Modeling and Simulation of an Asynchronous Generator Fed with RLC Series Circuit in an isolated Power Generation System

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Abstract—This paper expounds a simulation model of a self-excited asynchronous generator (SEASG) feeding RL load in conjunction with an AC/DC/AC converter fed RLC series circuit connected at the point of common coupling (PCC). Simulation model of the proposed system have been developed by using Mat lab/Simulink. The result shows that the effect of RLC series circuit when operated at variable frequency affects the generation voltage profile. This reflects that an additional capacitance or inductance effect is possible to inject when the RLC is operated at frequency lower than the resonance frequency or the higher than the resonance frequency. This simulation model validates the injections of capacitance in SEASG is possible to match the lagging reactive power of the RL load to maintain a constant voltage at the load bus.

I. INTRODUCTION

The use of non-conventional energy sources has become eminent due to fast depletion of conventional energy sources. The recent trend to tap solar, wind and tidal energy are becoming popular amongst the renewable energy sources. At present, to decentralize the power generation system, attempts have been in the direction of generating small power and distributing it locally. This prompted the use of wind and solar energy to cope with the present day energy crises. Self-excited asynchronous generator has emerged as a possible alternative for isolated power generation from renewable energy sources because of its low cost, less maintenance and rugged construction [1]-[3]. However, it requires a suitable controller to regulate the voltage due to variation of consumer loads. From the characteristics of voltage generation in a SEASG, it is essential to have a variable capacitance at the machine terminals to maintain constant voltage with variable load.

J. K.Chatterjee et al [4] has developed a variable lagging reactive volt-ampere (VAr) source/sink to maintain the generation voltage of SEASG constant. K. K. Ray [5] applied the above concept in a stand-alone system and verified it experimentally. S.S. Murthy et al [6]-[7] explain the steady state analysis of self-excited induction generators. R. Bonert et al [8]-[9] discussed the impedance controller of SEASG for voltage regulation. S.S. Murthy et al discussed the practical implementation of electronic load controller in his works [10]-[11]. Since voltage and frequency of an ASG is dependent on load and the speed of the prime mover, the authors made an attempt to investigate the effect of series resonance circuit on input side of uncontrolled rectifier experimentally by keeping the prime mover speed constant [12] - [13]. The subsequent section describes the system configuration. In Section–III Modeling of the proposed scheme has been explained in details. Control strategies have been discussed in section IV. Section V and VI discuss the interpretation of the result and conclusion respectively.

II. MATHEMATICAL MODELING

![Schematic arrangement of proposed stand alone power system](image)

Figure 1: Schematic arrangement of proposed stand alone power system
The mathematical model of the system refers the equations (1) - (13) is developed through using Matlab/Simulink software [14]. It is well known that when a squirrel cage induction motor is driven at a speed higher than the synchronous speed a voltage will be induced in the stator terminals when external capacitance is connected across the stator terminals. The magnitude of the voltage builds up depends on the capacitance value to neutralize the magnetizing reactance of the machines. This technique is known as self-excitation [1].

A. D-Q Axis Modeling of Asynchronous Generator

Figure 2: d-q axis equivalent circuit model of a SEASG

From Fig.2 the loop equations of the d-q axis

\[ R_i q + L_{s} \frac{dq}{dt} + \frac{1}{C} \frac{ds}{dt} + L_{m} \frac{dq}{dt} = \frac{v_d}{m} \]  
\[ R_i q + L_{s} \frac{dq}{dt} + L_{m} \frac{ds}{dt} = \omega L_{e} \]  
\[ R_i q + L_{s} \frac{dq}{dt} + L_{m} \frac{ds}{dt} = V_{dc} \]  
\[ R_i q + L_{s} \frac{dq}{dt} + L_{m} \frac{ds}{dt} = V_{qc} \]

The dynamic characteristic behavior of SEAS Gind–q Axis equivalent circuit model [15] is used for simulation. The magnetizing current \( i_m \) and generated air gap voltage can be calculated using equations (5) and (6) respectively:

\[ |i_m| = \sqrt{(0q_s + i_q r)^2 + (0d_s + i_d r)^2} \]  
\[ V_g = \phi L_m |i_m| \]

It should be noted that \( L_m \) is not constant but a function of the magnetizing current \( i_m \) given as

\[ L_m = f(|i_m|) \]

The developed electromagnetic torque and the torque Balance equations are written as

\[ \tau_e = \left( \frac{3}{2} \right) \left( \frac{p}{2} \right) L_m (G_{dr} i_{qs} - i_{qr} i_{ds}) \]  
\[ T_{Shaft} = \tau_e + \left( \frac{2}{p} \right) \frac{do_r}{dt} \]

The speed derivation of torque balance equation is expressed in equation (10)

\[ \frac{do_r}{dt} = \left( \frac{p}{2J} \right) (\tau_e - T_{Shaft}) \]

The generated phase voltage and the stator currents derived from d-q axes values using equation (11)
B. Modeling of Bridge Diode Rectifier

The diode bridge model is developed with ideal switches and the total loss of the bridge is represented by a lumped resistor R which is added to the dc resistance DC with the help of three Heaviside functions. These Heaviside functions determine whether the diode is in conducting state or in blocking state. The functions $g_k$ (where, $k = 1, 2, 3$) are defined from the graph shown in Fig.3. The three phase voltages are expressed through the equation (12).

\[
\begin{align*}
    v_a &= v_1 \cos \theta_1 + i_2 \sin \theta_1 \\
    v_b &= v_1 \cos \left( \theta_1 - \frac{2\pi}{3} \right) + i_2 \sin \left( \theta_1 - \frac{2\pi}{3} \right) \\
    v_c &= v_1 \cos \left( \theta_1 + \frac{2\pi}{3} \right) + i_2 \sin \left( \theta_1 + \frac{2\pi}{3} \right) \\
    i_a &= i_1 \cos \theta_1 + i_2 \sin \theta_1 \\
    i_b &= i_1 \cos \left( \theta_1 - \frac{2\pi}{3} \right) + i_2 \sin \left( \theta_1 - \frac{2\pi}{3} \right) \\
    i_c &= i_1 \cos \left( \theta_1 + \frac{2\pi}{3} \right) + i_2 \sin \left( \theta_1 + \frac{2\pi}{3} \right)
\end{align*}
\]  

Figure 3: Definition of the $g_k$ function ($k = 1, 2, 3$)

\[ e_1 = g_1 V_{dc}, e_2 = g_2 V_{dc}, e_3 = g_3 V_{dc} \]  

Using the above equation (12) the phase voltages are computed through the equation (13)

\[ u_1 = f_1 V_{dc}, u_2 = f_2 V_{dc}, u_3 = f_3 V_{dc} \]  

Where,

\[ f_1 = \frac{2g_1 - g_2 - g_3}{3}, f_2 = \frac{2g_2 - g_1 - g_3}{3} \text{ and } f_3 = \frac{2g_3 - g_1 - g_2}{3} \]

From the above equation (12) and (13) the dc side current is given by

\[ i_{dc} = g_{11} + g_{22} + g_{33} \]  

C. Inverter Model

A pulse width modulated (PWM) converter model was constructed with Insulated Gate Bipolar Transistor (IGBT). The current drawn by the RLC series circuit is synthesized to obtain the lagging and leading reactive power requirement to be injected into the system to maintain the load bus voltage constant. On the basis of this information the inverter is operated at frequencies either below or above the resonance frequency.

D. Simulation Model

A simulation model of the proposed isolated self excited Asynchronous power generation system Fig.A-1is developed in MATLAB. A 2.2kW, 415V, 50Hz, 4-pole, Y-connected asynchronous generator is considered as the rating of the machine model. The data of saturation characteristics of the machines is obtained from synchronous speed test. Simulation is carried in MATLAB version 7.1 in discrete mode with ode 23tb (stiff/TR-BDF-2) solver.

IV. CONTROL STRATEGY

The control scheme of the proposed stand-alone power generation system is shown in Fig. 4. The controller is used to provide the single point operation with constant voltage and frequency along with constant excitation capacitor of SEASG. The control scheme is based on the generation of reference source currents [16] given in equation (15). The instantaneous power delivered by the source is equal to the sum of the instantaneous power absorbed by the load and the RLC series circuit (assume the switching losses are...
negligible). The RLC series circuit compensates the lagging VAR required by the load when operated at a frequency lower than the resonance frequency.

\[
i_{\text{source}} = i_{\text{load}} + i_{\text{RLC}}
\]  

\( \text{(15)} \)

V. RESULT

The simulation results of the DC side input current of the Inverter is shown in Fig.4 for inverter frequency lower and higher than the resonance frequency. The waveform clearly shows that the frequency higher than the resonance Frequency the input side current is lagging where as with Frequency lower than the resonance frequency it is leading. This phenomenon of drawing leading and lagging current also observed at PCC shown in Fig.5

![Figure 4: Superimposed DC current waveform](image)

![Figure 5: Voltage and current waveform of the proposed system at PCC](image)

REFERENCES


![Figure A-1: Simulation block diagram of the proposed system](image)