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MODELLING AND SIMULATION OF SHUNT CAPACITOR EXCITED RELUCTANCE GENERATOR AS A STAND-ALONE GENERATOR

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Abstract: **This paper presents a methodology for accurately predicting the minimum value of capacitance necessary to initiate excitation in a standalone self-excited reluctance generator (SERG). The methodology is based on modeling, analysis and simulation of various capacitances to determine the range of capacitance needed for excitation. The dynamic and steady-state performances of the self-excited reluctance generator were analyzed under different operating conditions. This analysis was done by developing a complete dynamic model of SERG including the excitation capacitors and load. The performances of the machine under conditions of constant load, and varying loads were analyzed and presented. The modeling and simulation have been carried out using MATLAB-Simulink platform. The results obtained shows that for excitation to take place, the minimum value of capacitor needed is 61µf, below which the generator will not excite. The machine could excite and attained its rated voltage between 61µf to 110µf, above which the generator begins to generate over voltage. For the dynamic performance analysis, the results shows that with the variations in the connected loads, the output frequency of SERG remains constant, which makes it a good alternative for remote area applications.**

Keywords: **Reluctance generator, Modelling, Excitation Capacitance, Computer, Matlab Simulink.**

I. INTRODUCTION

Self-excited generators have been identified as better alternatives to Permanent Magnet Synchronous Generators (PMSG) and Doubly-Fed Induction Generators (DFIG) in the area of application such as stand alone, off-grid, Wind Energy Conversion Systems (WECS). Low cost of production and operation as well as simplicity offered SEG the needed advantage against PMSG and DFIG.

The most commonly investigated self-excited generator is the Self-Excited Induction Generator (SEIG) with squirrel cage rotor. SEIG has found its application in isolated wind turbine energy conversion and has gained prominence in recent years. This is due to its innumerable advantages over the conventional synchronous generator which includes simplicity, brushless, rigidity, and robustness in construction, relative low initial and maintenance cost, self production against excessive overload and short circuit contingencies. In addition, SEIG requires no extra DC supply for excitation and voltage regulation, and they have better transient performances.

However, it suffers from poor voltage and frequency regulation with changes in load and prime-mover speed, with an attendant need for voltage and frequency stability circuit.

In order to overcome the above shortfalls of SEIG, Self Excited Reluctance Generator (SERG) has been explored as an alternatives choice for use in stand-alone systems such as wind energy conversion system. Consequently, investigation has now shifted to SERG.

In addition to simplicity, robustness, and inexpensive, quite like induction generators, Self-Excited Synchronous Reluctance Generators (SESRG) have low core-loss, low noise, low rotor copper-loss and they also a well defined relationship between rotor speed and output frequency. Furthermore, SERGs have no cogging torque.

Excitation of self-excited generator was by means of capacitors connected either in shunt or series form.

In this paper, we have set-out to investigate the dynamic characteristics of shunt capacitor excited reluctance generators (SCERG) under varying condition of R-L load, excitation capacitance.

Our findings will help in proper deployment of the generator in wind energy conversion systems The use of shunt capacitor exited reluctance generator (SCERG)has been explored as alternative choice for use of external direct current (DC) supply, for excitation and voltage regulation, and they have better transient performance. However it suffers from poor voltage and frequency regulation with changes in load and prime mover speed. Shunt exited reluctance generator is simpler, robust and inexpensive quite unlike induction generators. A shunt excited reluctant generator have low core losses, low noise, low rotor copper loss and they also show a well defined relationship between rotor speed and output frequency. Furthermore shunt –excited reluctance generator has no caging torque. Reluctance machines have been known as early as induction machines but they have not been developed and exploited until the early sixties. The reason for lack of attention in the early days had been due to their poor overall performance with well established and develop squirrel – cage induction machines, But reluctance machine have attracted considerable attention during the last two decades or so, resulting in much improved performance. Earlier applications have been rather specialized, hence performance had been of secondary importance and reluctance machine were mostly of simple salient rotor construction. This work dealt with the effective deployment of reluctance generator and problem with self-excitation. Whereas most machine/generators has self-exciting capability namely lundell generators, VR generators was inherent completely passive and have no internal excitation means. This study will be investigated by which excitation could be provided to shunt-excited generator thereby permitting easy stand-alone operation without the need for a large bulky exciting means. In shunt excited reluctance generator it has no self-excitation capability of their own but a separate stack and winding could be installed to provide its excitation requirements during starting.

II. THEORY OF THE WORK

The main concern of this work is the Dynamic characteristics of an isolated self excited reluctance generator; a mathematical model is indispensible as Methodology this chapter develops mathematical models suitable for analyzing the dynamics characteristic of the machines for minimum excitation capacitance and under varying operating conditions of loads.

In general, there are third approaches for electric machine modeling-one is the model in the natural frame (also called ABC model); the other is in the reference frame called QD model. The first model has the following advantages of using machine variables and easy to compare with the actual measurement. In this section, a model of SERG in the natural variables is presented.

Figure 2.1 below shows a schematic representation of an SERG. The figure shows a 2-pole, 3-phase, wye-connected SERG with two danger (auxiliary or amortisseur) windings placed on the rotor d-and q-axis.

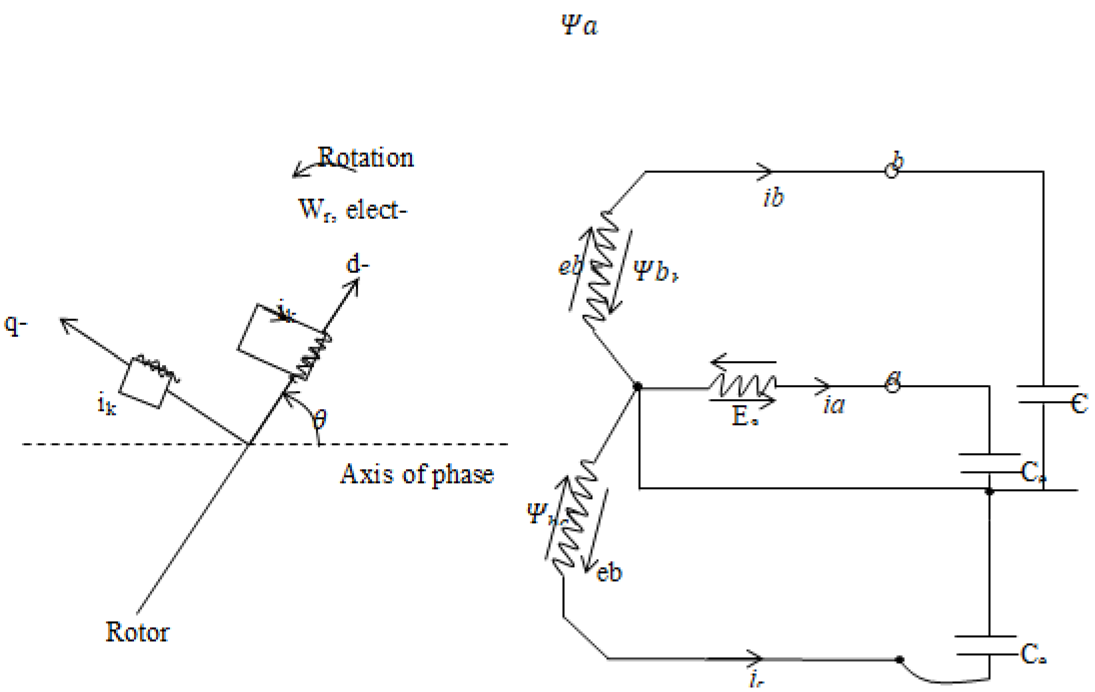
In developing equations of a self excited reluctance generator, the following simplifying assumptions are made:

- The stator windings are sinusoidal distributed along the air-gap as far as the mutual effects with the rotor are concerned
- The stator slots cause no appreciable variation of the rotor inductances with rotor position;
- Magnetic hysteresis is negligible;
- Magnetic saturation effects are negligible.

Assumptions (d) – (3) are reasonable while the last assumption is mate for convenience in analysis.

The machine equations will be developed first by assuming linear flux-current relationships.

In figure 2.1, the stator circuit is shown to consist of three-phase armature windings carrying alternating currents. The rotor circuit has tire amortisseur windings. In figure 3.1, for the sake of simplicity only one amortisseur circuit is assumed in each axis, and we wire write the machine equations based on this assumption. However implicitly consider an arbitrary number of such circuits; the substances k is used to denote this.



Figur1: Stator and rotor circuits of SERG

.1 Stator Circuit Equations

The voltage equations of the three phases are

$$e_a = \frac{d\Psi_a}{dt} - R_a\, i_b = P\Psi_a - R_a\, i_a$$

$$e_b = P\Psi_a - R_a\, i_b$$

$$e_c = P\Psi_a - R_a\, i_c$$

The flux linkage in the phase a writing at any instant is given by: $\Psi_a = L_{aa} i_a - L_{ab} i_b - L_{ac} i_c + L_{akd} i_{kd} + L_{akq} i_{kq}$

Similar expressions apply to flux linkages of windings b and c

The negative sign associated with the stator winding currents is due to their assumed direction.

All the inductances in equation 3.5 are functions of the rotor position and are thus time-varying as shown

2.2 Rotor Circuit Equations

The rotor circuit voltage equations are:

$$0 = P\Psi_{kd} + R_{kd} i_{kd}$$

$$0 = P\Psi_{kd} + R_{kd} i_{kd}$$

The rotor circuit flux linkages may be expressed as follows:

$$\Psi_{kd} = L_{kkd} i_{kd} - L_{akd}\left[i_a \cos\theta + i_b \quad \cos(\theta + \frac{2\pi}{3}) + \ i_c(\theta + \frac{2\pi}{3})\right]$$

$$\Psi_{kq} = L_{kkq} i_{kq} - L_{akq}\left[i_a \sin\theta + i_b \quad \sin\,(\theta + \frac{2\pi}{3}) + \ i_c(\theta + \frac{2\pi}{3})\right]$$

The stator and rotor circuits equations can be written in compact forms (ie., matrix form).

2.3 CAPACITOR VOLTAGE EQUATIONS

For the capacitor excited generator (SERG), the capacitor C and the Z_L=R_L+ jX_L are added to the machine terminal to shown in figure below:

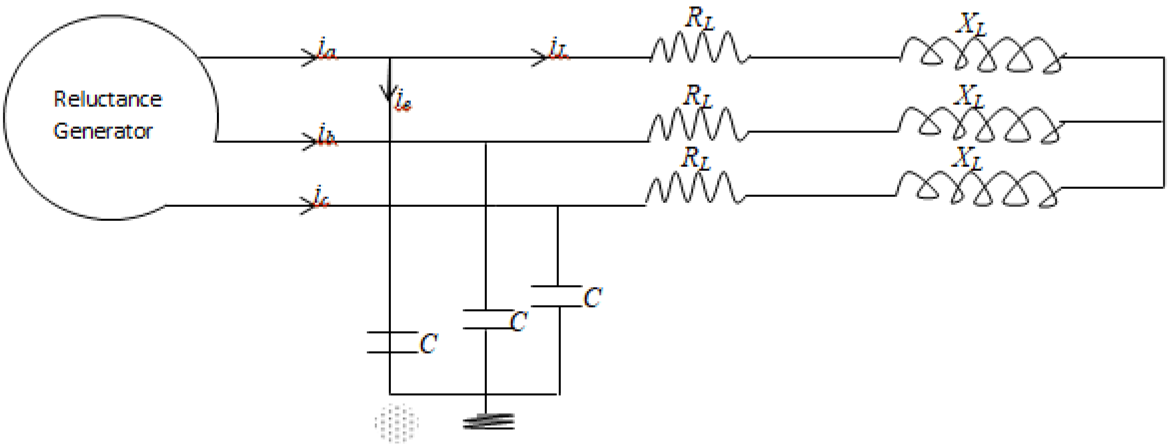


Figure 2: Connection diagram of capacitor connected of RG for manual-operation

The shunt-capacitor equations can be written directly in the d-q rotor reference frame as.

$$P^{V_{qs}} = w_r V_{ds} + \frac{I_{qs} - I_{qL}}{c}$$

$$P^{V_{ds}} = w_r V_{qs} + \frac{I_{ds} - I_{dL}}{c}$$

LOAD MODEL

From figure 3.3 series R-L load model is adopted and the following equations in d-q rotor reference frame holds.

$$P_{IqL} = (V_{qs} - R_L I_q L + w_r L_L I_{dL})/L_L$$

$$P_{IdL} = (V_{ds} - R_L I_d L + w_r L_L I_{qL})/L_L$$

III. METHODOLOGY

i) To develop Simulink model of a shunt capacitor connected self excited reluctance generator based on the mathematical equation.

ii) To modify reluctance generator mathematical equations to suit that of our shunt capacitor excited reluctance generator model.

iii) Determination of the minimum value of capacitance of capacitor needed to cause Excitation of our Generator model.

iv) To investigate the effect of sudden addition and removal of R-L load on the terminal voltage/current waveform of our generator model.

v) Development of a steady state model of the generator.

IV. RESULTS AND DISCUSSION

1) To develop Simulink model of a shunt capacitor connected self excited reluctance generator based on the mathematical equation

Step 1: The mathematical model of a self-excited generator as developed earlier and summarized above were firstly transformed into cause/effect using Matrix form.

Step 2: The transformed equations were then implemented in Simulink using embedded Matlab technique. The model developed is as shown below.

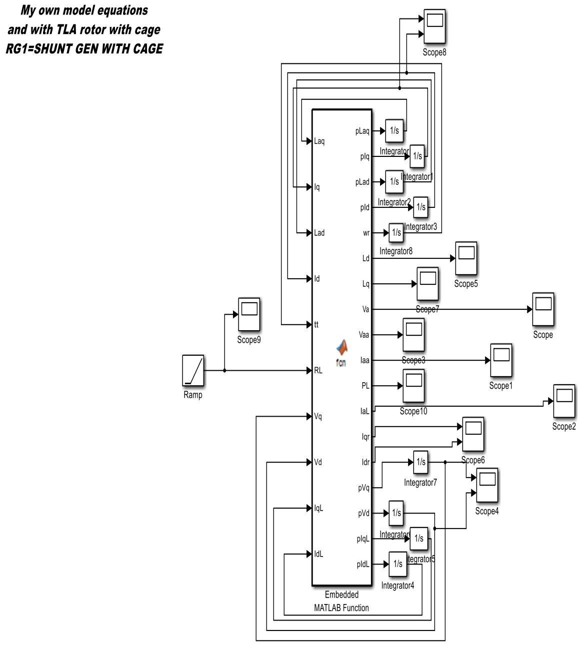


Figure 3: Our Simulink Model of A SERG

The codes in the embedded Matlab controller is appended as Al

2) To modify reluctance generator mathematical equations to suit that of our shunt capacitor excited reluctance generator model ,the mathematical models has been completed in chapter 3 of this paper and for ease of reference, its D-Q model equations are shown below.

D-Q MODEL EQUATION OF SCERG

$$V_q s = -R_s lqs + w_r \lambda ds + p\lambda ds$$

$$V_d s = -R_s lds \pm w_r \lambda qs + p\lambda ds$$

Where the flux linkages are given

By:

$$\lambda_q s = -(Lls + L_{mq}) l_{qs} + L_{mq} l'_q r$$

$$\lambda_d s = -(Lls + L_{md}) l_{ds} + L_{md} l_d r'$$

$$ddr' = (Lldr + L_{md})\, ldr' - L_{md}\, l_d s$$

$$dqr' = (Ll'qr + L_{mq})\, lqr' - L_{mq}\, l_q s$$

Also, the rotor mechanical equation is given as:

$$pwr\left(\frac{3}{4} P_r [I_{qs}(I_{ds} + I d_r{}') L_{md} - I_{ds}(I q_s + I q_r{}') L_{mq}] - T_L\right) \frac{P_r}{2_J}$$

3) Determination of the minimum value of capacitance of capacitor needed to cause Excitation of our Generator model.

Steps

1 A typical Reluctance generator was selected and modified to suit a reluctance generator. The parameters of the chosen synchronous generator are as under Table 1

TABLE 1: PARAMETERS OF THE SERG

P(kw)	Rs(Ω)	R_{qr}	R_{dr}	Ll_{qr}(MH)	Ll_{dr}	Lls	F	w(rpm)
1.5	0.7	1.4	1.1	2.4	2.2	2	50	1500

1. Signal builder icon in Simulink was connected to input of the capacitor terminal of our Simulink model of the generator. The modified model is as shown below.

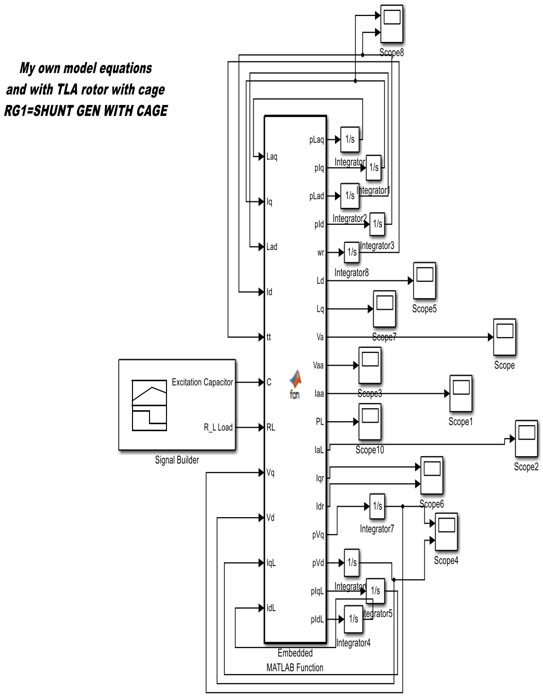


Figure 4: Our Simulink Model of SCERG for Studying the effect of Varying Capacitance

2. With the aid of the signal builder, load was kept constant and capacitance varied from 61μF-110μF and the output voltage waveform was monitored using the scopes. The capacitances needed to attain and sustain the machine rated voltage was read. The corresponding terminal voltage and current waveforms when the machine has attained excitation is as shown below.

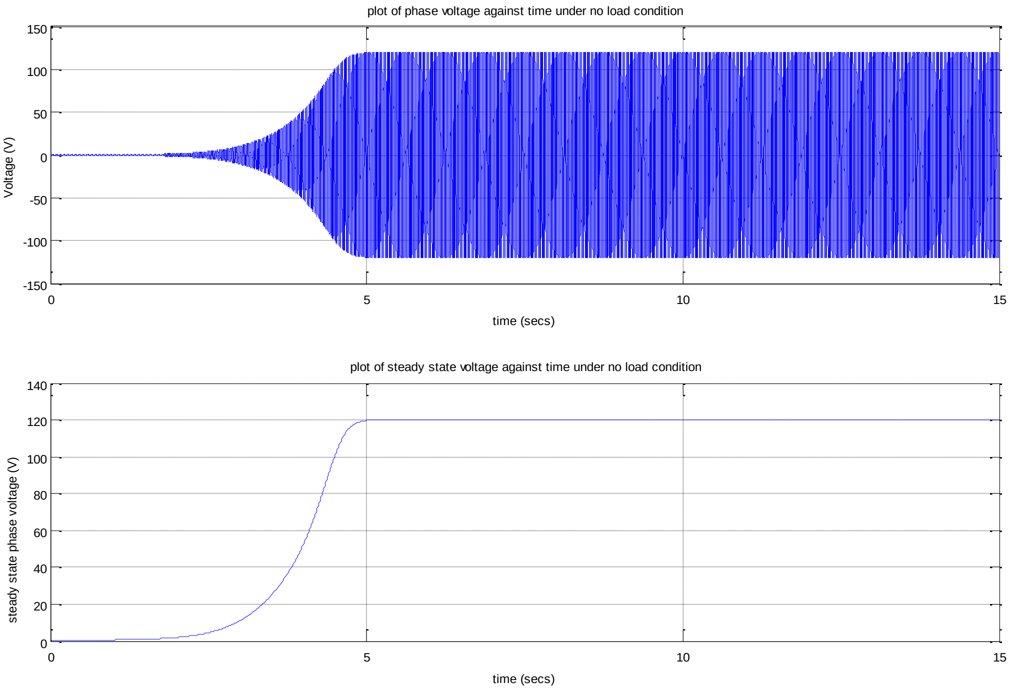


Figure 5: Voltage waveform during start-up (No load conditions) at constant excitation Capacitance of 61μF

V. DISCUSSIONS

From the voltage waveform shown in Fig 4.3a the machine took up to 5 seconds to build up its voltage and subsequently attained its rated voltage of 120v and remained steadily at that level. This can be seen clearly on the steady state plot of the phase voltage also contained in fig 4.3b.Similaly, the current waveform (fig 5b) shows that the machine was drawing very small current ,this is in tune with the behavior of a machine generating on No load. It was equally observed that for excitation to take place, a minimum capacitance of 61μF will be required below which the machine will not excite. The machine could excite and attained its rated voltage between 61μF-110μF. Above 110μF the machine begins to generate over voltage.

4) To investigate the effect of sudden addition and removal of R-L load on the terminal voltage/current waveform of our generator model.

Step 1: A signal builder was again connected as input at the R-L load terminal of our model.

Step 2: To simulate addition/sudden loss of load, an R-L load of specific impedance was connected through the signal builder for a time duration after which the load loss condition was achieved by increasing the R-L load of the signal builder to a very high impedance value (open circuit condition). The simulation lasted for 15 seconds, in each case the voltage/current waveforms were all monitored from the scopes connected at their various ports.

VI. RESULT

The waveforms for both the loads and the corresponding response of the generator voltages and current are as shown below.

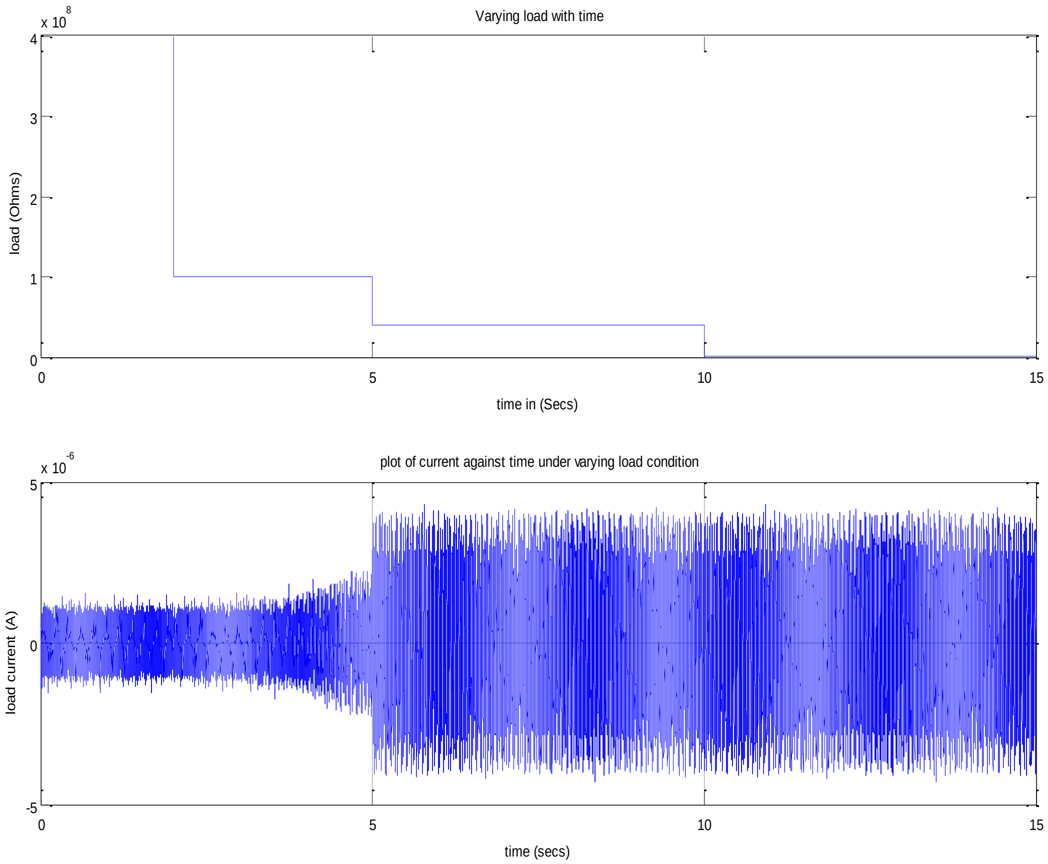


Figure 6: Load current under varying load conditions

5) Development of a steady state model of the generator.

Step 1: This is quickly achieved by eliminating time pulsating variables in the model equations.

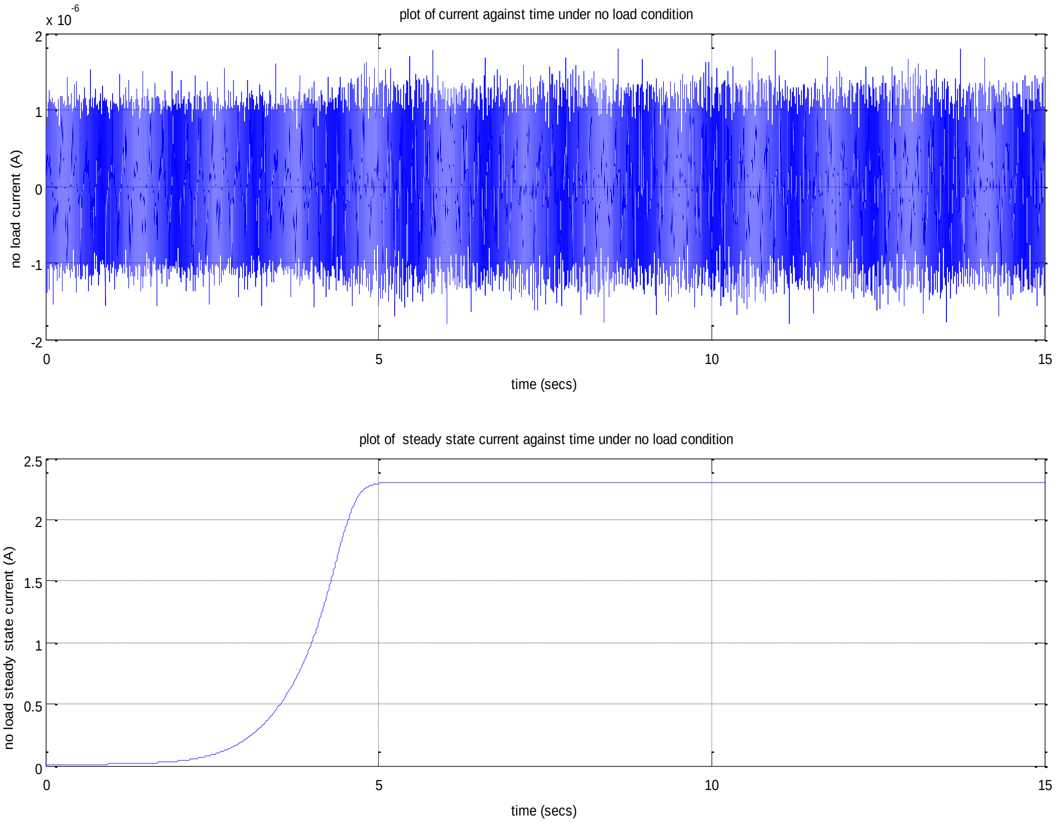


Figure 7: Steady state current against time at constant excitation capacitance of 61uf

VII. CONCLUSION

It has been demostrated that Shunt Capacitor Excited Reluctance Generator(SCERG) is a machine with high potentials in the areas of power generation given that the excitation systerm is properly choosen and sized. In this work a simulation program has been used to investigated succesfully its conditions of exictation and behaviours under varing load.The no load model developed had R-L load of specific impedance connected to it through the signal builder which was connected to the R-L load input port. The load was sustained for a peroid of time and after which a condition of load loss was simulated .

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