Modeling and Analysis of Self Excited Induction Generator in Wind Power Generating System

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Abstract— Generation of pollution free power has become the main aim of the researchers in the field of electrical power generation. Self-Excited Induction Generators (SEIG) used for wind energy conversion in remote and rural areas due to many advantages as standalone induction generator over Grid Connected Induction Generators. However, poor voltage and frequency regulation under varying load and speed is the prime drawbacks of standalone SEIG. Nowadays, modelling is the basic tool for analysis, such as optimization, project, design and control. Steady state analysis for such machines is important to understand their behavior under varying operating conditions. This paper presents a d-q model of SEIG using Matlab/Simulink which put in to the development of SEIG modeling with a limited difficulty. From the sweeping d-q model, the effect of different constraints such as, variation of prime mover speed, and excitation capacitor bank size, on the SEIG output built up process have been addressed and analyzed. The variation of the magnetizing inductance and the non-linearity is also considered in this paper.

Key words: Self Excited Induction Generator, D-Q Model, Matlab/Simulink

I. INTRODUCTION

Wind power generation is increasingly becoming cost Competitive of all the environmentally clean and safe renewable energy sources. Fixed Speed wind power generating systems have gained much popularity among the manufacturers and developers in this field mainly due to the fact that fixed speed wind turbines choice of generator is Squirrel Cage Induction Generator. Unfortunately, the main disadvantage of this generator is that instead of generating reactive power it absorbs reactive power required for real power generation. Two techniques to provide VAR requirements have been for Induction Generator, namely: 1)Grid Connected Induction Generator (GCIG) and-2) Self-Excited Induction Generator (SEIG). In Grid Connected Induction Generator (GCIG) configuration, the generator draws its reactive power from the grid which might have a negative impact on the grid voltage stability when it is connected to a weak power grid. [6, 8] have in detailed explained the principal operation of Grid Connected Induction Generator.

The second method to provide reactive power (VAR) support is provided by connecting appropriate capacitors across the terminals (SEIG principle) which eliminates the need for absorbing reactive power from grid. When the capacitor banks are connected across the stator terminals of an Induction Generator and the Induction Generator is driven externally by a prime mover, the capacitor banks can provide the magnetizing requirement of the Induction Generator. Initially, when the motor first starts to run, the residual magnetism in the rotor circuit will induce a small induced voltage across the stator terminals. If the induced voltage is sufficient, it will produce a capacitive (leading) current flow. The magnetic flux produced by these currents will further assist the residual magnetism in the rotor circuit leading to larger induced voltage. This in turn increases the capacitive currents and resulting flux. The induced voltage and capacitive currents continue to rise until the machine reaches the saturated state [5]. At this operating point, the voltage and current continue to oscillate at a given peak value and frequency. Therefore, for Self Excitation to occur these conditions are necessary to have a sufficient residual magnetism in the rotor circuit. Without residual magnetism in rotor no voltage will build up. In addition, the capacitor banks should have the required size and capability to supply the required excitation VAR.

The main disadvantages of Self-Excited Induction Generator compare to the Grid Connected Induction Generator is that due to off grid mode of operation, the generated terminal voltage and frequency are no longer grid dependent instead they are dependent on factors such as load characteristics, excitation capacitance and prime mover speed. Therefore, any variation in these factors will cause poor voltage and frequency regulations. Understanding the terminal voltage build up process of SEIG and its performance under steady state and dynamic condition is a crucial step toward developing more efficient and competitive SEIG technology. To study and understand the SEIG, it becomes extremely important to have more variety and less complexity in models and simulation tools.

In this Paper, SEIG Model and analysis of its performance under different operating conditions is introduced. A step by step simple d-q model of SEIG is introduced with the implementation of all the required model equations. The first part of this work presents a Matlab/Simulink model which contributes to the development of SEIG modeling with a limited complexity. Since, terminal voltage and frequency depend on prime mover speed, terminal capacitance and load, it is essential to perform the steady-state analysis on such a machine in order to observe its behavior under varying conditions and designing accordingly. a comprehensive study and analysis of SEIG performance is also introduced in this paper. The study demonstrates how excitation capacitance and prime mover speed affect the steady state performance of SEIG under heavy resistive and inductive loads. The paper is organized as follows. Section II presents the set of equations of the d-q model of SEIG. The implementation of the d-q model using Matlab/Simulik has been presented in section III while in section IV simulation results are presented and discussed. The conclusion is drawn in section V. Finally, the specifications of the machine that used in this paper have been listed in section VI.

II. SELF EXCITED INDUCTION GENERATOR MODELING

To understand the dynamic model of SEIG the first step is to convert the 3-phase to 2-phase (d-q) model using Park's transformation. The d-q equivalent circuit of a SEIG connected to an inductive load is shown in Fig 1.

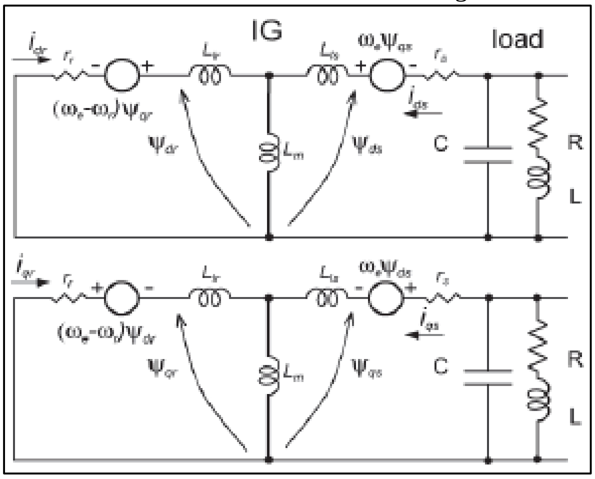

Fig. 1: D-P Model of 3-Phase Induction Generator Connected to an Inductive Load

All the parameters in the d-q equivalent circuit have been obtained experimentally and can be used directly. However, for SEIG application the variation of the magnetizing reactance Lm (or the saturation characteristic of the magnetic core) with voltage should be taken into consideration. Transforming the machine model to d-q axis has changed the machine parameters from time varying to time independent quantities which can be numerically solved.

The instantaneous voltages and currents of the SEIG during
the self excitation process are presented in Equation 1[4].

$$\frac{d}{dt}i_{qs} = L_m K(v_{qr} + \omega L_m i_{ds} - R_r i_{qr} + \omega L_r i_{dr}) - L_r K(v_{qs} - R_s i_{qs} - v_{Lq})$$
$$\frac{d}{dt}i_{ds} = L_m K(v_{dr} + \omega L_m i_{qs} - R_r i_{dr} + \omega L_r i_{qr}) - L_r K(v_{ds} - R_s i_{ds} - v_{Ld}) \quad (1)$$
$$\frac{d}{dt}i_{qr} = L_m K(v_{qs} - R_s i_{qs} - v_{Lq}) - L_s K(v_{qr} + \omega L_m i_{ds} - R_r i_{qr} + \omega L_r i_{dr})$$
$$\frac{d}{dt}i_{dr} = L_m K(v_{ds} - R_s i_{ds} - v_{Ld}) - L_s K(v_{dr} + \omega L_m i_{qs} - R_r i_{dr} + \omega L_r i_{qr})$$

Where,

$$K = \frac{1}{L_m^{\,2} - L_s L_r}$$

The parameters L*s* and L*r* are the leakage inductances of the stator and rotor, respectively. R_s and R_r are the resistances of stator and rotor windings respectively. *R* and *L* are the load resistance and inductance respectively. ω_r is the rotor speed. C is the excitation capacitor.

The variation of the magnetizing inductance is the main factor in the dynamics of the voltage build up and stabilization in SEIGs. The relationship between magnetization inductance L*m* ,and the magnetization current for each induction machine was obtained experimentally by driving the induction machine at synchronous speed.

Lm = 0.205 + 0.0053*Im - 0.0023*Im^2 + 0.0001*Im^3 (2)

The electromagnetic torque developed by the generator is given by Equation 3.

$$T_e = 0.75MP(i_{ds}i_{qr} - i_{qs}i_{dr}) \quad (3)$$

M=Lm is the magnetizing inductance, and *P* is number of poles. $i_{ds}, i_{qr}, i_{qs}, i_{dr}$ are the components of stator and rotor currents on d-q axis.

The magnetizing current is given by Equation 5.4.

$$I_m = [(i_{ds} + i_{dr})^2 + (i_{qs} + i_{qr})^2] \quad (4)$$

For an inductive load conditions, the state equations that describe the voltage across the load terminals of the generator to the current through any RLC load is shown below:

$$i_{cd} = i_{ds} - i_{Ld} \quad (5)$$
$$pV_{Ld} = \frac{i_{cd}}{C} = \frac{i_{qs} - i_{Lq}}{C} \quad (6)$$
$$pV_{Lq} = \frac{i_{qs}}{C} = \frac{i_{qs} - i_{Lq}}{C} \quad (7)$$
$$pi_{Ld} = \frac{V_{Ld} - R_{Ld}}{L} \quad (8)$$
$$pi_{Lq} = \frac{V_{Lq} - R_{Lq}}{L} \quad (9)$$

The stator voltage on both d and q axis are given by 10 and 11.

$$pV_{ds} = \frac{-1(i_{ds} - i_{Ld}\ )}{C} \quad (10)$$
$$pV_{qs} = \frac{-1(i_{ds} - i_{Ld}\ )}{C} \quad (11)$$

Self excited induction generator with an inductive load can be established by implementing the state equations from (1) to (11).

III. THE MATLAB/SIMULINK MODEL

Matlab/Simulink is a powerful software tool for modeling and simulation. The equations (1) to (11) has been implemented in Matlab/Simulink. All the Matlab/Simulink implementation Is shown in Fig.2

IV. SIMULATION RESULTS

The model has been simulated assuming constant speed and no controller using Matlab/Simulink.

Data for simulation

f = 50;	System Frequency, Hz.
Lm = 0;	Mutual Inductance, H.
Ls = 3.49/w;	Leakage Inductance of Stator, H.
Lr = Ls;	Leakage Inductance of Rotor, H.
Rs = 0.696;	Resistance of Stator, Ohm.
Rr = 0.743;	Resistance of Rotor, Ohm.
Lsm = Ls;	Temporary Variables.
Lrm = Lr;	Temporary Variables.
Wr = 314;	Rotor-coupled-Shaft Speed in rad/sec.
P = 4;	Number of Poles.
Td = 15;	Drive-Shaft Torque.(N-m)
J = 0.015;	Inertia of Rotor. (kg-m2)
Rl = 150;	Load Resistance (RL Load), Ohms.
Ll = 50e-3;	Load Inductance (RL Load), H.
Vds = 0.5;	Stator Remnant flux (voltage) - d-axis.
Vqs = 0.5;	Stator Remnant flux (voltage) - q-axis.
C = 57e-6;	Self excitation Capacitance

In below fig Simulink Implementation of SEIG Shown

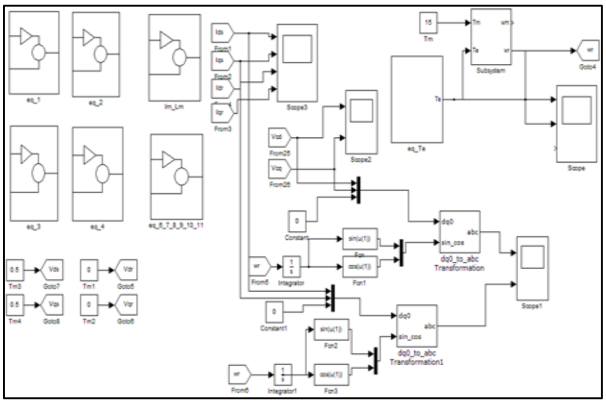

Fig. 2: Simulink Implementation of SEIG Shown

A. *The Output Phase Voltage And Current*

Figure 3 show the output voltage and current of the induction generator, the buildup process of the generated voltage is successful. where the capacitance value Cg is equal to 107.5 µf, then the amount of reactive power produced from the excitation capacitor is sufficient to the SEIG excitation process.

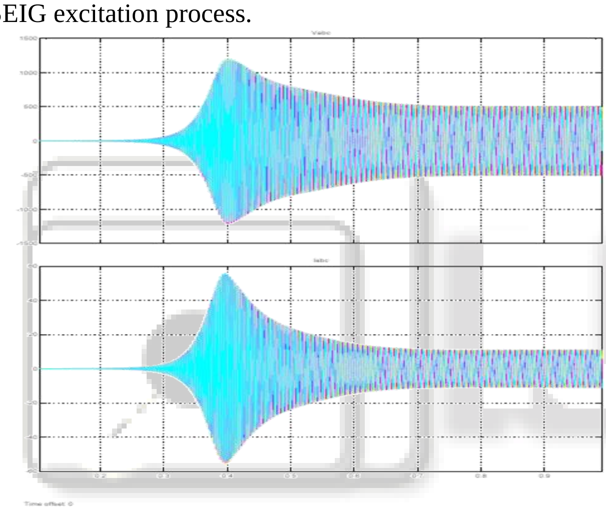

Fig. 3: The output phase voltage waveform and output current waveform when Td=15 N.m C=57 µF, and load L R =100Ω, L=20mH

B. *Self Excitation Capacitance Effect*

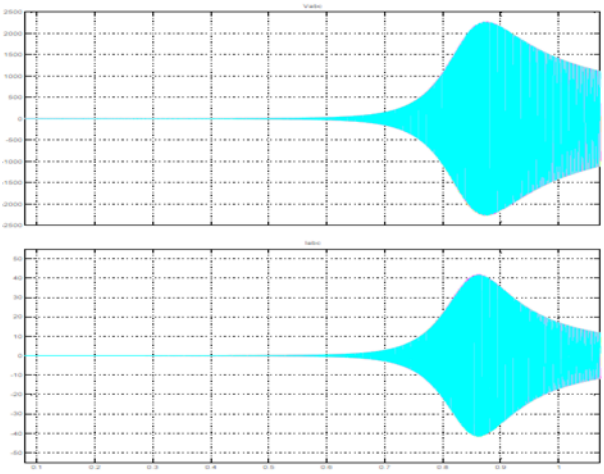

Fig .4: The output phase voltage waveform and output current waveform when Td=15 N.m C=10 µF, and load L R =50Ω, L=50mH

Figure 4 shows build up process of generated voltage is also successful, but after a longer time, due to decreasing the value of the excitation capacitor and then the amount of the reactive power produced from is critically sufficient to the SEIG excitation process.

C. *Drive-Shaft (Input) Torque Variation Effect*

Figure 5 shows build-up process of generated voltage is also successful but after a Longer time, due to decreasing the Drive-Shaft Torque to 3 Nm.

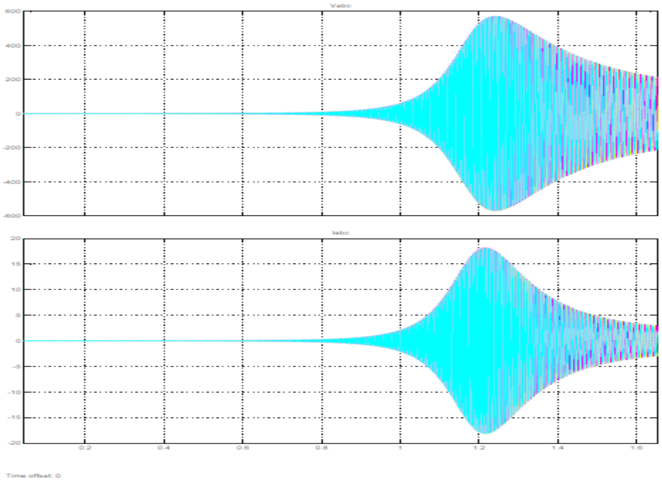

Fig. 5: The output phase voltage waveform and output current waveform when *Td=3 N.m C=*57 µF, and load *L R* =150Ω, L=50mH

V. CONCLUSION

Even though, tremendous literature is available on modeling of self-excited induction generator, a lack of d-q model variety has been noticed especially in terms of the simplicity of the implementation. In this paper, a detailed d-q model of SEIG is presented using Matlab/Simulink which contributes to the development of SEIG modeling with a limited complexity. The proposed model is much simpler from the implementation point of view. Since, terminal voltage and frequency depend on prime mover speed, excitation capacitor and load, it is essential to perform the steady-state analysis on such a machine in order to observe its behavior under varying conditions and designing accordingly. Therefore, a comprehensive study and analysis of SEIG performance is also introduced in this paper. The study demonstrates how excitation capacitance and prime mover speed affect the steady state performance of SEIG under heavy resistive and inductive loads. The results have shown that the value of the excitation capacitor must be well calculated in order to assure a successful starting of the SEIG. Furthermore, it was concluded that self-excited induction generator has critical excitation capacitor size at constant rotor speed. The output voltage magnitude follows the variation of the rotor speed, decreasing the rotor speed will lead to decrease the output voltage. This demonstrates the voltage regulation problem of the SEIG when it is used for wind application (rotor speed varying with wind speed varying). The output build up voltage process follows the variation of the magnetizing inductance. The relationship between the magnetizing inductance and the magnetizing current has to be taken into account to derive the magnetizing inductance

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