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Modeling and Simulation of an Asynchronous Generator with AC/DC/AC Converter Fed RLC Series Circuit in an Isolated Power Generation System

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ABSTRACT

The aim of the study is to simulate the model of a self-excited asynchronous generator (SEASG) feeding R L 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 has been developed by using Matlab/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 a frequency lower or higher than the resonance frequency. This simulation model validates that the injections of capacitance in a SEASG are possible to match the lagging reactive power of the RL load to maintain a constant voltage at the load bus.

Keywords-*asynchronous generator; rectifier-inverter, simulation model*

NOMENCLATURE

VAR	Volt-Amperes Reactive
ASG	Asynchronous Generator
RSE	Renewable Sources of Energy
SEASG	Self-Excited Asynchronous Generator
DC	Direct Current
AC	Alternating Current
ASDs	Adjustable Speed Drives
UPS	Uninterruptible Power Supplies
FACTS	Flexible AC Transmission Systems
VSIs	Voltage Source Inverters
CSIs	Current Source Inverters
THD	Total Harmonic Distortion
PWM	Pulse Width Modulation
IC	Integrated circuit
IGBT	Insulated Gate Bipolar Transistor
v_{ds}, v_{qs}	d- and q- axis stator voltages
v_{dr}, v_{qr}	d- and q- axis rotor voltages
i_{ds}, i_{qs}	d- and q- axis stator currents
i_{dr}, i_{qr}	d- and q- axis rotor currents
ds, qs	d- and q- axis stator flux linkages
dr, qr	d- and q- axis rotor flux linkages

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 made 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 crisis. Self-excited asynchronous generator(SEASG) 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] have 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] explained 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 detail. Control strategies have been discussed in section IV. Section V and VI discuss the interpretation of the result and conclusion respectively.

An instantaneous reactive power compensator (i.e. AC/DC/AC along with RLC series circuit)is proposed in this paper to balance the instantaneous reactive power required by the load.

II. SYSTEM CONFIGURATION

The schematic arrangement of the proposed system is shown in Fig.1. It consists of a SEASG, rectifier – inverter fed RLC series circuit with RL load. SEASG is driven at a constant speed along with static capacitor at the stator terminals of the SEASG. The effect of changing load on the generated voltage was found to be drooping with an increase of load. To compensate this drooping voltage, an R L C series resonance circuit fed from an AC/DC/AC converter is connected at PCC.

The AC/DC/AC converter is operated at a frequency lower than the resonance frequency to inject the capacitance effect on the system such that the voltage drop due to inductive load is compensated. The resonance circuit thus could operate to inject lagging or leading VAR effect on the input current by operating the AC/DC/AC converter at various frequencies. An instantaneous reactive power compensator (i.e. AC/DC/AC along with RLC series circuit)is proposed in this paper to balance the instantaneous reactive power required by the load.

III. MATHEMATICAL MODELING

The mathematical model of the system refering equations (1) - (13) is developed 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 built up depends on the capacitance value to neutralize the magnetizing reactance of the machines. This technique is known as self-excitation [1].

A. Dynamic D-Q Model

The dynamic performance of an ac machine is somewhat complex because the three-phase rotor windings move with respect to the three-phase stator windings as shown in figures.1(a),1(b) and 1(c)

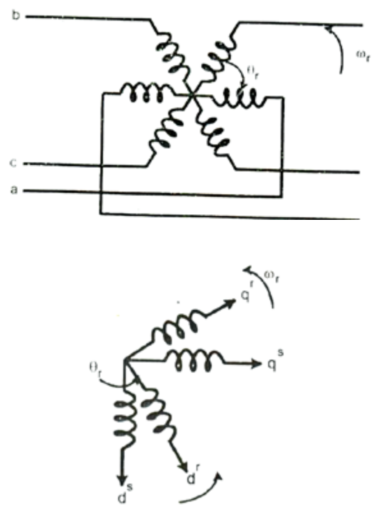

Fig. (a)Coupling effect in three-phase Stator and rotor windings (b). Equivalent two-phase machine

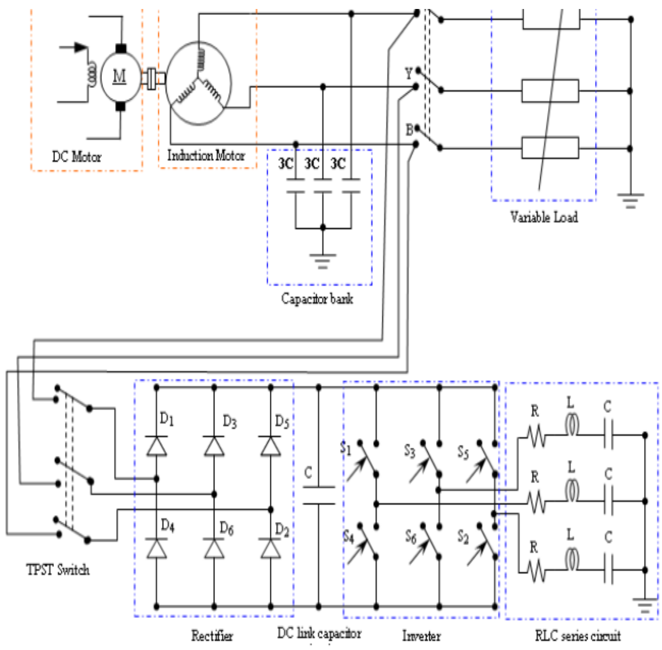

Fig.1(c). Schematic arrangement of proposed stand alone power system

B. D-Q Axis Modeling of Asynchronous Generator

The d-q axis equivalent circuit model of a SEASG is shown in Fig. 2(a) and Fig. 2(b) respectively.

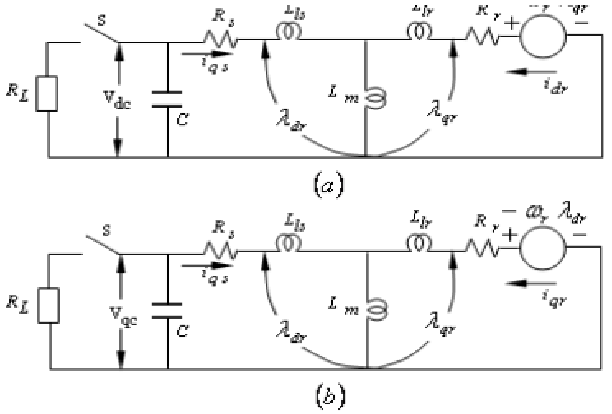

Fig 2 D-Q axis model of asynchronous generator with RL load

The loop equations of the d-q axis equivalent circuit of SEASG could be written as:

$$R_s i_{qs} + L_{ls}\frac{di_{qs}}{dt} + \frac{1}{C}\frac{di_{qs}}{dt} + L_m\frac{di_{qr}}{dt} = V_{dc} \quad ....1$$

$$R_r i_{qr} + L_{lr}\frac{di_{qr}}{dt} + L_m\frac{di_{qs}}{dt} = \omega_r\lambda_{dr} \quad ....2$$

$$R_s i_{ds} + L_{ls}\frac{di_{ds}}{dt} + L_m\frac{di_{dr}}{dt} = -V_{dc} \quad ....3$$

$$R_r i_{dr} + L_{lr}\frac{di_{dr}}{dt} + L_m\frac{di_{ds}}{dt} = V_{qc} \quad ....4$$

The dynamic characteristic behavior of SEASG in d–q axis equivalent circuit model is used for simulation. The magnetizing current i_m and generated air gap voltage $V_g$can be calculated using equations (5) and (6) respectively.

$$|i_m| = \sqrt{(i_{qs}+i_{qr})^2 + (i_{qs}+i_{qr})^2} \quad ....5$$

$$V_g = \omega L_m |i_m| \quad ....6$$

It should be noted that Lm is not constant but a function of the magnetizing current i_m given as

$$L_m = f(|i_m|) \quad ....7$$

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

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)L_m\left(i_{dr}i_{qs} - i_{qr}i_{ds}\right) \quad ....8$$

$$T_{shaft} = T_e + J\left(\frac{2}{P}\right)\frac{d\omega_r}{dt} \quad ....9$$

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

$$\frac{d\omega_r}{dt}\left(\frac{P}{2J}\right) = \left(T_e - T_{shaft}\right) \quad ....10$$

The generated phase voltages and the stator currents derived from d-q axes values are given in equation (11)

$$\left.\begin{aligned}
V_a &= V_{a1}\cos\theta_1 + i_2\sin\theta_1 \\
V_b &= V_1\cos\left(\theta_1 - \frac{2\pi}{3}\right) + i_2\sin\left(\theta_1 - \frac{2\pi}{3}\right) \\
V_c &= V_1\cos\left(\theta_1 + \frac{2\pi}{3}\right) + i_2\sin\left(\theta_1 + \frac{2\pi}{3}\right) \\
i_a &= i_1\cos\theta_1 + i_2\sin\theta_1 \\
i_b &= i_1\cos\left(\theta_1 - \frac{2\pi}{3}\right) + i_2\sin\left(\theta_1 - \frac{2\pi}{3}\right) \\
i_c &= i_1\cos\left(\theta_1 + \frac{2\pi}{3}\right) + i_2\sin\left(\theta_1 + \frac{2\pi}{3}\right)
\end{aligned}\right\} \quad ....11$$

The electrical transient model in terms of voltages and currents can be given in matrix form as

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + SLs & weLs & SLm & weLm \\ -weLs & Rs + SLs & -weLm & SLm \\ SLm & (we-wr)Lm & Rs + SLr & (we-wr)Lr \\ -(we-wr)Lm & SLm & -(we-wr)Lr & Rr + SLr \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

C. 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 R_{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 (13).

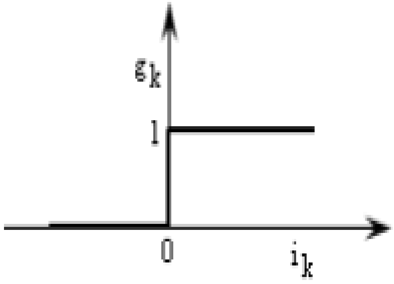

Fig. 3 Definition of the g k function (k = 1,2,3).

$$e_1 = g_1 V_{dc};\ e_2 = g_2 V_{dc}\ \&\ e_3 = g_3 V_{dc} \quad ....13$$

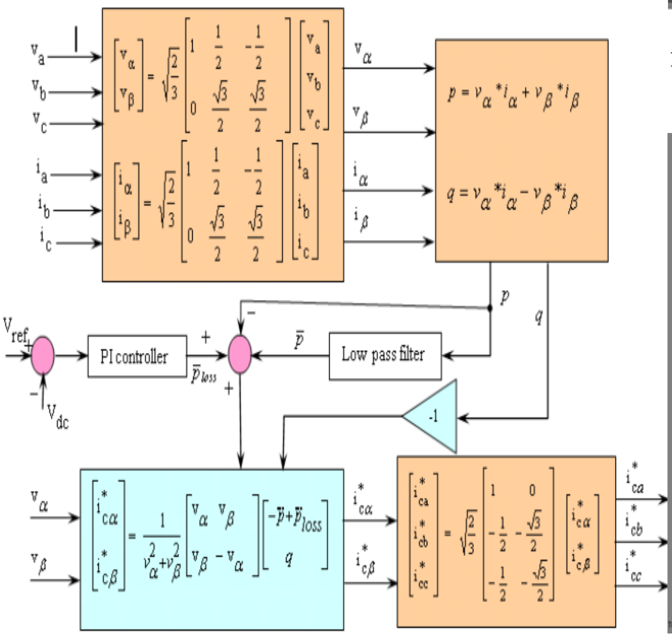

Fig.4 Control block for constant instantaneous power control strategy

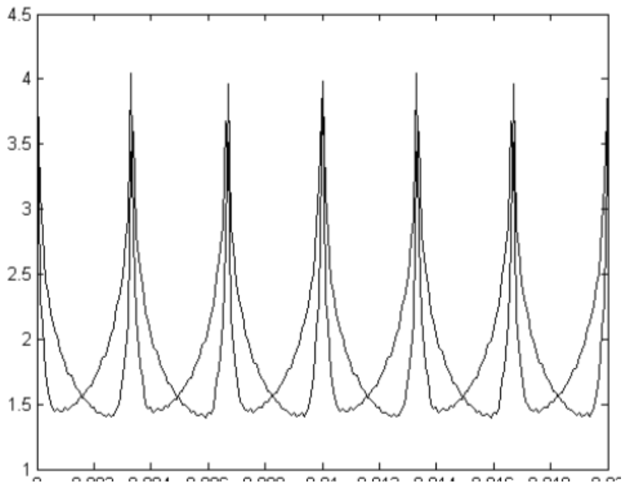

Fig. 5 Superimposed dc current waveform

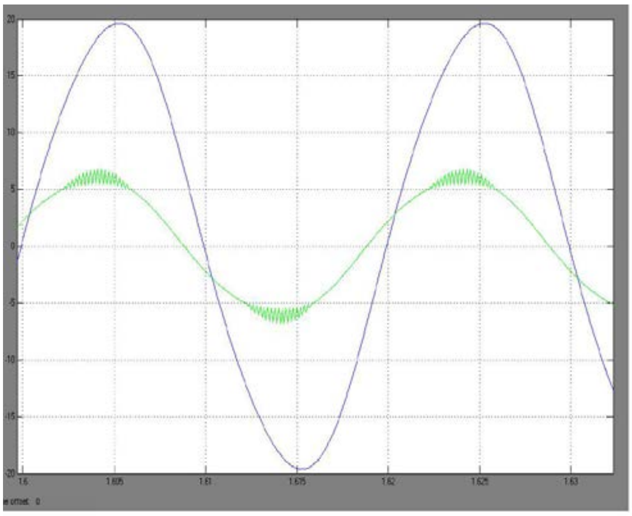

Fig. 6 Voltage and current wave form of the proposed system at PCC

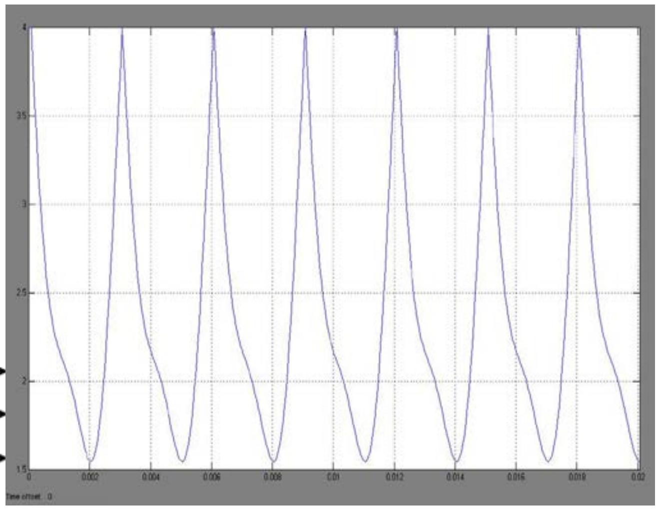

Fig.7 dc current waveform

IV. 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 are 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.

V. SIMULATION MODEL

A simulation model of the proposed isolated self excited asynchronous power generation system Fig.1(c) is 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 machine 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.

VI. 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

$$\mathbf{i}_{\mathbf{source}} = \mathbf{i}_{\mathbf{load}} + \mathbf{i}_{\mathbf{RLC}}$$

The instantaneous power delivered by the source is equal to the sum of the instantaneous powers absorbed by the load and the RLC series circuit (assuming that 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 ($\omega < \omega o$).

VII. RESULT

The simulation results of the dc side input current of the inverter is shown in Fig.5 for inverter frequency lower and higher than the resonance frequency. The waveform clearly shows that for 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 as shown in Fig.6

VIII. CONCLUSION

It is evident that the RLC series circuit when operated either at a frequency lower or higher than the resonance frequency, the system power factor gets affected. This characteristics phenomenon can be implemented in controlling the leading VAR requirements for constant voltage operations of the SEASG.

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