MATLAB SIMULINK Based DQ Modeling and Dynamic Characteristics of Three Phase Self Excited Induction Generator

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Abstract—In this paper, DQ-modeling approach for Transient State analysis in the time domain of the three-phase self-excited induction generator (SEIG) with squirrel cage rotor is presented along with its operating performance evaluations. The three-phase SEIG is driven by a variable-speed prime mover (VSPM) such as a wind turbine for the clean alternative renewable energy in rural areas. Here the prime mover speed has been taken both as fixed and variable and results have been analyzed. The basic Dynamic characteristics of the VSPM are considered in the three-phase SEIG approximate electrical equivalent circuit and the operating performances of the three-phase SEIG coupled by a VSPM in the Transient state analysis are evaluated and discussed on the conditions related to transient occurs in the system and speed changes of the prime mover.

The whole proposed system has been developed and designed using MATLAB / SIMULINK.

1. Introduction

A wind electrical generation system is the most cost competitive of all the environmentally clean and safe renewable energy sources in the world. It is well known that the three phase self excited induction machine can be made to work as a self-excited induction generator [3, 4], provided capacitance should have sufficient charge to provide necessary initial magnetizing current[5, 6]. In an externally driven three phase induction motor, if a three phase capacitor bank is connected across it's stator terminals, an EMF is induced in the machine windings due to the self excitation provided by the capacitors. The magnetizing requirement of the machine is supplied by the capacitors. For self excitation to occur, the following two conditions must be satisfied:

1 The rotor should have sufficient residual magnetism.

2 The three capacitor bank should be of sufficient value.

If an appropriate capacitor bank is connected across the terminals of an externally driven Induction machine and if the rotor has sufficient residual magnetism an EMF is induced in the machine windings due to the excitation provided by the capacitor. The EMF if sufficient would circulate leading currents in the capacitors. The flux produced due to these currents would assist the residual magnetism. This would increase the machine flux and larger EMF will be induced. This in turn increases the currents and the flux. The induced voltage and the current will continue to rise until the VAR supplied by the capacitor is balanced by the VAR demanded by the machine, a condition which is essentially decided by the saturation of the magnetic circuit. This process is thus cumulative and the induced voltage keeps on rising until saturation is reached. To start with transient analysis the dynamic modeling of induction motor has been used which further converted into induction generator [8, 11]. Magnetizing inductance is the main factor for voltage buildup and stabilization of generated voltage for unloaded and loaded conditions. The dynamic Model of Self Excited Induction Generator is helpful to analyze all characteristic especially dynamic characteristics. To develop dynamic model of SEIG we first develop the dynamic model of three phase induction motor in which the three phase to two phase conversion has been done using Park's transformation, then all the equations have been developed. The traditional tests used to determine the parameters for the equivalent circuit model are open circuit and short circuit test. In this paper the DQ model shown in Fig. 1 has been used to obtain the dynamic characteristics and further a flux oriented controller is proposed to improve the dynamic characteristics.

2. Modeling of Self Excited Induction Generator

The equation shown is used for developing the dynamic model of SEIG

$$[V_G] = [R_G][i_G] + [L_G]p[i_G] + w_{rG}[G_G][i_G] \tag{1}$$

Where **p** represents the derivative w. r. t. time, $[V_G]$ and $[i_G]$ represents 4×1 column matrices of voltage and which is given as $[V_G] = [V_{sd} \quad V_{sq} \quad V_{rd} \quad V_{rq}]^T$ and $[I_G] = [i_{sd} \quad i_{sq} \quad i_{rd} \quad i_{rq}]^T$ $[R]$, $[L]$ and $[G]$ represents 4×4

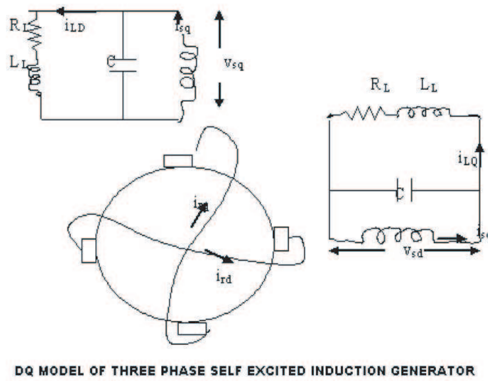

Figure 1: DQ model of three phase induction generator.

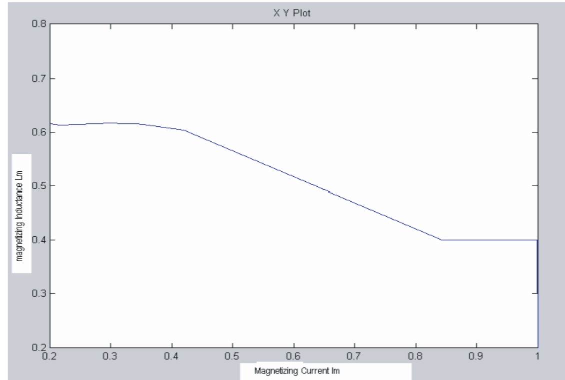

Figure 2: Magnetizing inductance Vs magnetizing current.

matrices of resistance, generator inductance and conductance as given. Further Lm the magnetizing inductance, which can be obtained from the magnetizing curve of the machine shown in Fig. 2,

$$[L]=\begin{bmatrix} L_{sd} & L_{dq} & L_{md} & L_{dq} \\ L_{dq} & L_{sq} & L_{dq} & L_{md} \\ L_{md} & L_{dq} & L_{rd} & L_{dq} \\ L_{dq} & L_{mq} & L_{dq} & L_{rq} \end{bmatrix} [G]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & L_m & 0 & L_r \\ -L_m & 0 & -L_r & 0 \end{bmatrix} [L]=\begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix}$$

The Relation between L_m and i_m is given as

$$L_m = |\Psi_m|/|i_m| \tag{2}$$

Where $|\Psi_m|$ and i_m are the magnetizing flux linkage and magnetizing current. The equation defining L_m Vs $|i_m|$ used in the model is

$$|i_m| = 1.447 * L_m^6 - 8.534 * L_m^5 + 18.174 * L_m^4 - 17.443 * L_m^3 + 7.322 * L_m^2 - 1.329 * L_m + 0.6979 \tag{3}$$

L_{dq} used in matrix L represent the cross saturation coupling between all axes in space quadrature and is due to saturation. $L_{dq} = L_m + i_{md}/i_{mq} * L_{dq}$, $L_{mq} = L_m + i_{mq}/i_{mq} * L_{dq}$. It follows that above equations representing L_{dq}, L_{md}, and L_{mq} that under linear magnetic conditions, $L_{dq} = 0$ and $L_{md} = L_{mq} = L_m$, as expected. The two axes values of the total stator and rotor inductances are $L_{sd} = L_{s1} + L_{md}$, $L_{sq} = L_{s1} + L_{mq}$ and $L_{rd} = L_{r1} + L_{md}$, $L_{rq} = L_{r1} + L_{mq}$.

The above equations L_{s1} and L_{r1} are the leakage inductances of the stator and rotor, respectively. Because of saturation, L_{sd} ? L_{sq}, but it follows from previous arguments that under linear magnetic conditions $L_{sd} = L_{sq}$. Hence $L_r = L_{r1} + L_m$

The electromagnetic torque developed by the generator is given by

$$T_e = (3/4) * P * L_m * (i_{sq} \quad i_{rd} - i_{sd} \quad i_{rq}) \tag{4}$$

Thus it sees that Eq. (1) consists of four first order equations. An induction motor is hence represented by these four first order differential equations. Because of the non-linear nature of the magnetic circuit, the magnitude of magnetizing current, I_m is calculated as

$$I_m = [(i_{sd} + i_{rd})^2 + (i_{sq} + i_{rq})^2]^{1/2} \tag{5}$$

Capacitor side equations are

$$p[v_{sG}] = (1/C)[i_C] \tag{6}$$

further

$$[i_C] = [i_{sG}] + [i_L] \tag{7}$$

Where $[v_{sG}]$, $[i_{sG}]$, $[i_L]$ Column matrices representing direct and quadrature axis component of capacitor current generator stator current and load current respectively.

Load Side Equations

$$[v_{sG}] = L_L \, p \, [i_L] + R_L[i_L] \tag{8}$$

Thus it is seen that complete transient model of the SEIG in d-q axis quasi stationary reference frame consists of equations from (1) to (8).

3. Modeling of Self Excited Induction Generator Using MATLAB SIMULINK

MATAB SIMULINK is powerful software tool for modeling and simulation and accepted globally. The equations from (1) to (8) have been implemented in MATLAB SIMULINK using different blocks. In this paper the step by step modeling of SEIG using SIMULINK has been described.

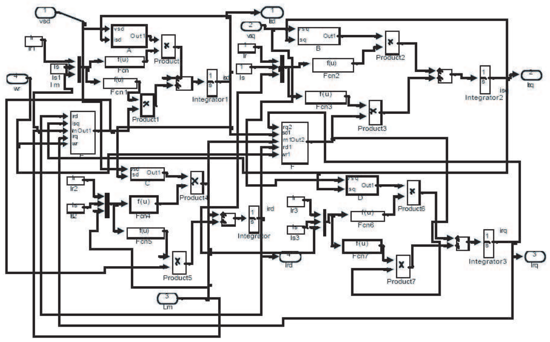

Figure 3: Stator and rotor dq currents.

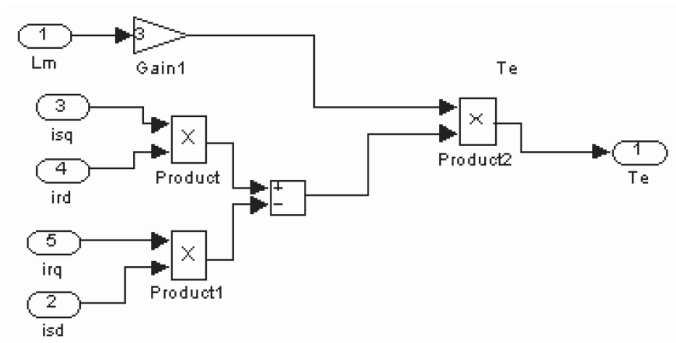

Figure 4: Electromagnetic torque generated.

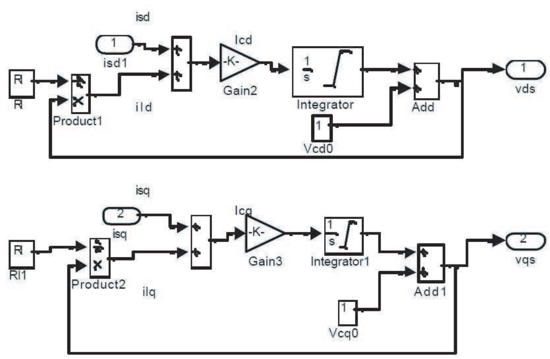

Figure 5: Load voltages.

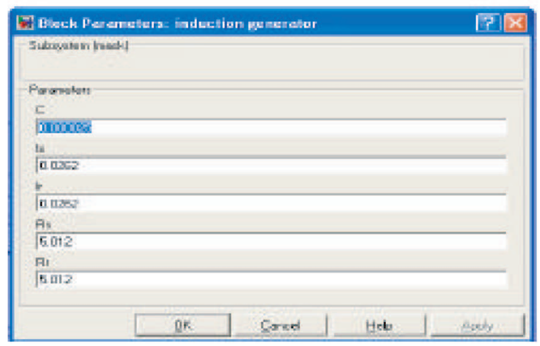

Figure 6: SEIG parameters.

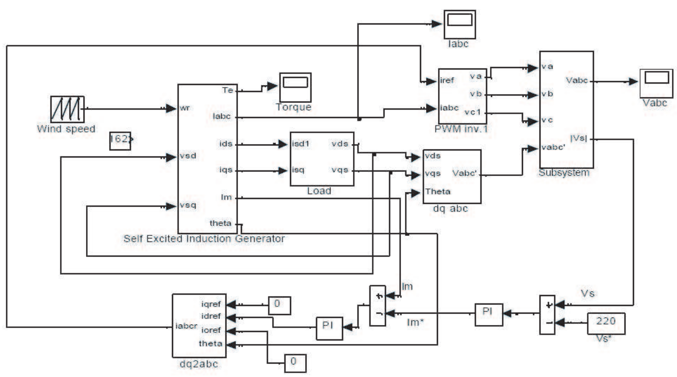

Figure 7: Simulink model of proposed system.

Equation (1) shown has four first order differential equations, for which the solutions gives the four currents (stator *d*-*q* axis currents and rotor *d*-*q* axis currents). Further these currents are the function of constants viz. Stator and rotor Inductances and Resistances, speed, Excitation Capacitance, load resistances. And also variables like Magnetizing Inductance, Magnetizing currents, Electromagnetic torque generated, has been evaluated using (3) to (5). The constraints of non linear magnetizing inductance have been taken into accounts, the curve between Non linear magnetizing inductance vs magnetizing currents is shown in Fig. 2. The equation of this non linear graph has been obtained by curve fitting and hence sixth order nonlinear polynomial equation which is showing the relation between magnetizing inductance vs Magnetizing current. This equation has been implemented using function block in SIMULINK block sets. In Fig. 3, the SIMULINK model of stator and rotor dq currents has been shown, Similarly Fig. 4, shows the electromagnetic torque generated. The load block in which the stator voltage determined has been shown in Fig. 5. To put the various parameters the masking of overall blocks has been done. The values and the masked blocks have been shown in Fig. 6.

4. Modeling Using MATLAB SIMULINK

The equation above described has been implemented in MATLAB / SIMULINK block sets. The equations from 1 to 7 have been implemented in subsystem "Self Excited Induction Generator" whose outputs are Torque, currents, rotor angle (theta), magnetizing current. Similarly the other blocks are Inverter, load, and a subsystem to find three phase voltages.

5. Results and Discussions

The Model has been simulated using MATLAB/SIMULINK shown in Fig. 7. The analysis has been done taking various constraints mainly-(i) assuming constant speed and no controller (Fig. 8), (ii) assuming variable speed without controller (Fig. 9), (iii) Constant speed which going to constant at 0.1 sec with controller (Fig. 10). And finally (iv) variable speed with controller (Fig. 11).

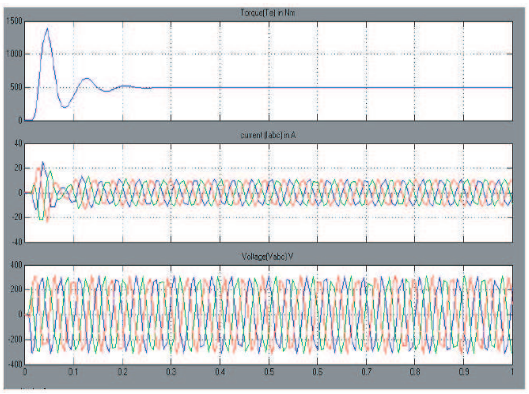

Figure 8: Electromagnetic torque, three phase voltage, current at constant wind speed.

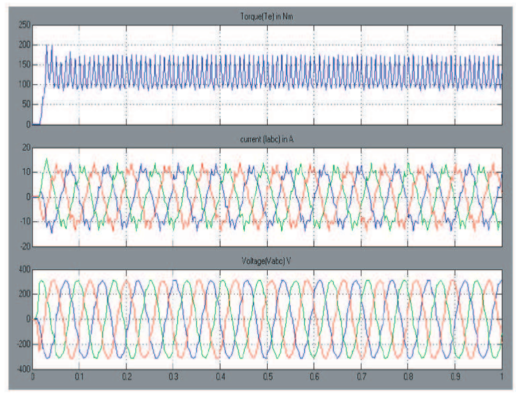

Figure 9: Electromagnetic torques, three phase voltage, current at variable wind speed without controller.

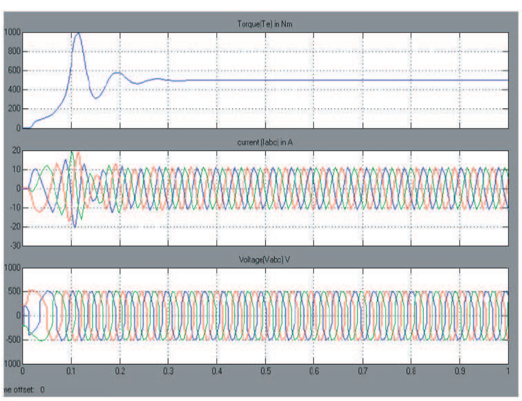

Figure 10: Electromagnetic torque, three phase voltage, current at constant wind speed with controller.

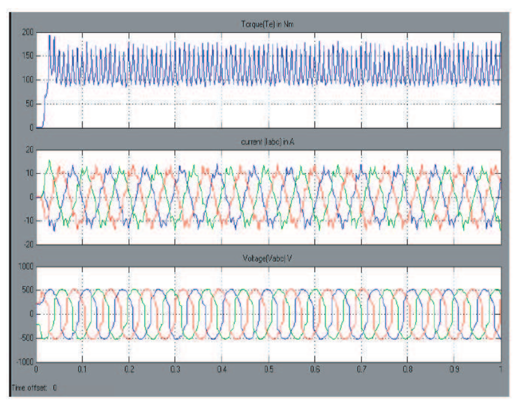

Figure 11: Electromagnetic torque, three phase voltage, current at variable wind speed with controller.

In first case the electromagnetic torque generated has been reached to steady state 0.2 second. Initially transients occur at 0.05 sec when currents goes to 10 ampere provided constant voltage. Note that load is constant all the time and for sake of simplicity resistive load has been considered. In second case the variable wind speed has been considered. To implement the variable speed in SIMULINK a repeating sequence block has been used. It has been observed that the electromagnetic torque developed has been a vibrations in steady state. The currents in this case have some ripple in the waveform. In the third case the controller has been implemented and response has been observed. A ramp signal has been taken which further becomes constant at 0.05 sec, as constant speed starting from zero. As a result a transient has been occurring at 0.05 sec which then comes to steady state at 0.1 sec. And finally the wind speed has been taken as variable speed with controller has been implemented which result no transients has been occur at output currents but some ripples have been still remaining in currents waveform as shown in Fig. 9.

6. Conclusions

Self Excited Induction generator has been found suitable applicability for isolate applications. The estimation of non linear magnetizing inductance is the main factor of converting the Induction motor as self excitation induction generator. To develop the system as wider applicability the controller has been designed to improve the dynamic characteristics of the system. It has been shown that the transients have been removed when controller has been implemented.

7. Specifications of the Machine

10 h.p (7.5 kW), 3-phase, 4 poles, 50 Hz, 415 volts, 3.8 A Delta connection,
Base Voltage / Rated Voltage = 415 V
Base Current / Rated Current = 2.2 A
Rs = 1.0 ohm
Rr = 0.77 ohm
Xls = Xlr = 1.0 ohm
J = 0.1384 kg-m^2

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