

Dynamic Modelling and Analysis of Three Phase Self Excited Induction Generator using Matlab

Bhim Singh, Madhusudan, and A.K. Tandon

Abstract--This paper presents a dynamic modeling and analysis of a self excited induction generator using MATLAB and Simulink toolbox. The dynamic model of the self-excited induction generator (SEIG) in direct-quadrature axes and stationary reference frame is derived from fundamentals with sufficient physical insight. The current state space modeling of the induction generator has been considered. The three-phase machine is assumed to have balanced windings, thus making zero sequence components to be zero. This model allows elegant simulation of self excited induction generator for detailed analysis on the behaviour of electrical variables under transient conditions. The transient voltage build up is analysed and observed to be satisfactory. The SEIG system is observed to withstand under sudden load perturbation also and it reaches new steady state without much overshoot.

Index-Terms--Self excited induction generator, Dynamic modeling, MATLAB.

I. INTRODUCTION

In recent years, with the ever-increasing crises of electrical energy especially in developing countries, there is a growing trend towards the utilization of renewable energy sources such as wind, hydro etc. in the generation of electric power. In most of the cases, induction generator driven by wind or hydraulic turbines is used for generating electricity.

This is mainly due to their robust and simple construction, low price and reduced maintenance cost, no synchronization required, better transient characteristics. The fundamental problem with the SEIG is its inability to control the terminal voltage and frequency under varying load conditions. In order to regulate its terminal voltage with the load and utilize the machine to its rated capacity, an external source of reactive current is required [1]-[6].

Steady state analysis of induction generator is of interest both from design and performance calculation point of view [7]. Whereas, the dynamic analysis [8]-[14] is one of the key steps in the validation of the design process of the generator systems and its protection circuits and thus eliminating inadvertent design mistakes and resulting errors in the prototype construction and testing. In the later analysis is more involved. A dynamic model of the generator is used to design the controller for regulating voltage and to analyze the transient response of the system under sudden load changes in actual operating condition.

Bhim Singh is with the Deptt. of Electrical Engg. Indian Institute of Technology, New Delhi-110016, E-mail: bsingh@ee.iitd.ac.in
 Madhusudan is with the Deptt. of Electrical Engg. Delhi College of Engg., Delhi-110 042
 E-mail : madhusudan_s2@rediffmail.com
 A.K. Tandon is with the Deptt. of Electrical Engg., Delhi College of Engg., Delhi-110 042

In this paper, a MATLAB/Simulink [15]-[18] based dynamic model of a SEIG is presented. The d-q axes model in a stationary reference frame is developed in order to simulate the investigated system consisting of the SEIG and self-excitation capacitor.

II. DESCRIPTION OF THE SEIG SYSTEM

Fig.1. shows the schematic diagram of a three phase SEIG feeding a three-phase load. A delta connected balanced excitation capacitor bank combined with a delta connected balanced three phase load is connected to stator terminal of the SEIG. The three-phase capacitor bank feeds the reactive power necessary for initiating self-excitation, when a prime mover is used to drive the rotor of the machine around the base synchronous speed of the machine to develop voltage at rated frequency.

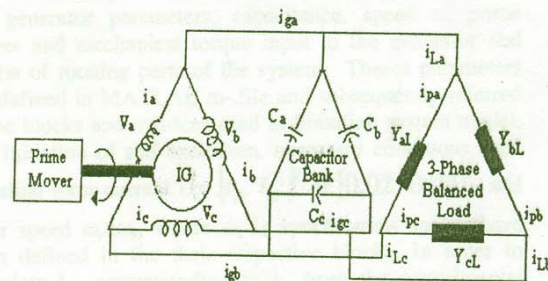


Fig.1.Schematic of the SEIG system

III. MODELLING OF THE SEIG

The circuit model of a three-phase capacitor excited induction generator in stationary d-q axes reference frame is shown in Fig.2. The voltage and current relation ship of the SEIG in d-q stationary reference frame is described as:

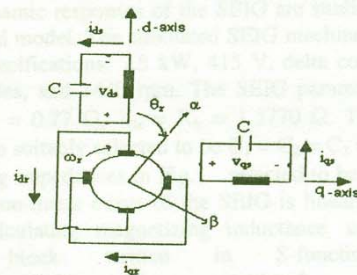


Fig.2 Circuit model of three phase SEIG in the d-q axis stationary reference frame

$$[v] = [R][i] + [L] p [i] + \omega_r [G][i] \quad (1)$$

where p is time derivative and $[v]$, $[i]$, $[R]$, $[L]$ and $[G]$ are the voltage, current, resistance, and transformer inductance and rotational inductance matrices defined as :

$$[v] = [v_{ds} \ v_{qs} \ v_{dr} \ v_{qr}]^T \quad (2)$$

$$[i] = [i_{ds} \ i_{qs} \ i_{dr} \ i_{qr}]^T \quad (3)$$

$$R = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & 0 & R_r & 0 \\ 0 & 0 & 0 & R_r \end{bmatrix} \quad (4)$$

$$L = \begin{bmatrix} L_{ls} + L_m & 0 & L_m & 0 \\ 0 & L_{ls} + L_m & 0 & L_m \\ L_m & 0 & L_{lr} + L_m & 0 \\ 0 & L_m & 0 & L_{lr} + L_m \end{bmatrix} \quad (5)$$

$$G = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & -L_m & 0 & -(L_{lr} + L_m) \\ L_m & 0 & L_{lr} + L_m & 0 \end{bmatrix} \quad (6)$$

Where subscripts denote

s, r = stator and rotor quantities

L_{ls} , L_{lr} = stator and rotor leakage quantities

m = variables quantities associated with magnetizing flux and current.

The SEIG operates in the saturation region and its magnetizing characteristic is non linear in nature. The magnitude of magnetizing current is calculated as:

$$i_m = \sqrt{(i_{ds} + i_{dr})^2 + (i_{qs} + i_{qr})^2} \quad (7)$$

Magnetizing inductance (L_m) is calculated from the magnetizing characteristic plotted between L_m and i_m through synchronous speed test on the machine. The mechanical torque equations of the SEIG can be described as:

$$T_m - T_e = \frac{2J}{P} \frac{d\omega_r}{dt} \quad (8)$$

Further, developed electromagnetic torque is as:

$$T_e = \frac{3}{2} \left(\frac{P}{2} \right) L_m (i_{dr} i_{qs} - i_{qr} i_{ds}) \quad (9)$$

where P is the number of poles, ω_r the rotor speed, J the inertia constant of the system and T_m the applied torque, T_e the electromagnetic torque of the generator.

Initiation of self-excitation is based on residual magnetism in the rotor circuit and voltage build up with the support of reactive current supplied by the fixed capacitor. The voltage matrix $[v_s] = [v_{ds} \ v_{qs}]^T$, comprising the direct and quadrature axes components of the stator voltage is the set of dependent variables derivable from the terminal

capacitance C and its charge $[q_c] = [q_{cd} \ q_{cq}]^T$ as $[v_s] = [q_c]/C$ which on differentiation w.r.t. time gives:

$$p[v_s] = \frac{1}{C} [i_c] \quad (10)$$

$$[i_c] = [i_s] - [i_L] \quad (11)$$

where, $[i_c]$, $[i_s]$ and $[i_L]$ are 2×1 column matrices representing direct and quadrature axes components of capacitor current, generator stator current and load current respectively.

$$[i_c] = [i_{dc} \ i_{qc}]^T, [i_s] = [i_{ds} \ i_{qs}]^T,$$

$$[i_L] = [i_{dL} \ i_{qL}]^T$$

Hence the SEIG system is represented by equations (1)-(11). The dynamic equations are written in current and speed derivative form, which can be implemented in MATLAB/Simulink for dynamic analysis of SEIG system.

IV. MATLAB / Simulink SIMULATION

The set of system model equations given by equations (1)-(11) for balanced excitation are implemented using Simulink library functions and some S- function blocks, especially required for calculating L_m from experimental magnetization characteristic of the SEIG.

The input data to the simulation blocks consist of the generator parameters, capacitance, speed of prime mover and mechanical torque input to the generator and inertia of rotating parts of the system. These parameters are defined in MATLAB m-file and subsequently referred to the blocks and matrices used in Simulink system model. For initiation of self excitation, necessary conditions such as initial rotor current i.e. $[i_{dr} \ i_{qr}]^T = [0.02 \ 0.02]^T$ and

rotor speed $\omega_r \geq \omega_s$, where ω_s is synchronous speed, have been defined in their respective blocks. In order to calculate L_m corresponding to i_m from the experimental magnetizing characteristic of the SEIG a S-function termed as L_m estimator has been developed using MATLAB script and thus the magnetizing current value is continuously updated which subsequently update the $[L]$ and $[G]$ matrices to obtain $p[i]$, $p\omega_r$ and $p[q]$. Finally using reverse transformation three phase quantities $[v]_{abc}$ and $[i]_{abc}$ are obtained from their respective d-q variables.

V. RESULTS AND DISCUSSION

Dynamic responses of the SEIG are studied using the developed model. The simulated SEIG machine has the following specifications: 7.5 kW, 415 V, delta connected, 50 Hz, 4 poles, and 1440 rpm. The SEIG parameters are $R_s = 1 \ \Omega$, $R_r = 0.77 \ \Omega$, $X_{ls} = X_{lr} = 1.3770 \ \Omega$. The three capacitors are suitably selected to be $C_1 = C_2 = C_3 = 90 \ \mu F$. Three loading impedances in Fig.1 selected to be at $60 \ \Omega$ each. The non-linear curve of the SEIG is linearized and used for calculating magnetizing inductance, using L_m estimator block written in S-function of MATLAB/Simulink. The simulated dynamic characteristics and their associated experimental results

under different switching conditions are shown in Fig.3. to Fig.8.

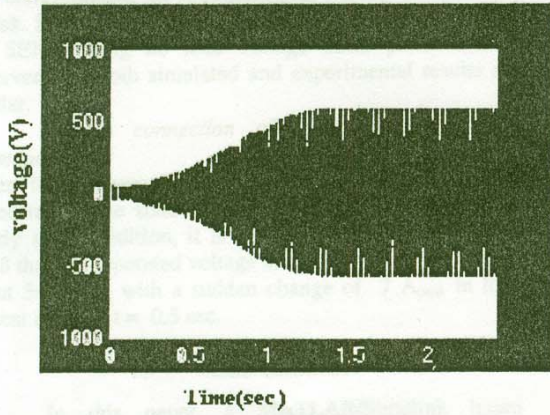


Fig.3. Simulated dynamic response of the SEIG during no load voltage buildup process

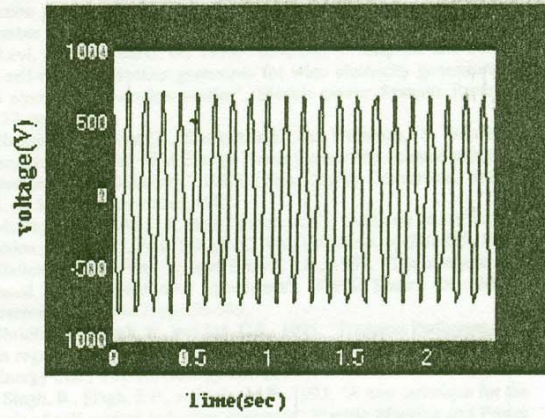


Fig.6. Simulated dynamic response of SEIG voltage on load

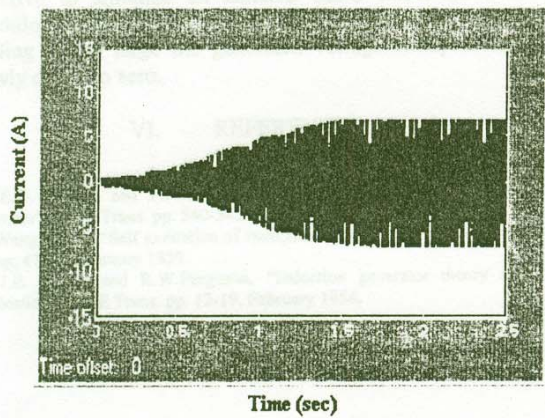


Fig.4. Simulated SEIG current during no load voltage buildup process

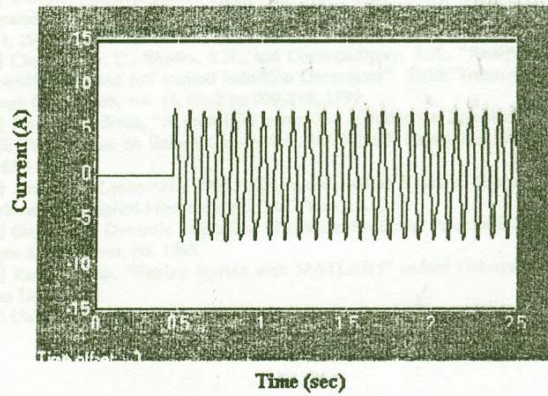
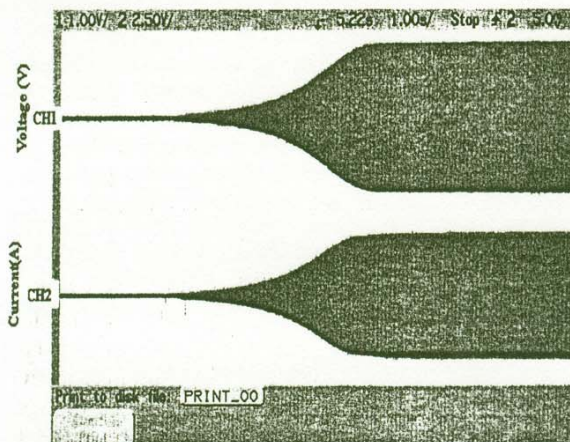
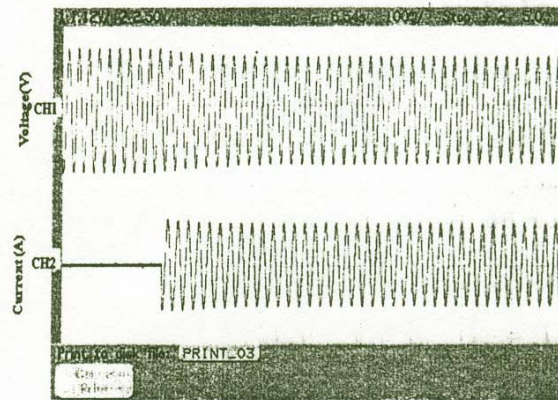


Fig. 7. Simulated load current



Actual Scales on Y-axis, CH1, 391V/div, CH2, 4.7A/div
Fig.5. Experimental dynamic response of the SEIG during no load voltage buildup process



Actual Scales on Y-axis, CH1, 391V/div, CH2, 7A/div
Fig. 8 . Experimental dynamic response of SEIG voltage and load current

A. Voltage buildup process under No-load condition. Fig.3 and Fig.4 show the simulated responses of the SEIG no load voltage build up and the corresponding generator

current with balanced excitation capacitors. It is observed that the steady state generated voltage is about $587 V_{\text{peak}}$ and corresponding no load generator current is about $9.8 A_{\text{peak}}$. Fig.5 shows the experimental dynamic response of the SEIG during no load voltage build process. It is observed that both simulated and experimental results are similar.

B. Sudden connection of three phase balanced resistance loads

When three identical resistive loads are simultaneously connected to the stator terminals of the SEIG under the steady state condition, it is observed from the Fig.6. and Fig.8 that the generated voltage dropped from $587 V_{\text{peak}}$ to about $542 V_{\text{peak}}$ with a sudden change of $7 A_{\text{peak}}$ in load current at about $t = 0.5$ sec.

V. CONCLUSION

In this paper, a MATLAB/Simulink based dynamic model of the SEIG system has been discussed and the experimental and simulated results under various switching conditions are presented. Both experimental and simulated results are very close. The developed model is effective to simulate an isolated SEIG under no load condition as well as sudden switching in resistors. If the loading is too large the generated voltage collapses and slowly decay to zero.

VI. REFERENCES

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