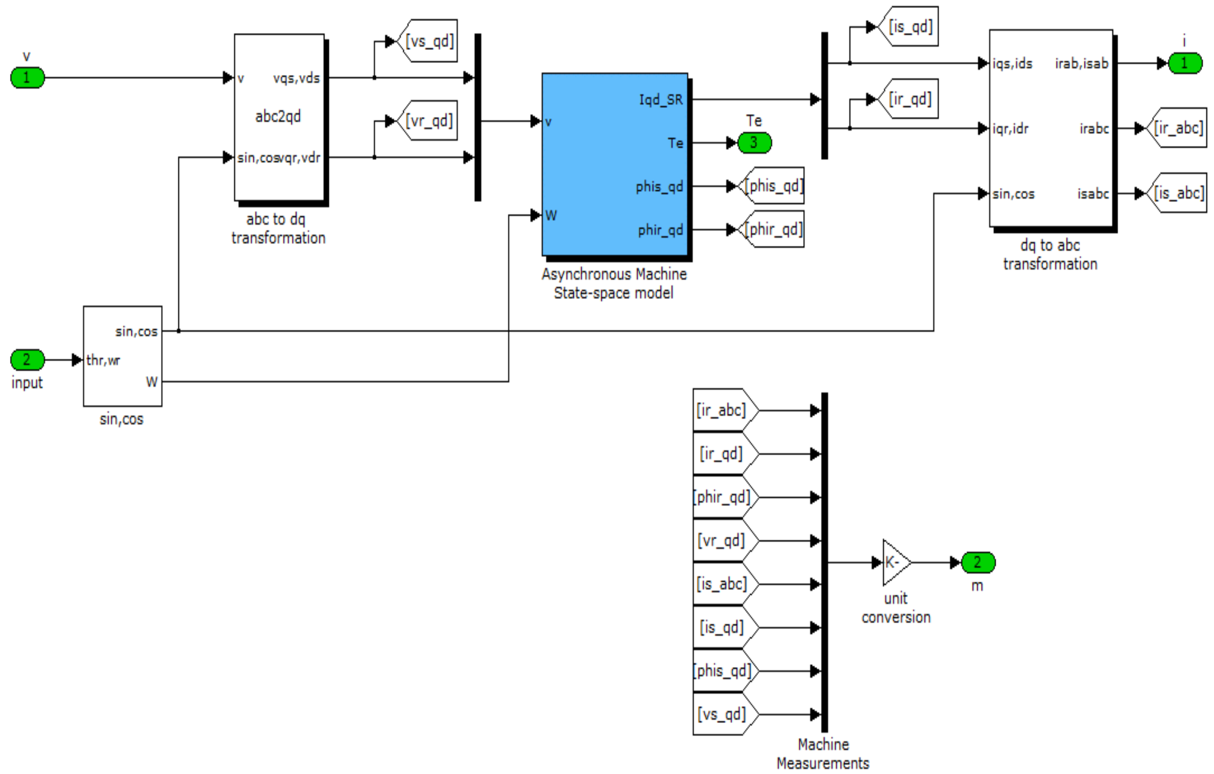

Fig.4. DFIG is a semi-system that calculates the model of the electrical part.

The input parameters of the electrical part of the AGDS in Figure 4 are the time-dependent parameters of the projection of wind speed, rotor and stator currents, voltages and currents on the d and q axes. The output parameters are the values of the projection of the stator and rotor currents on the d and q axes and the values of the time dependence of the stator and rotor currents on the ABC phase coordinate system.

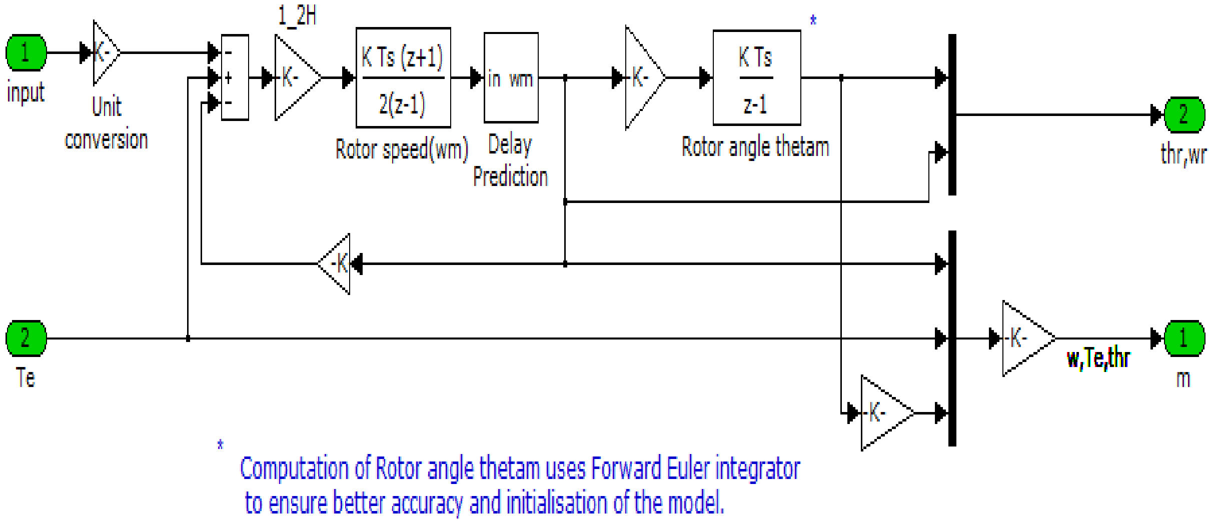

Fig.5. DFIG - semi-system for calculating mechanical parts.

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The input parameters of the subsystem for calculating the mechanical part of the DFIG in Figure 5 are the time-dependent values of the stator and rotor coordinate system (ab) and the electromagnetic torque, and the output parameters are the rotor speed, the angular position of the rotor and the electromagnetic torque.

The wind utilization efficiency of a wind turbine is achieved by changing the angular position of the turbine blade at different wind speeds to change Sr. The model in Figure 6 is used to model this process.

The input parameters of the wind turbine unit and the control mechanism in Fig. 6 are the wind angle position, wind speed and generator rotor speed, and the output parameters are mechanical torque.

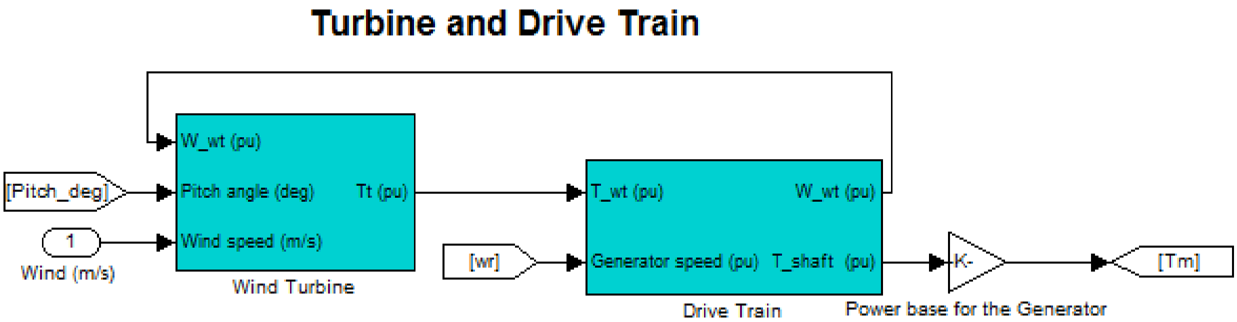

Fig.6. Wind generator and steering mechanism

The modification model of the rotor and bridge of the DFIG wind turbine model in Figure 2 is shown in Figure 7 below.

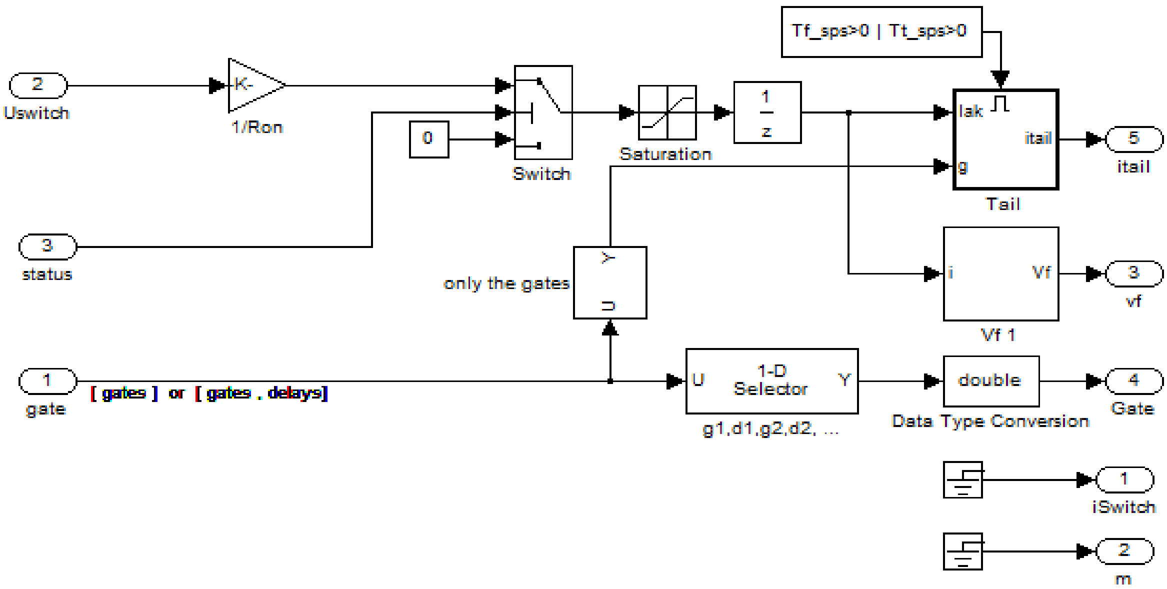

Fig.7. Model of a rotor in a rotor circuit and transformers in parts of the network.

Using the model in Figure 7, it is possible to solve the problem of maximizing the use of wind energy at DFIG speeds below and above the synchronous speed.

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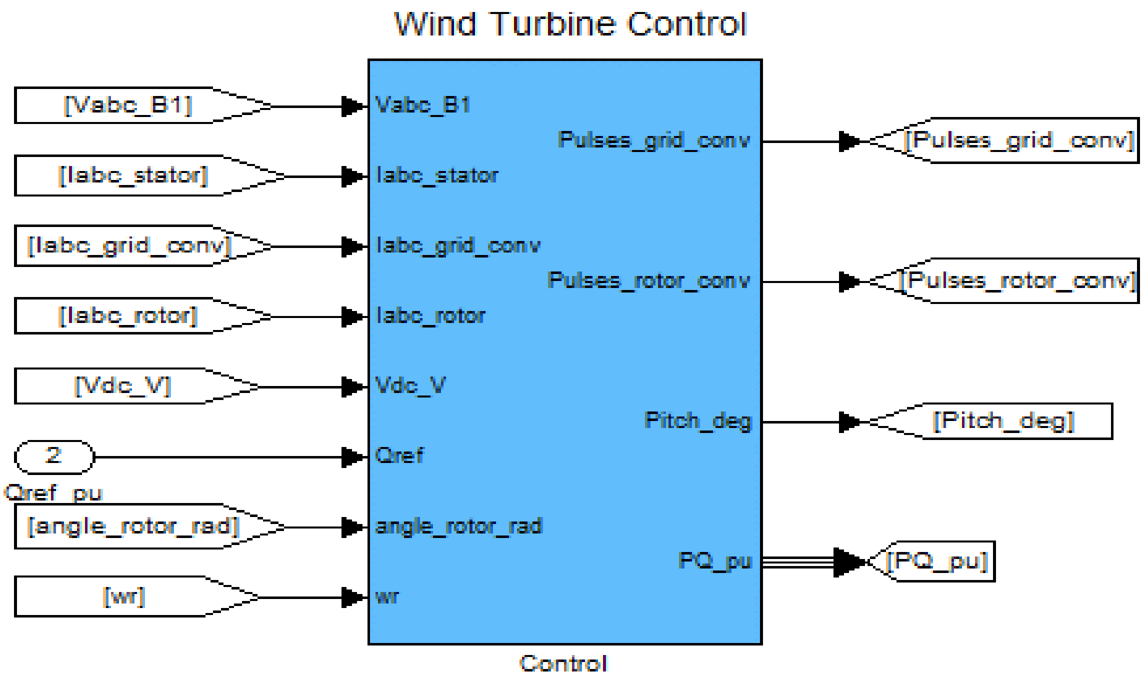

Fig.8. Wind turbine control unit model

Using the model of the wind turbine control unit in Fig. 8, a rotor control signal is generated in the rotor circuit and IGBT transistors in the network, in addition, the angular position of the wind turbine blade, the active and reactive power produced are controlled.

The wind turbine control unit shown in Figure 8 consists of four control units, namely:

1) Filtering and measuring unit;
2) Speed controller and wind turbine tilt angle control unit;
3) Control unit for the network part of the rotor circuit converters;
4) Control unit for the rotor part of the rotor circuit converters.

Using the model of the filtering and metering unit, it is possible to regulate the output parameters of the generator rotor circuit in accordance with the network parameters, as well as the output active and reactive power. The frequency of the rotor circuit is adjusted to the network frequency using a part of the automatic phase frequency adjustment model of the filtering and measuring unit. The wind turbine blade position and speed controller model simplifies the control of the wind turbine blade angle position at high wind speeds and the generator shutdown at low wind speeds. The parameters of the rotor chain are adjusted to the parameters of the network using a model of the control unit of the converters of the network part of the rotor chain. The control of the electromagnetic torque and rotor circuit currents is carried out using a control unit for the model of the rotor part of rotor chain converters.

III. RESULTS AND DISCUSSION

The active power generated by the DFIG wind turbine, the rotation speed of the generator rotor, the rotation speed of the turbine and the angular position of the blades are simulated under the following variable wind speed.

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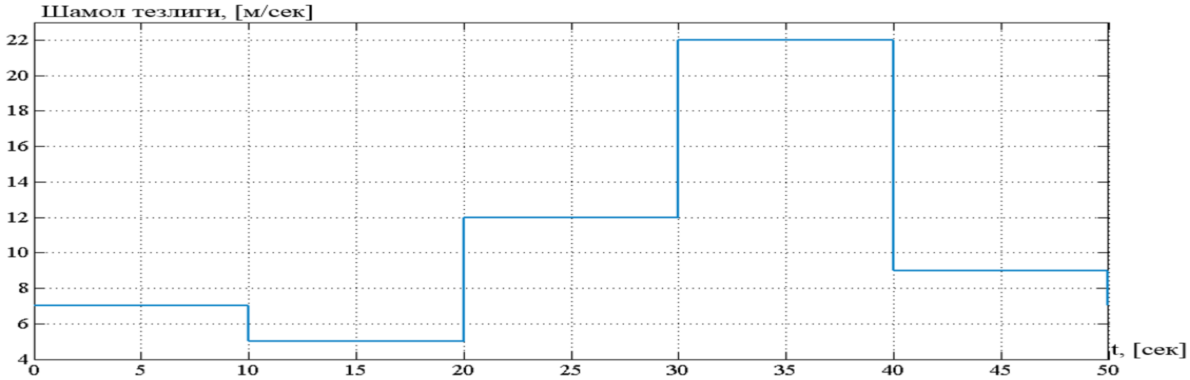

Fig.9. Variable wind speed

The dynamic operating mode of a 1.5 MW DFIG with variable wind speed was simulated, shown in Figure 9. The simulation results of the dynamic operating mode are presented in Fig.10.

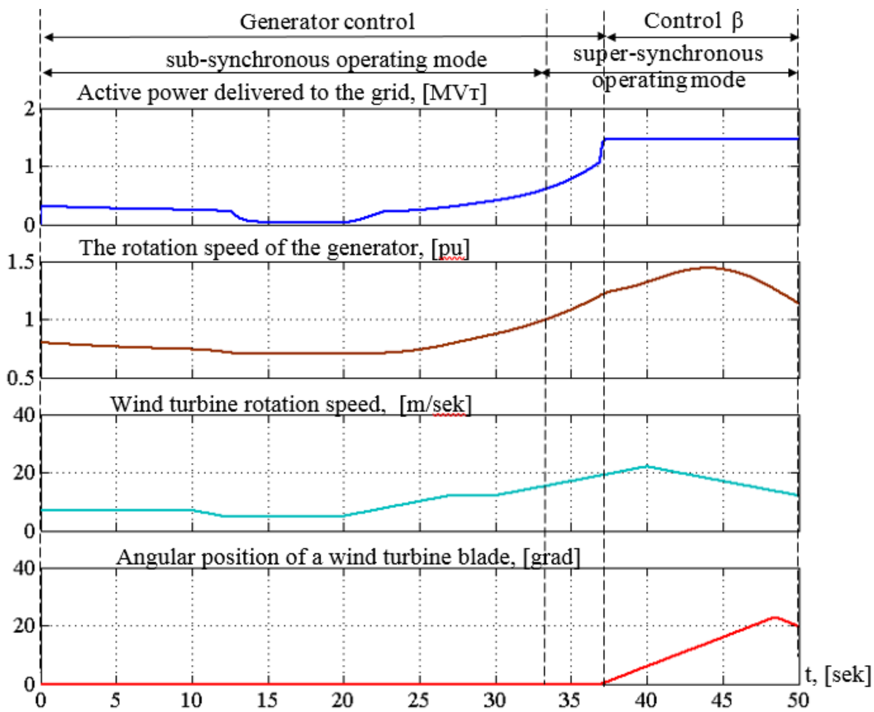

Fig.10. Model of the dynamic operating mode of a 1.5 MW DFIG wind turbine at variable wind speed.

The Matlab Simulink program, developed in addition to the above, simulates the transient processes that occur in the DFIG when the network voltage is reduced by 2 times.

In this simulation, the wind speed is kept constant at 15 m/s. The control system sets the speed to 1.2 n.b. uses a torque controller to hold at The reactive power produced by the wind turbine is set at 0 MW. With this simulation, it is possible to observe the steady state of the DFIGS and its dynamic response to the voltage drop caused by a remote fault in the 110 kV system. To simulate a voltage source, open the "110 kV" block and use a six-stroke 0.5 n.p. at t=0.03 s. The voltage drop is programmable.

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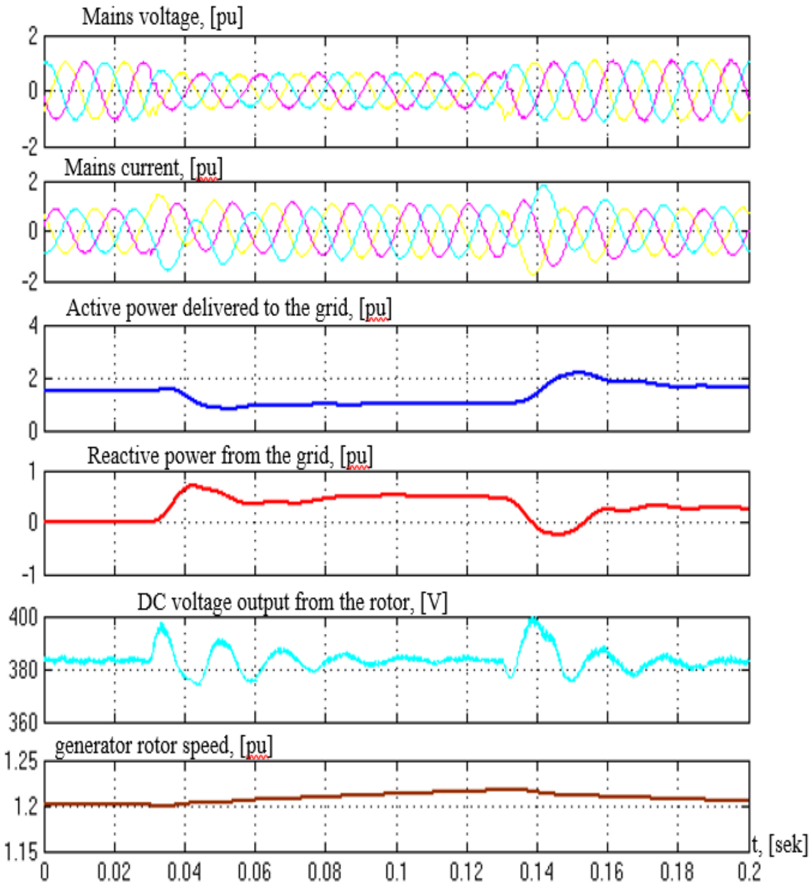

Fig.11. Transient processes occurring in the DFIG when the network voltage changes.

Initially, the DFIG wind turbine will produce 1.5 MW of electricity. The speed of the corresponding turbine is 1.2 bp. generator synchronous speed. The DC rotor circuit voltage is regulated at 380 V and the reactive power is maintained at 0 MV. At t=0.03 s, the positive sequence voltage suddenly drops to 0.5 np. This causes fluctuations in the mains voltage and output power of the DFIG. When the voltage drops, the control system tries to maintain constant voltage and reactive power at the specified values (380V, 0 Mvar). The system recovers in approximately 4 cycles.

This simulation is set up so that all states are initialized to start from a steady state. Otherwise, due to the large time constants of the electromechanical part of the wind turbine model and its relatively slow adjustment, you have to wait tens of seconds.

VI. CONCLUSIONS

1. Stator voltage vector control is used to control the power converter on the generator side, and line voltage vector control is used to control the power converter on the grid side.

2. Computer modeling allows you to study the static and dynamic characteristics of wind turbines using DFIG.

3. Power flows, rotor and stator power sliding It has been established that the direction of the rotor power flow changes when switching from subsynchronous mode to supersynchronous mode.

4. The reactive power drawn from and supplied to the grid at different wind speeds is maintained at 0 MVar by the rotor and grid side converter (i.e. IGBT power transistor).

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