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MODELING AND CONTROL OF WIND TURBINE AND FAULT

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Abstract- This paper deals with the modeling of doubly fed induction generator (DFIG) cooperating with wind turbine. The wind turbine and the DFIG models are presented step by step. Overall control system of the DFIG is modeled in details in program ATP-EMTP. A breakdown on the model was formed thanks to phase-ground short circuit. Active and reactive power curved lines and stator voltage curved lines were observed.

Keywords: Induction Generator, Wind Turbine, Converter AC/AC, Power System.

I. INTRODUCTION

Wind energy is one of the most important and promising sources of renewable energy all over the world. It is connected with reduction of CO_2, NO_x, SO_2 emissions generated by traditional fossil fuel and economical considerations. Combined with other renewable technologies and efficient energy use, wind power is crucial in reducing global climate change, acid rain and other environmental problems, because it produces no carbon dioxide (a gas that contributes to global warming), sulphur dioxide or nitrogen oxides (gases that contribute to acid rain), and hazardous or radioactive wastes. Global climate change and greenhouse effect the history of the planet shows that climate changes occur from time to time in different parts of the world. The greenhouse effect can be defined briefly as an atmospheric temperature increase, due to gas emitted by human activities. Emissions of the main anthropogenic greenhouse gas, CO_2, are influenced by: size of the human population, amount of energy used per person, and level of emissions resulting from energy use.

Wind turbine technology with wind energy economics and wind systems are evaluated. Wind energy current states are given year by year for some countries where electricity generation by wind energy increases in an unprecedented manner.

According of Concept European Union in 2010 year power of installed in renewable energy should be 75000MW and 2020 should achieve 150000 MW [1, 2]. So at same time, there has been a rapid development wind technology [3, 4]. With increased penetration of wind power into electrical grids, DFIG wind turbines are largely deployed due to their variable speed feature and hence influencing system dynamics. This has created an interest in developing suitable models for DFIG to be integrated into power system studies. The continuous trend of having high penetration of wind power, in recent years, has made it necessary to introduce new practices. The main advantage of the DFIG include: wide range of control of the output power extracting from the wind, separate active and reactive power control and relatively fast response to significant grid disturbances [5, 6].

Industry requires engineers to model a system before they are allowed to perform experiments. After developing an analytical model an experimental test plan was conducted to provide necessary and sufficient data to improve the accuracy of the analytical model. In this study active, reactive and stator curved lines in a wind turbine which was modelled in [7] reference, in case of any breakdown, have been observed.

II. MATHEMATICAL MODEL OF GENERATOR AND WIND TURBINE

Functions approximation is a way of obtaining relatively accurate representation of a wind turbine. It is made by using a few parameters which represent model of wind turbine. It is current source, capacitor and resistance. Equation described behavior of wind turbine is the following:

$$J_m \frac{d\omega_r}{dt} + D_m \omega_r = T_m - T_e \tag{1}$$

where, on the basic of duality principle, mechanical variables are represented by adequate electrical quantities:

a) Inertia constant J_m [kg.m^2], capacitance C [F]
b) Friction coefficient D_m [N.m/(rad/s)], conductance $1/R$ [1/Ω], $T_e = \frac{3}{2} p(\psi_d i_q - \psi_q i_d)$
c) Mechanical torque T_m [N.m], current i [A]
d) Angular velocity ω_r [rad/s], voltage u [V]

Therefore, the instantaneous value of voltage u [V] is equivalent to the rotor angular velocity ω_r [rad/s]. The current at the machine input represents the torque shaft, which is balanced with the electromagnetic torque.

$$T_e = \frac{3}{2} p(\psi_d i_q - \psi_q i_d) \tag{2}$$

where p is number of machine pair of poles and ψ_d, ψ_q, i_d, i_q are electromagnetic flux and current, respectively, in d and q coordinate. Structure of the considered model is showed in Figure 1.

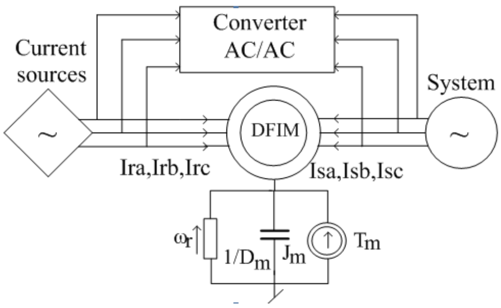

Figure 1. Structure of the considered model

This model is fed up from the both sides. The stator winding of the generator is directly connected to the grid and rotor windings are fed from the grid using voltage source converter AC/AC. In order to simplified phenomena analysis in electric machine was introduced classic theory of rotating fields and the well known d-q model, as well as both three-to-two and two to three axes transformations. Stator side current and voltage components are referred to the stationary reference frame, while the rotor side current and voltage components are referred to a reference frame rotating at rotor electrical speed ω_r. Figure 2 present vector diagram of the machine.

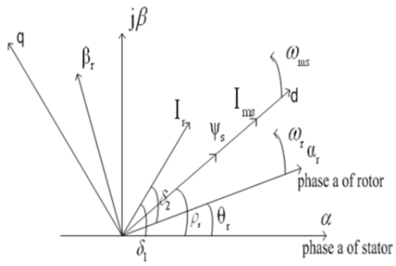

Figure 2. The machine vector diagram

Any three phase stator or rotor electrical magnitude x can be expressed according natural reference frame-stationary if it is a stator side and rotating at rotor electrical speed ω_r if it is a rotor side-direct, quadrature and zero-sequence components as follows:

$$\begin{bmatrix} X_d \\ X_q \\ X_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \tag{3}$$

where x represents the stator or rotor side voltage, current or flux-linkage.

The Clarke's inverse transformation allowed obtain three phase value from direct, quadrature, and zero components as follow;

$$\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix}\begin{bmatrix} X_d \\ X_q \\ X_0 \end{bmatrix} \tag{4}$$

III. OVERALL MODEL OF DFIG

Structure of the considered model is shown in the Figure 3. The control procedure for determination of needed voltage in the rotor circuit was realized in the form of models module (block converter AC/AC in Figure 3). There are 3-phase signals at the input of this block: current at both sides of the generator and voltage of stator and at the output 3-phase voltage source control signal. This method allows regulate wind turbine only by using signals measured in both sides of generator. On the table showed electrical parameters of machine.

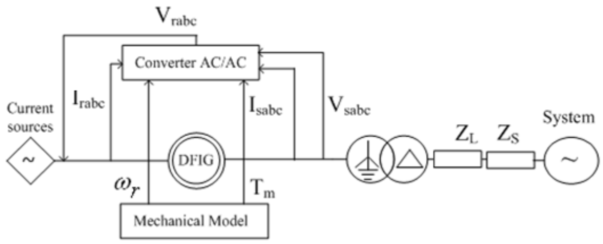

Figure 3. Structure of the considered model

For simplicity the phase current sources in the rotor circuit was presented by using controlled current sources. This current is applied only by starting simulation and is switched-off after 0.0001s.

Table 1. Electrical parameters machine

Parameters [Ω]	Value [Ω]
R_s Resistance stator	0.0017
X_{ls} Inductance stator	0.0172
X_m Inductance magnetizing	0.7391
R_r Resistance rotor	0.0055
X_{lr} Inductance rotor	0.0172

Dynamical parameters of model are defined as follows;

$$L_m = \frac{X_m}{2\Pi f_s} \tag{5}$$

$$L_{ls} = \frac{X_{ls}}{2\Pi f_s} + L_m \tag{6}$$

$$L_{lr} = \frac{X_{lr}}{2\Pi f_s} + L_m \tag{7}$$

Voltage of system: U_S=20 kV
Impedance of system; R=0.18 Ω ; X=1.13 Ω
Transmission line parameters; R_L=0.5 Ω; X_L=0.37 Ω
Transformer; S_T=1.8 MVA, ϑ_T=20000/690 (V/V)

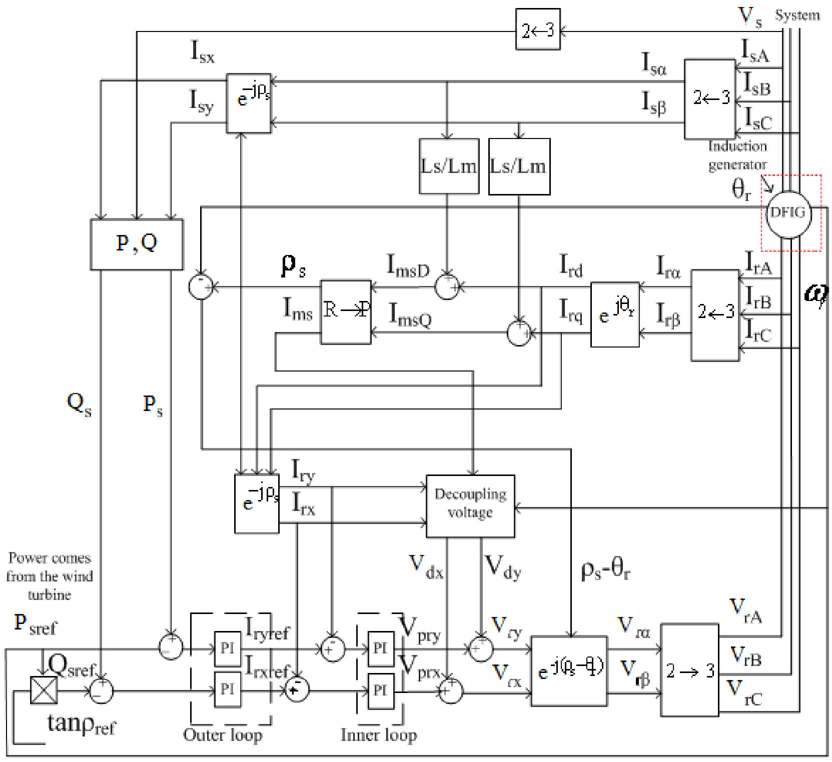

Figure 4. Overall control of DFIG

IV. OVERALL CONTROL OF DFIG

Overall control of DFIG is presented in the Figure 4. As the rotor position is concerned, in the non-sector application this variable can be estimated on the bases of measured quantities: the rotor current L_r and the stator current I_s and voltage U_s. From the Figure 2, we can conclude, that position of the rotor is determined by the angle;

$$\theta_r = \delta_1 - \delta_2 \tag{8}$$

The angle δ_2 can be obtain from the measured 3-phase current rotor by using Clarke's transformation.

$$I_{rr\alpha} = \left(2I_{Ar} - I_{Br} - I_{Cr}\right)/3 \tag{9}$$

$$I_{rr\beta} = \left(I_{Br} - I_{Cr}\right)/\sqrt{3} \tag{10}$$

and finally;

$$\delta_2 = \text{arctg}\left(\frac{I_{rr\beta}}{I_{rr\alpha}}\right) \tag{11}$$

For the determination angle δ_1 we can use adequate components of measured stator quantities;

$$\delta_1 = \text{arctg}\left(\frac{I_{r\beta}}{I_{r\alpha}}\right) \tag{12}$$

where;

$$I_{r\alpha} = \frac{X_s I_{s\alpha} + R_s I_{s\beta} + U_{s\beta}}{X_m} \tag{13}$$

$$I_{r\beta} = \frac{X_s I_{s\beta} - R_s I_{s\alpha} - U_{s\alpha}}{X_m} \tag{14}$$

and $X_m = \omega_s L_m$; $X_s = \omega_s L_s$, $I_{s\alpha}$, $I_{s\beta}$, $I_{s\beta}$, $U_{s\beta}$ are the stator current and voltage space vector components calculated from measured quantities, similarly as in Equations (9) and (10).

Estimation phase angle of the stator-flux-linkage space phasor ρ_s demanded obtain rotor current changed from their natural axes to the stationary reference frame. For these equations is necessary measure rotor angle θ_r;

$$I_{rd} = I_{r\alpha}\cos(\theta_r) - I_{r\beta}\sin(\theta_r) \tag{15}$$

$$I_{rq} = I_{r\alpha}\sin(\theta_r) + I_{r\beta}\cos(\theta_r) \tag{16}$$

Direct- and quadrature- axis stator magnetizing current components respectively, expressed in the stationary reference frame, can be calculated as follow;

$$I_{msD} = \frac{L_s}{L_m} I_{s\alpha} + I_{rd} \tag{17}$$

$$I_{msQ} = \frac{L_s}{L_m} I_{s\beta} + I_{rq} \tag{18}$$

and finally;

$$\rho_s = \text{arctg}\left(\frac{I_{msQ}}{I_{msD}}\right) \tag{19}$$

Direct and quadrature axis rotor current components respectively, expressed in the stator flux oriented reference frame, can be represented by

$$I_{rx} = I_{rd}\cdot\cos(\rho_s) + I_{rq}\cdot\sin(\rho_s) \tag{20}$$

$$I_{ry} = I_{rq}\cdot\cos(\rho_s) - I_{rd}\cdot\sin(\rho_s) \tag{21}$$

On basis space vector current stator expressed in axis x, y (reference to the direct and quadrature axis rotor components) can computed active and reactive power obtain from the machine;

$$P_s = \frac{3}{2}\cdot|\overrightarrow{V_s}|\cdot I_{sy} \tag{22}$$

$$Q_s = \frac{3}{2} \cdot |\overrightarrow{V_s}| \cdot I_{sx} \tag{23}$$

where:

$$I_{sx} = \frac{L_m}{L_s} \cdot (I_{ms} - I_{rx}) \tag{24}$$

$$I_{sy} = -\frac{L_m}{L_s} \cdot I_{ry} \tag{25}$$

Equations (24) and (25) confirm dependence, that components current stator in axis x, y, I_{sx} and I_{sy} should be proportionally to the current rotor in the same axis I_{rx}, I_{ry}. It means that, the stator side-active and reactive power may be governed separately just by controlling the stator current I_{sx} and I_{sy} components, respectively.

In scheme control contains two cascaded control-loops. The outer one (current regulator) serve to the control power obtain from generator and decrease about reference power, which come from turbine.

$$I_{ry}ref = P_s - P_s ref \tag{26}$$

$$I_{rx}ref = Q_s - Q_s ref \tag{27}$$

The inner-loops, which has aim to control voltage rotor as result decoupling with signal voltage came from stator, cause voltage stability and control power.

$$V_{pry} = I_{ry}ref - I_{ry} \tag{28}$$

$$V_{prx} = I_{rx}ref - I_{rx} \tag{29}$$

In order to improve decoupling between x and y axes, the V_{pry} and V_{prx} decoupling voltage components given above are added to V_{drx} and V_{dry} in the following way;

$$V_{rx} = V_{drx} + V_{prx} \tag{30}$$

$$V_{ry} = V_{dry} + V_{pry} \tag{31}$$

$$V_{drx} = -X_{s1} \cdot L_{pr} \cdot I_{ry} \tag{32}$$

$$V_{dry} = (2\pi f - \omega_r) \cdot L_r \cdot I_{rx} - X_{s1} \cdot (I_{ms} - I_{rx}) \tag{33}$$

$$L_{pr} = \frac{L_{lr} + L_m - L_m{}^2}{L_{ls} + L_m} \tag{34}$$

$$X_{s1} = (2\pi f - \omega_r) \cdot L_{pr} \tag{35}$$

An inner control loop consists of a current regulator, which controls the magnitude and phase of the voltage generated by the converter. Expression of V_{rx} and V_{ry} according to the rotor natural reference frame as follows:

$$V_{r\alpha} = V_{rx} \cdot \cos(\lambda) - V_{ry} \cdot \sin(\lambda) \tag{36}$$

$$V_{r\beta} = V_{rx} \cdot \sin(\lambda) + V_{ry} \cdot \cos(\lambda) \tag{37}$$

where $\lambda = \rho_s - \theta_r$ is a different between phase angle of stator flux-linkage space phasor with respect to the direct-axis of the stationary reference frame and angle of rotor. On basic expression (3) we can compute voltage stator in three-phase.

V. SIMULATION RESULTS

The model was prepared by using of ATP-EMTP program (Figure 5) [7]. Power of the generator is equal 2MWA. Some simulation results are presented. Figure 6 presents compared active and reactive power of generator and obtained from the wind turbine. These parameters are covered, so it's mean that regulators applied in model operate very well. The range of the changing of power load of the machine is very wide. Figure 7 shows the change stator voltage curved lines when a breakdown was formed through ground- phase short circuit which is varies according to changing generator load.

VI. CONCLUSIONS

This paper presents a detailed model for a wind turbine based on DFIG, so that special attention is paid to the description and design overall control system. This control system of DFIG allows governing independently stator side or net active and reactive power. In this model range of changes of generator load is very wide. Simulation result obtain during investigate this model are very satisfactory. The effectiveness of the model was displayed with short circuit curved lines. The design process has been applied to the optimization of wind energy system. Important topics from model and engineering economics are key tools in the optimization process. This practical application will help to motivate students to better understand the theory presented in the classroom.

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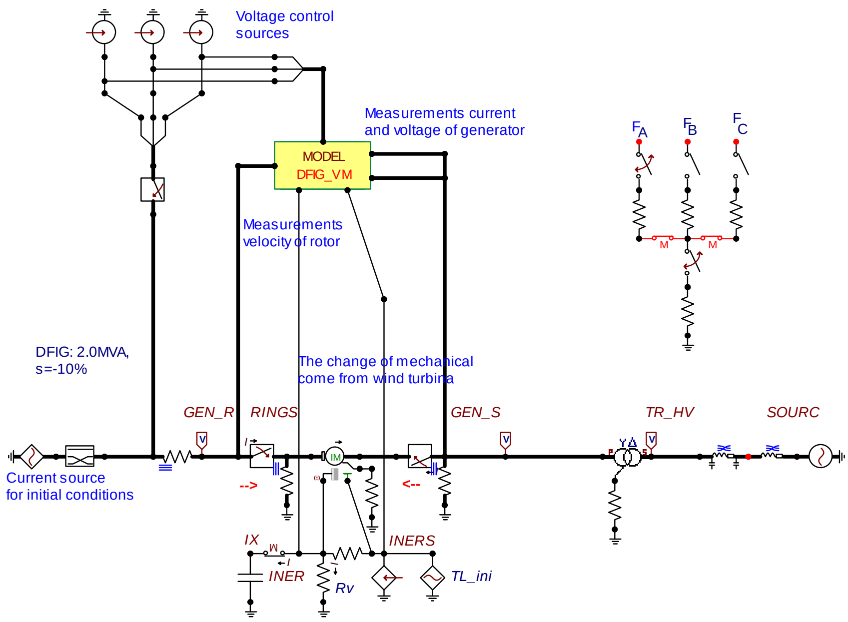

Figure 5. Short circuit diagram in ATP-EMTP

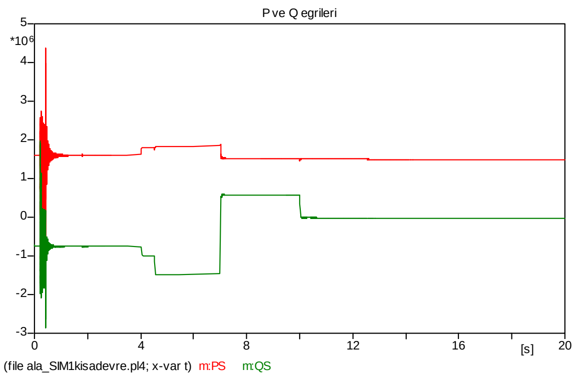

Figure 6. Short circuit, active P_n and reactive Q_n power of the generator come from wind turbine

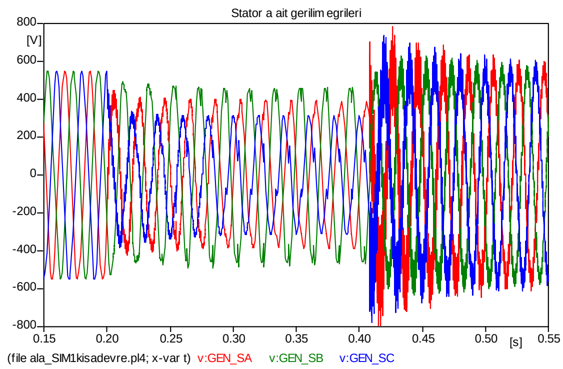

Figure 7. Stator voltage

BIOGRAPHIES

Ahmet Nayir was graduated from Yildiz Technical University (Istanbul, Turkey) with honor diploma on the field of Electrical Engineering (B.Sc.) in 1991. He received the Ph.D. degrees from Physical Institute of Azerbaijan National Academy of Sciences (Baku, Azerbaijan) in 2002. He has been Fatih University (Istanbul, Turkey), where he is currently an Assistance Professor. Since May 2010, he has been work visiting scholar in Institute of Electrical Power Engineering, Wroclaw University of Technology (Wroclaw, Poland). His research interests are focused on wind energy generation, control, analysis and applications in power systems.

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