Design of Dynamic Model of Axial Flux Permanent Generator Using Matlab/Simulink

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***Abstract*—This paper presents an innovative design of a low-speed, direct-drive axial flux permanent magnet (AFPMG) generator with coreless stator and rotor for a wind turbine power generation systemthat is developed using mathematical and analytical methods,dynamic model of the axial flux generator developedusing Simulink / MATLAB that is beneficial tool in electric machines and power electronics courses, or that can be used as a research tool in the laboratory is presented. The model is used to study the dynamic behavior of theaxial flux generator and can be used in various generator -drive topologies with small modifications. The generator model presented is based on the T-type d-q model. A block model approach is used in the construction of the generator** model **that will allow users of the model to resolve reference frame theory issues. The model developed is easy to use, and allows all generator parameters to be easily accessed for monitoring and comparison purposes**

IndexTerms—Dynamic Model,Axial flux permanent magnet,d-q model .

I. INTRODUCTION

Dynamic modeling and simulation ofaxial flux permanent magnet(AFPMG) generator***r***is of great importance to both industry and academiadue to the prevalence of these types of drives in variousindustrial settings. The AFPMG has seen increaseduse in industry in its evolution due to low costs, high electrical loading , resistance and inductance is low because of high torque and better power destiny than radial flux machines(1,2) .The main application these features are attractive are traction and energy generation therefore theses can directly coupled to turbines in low speed energy systems (3,4)wind and hydro generators systems. Dynamic simulations play an important role in thepre-testing of a AFPMG drive systems. (5) Pre-testing is conducted by engineers in industry as well as by researchers in academia. Pre-testing using dynamic simulations can helpresearchers determine the experimental setup that will be usedfor a given set of experimental tests. Simulation techniques have been ongoing and continue toadvance with technology since the inception of simulation studies at institution .The transient behavior of an electric machineis of particular importance when the drive system is to becontrolled [6]. Many different methods and controlalgorithms are available in the literature a lot of technologies had been proposed for direct coupled wind generating applications. But In this paper we use axial flux permanent magnet machine which uses high energy neodymium magnets for rotor field. Application potential includes electricity for remote villages, rural farms and portable power supply. However, these models provide access to a limited number of machine parameters.

For researchers building a dynamic model of an induction motor or other electric machine using basic Simulink blocks is used to studying the dynamic behavior of an electric machine. This paper is organized as follows, is proposed AFPMG are introduced in section II.PROPOSED AFPMG III.Dynamic ModelIV.Mat lab/ Simulink Model.VSimulation Results.VI. Section would be of conclusion.

II. PROPOSED AFPMG

Different topologies of AFPM generators exist in literature. Some designs have single stator and rotorwhile some have multiple stators and rotors. Depending on their configuration, AFPM generator canbe classified as, single-sided, double-sided and multi-stage (modular) generator. These topologies arefurther classified on the basis of the type of stator and rotor being used.The proposed direct-drive, modular AFPM generator has been designed and itsparameters, for a single module, are shown

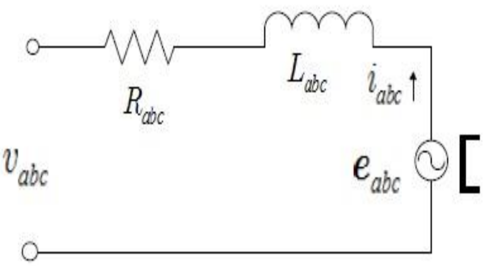


Fig.2 Equivalent Circuit of. AFPMG

Each module of the generator can be electricallydescribed using the equivalent circuit shown in figure 1 The three phase voltage equation of the generator is as follows:

$$V_{abc} = E_{abc} - R_{abc} I_{abc} - L_{abc} \frac{di_{abc}}{dt} \quad (1)$$

E_{abc} is the induced EMF

V_{abc} is the terminal voltage in the single stators of asingle generator module. In order to linearize the time varying inductances

L_{abc}, the three phase dynamic equation at (8) can be converted into *dq0* or synchronous reference frame using the Park's transformation [9]

III. DYNAMIC MODEL

Simulations and analysis in this paper are based on the d-q or dynamic equivalent circuit of the AFPMG represented in the rotating reference frame.

$$K_s = \frac{2}{3}\begin{bmatrix} \cos\theta_m & \cos\left(\theta_m - \frac{2\pi}{3}\right) & \cos\left(\theta_m + \frac{2\pi}{3}\right) \\ \sin\theta_m & \sin\left(\theta_m - \frac{2\pi}{3}\right) & \sin\left(\theta_m + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} (2)$$

$$\theta_m = \int \omega_e dt$$

θ_m is the electrical angular displacement of the generator. After the transformation, the generator dynamic equations are

$$V_d = e_d - R_s I_d - L_d \frac{di_d}{dt} - \omega_e L_q I_q \quad (3)$$

$$V_q = e_q - R_s I_q - L_q \frac{di_q}{dt} - \omega_e L_d I_d (4)$$

$$V_0 = e_0 - R_s I_0 - L_0 \frac{di_0}{dt} \quad (5)$$

Zero sequence quantities can be neglected since the proposed generator is electrically balanced[9]. Moreover, the d-axis reference frame is always aligned along the permanent magnet fluxposition, making the EMF in d-axis of the stator to be zero. Therefore, the dynamic equations of the generator model becomes

$$V_d = -R_s I_d - L_d \frac{di_d}{dt} - \omega_e L_q I_q (6)$$

$$V_q = \omega_e K_{emf} - R_s I_q - L_q \frac{di_q}{dt} - \omega_e L_d I_d \quad (7)$$

Where *d* is the direct axis, *q* is the quadrature axis

V_d is the *d*-axis stator voltage,

V_q is the q-axis stator voltage,

I_d is the *d*-axis stator current

I_q is the *q*-axis stator current

R_s is the stator resistance,

L_d is the *d*-axis inductance,

L_q is the *q*-axis stator self-inductance.

Since in (10)

$$L_q = L_d = L_s (8)$$

The above equations is reducedtoAfter making substitutions, the currents can be expressed as

$$\frac{V_d}{L_s} - \omega_e I_q - \frac{R_s I_d}{L_s} = \frac{di_d}{dt} (9)$$

$$\frac{\omega_e K_{emf}}{L_s} - \frac{V_q}{L_s} - \omega_e I_d - \frac{R_s I_q}{L_s} = \frac{di_q}{dt} (10)$$

Taking Laplace transformation of equations 8 and equations 9 and expressed in terms of current

$$I_d = \left[\frac{\omega_e K_{emf}}{L_s}\frac{1}{S} - \frac{V_q}{L_s}\frac{1}{S} - \omega_e I_d \frac{1}{S} - \frac{R_s I_q}{L_s}\right] (11)$$

$$I_q = \left[\frac{V_d}{L_s}\frac{1}{S} - \omega_e I_q \frac{1}{S} - \frac{R_s I_d}{L_s}\frac{1}{S}\right] (12)$$

The Torque generator of the machine can be written as

$$T_e = 4.85 * P_M * I_q (13)$$

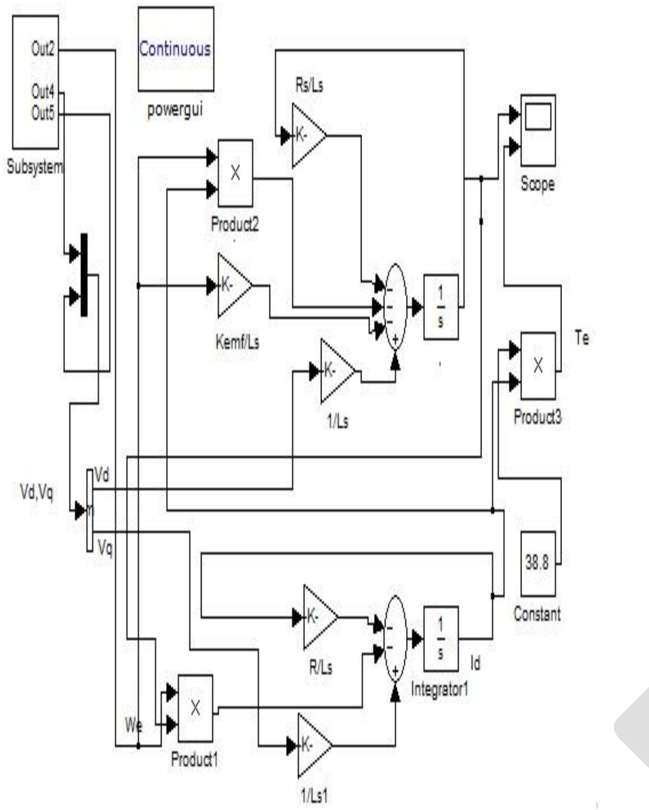
P_M is Number of pole pairs in rotor of AFPMG

Three-phase voltagesis converted to the two-phase stationary frame using the following relationship

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} -(R_s + L_s S) & -(\omega_e L_s) \\ -(\omega_e L_s) & -(R_s + L_s S) \end{bmatrix} \begin{bmatrix} I_q \\ I_d \end{bmatrix} + \omega_e \begin{bmatrix} K_{emf} \\ 0 \end{bmatrix} \quad (14)$$

IV. MAT LAB / SIMULINK MODEL

The approach used to build the Simulink model in this paperis a block type or modular approach. The approach is basedon the idea presented The Simulink model can now be constructed by creating Simulink using (6-7), (12, 13), and (11)equations. EachSimulink system solves one of the model equations in aneasy to understand. The system is constructedusing basic Simulink blocks such as the integrator, gain, sum,etc. The basic Simulink blocks are standard on all versions ofMATLABThe Simulink model presented can also be thought of as being built in layers. TheSimulink model ofAFPMG shown in Figure 2 can be simulated inSimulink or from an *m* file in MATLAB.



The *m* file can be saved, and the Simulink model can be simulated in MATLAB/Simulink by running the *m* file. The subsystem is the transform matrix that converts the three-phase voltages from the abc frame to the two-phase stationary frame.The matrix can be defined in the MATLAB editor. This subsystem implements the sine and cosine functions that are used within the other blocks shown in Figure 3. The trigonometric function block must be used in the implementation of (10-13) for the sine and cosine functions. After all of the model equations have been Implemented in Simulink, all of the subsystems must be tied together to produce Simulink Model of AFPMG system shown in fig .2

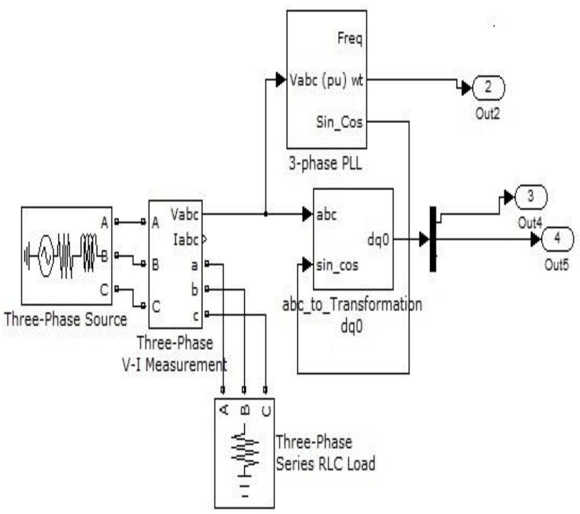


Fig.3. Subsystem that implements Simulink Model of AFPMG

Implemented in Simulink, all of the subsystems must be tied together to produce Simulink Model of AFPMG system shown in fig .2.

V. SIMULATION RESULTS

The system shown in Figure.1.is simulated using the Simulink AFPMG model shown in Figure.2.The parameters of the AFPMG shown in Figure.1.were:L_s= 0.845mH, K_{emf} =4.25Vs ,R_s= .925Ω The model can be used to study the dynamic behavior of theAFPMG, or can be used in various motor-drive topologies with minor modifications. New subsystems can be added to the model presented to implement various types of control schemes

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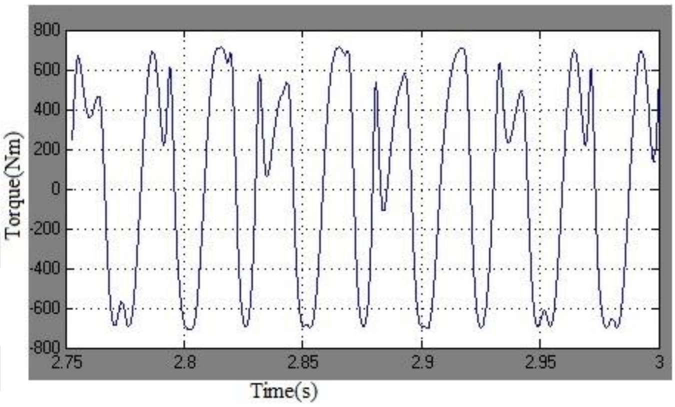

Figure.4. SimulinkElectromagnetic Torque plots of AFPMG.

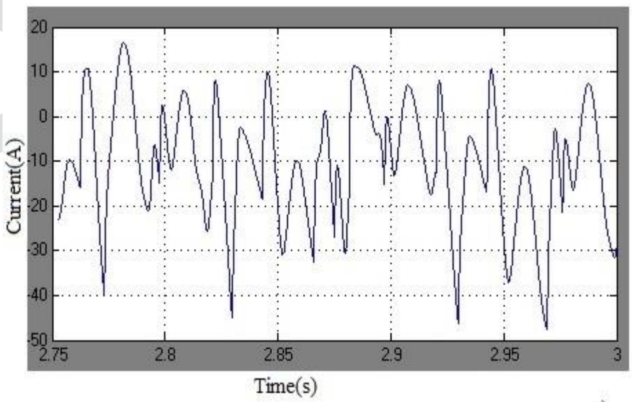

Figure.5. SimulinkCurrent plots of AFPMG

New subsystems can be added to the model presented to implement various types of control schemes. The simulation results for the load torque and the current of theAFPMG are shown in Figure.4.and Figure.5and The model shown in Figure .2. was simulated again with all parameters

VI. CONCLUSION

A dynamic model of theAFPMGdeveloped using Simulink / MATLAB is beneficial for use in electric machines and power electronics courses, or that can be used as a research tool in the laboratory has been presented. A block model approach was used in the construction of the generator model that allows students to resolve reference frame theory issues. The model develop dis intuitive, easy to use, and allows all the parameters to be easily accessed for monitoring and comparison purposes.

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