ANALYSIS OF DIFFERENT CONFIGURATION OF SELF EXCITED INDUCTION GENERATOR IN ISOLATED MODE OPERATION UNDER VARIOUS LOADING CONDITIONS

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CERTIFICATE

This is to certify that the dissertation entitled "**Analysis of Different Configuration of Self excited induction generator in isolated mode operation under various loading conditions**" submitted by Ms. VIJAYA SHARMA in partial fulfillment of the requirements for the award of Master of Technology degree in Electrical Engineering with specialization in "Power System" during session 2013-2015 at Delhi Technological University and is an authentic work by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

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ABSTRACT

This dissertation deals with the performance analysis of the three phase and single phase Self Excited Induction Generators (SEIG). Steady state analysis of the SEIG is done to predict the performance under different loading conditions. Steinmetz connection is described in this thesis report which is used to feed single phase load from a three phase SEIG. Software matlab simulation of some of the important configurations of SEIG is done. Basically three important configurations of SEIG which is shunt only, short shunt and long shunt configurations are discussed and studied in details in this dissertation. These three configurations of SEIG are used depending upon the requirement of the system. The performance of these configuration differ in many ways from each other which is discussed in details in this thesis report. It is very important to identify the factors like speed, value of capacitance and type of load etc which affect the performance of the SEIG. Slight change in any one of the parameters affects the working and performance of SEIG greatly. Further in this dissertation using FACT devices the control loop operation for voltage control is studied. MATLAB simulink toolbox is used for the purpose to verify the results.

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NOMENCLATURE

Csh Shunt capacitance

Cse Series capacitance

C1 phase balancing capacitance

C2 phase balancing capacitance

C3 voltage regulating capacitance

C4 series capacitance for single phase IM load

Vabc Terminal voltage of SEIG in volts

Iabc Current generated by SEIG in currents

Freq Frequency

P Active power in Watts

Q Reactive power in Vars

Sim Simulated value in pu

Exp Experimental value in pu

Vs source voltage in volts

Is source current in amperes

Wr Induction motor speed in rps(rad per sec)

Ir Rotor current in amperes

RL Resistive load

XL reactive load

Pf power factor

Wr induction generator speed in rps(rad per sec)

MOV metal oxide varistor

s slip

Xmm magnetizing reactance of motor

Xm magnetizing reactance of generator

Iim Induction motor current in amperes

Wim Induction motor speed in rps

Ic current in shunt capacitance in amperes

VL Load voltage in volts

IL load current in amperes

W1 Load 1 in watts

W2 Load 2 in watts

V1 voltage across load 1in volts

I1 current across load 1in amperes

V2 voltage across load 2 in volts

I2 current across load 2 in amperes

P1 Active power across load W1 in watts

Q1 reactive power across load W1 in vars

P2 Active power across load W2 in watts

Q2 reactive power across load W2 in vars

Im Main winding current of split phase IM

Ib Auxiliary Current of split phase IM

CHAPTER 1

INTRODUCTION

The Wind Energy systems are becoming more and more popular nowadays due to environmental considerations. The Self Excited Induction Generators mainly driven by wind turbine. The three phase Self Excited Induction Generators are nothing but Induction Generators excited by three capacitors. The value of this capacitor should be greater than the value of minimum capacitor. This type of connection is also called as shunt only compensation of SEIG. The induction generator has a problem of voltage regulation which will be studied later in the chapters. To overcome this problem various configurations of the three phase SEIG such as shunt, short shunt and long shunt configurations are used. Long shunt and short shunt configuration of SEIG are studied in this report. The problem becomes even more worse when dynamic loads are concerned. This report shows various configurations of SEIG when feeding induction motor load.

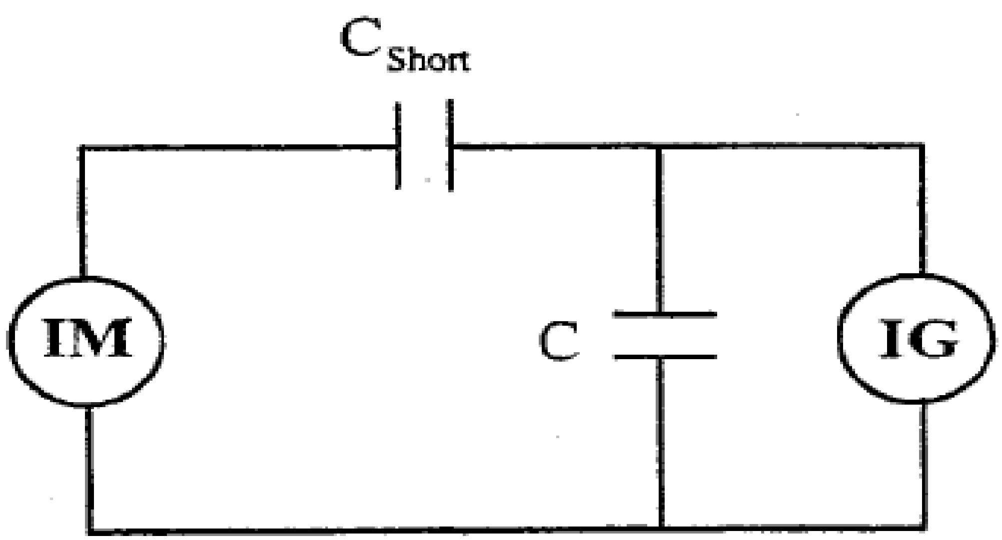

Fig 1.1 Short shunt configuration of SEIG feeding induction motor load[15]

The fig 1.1 shows short shunt configuration of SEIG feeding IM load. The series is denoted by Cshort in the fig. The excitation capacitance is denoted by C. In short shunt configuration the series capacitor is connected near the load side as shown from the figure.

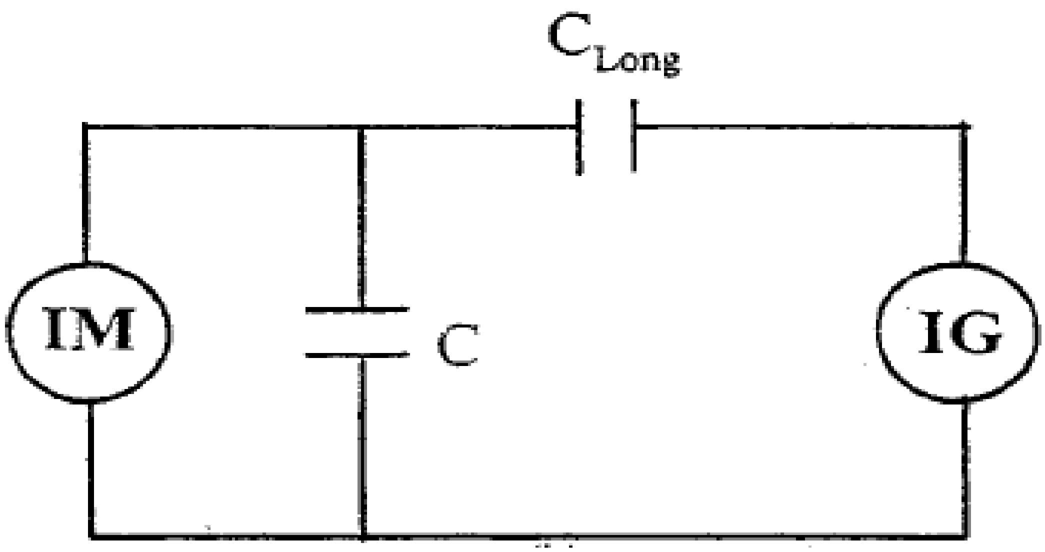

Fig 1.2 Long shunt configuration of SEIG feeding induction motor load[15]

The fig 1.2 shows long shunt configuration of SEIG feeding IM load. The series is denoted by Clong in the fig. The excitation capacitance is denoted by C. In long shunt configuration the series capacitor is connected near the generator side as shown from the figure.

Due to the increasing demand and development of the renewable energy resources such as wind energy, the SEIG commonly known as SEIG has been widely used as a source of power generation. The Steinmetz connection which is described in this thesis is mainly used to feed the single phase Induction motor as load from a 3 phase Induction generator by providing proper excitation capacitance. For SEIG the excitation is provided by using value of capacitance which is greater than some minimum calculated value which can be obtained by using steady state analysis.

The circuit connection of the single-phase SEIG based on the Steinmetz connection for a delta connected induction machine is studied in this chapter. The rotor is driven in such a direction that it traverses the stator winding in the sequence ABC. The single-phase load is connected across A-phase (the reference phase), while the shunt (main) excitation capacitance C_{sh} is connected across B-phase (the lagging phase). Besides providing the reactive power for initiating and sustaining self-excitation, C_{sh} also acts as a phase balancer by injecting a line current I_2 into the 'free' terminal of the stator winding. The compensation capacitance C_{se} is in series with the load and provides additional reactive power when the load current increases, resulting in a reduced voltage drop. In this thesis report steady state analysis of SEIG is carried out with certain assumptions.The performance analysis is carried out and appropriate results are taken and using the genetic algorithm. The results are compared with the results taken with hookes jeeves described in [20].

The main aim of the report is to study the long shunt and short shunt configurations of three phase SEIG and to analyse the behaviour of SEIG when three phase and single phase induction motor load is fed. The steady state analysis of these configurations of SEIG is also done to predict the performance. Later in the chapters we will also study the single phase connection of the SEIG and closed loop control is also done.

CHAPTER 2

LITERATURE SURVEY

The usage of self-excited induction generator (SEIG) has been increasing due to fast depletion of non-conventional energy sources. At present, to decentralize the power generation, 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 crisis. The recent trend is to tap solar, wind and tidal energy and these are becoming popular amongst the renewable energy sources. Squirrel cage induction generator (SCIG) has emerged as a possible alternative to conventional generator in an isolated power generation because of its low cost, less maintenance and rugged construction [1][2].

The possible contribution of wind energy in minimizing the rate of depletion of non-renewable resources is at present of great interest as it has been estimated that there is about 105 MW potentially recoverable from the wind on a global basis, about 10 times the hydropower of the world[3] . Many schemes such as variable speed drives which are desirable for the wind generation can be used [4]. The self-excited induction generator with controlled rectifier can allow wide changes in wind turbine speed, optimum generating power being set at all speeds by rectifier delay-angle control, provided a suitable sink for the power is available.

Normally designed induction motor can be successfully used as a three phase self-excited generator for low power applications [5].The rating of capacitance should be greater than the minimum value (Cmin) of capacitance which has to be calculated using different algorithm. If capacitance value is below Cmin then the SEIG will fail to excite and voltage will be zero[6]. For SEIG the excitation is provided by using value of capacitance which is greater than some minimum calculated value which can be obtained by using steady state analysis and a simple method for computing the minimum value of capacitance required for initiating voltage build-up in a three-phase self-excited induction generator[6]. Consideration of the equvalent circuit conductance of SEIG yields a 6th-degree polynomial in the per-unit frequency. The polynomial can be solved for real roots, which enables the value of C, to be calculated. Matlab Symbolic computation technique is very effective for the simulation of SEIG as there is no need to manually derive the complex coefficients of the polynomial equations also modeling becomes very simple yet versatile and core loss and other component can be included easily[7]. The capacitor, speed of SEIG and the type of load greatly influences the performance of SEIG [8]. When different loads are connected then the use of series capacitor with the load, improves considerably the output voltage characteristic of the SEIG. This series capacitor must have an adequate capacitance value [9].The SEIG suffers from problem of voltage regulation as it is very poor so series compensation is required. The optimum value of shunt capacitance Csh for both shunt and short shunt configuration are same while for long shunt it is different[10]. Both Long shunt and Short shunt configurations are used to regulate the voltage but the long shunt can maintain lower voltages while short shunt has better higher voltage regulation [11]. The performance of short shunt is more superior both in terms of economy and voltage regulation [12][13]. If the SEIG is used to feed induction motor as a load then there are unwanted oscillations in case of long shunt configuration [14][15].There are different techniques which can be used to control the load voltage and load parameters using electronic devices which can be used for wide range of application, operation and control [16].

Singaravelu and sasikumar have described in his paper [17] the steady state modeling of series compensated SEIG using nodal method and have used the genetic algorithm to describe the performance. L Sridhar in his paper [18] has addressed algorithm to predict the performance of SEIG in steady state conditions under dynamic loads. Certain assumptions are used to carry out the steady state analysis if the SEIG stated in [19]-[20].A single phase Induction motor is fed as load from a 3 phase Induction generator by providing proper excitation capacitance [21].

It is studied and evaluated that out of the many connected topologies of the capacitors for the single phase SEIG the delta connected, lagging phase excitation, series compensation and star connected shunt compensation are the best topologies[22] [23]. The single phase SEIG when compared to the self excited synchronous generators has better voltage regulation when operated at fixed speed [24]. Genetic algorithm modelling described in [25] is very useful in determining the performance of SEIG which is implemented in this thesis report.

CHAPTER 3

STEADY STATE MODELLING OF DIFFERENT CONFIGURATIONS OF SEIG IN ISOLATED MODE UNDER DIFFERENT OPERATING CONDITIONS

3.1 INTRODUCTION

With the help of Steady state analysis the performance of the SEIG can be easily analyzed. In this chapter the steady state analysis of both the short shunt and long shunt configuration of SEIG is carried out using loop method. The induction motor is fed as a load for both the configuration. It is very uncertain to predict the performance of the SEIG specially when feeding dynamic load or induction motor load. The steady state analysis of the SEIG can also be used to calculate certain parameters. Matlab simulink model is used to describe the steady state model feeding induction motor load in this chapter. A matlab code is also generated for both the configurations and Genetic algorithm is used to validate the results. With the matlab code for long and short shunt configuration four parameters namely slip s, magnetizing reactance of the generator Xm, magnetizing reactance of motor Xmm and the speed is calculated using the genetic algorithm optimization technique. The values obtained from the long shunt and short shunt simulink model of SEIG is then compared with the results obtained from the GA. Closeness between both the obtained values verifies the results.

3.2. MODELING OF THREE PHASE SEIG

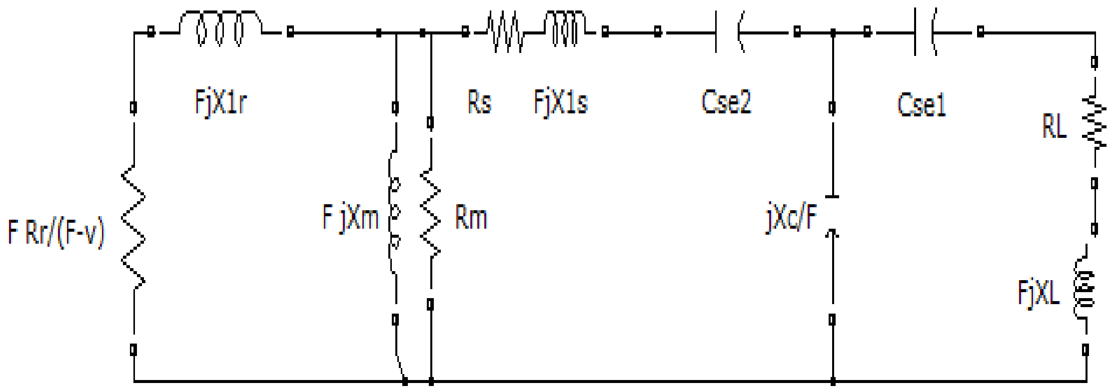

Fig 3.1 Equivalent circuit of long Shunt SEIG feeding RL load

The fig 3.1 shows when RL load is fed to the SEIG. Based on the connections of the shunt and series capacitance different configurations of SEIG are obtained.

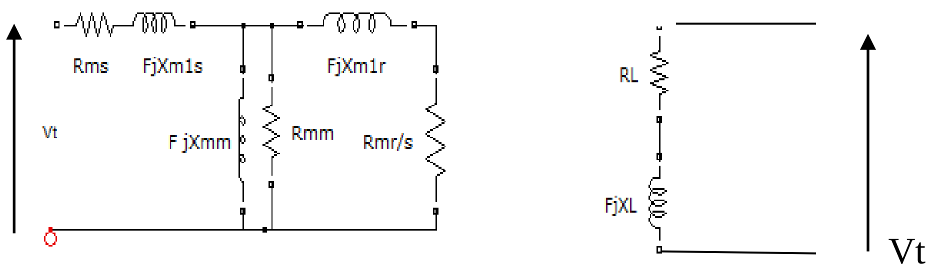

Fig 3.2 Conversion of IM into equivalent RL circuit

In this ways as described the induction motor load is changed into its equivalent RL load. By doing so the analysis becomes easier. Simple loop method can be applied and analysis can be done.

Steady state equations

$$A = (Rmr/s) + (1i * f * Xmr) \quad (3.1)$$

$$F = ((1i * f * Xmm * Rmm)/((1i * f * Xmm) + Rmm)) \quad (3.2)$$

$$B = (A * F)/(A + F) \quad (3.3)$$

$$C = A + B + Rms + (1i * f * Xm1s) - (iXcse1) \quad (3.4)$$

$$D = (-1i * Xc/f) \quad (3.5)$$

$$E = (C * D)/(C + D) \quad (3.6)$$

$$G = E - (iXcse2/f) \quad (3.7)$$

$$Z1 = ((f * Rr)/(f - v)) + (1i * f * X1r) \quad (3.8)$$

$$Z2 = (1i * f * x(2) * Rm)/((1i * f * x(2)) + Rm) \quad (3.9)$$

$$Z3 = (Z2 * Z1)/(Z2 + Z1) \quad (3.10)$$

$$Z4 = Z3 + (1i * f * X1s) + Rs \quad (3.11)$$

With the help of KVL we get this equation

$$Z4 + G = 0 \quad (3.12)$$

From this equation the values can be minimized in the range 1e-4 using genetic algorithm for both the configurations. Four unknown variables are F, Xmm, Xm and s with initial value 0,20,70 and 0.4 respectively. Maximum value of F, Xmm, Xm and s are specified to be 1,40,184.46,1 with population size of 40 and proportional scaling function and roulette selection function and mutation being constrained dependent.

3.2.1 Long shunt configuration

When the capacitance Cse1 is not connected in the circuit and only the shunt capacitance and the capacitance Cse2 are connected then this type of configuration is long shunt configuration.

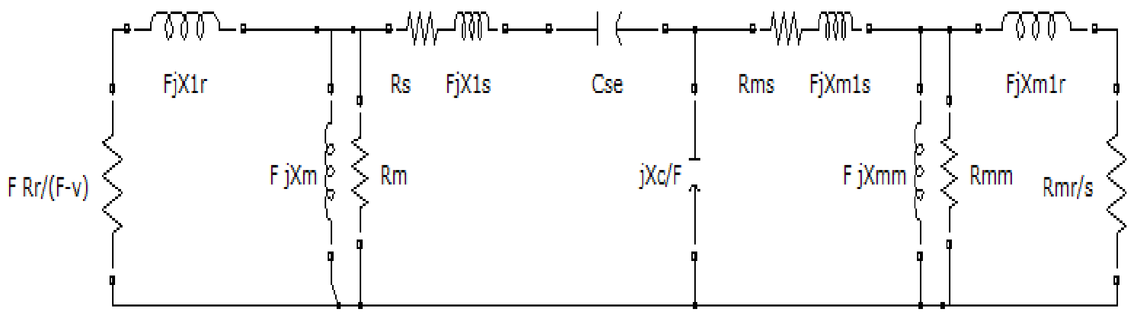

Fig 3.3 Equivalent circuit of long Shunt SEIG feeding IM load

Steady state is done in the same ways as stated above

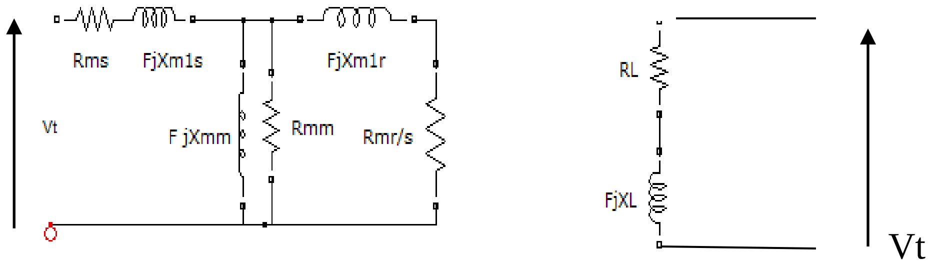

Fig 3.4 Conversion of IM into equivalent RL circuit

The Equivalent impedance along Vt of the circuit described in fig 3.2 is obtained. This equivalent impedance is the objective function which has to be minimized. There are four unknown variables s, Xmm, Xm and F which are obtained using the Genetic algorithm optimization technique.

3.2.2 Short shunt configuration

When the capacitance Cse2 is not connected in the circuit and only the shunt capacitance and the capacitance Cse1 are connected then this type of configuration is short shunt configuration.

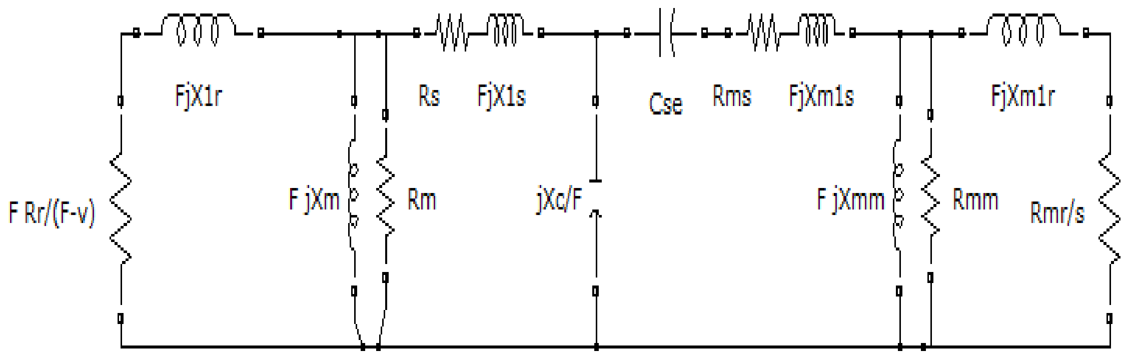

Fig 3.5 Equivalent circuit of short Shunt SEIG feeding IM load

3.3 MODELING OF SINGLE PHASE SEIG

3.3.1 Star connected SEIG

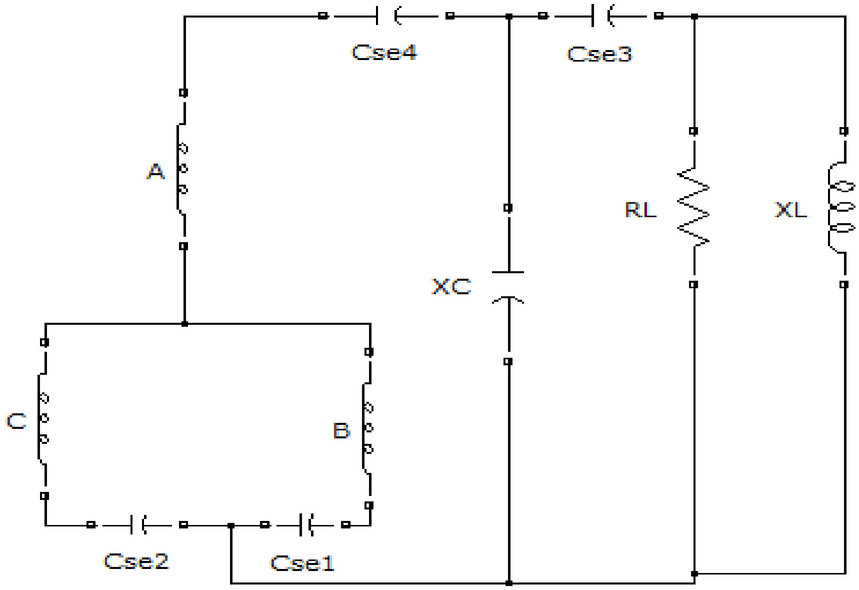

Fig 3.6 Equivalent circuit of star connected single phase SEIG feeding RL load

The modelling of the star connected is stated below:

$$ZL = RL + jXL \quad (3.12)$$

$$Z3 = ZL - jXcse3 \quad (3.13)$$

$$Z4 = -jXc \quad (3.14)$$

$$Z5 = (Z3 * Z4)/(Z3 + Z4) \quad (3.15)$$

$$Za = Z5 - jXcse4 \quad (3.16)$$

Z1= Positive sequence impedance of SEIG

Z2= Negative sequence impedance of SEIG

$Zc = -jXcse2$ (3.17)

$Zb = -jXcse1$ (3.18)

Applying KVL in fig 3.6 and solving we get equation

$$3Z1Z2 + (Z1 + Z2)(Za + Zb + Zc) + (ZaZb + ZbZc + ZcZa) = 0 \quad (3.19)$$

Equation can be solved by using any of the method like genetic algorithm or newton raphson method etc.

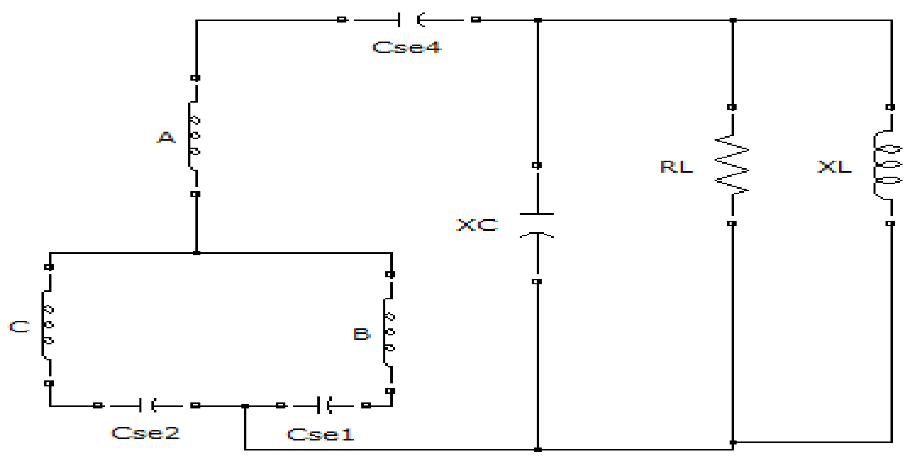

Fig 3.7 Equivalent circuit of long Shunt single phase SEIG feeding RL load

The fig shows long shunt connection of SEIG. If the series capacitance Cse3 is not connected to the circuit then such configuration is known as long shunt SEIG.

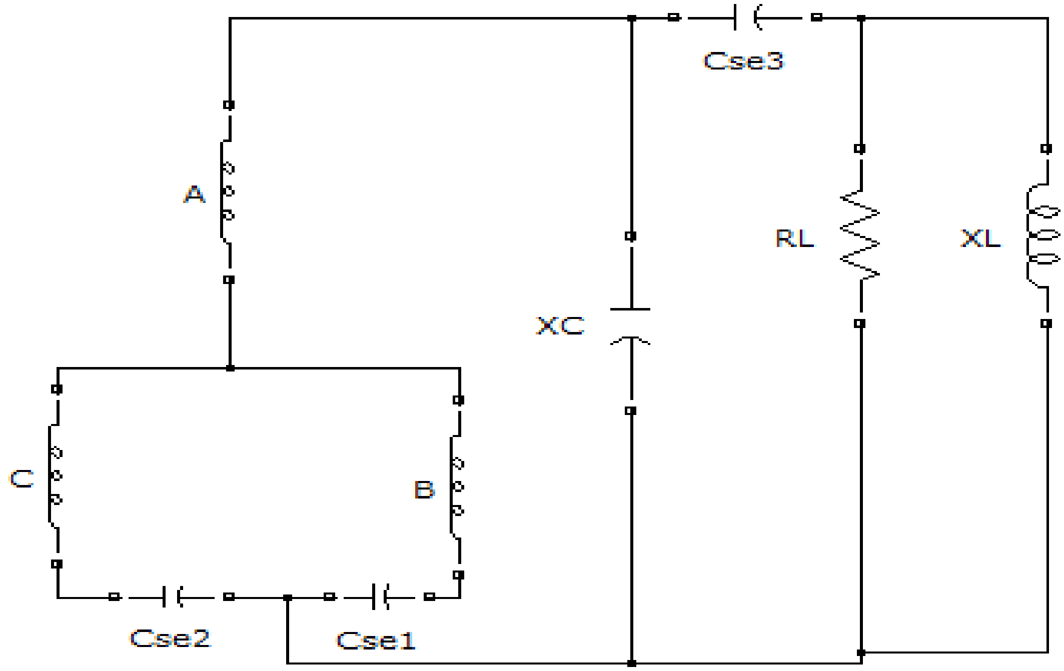

Fig 3.8 Equivalent circuit of short Shunt single phase SEIG feeding RL load

The fig shows short shunt connection of SEIG. If the series capacitance Cse4 is not connected to the circuit then such configuration is known as long shunt SEIG.

3.3.2 Delta connected SEIG

The steady state analysis of the SEIG is carried out according to the procedure and equations described in [23].

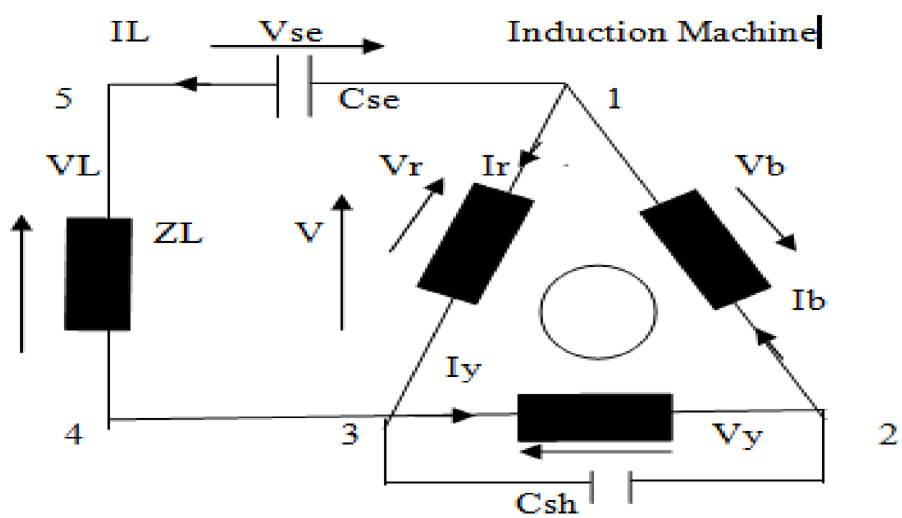

Fig 3.9 Steinmetz equivalent circuit of three phase delta connected

The circuit connection of the single-phase SEIG based on the Steinmetz connection for a delta connected induction machine is shown in fig 3.9. The single-phase load is connected across R phase while the shunt excitation capacitance C_{sh} is connected across Y phase which is the lagging phase.

$$V = Vr \qquad (3.20)$$

$$Vr + Vy + Vb = 0 \qquad (3.21)$$

$$I = Ir - Ib \qquad (3.22)$$

$$I2 = \frac{Vy}{Zsh} = Ib - Iy \tag{3.23}$$

$$IL = -I = \frac{v}{Zl+Zse} \tag{3.24}$$

Where

$$Zsh = \frac{1}{j2\pi fbase*Csh*a2} = -jXsh \tag{3.25}$$

$$Zse = \frac{1}{j2\pi fbase*Cse*a2} = -jXse \tag{3.26}$$

and

$$Zl = (Rl/a) + jXl \tag{3.27}$$

The symmetrical component equations for a delta connected system can also be written

$$\begin{bmatrix} Vr \\ Vy \\ Vb \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \propto^2 & \propto \\ 1 & \propto & \propto^2 \end{bmatrix} \begin{bmatrix} Vo \\ Vp \\ Vn \end{bmatrix} \tag{3.28}$$

$$\begin{bmatrix} Ir \\ Iy \\ Ib \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \propto^2 & \propto \\ 1 & \propto & \propto^2 \end{bmatrix} \begin{bmatrix} Vo/Zo \\ Vp/Zp \\ Vn/Zn \end{bmatrix} \quad (3.29)$$

Where Z_o , Z_P and Z_n are the zero-, positive- and negative sequence impedances of the induction machine and ∝ is the unit complex operator exp (j2n/3). In the subsequent analysis it is assumed that all the equivalent circuit parameters are constant except the magnetising reactance X_m ,(which is a function of the positive-sequence air gap voltage E_1). From eqns. 2 and 9 it is apparent that zero sequence voltage and current are absent from the machine system.

$$Vp = \sqrt{3}V \frac{zp(Zsh + \frac{e^{j\pi/6}}{\sqrt{3}}Zn)}{ZpZn + ZpZsh + ZnZsh} \quad (3.30)$$

$$Vn = \sqrt{3}V \frac{zn(Zsh + \frac{e^{j\pi/6}}{\sqrt{3}}Zp)}{ZpZn + ZpZsh + ZnZsh} \quad (3.31)$$

The input impedance of induction generator can be expressed as:

$$Zin = \frac{ZpZn + zpZsh + ZnZsh}{3Zsh + Zp + Zn} \quad (3.32)$$

$$Zin + Zl + Zse = 0 \quad (3.33)$$

For given values of C_{sh} , C_{se} , Z_L per-unit speed b, eqn.14 may be solved to give the per-unit frequency *a* and magnetising reactance X_m of the single-phase SEIG can then be calculated using eqns. 1 to 12, provided that the magnetisation curve of the induction machine is known.

3.4 SIMULINK MODEL OF SEIG

3.4.1 Short shunt model

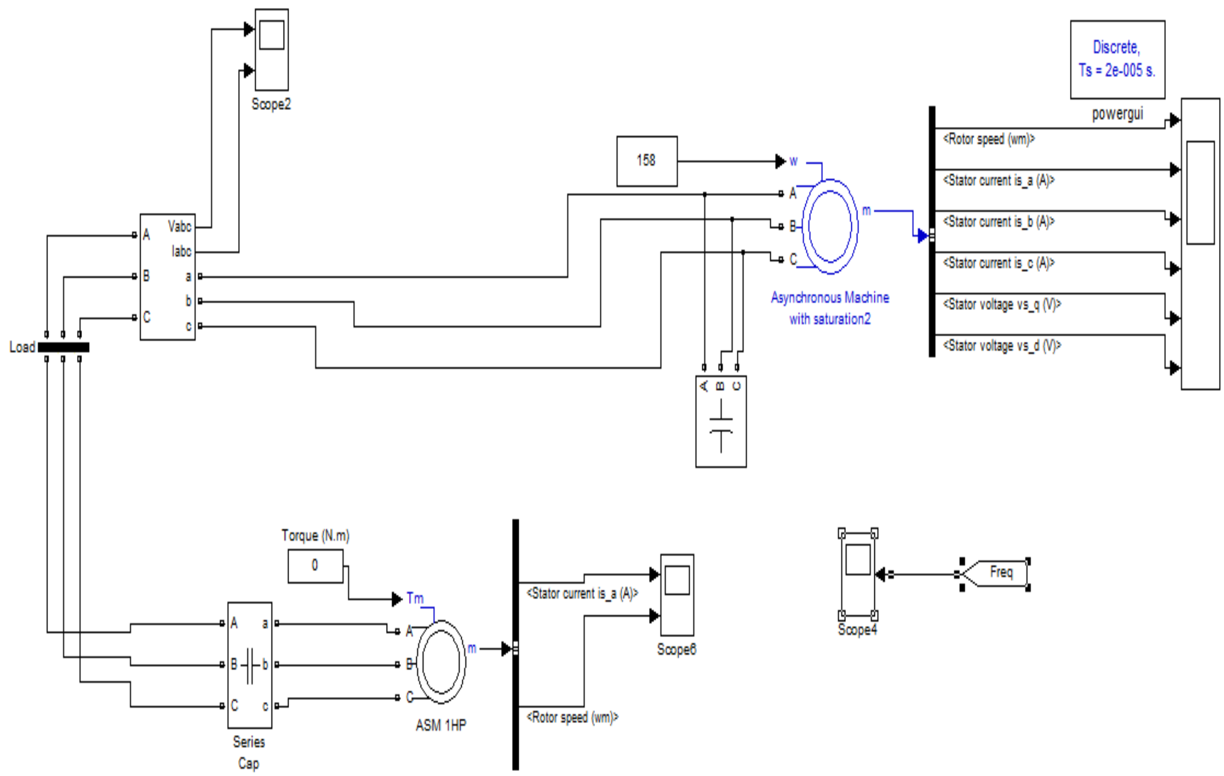

Fig 3.10 Simulink model of short shunt SEIG

The Simulink model described in fig 3.10 is the short shunt connection of the SEIG feeding IM load. This is the model which is used to verify the results which are obtained from the steady state analysis of short shunt SEIG. The SEIG is 5 hp motor and the rating of induction motor load is 1 hp. The series capacitor is connected near the IM load. The results are obtained from this model and are compared with the results obtained with the Genetic algorithm optimization technique. Series capacitance value is 17 microfarad. Shunt capacitance provides 3500 vars to the system.

3.4.2 Long shunt model

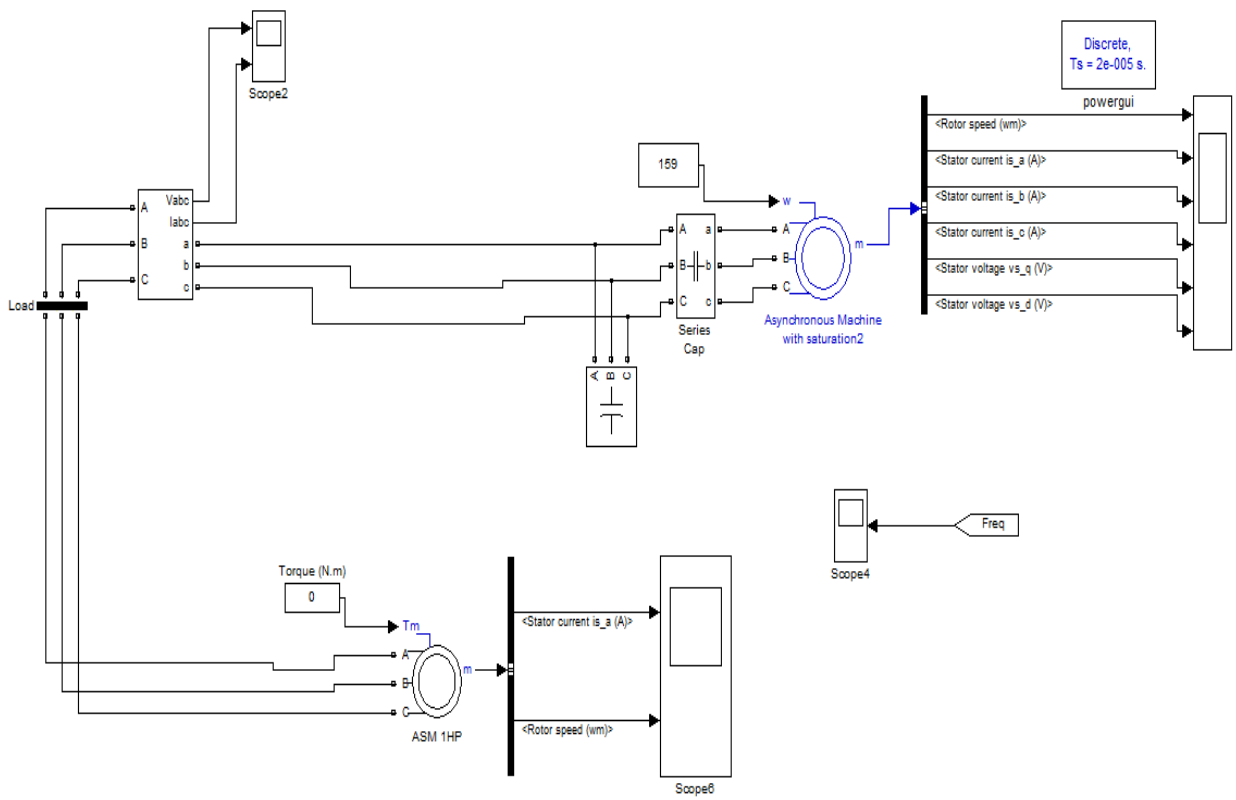

Fig 3.11 Simulink model of long shunt SEIG

The Simulink model described in fig 3.11 is the long shunt connection of the SEIG feeding IM load. This is the model which is used to verify the results which are obtained from the steady state analysis of long shunt SEIG. The SEIG is 5 hp motor and the rating of induction motor load is 1 hp. The series capacitor is connected near the IM load. The results are obtained from this model and are compared with the results obtained with the Genetic algorithm optimization technique.

3.5 RESULTS AND DISCUSSIONS

3.5.1 Results for three phase SEIG feeding IM load obtained from simulink model

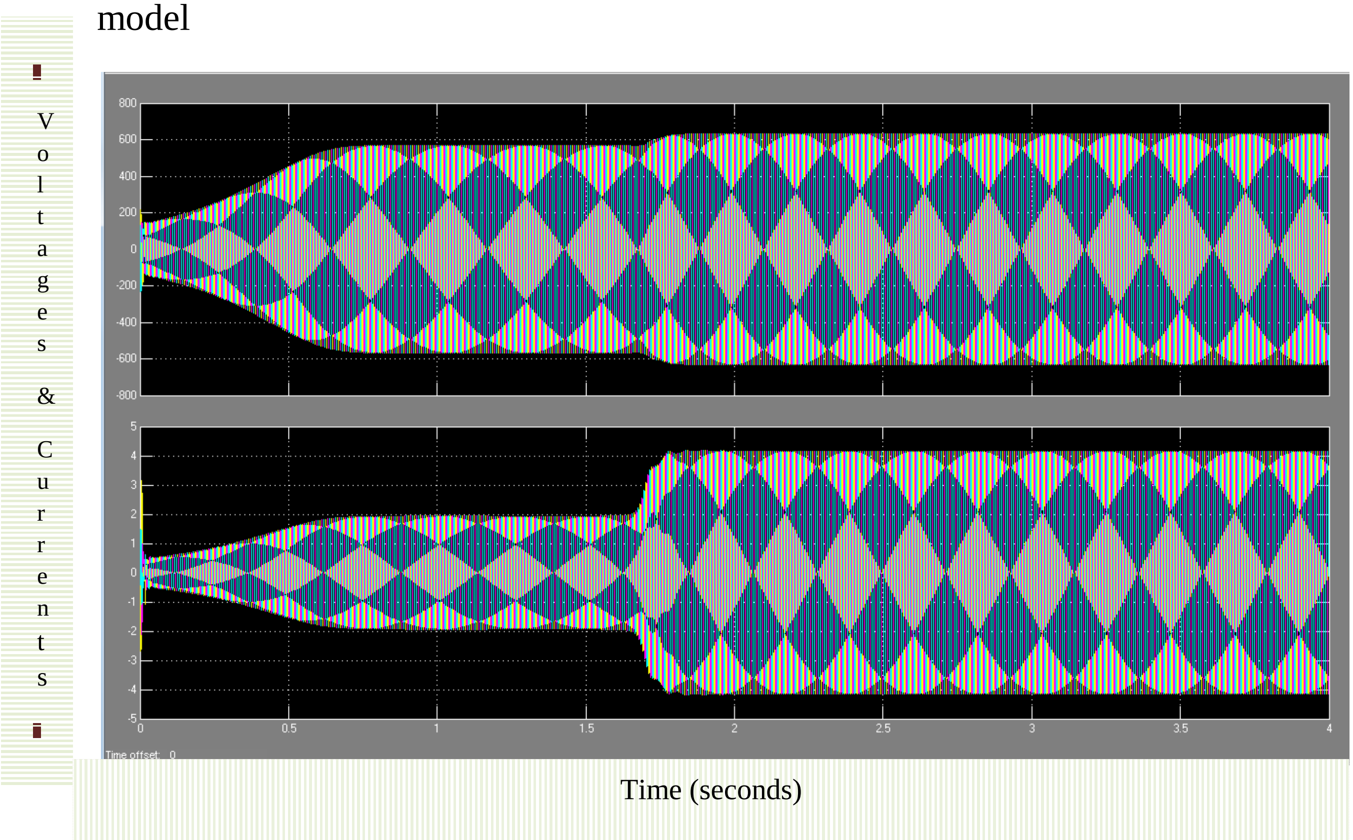

Fig 3.12 Variation of VL and IL Vs Time

The fig 3.12 shows the voltage and current across the short shunt connected Induction motor load. This value of voltage is compared with that obtained by the steady state analysis.

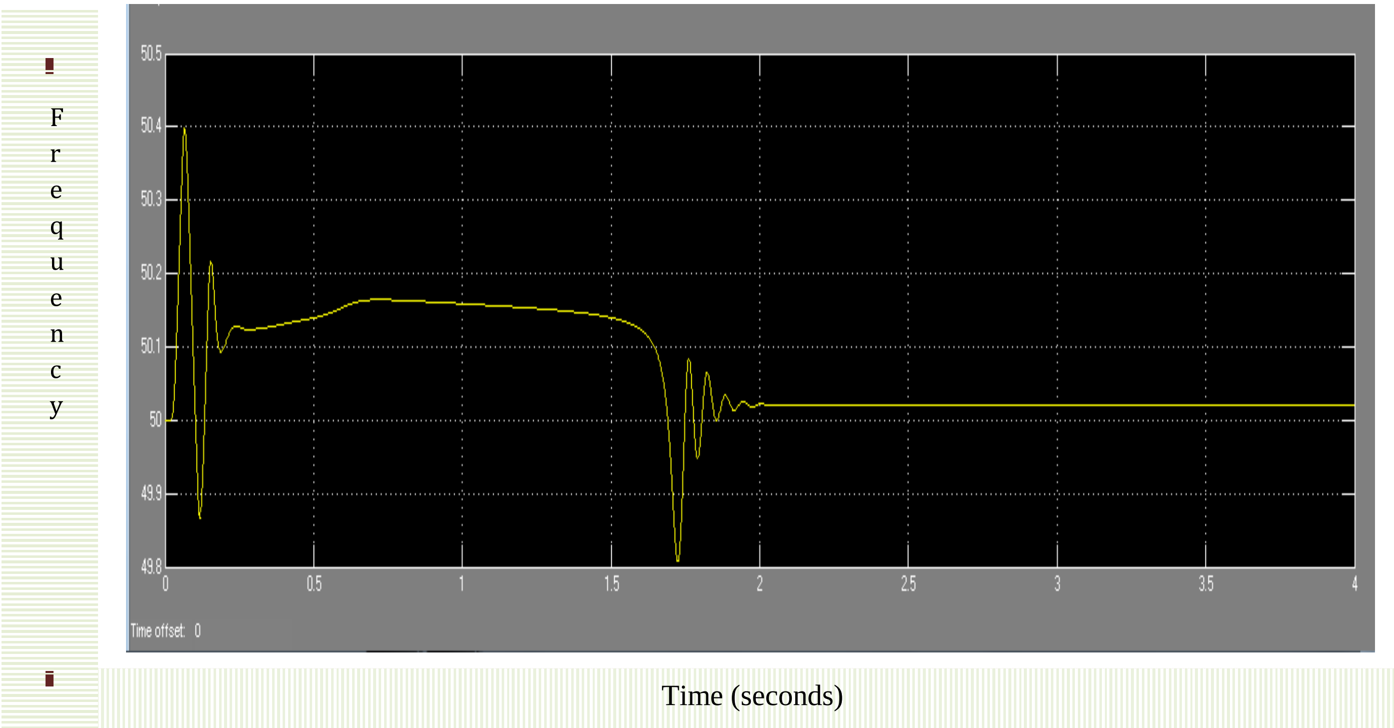

Fig 3.13 variation of frequency with time

The fig 3.13 shows the frequency of the system for the short shunt connection. This value is also compared with the value obtained by the steady state analysis.

3.5.2 Results for Single phase SEIG from Steady state analysis

The written matlab program is simulated through genetic algorithm tool and results thus obtained are compared with results by Hooke Jeeves method [23].

Table 3.1 Computed results for single phase SEIG

R_L (p u)	$A_{(p\ u)}$	$a_{(p\ u)}$	$X_{m(p\ u)}$	$x_{m(p\ u)}$	$Z_{(a,xm)}$ (p u)	$z_{(a,xm)}$ (p u)
50	0.9916	0.9942	1.6226	1.6158	9.06×10^{-4}	7.05×10^{-4}
10	0.9900	0.9926	1.6329	1.6253	1.32×10^{-4}	1.28×10^{-4}
5	0.9880	0.9906	1.6443	1.6358	6.24×10^{-5}	4.04×10^{-5}
2	0.9823	0.9850	1.6686	1.6575	1.32×10^{-5}	6.15×10^{-6}
1	0.9737	0.9763	1.6771	1.6626	6.43×10^{-7}	7.37×10^{-8}
0.5	0.9593	0.9619	1.5982	1.5821	8.53×10^{-7}	5.43×10^{-7}
0.3	0.9455	0.9482	1.4056	1.3943	2.92×10^{-7}	2.7×10^{-7}
0.1	0.9240	0.9263	0.8335	0.8226	4.0×10^{-7}	2.96×10^{-7}

Above values are obtained for Csh=125µF, Cse=350 µF, P.F=1.0,K=0.357

From the results obtained by genetic algorithm, graphs are plotted.

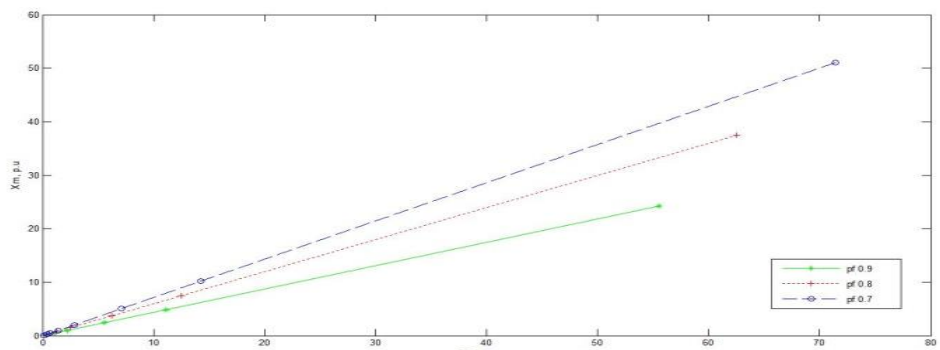

Fig 3.14 Shows variation of magnetic reactance with impedances for varying power factor

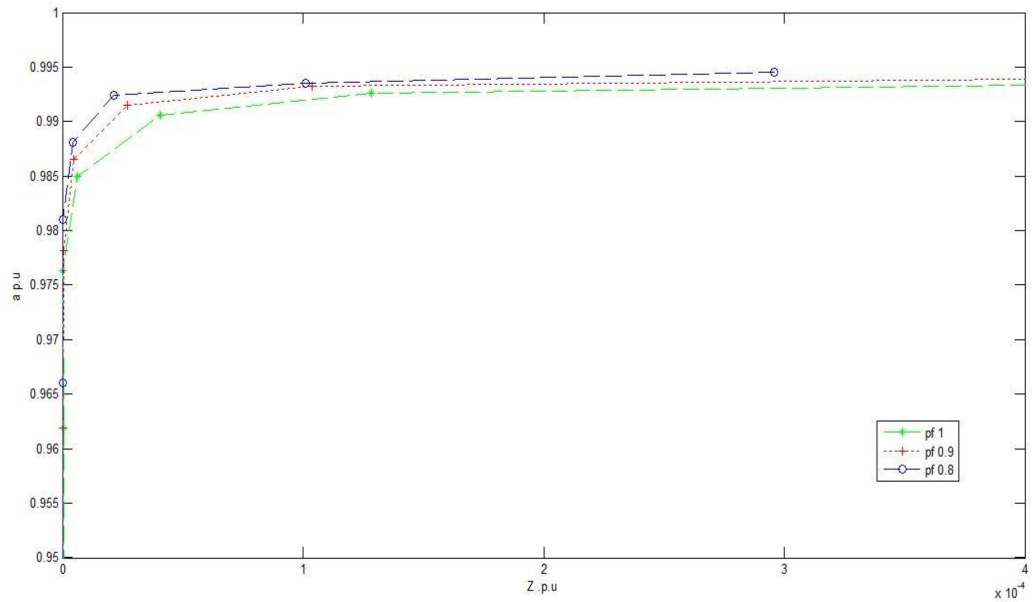

Fig 3.15 Shows variation of frequency with impedances for varying power factor,Csh=125μF, Cse =350 μF, P.F=1.0,K=0.357.

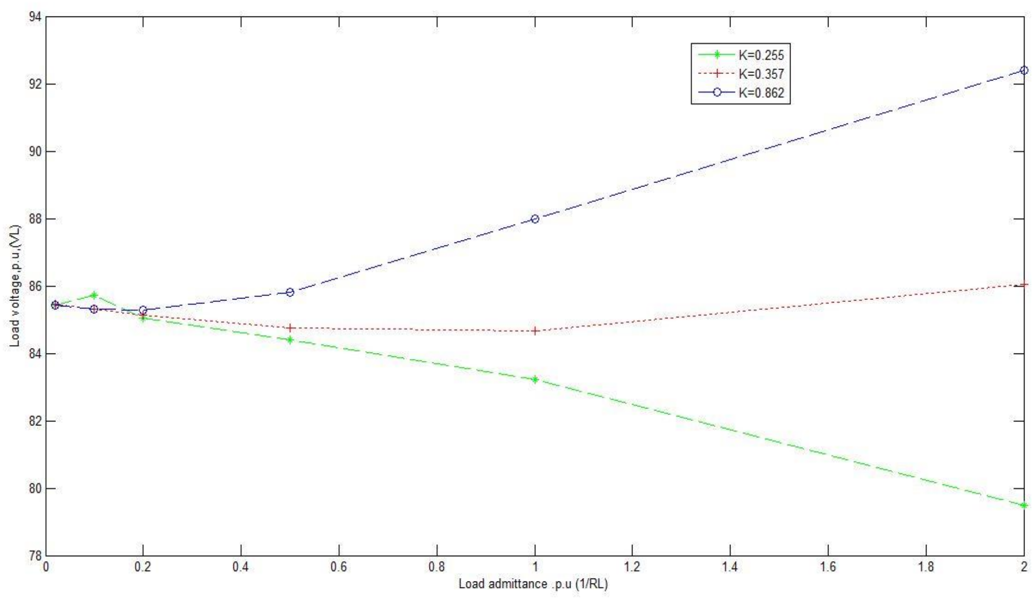

Fig 3.16.Shows variation of load voltage with load admittance,Csh=125μF, P.F=1.0, for varying value of K= 0.255,0.357,0.862.

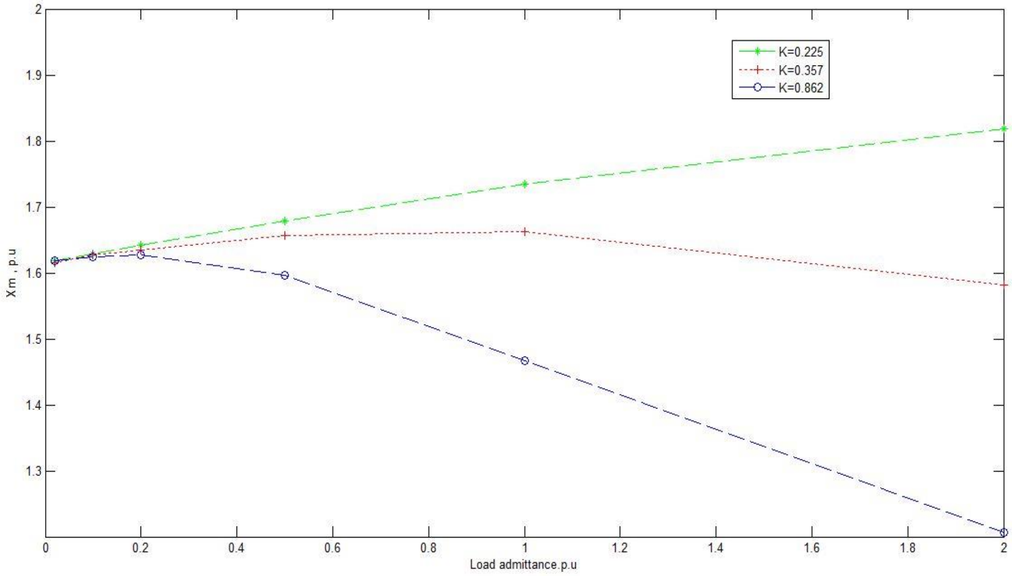

Fig 3.17.shows variation of reactance with load admittance, P.F=1,Csh=125 µF for varying value of K=0.255,0.357,0.862.

The steady state analysis has been done in this thesis. The optimization function is the equivalent impedance of the system. The value is less than specified value which is 1e-4. The values obtained with that of the simulink model has a close approximation with that obtained by the steady state analysis. The genetic algorithm is a very effective tool for optimization as seen from the results which are verified.The studies have confirmed that use of an induction machine as a generator becomes popular for the interaction of electrical energy from the renewable energy sources. Steady state analysis of SEIG is carried out for evaluating running performance. Using the steady state analysis, voltage regulation, frequency regulation, can be assessed. The developed computer algorithm facilitates prediction of performance under the given speed, capacitor and load conditions, which helps in estimating system parameter.The developed matlab program predicts the suitable parameters i.e suitable frequency and magnetic reactance value for simulated machine. The results thus obtained by genetic algorithms prevail better then hookes jeeves method. Solution from Genetic algorithm method gets better with time.

CHAPTER 4

MODELING OF DIFFERENT CONFIGURATION OF SEIG USING SIMULINK

4.1 INTRODUCTION

We know that the induction motor is connected with excitation capacitance to work as an induction generator. The performance of the SEIG is affected by many parameters. In this chapter the performance of the SEIG is analysed.

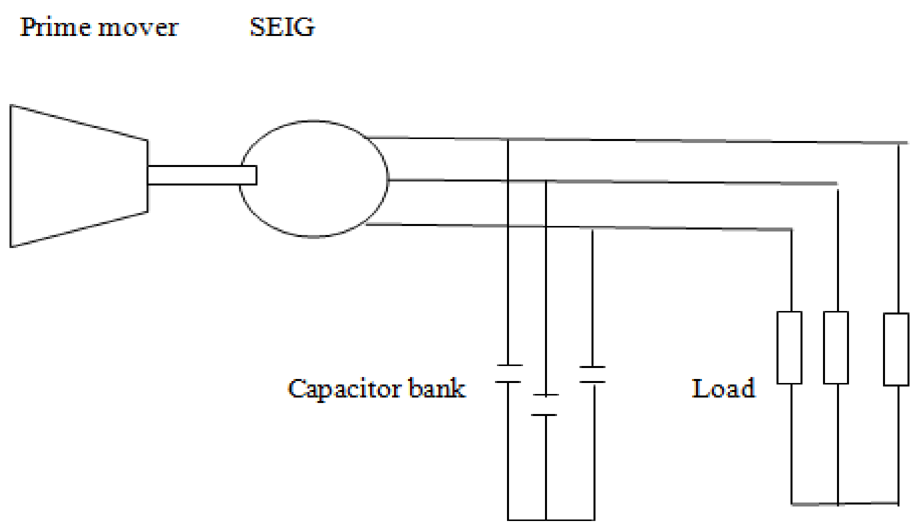

Fig 4.1 Diagram of SEIG with Capacitor bank

The fig 4.1 shows SEIG excited by capacitor which supplies the load. The performance mainly depends upon the speed of operation Wr, excitation capacitance C and the type of load connected to the SEIG. Changing any of these parameters changes the operating parameters and hence the performance of the system. The voltage of the system is mainly the concern.

The voltage regulation provided by the SEIG is very poor. In this chapter we will study the regulation provided by the SEIG to different types of load mainly the reactive load and induction motor load with the help of the simulink model of SEIG in matlab. In this thesis report Short shunt and long shunt self excited induction generators are studied. The series compensation of Self Excited Induction Generators are done in such a way that the load voltage is always maintained at rated voltage. In this model three set of resistive load is applied to the SEIG under different operating conditions. The value of series capacitance Cse is chosen such that when the speed, excitation capacitance Csh and the load is changed, the value of load voltage is maintained at rated value everytime.

The speed of the rotor is varied widely but it is kept constant throughout the operation. The load applied is purely resistive load. Whenever short shunt connection is used for the SEIG it is easy to maintain rated voltage at the load by proper choice of the series capacitance Cse.

The Wind Energy systems are becoming more and more popular nowadays due to environmental considerations. The Self Excited Induction Generators mainly driven by wind turbine. The Self Excited Induction Generators are nothing but Induction Generators excited by capacitors.

This thesis presents the study of the self excited induction generator with the long shunt configuration. The SEIG is provided by this series compensation to analyze the performance. The shunt capacitance is provided to the system for self excitation of the SEIG. It is very difficult to analyze the behaviour of the long shunt configuration especially when feeding dynamic loads such as induction motor loads are fed to the system. In this chapter with the help of simulink model the performance of SEIG is analyzed. According to Li Wang [21] this type of configuration with SEIG and induction motor is highly unstable. All the system parameters are highly unbalanced. This oscillatory behaviour of the long shunt configuration feeding dynamic load is verified using the results.

In this thesis report the performance of Long shunt is carried out with different values of shunt capacitance.

This chapter analyses the Self Excited Induction Generators operating in long Shunt configuration. A simulink model of long shunt SEIG has been developed using MATLAB (R2010a) user friendly toolbox. The results are verified by conducting experiments on the same SEIG. Different results are taken for different loading conditions. The values of Shunt and Series capacitance is also changed for different loads and the performance is analysed.

In this chapter the series compensated SEIG is then used to run three phase Induction motor as load along with connected resistive loads. The series compensated SEIG is also used to run a single phase induction motor using steinmetz connection in short shunt configuration. The matlab simulink model is used for the study of the system parameters and is described in this chapter. The various parameters like voltage, current and power are calculated. Further the results and discussions are done to check the behavior of this dynamic system.

4.2 SIMULINK MODEL

A) Three phase simulink model

4.2.1 Three phase SEIG simulink model with three phase RL load in shunt only configuration

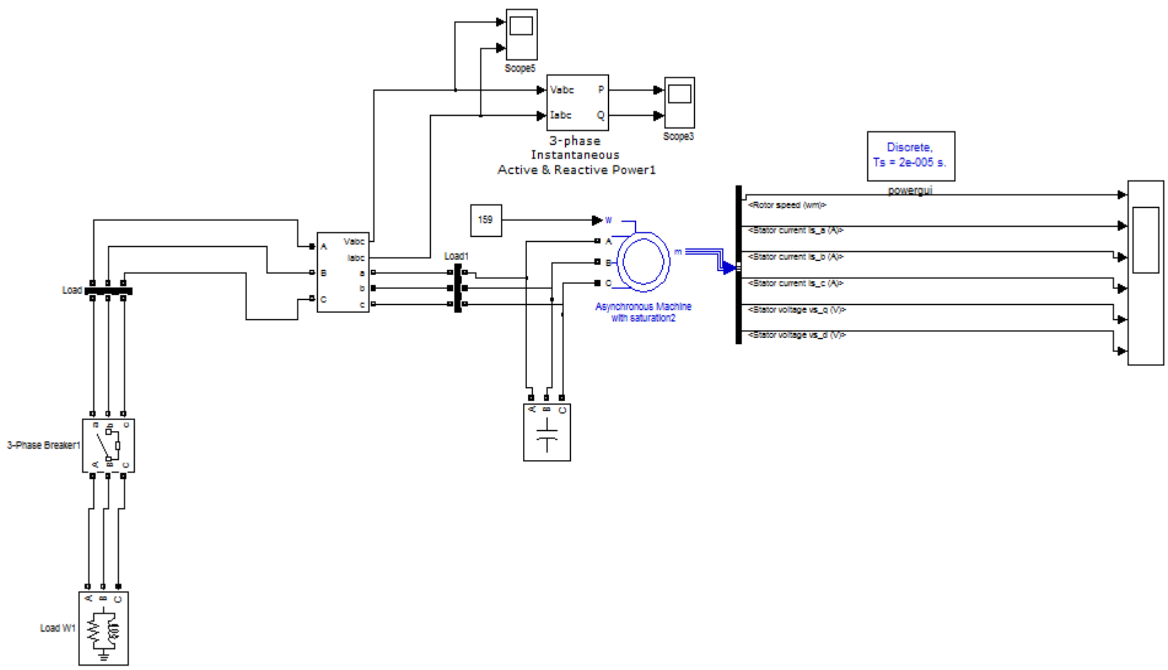

Fig 4.2. Simulink model of SEIG feeding reactive and resistive load

The simulink model of the SEIG is shown in fig 4.2. The SEIG is excited by excitation capacitance which provides the reactive Vars to the system. In this model load W1 is connected to the SEIG. The load is connected with breaker in the circuit which is initially open. The transition time of breaker is 2 seconds. The parameters which decide the performance of the SEIG is varied such as speed of rotor of SEIG Wr, capacitive Vars and the load. Different results are taken and then it is analysed.

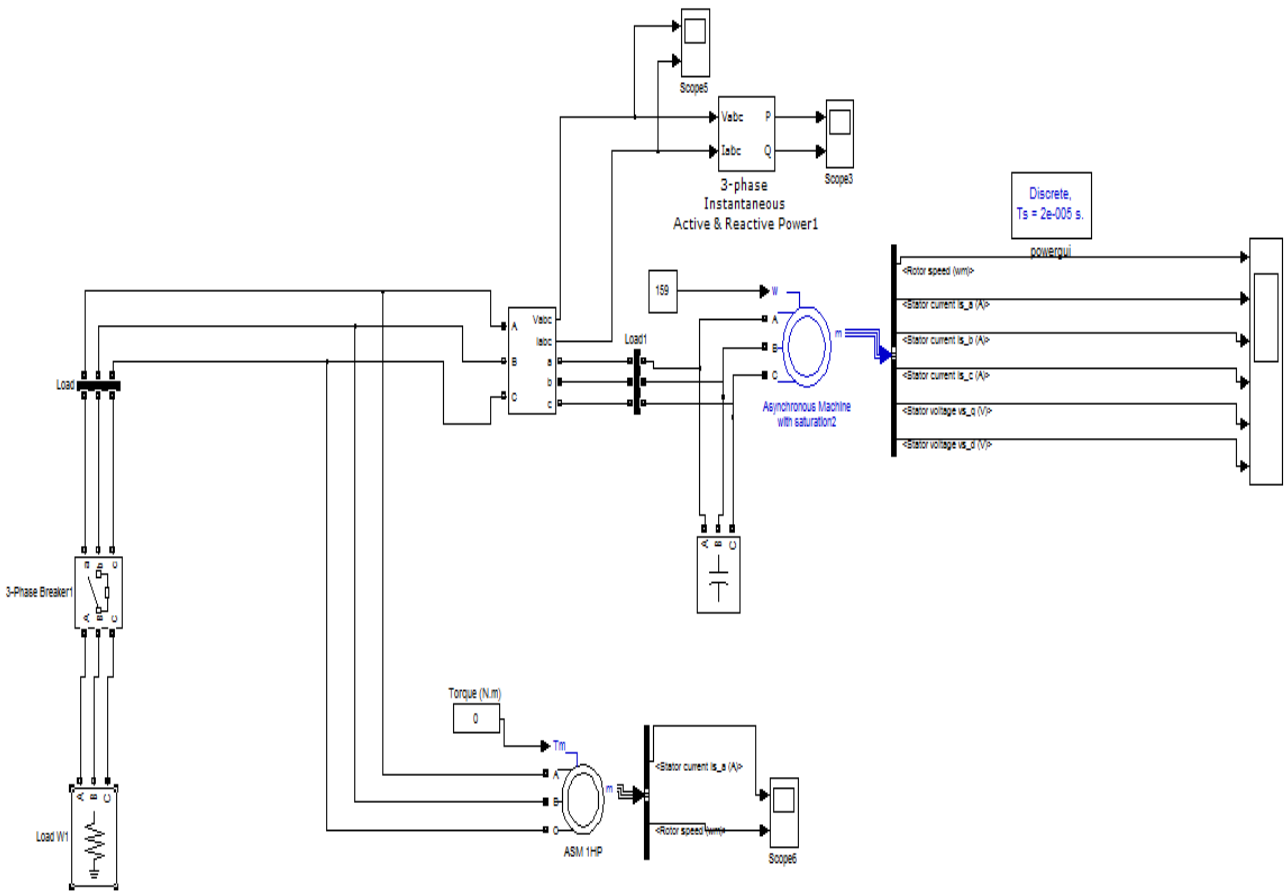

Fig 4.3 Simulink model of SEIG feeding induction motor load

The fig 4.3 shows the simulink diagram of the SEIG feeding a resistive load through breaker having a transition time of 2 secs which is initially open. Load W1 is 100 watts. The rating of induction motor is 1hp. The SEIG rating is 5 hp. The induction motor is run with the help of shunt only compensation and then the performance is analysed. Speed of SEIG is constant at 159 rps. Shunt capacitance provides 4000 vars to the system.

4.2.2 Three phase SEIG simulink model with three phase IM load in short shunt configuration

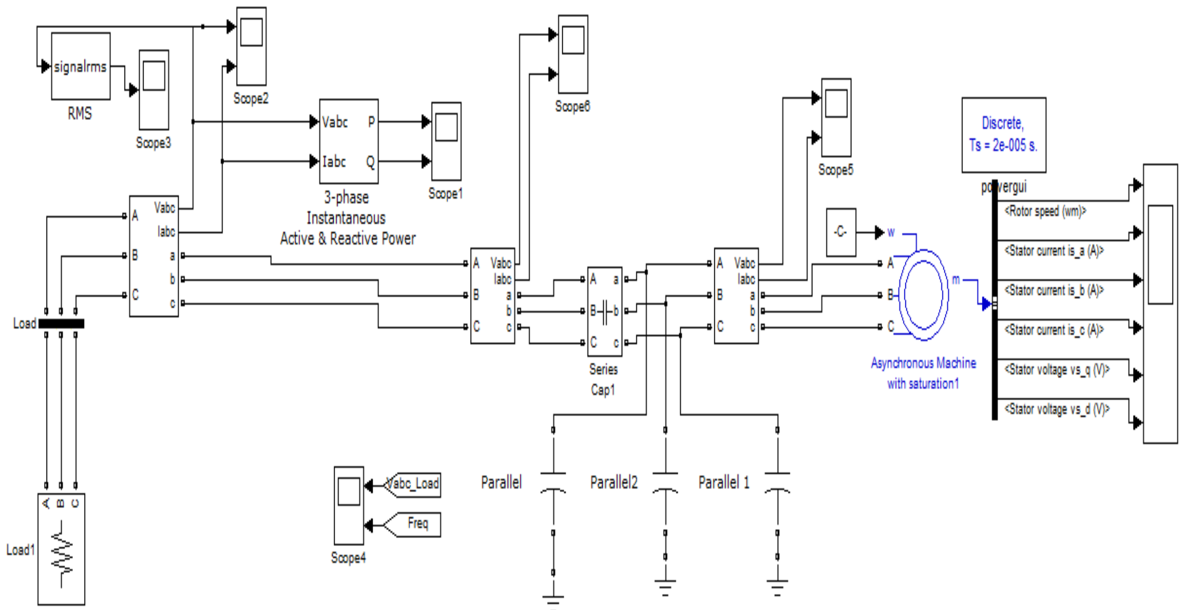

Fig 4.4 Simulink model of Short Shunt Self Excited Induction Generator

In the fig 4.4 1 hp induction motor is used which is excited by three capacitors Csh connected in shunt.

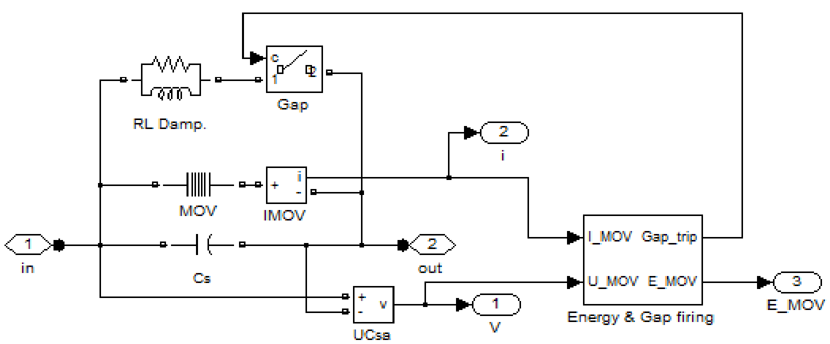

Fig 4.5 Simulink Model of series capacitance

The series capacitance is connected as shown in fig 4.4. The series capacitance is protected by MOV switch.

A series capacitor bank consists of the capacitors and their protective system. MOV's provide overvoltage protection for the capacitors and are a significant member of the protection system. The general purpose of these banks, are to increase the power flow on an existing system by reducing the line impedance.

A) Capacitor bank

Capacitor banks are used to achieve the compensation for transmission line inductance so as to reduce the electrical distance between two substations and improve the system transient stability.

B) MOV

MOV has good non-linear characteristic. It provides overvoltage protection for capacitor banks to limit the overvoltage cross capacitor bank at the protection level 2.0pu ~ 2.5pu (typically) or less, to ensure the safe operation of capacitor bank.

C) Spark Gap

The duration from turn-on command issuing to completely spark gap conduction is less than 1ms. It prevents the MOV against damage due to the excessive absorption of energy.

D) Damping Circuit

The damping device comprises damping reactors and linear resistor string gap (or non-linear resistance). When the series compensation device is in bypass state, the damping circuit can facilitate and speed up the energy storage in capacitor.

E) Bypass Switch

The closing time of bypass switch is longer than the conduction time of spark gap, but it can cause the spark gap interrupted. In addition, it provides normal operation and maintenance functions for series compensation devices.

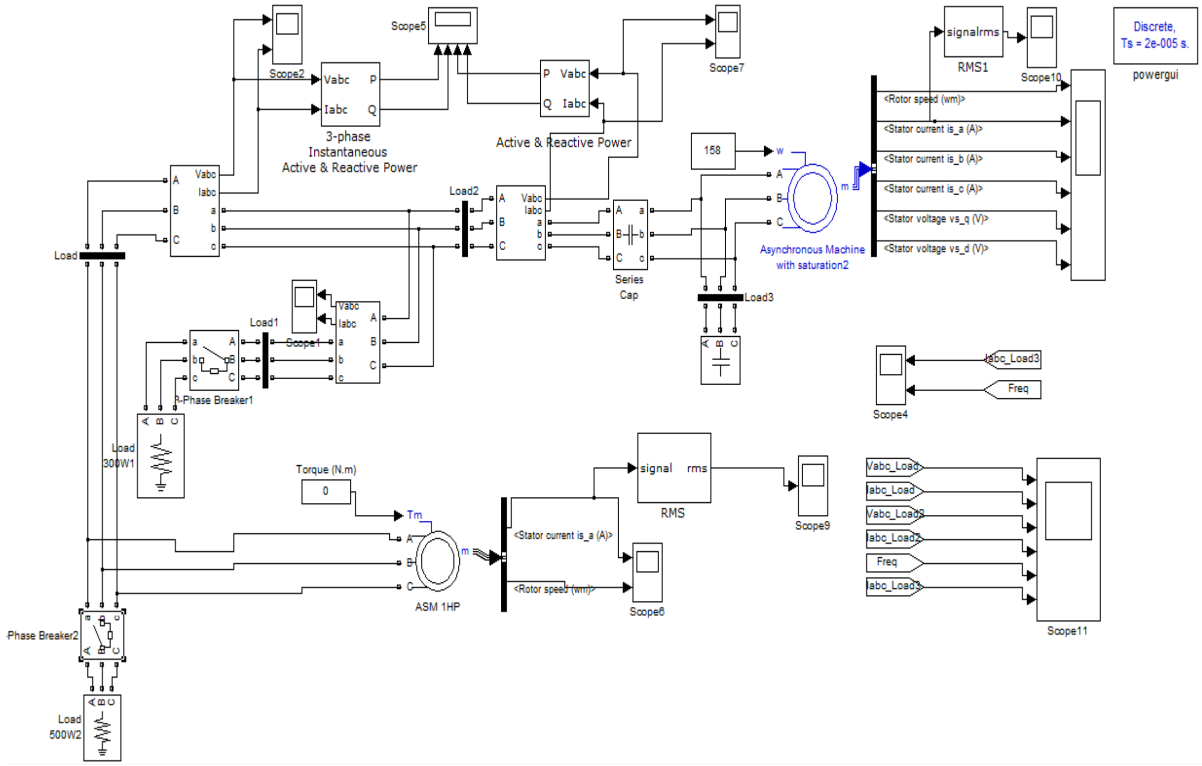

Fig. 4.6 Simulink model of SEIG feeding 3 phase induction motor

In the fig 4.6 short shunt configuration is used in which three capacitors in each phases are connected in series for series compensation. The parallel connected capacitance for the SEIG is used to provide 3400 Vars for self exciting the Induction generator. The speed of the SEIG and series capacitance is varied and corresponding voltages, currents and the parameters are compared. Two different values of resistive load W1 and W2 of values 300 watts and 500 watts is also connected which will remain constant throughout the operation. Both the loads are connected with breakers. Both the breakers are initially open.The transition time for the breaker 1 is 2 sec which is connected to a load of 300 Watts and the transition time for breaker 2 is 1 sec which is connected to a load of 500 Watts. All the results are seen using different scopes connected to the system.

4.2.3 Three phase SEIG simulink model with three phase resistive load in long shunt configuration

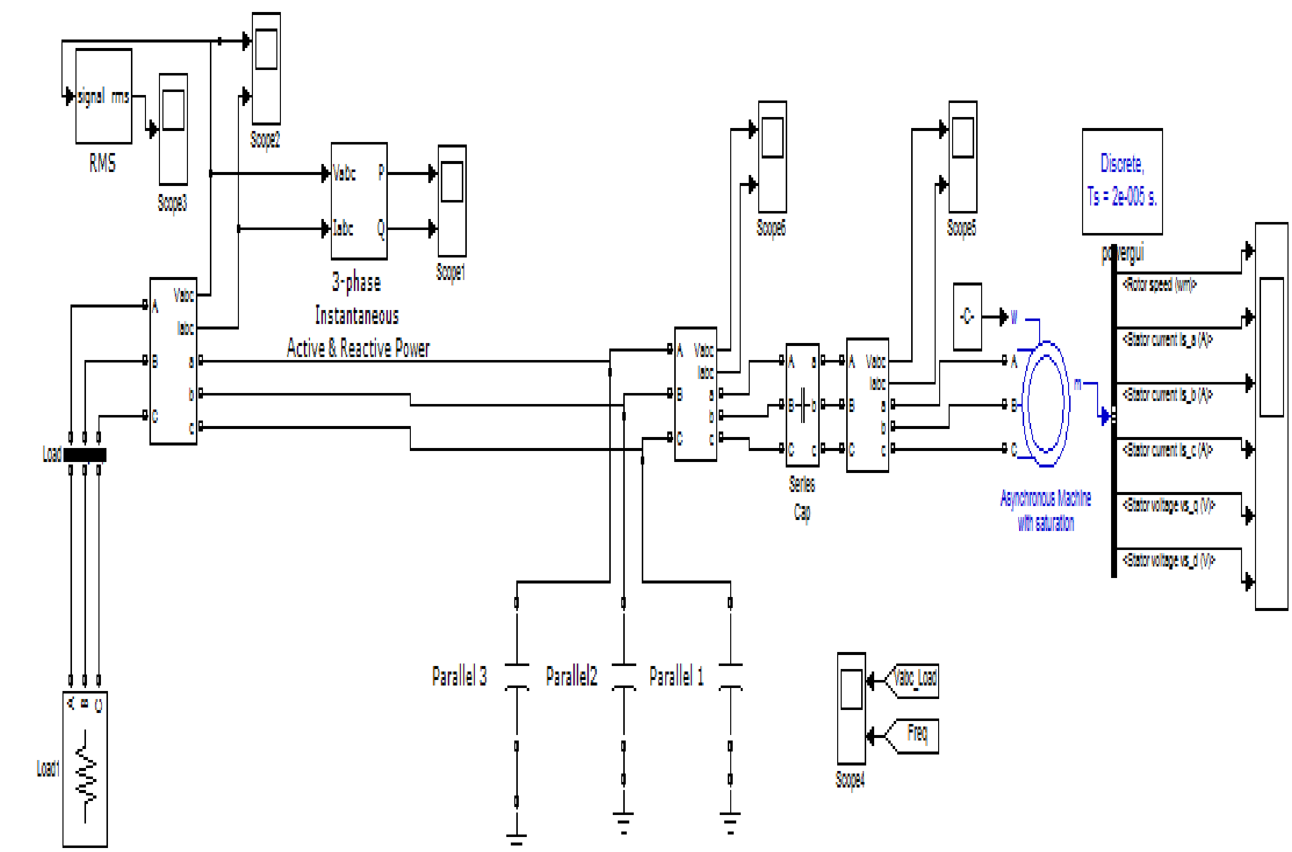

Fig 4.7 Simulink model of long shunt SEIG

In the fig 4.7 the Induction Generator is excited by Shunt capacitance Csh as well as Series capacitance Cse. In this model commonly known as long shunt configuration, three set of resistive loads 400Ω, 350Ω, 300Ω are taken. The SEIG is made to operate under these three different loads using different values of Csh, Cse and rotor speed W. Results for the experimental and simulated are compared.

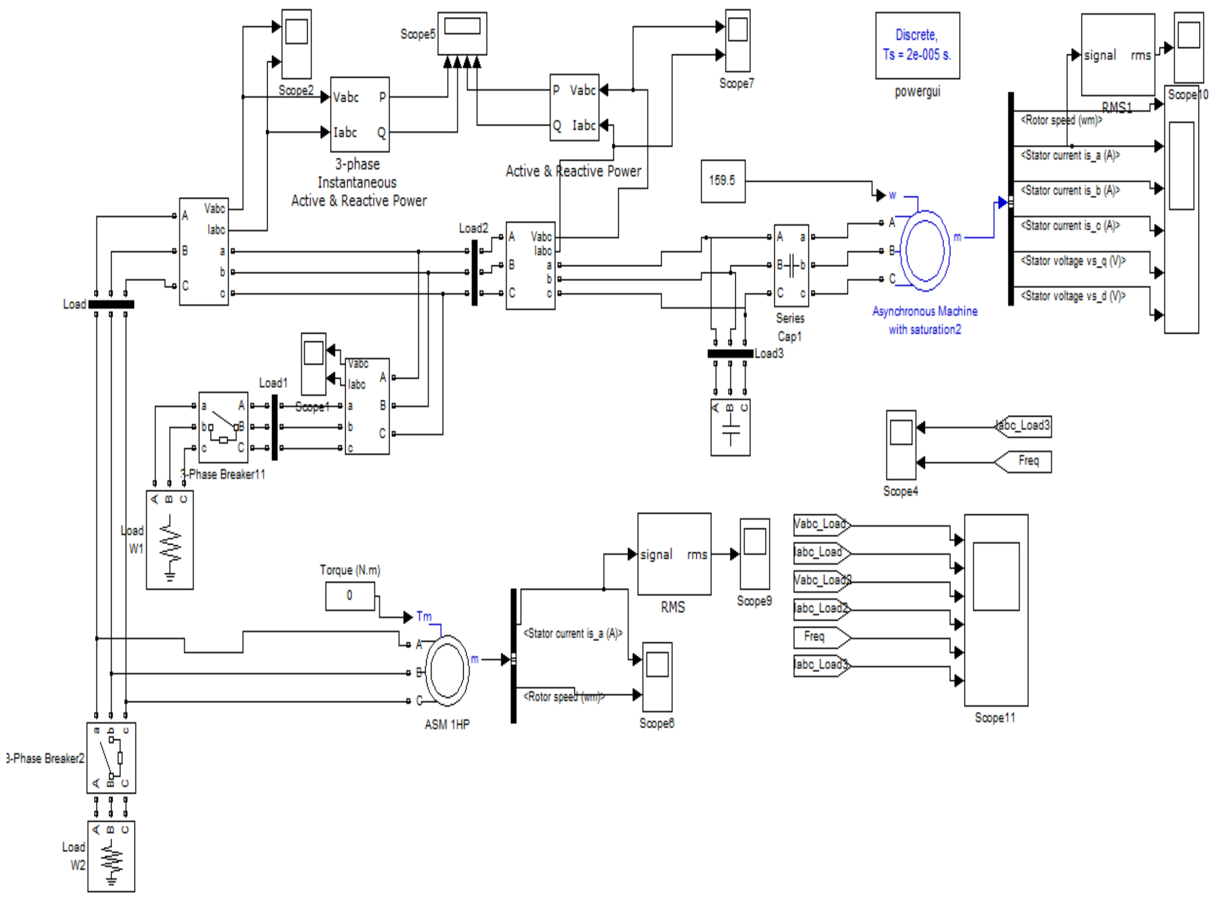

Fig 4.8. Simulink model of long shunt SEIG feeding an Induction motor

The fig 4.8 describes the model of SEIG with series compensation. The model described is a connection known as long shunt connection. The value of the series compensation Cse is 213 microfarad. The shunt capacitance provides a reactive power of 9000 Vars to the system. Two different resistive loads W1 and W2 having values of 300 watts and 500 watts are connected to the system along with induction motor load. The induction motor is a 1 hp motor and the rating of the SEIG is 5 hp induction generator. Both the resistive loads are connected with breakers which are initially opened. The breaker 1 which is connected to load W1 has a transistion time of 0 second and the breaker 2 which is connected to load W2 has a transition time of 1 second.The induction motor is not connected with any breaker.

B) Three phase SEIG feeding Single phase IM as load

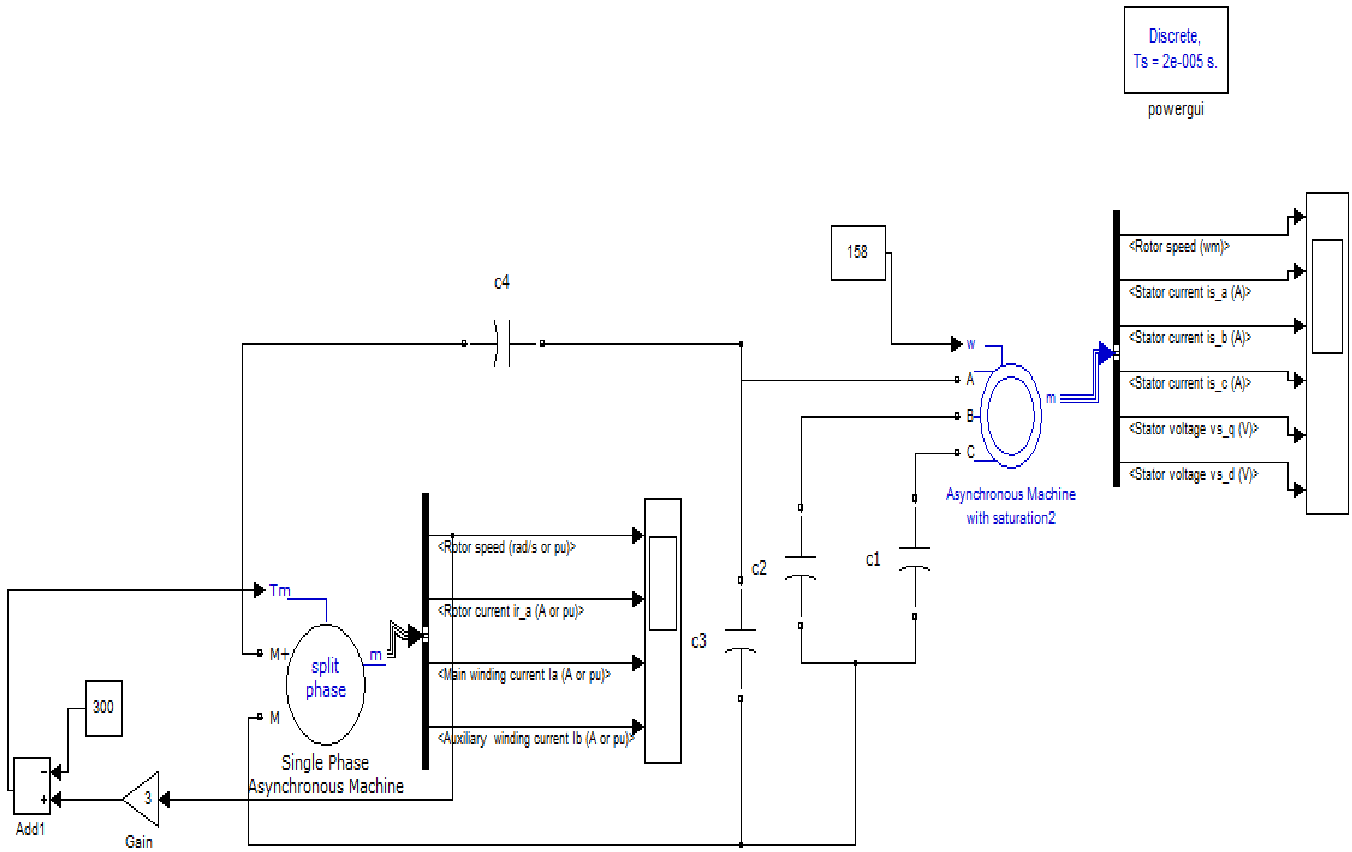

Fig 4.9 Three phase Induction generator feeding Single phase induction motor in short shunt configuration

The fig 4.9 shows the three phase induction generator to which a single phase induction motor is connected. The SEIG is a 5 hp motor which is provided with fixed rotor speed of 158 rps. The three phase supply is changed to a single phase supply using Steinmetz connection. The single phase induction motor is split phase motor having power of 186.5 watts. The configuration used for the modeling purpose is the short shunt configuration. As seen from the figure that the series capacitor C4 is connected near the single phase induction motor so such configuration is referred as short shunt configuration. The value of C4 is 20 microfarad. The capacitors C1 and C2 are used for phase balancing having equal values of 50 microfarad. The capacitor C3 has a value of 300 microfarad.

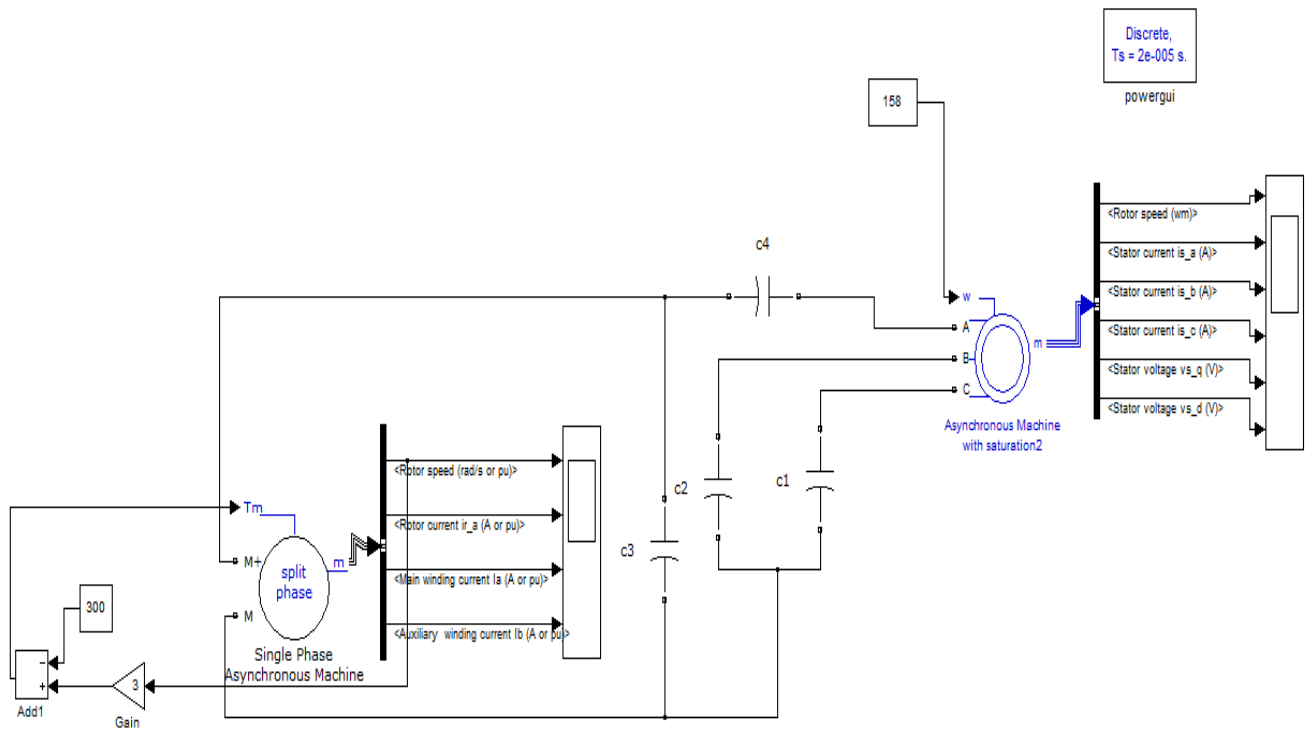

Fig 4.10 Three phase Induction generator feeding Single phase induction motor in long shunt configuration

The fig 4.10 shows the three phase induction generator to which a single phase induction motor is connected. The SEIG is a 5 hp motor which is provided with fixed rotor speed of 158 rps. The three phase supply is changed to a single phase supply using Steinmetz connection. The single phase induction motor is split phase motor having power of 186.5 watts. The configuration used for the modeling purpose is the long shunt configuration. As seen from the figure that the series capacitor C4 is connected near the three phase induction generator so such configuration is referred as long shunt configuration. The value of C4 is 100 microfarad. The capacitors C1 and C2 are used for phase balancing having equal values of 100 microfarad. The capacitor C3 has a value of 500 microfarad.

4.3 RESULTS AND DISCUSSIONS

4.3.1 Results taken from three phase SEIG simulink model with three phase RL load in shunt only configuration

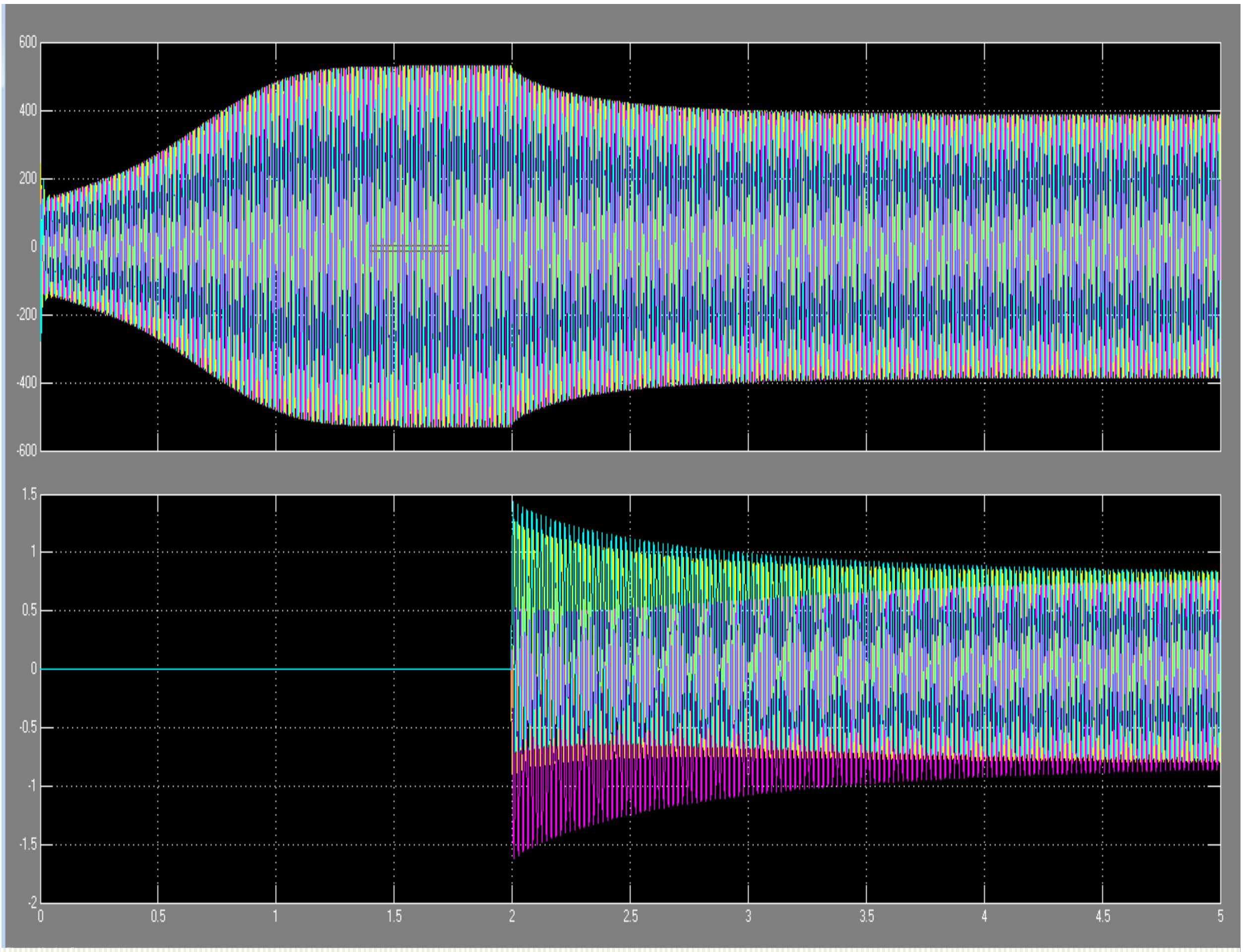

Fig 4.11. variation of VL and IL Vs Time

The Fig 4.11 shows graph of the load voltage and the load current with respect to time. The SEIG has resistive load of 500 watts and the reactive load is 300 vars. The speed of operation of SEIG is 159.08 rps. The voltage is 385 volts peak and current is 0.95 amperes. The currents as seen from the figure is not balanced. The shunt compensation provided is 4000 Vars to the system from the excitation capacitance.

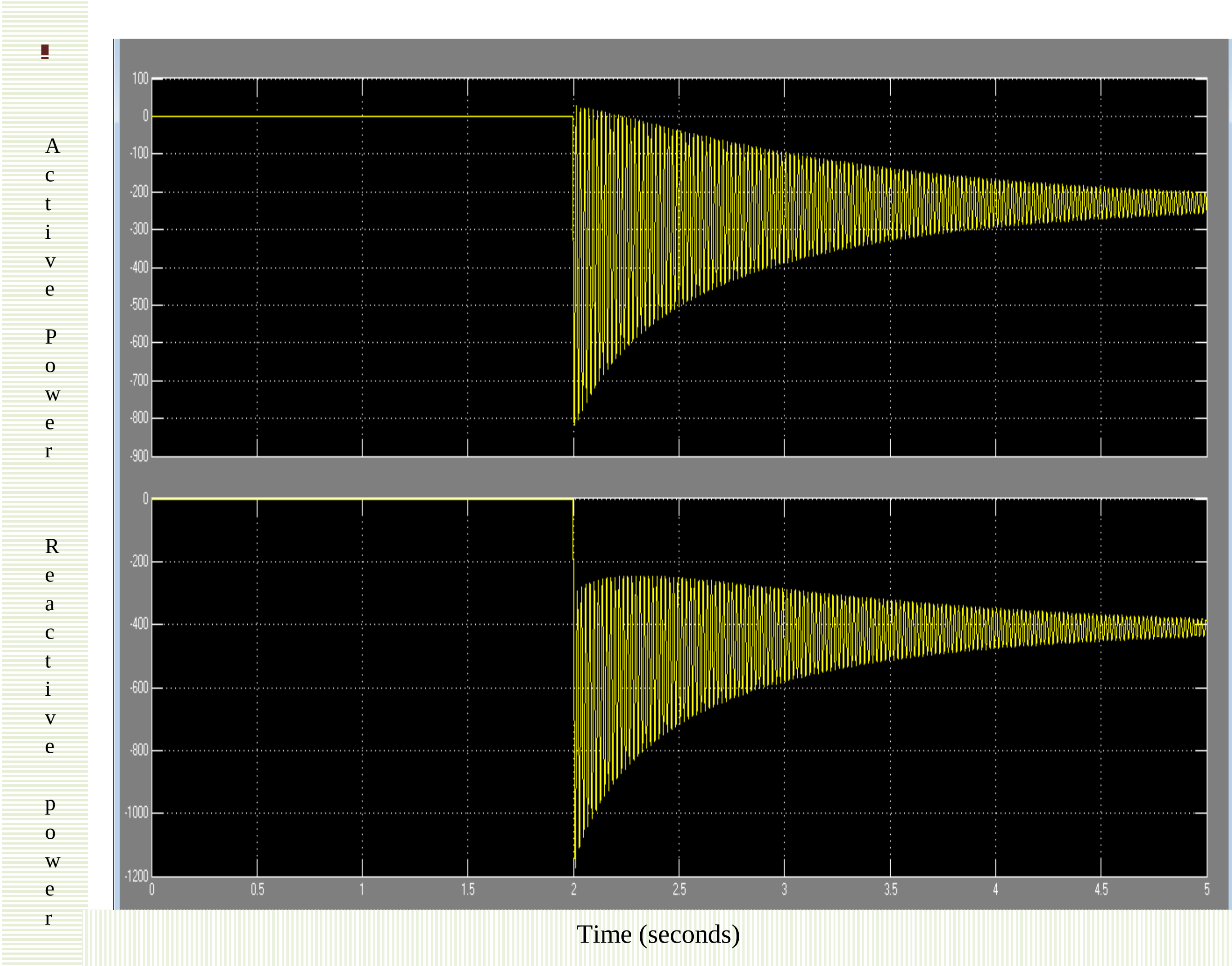

Fig 4.12 Variation of P and Q with Time

The fig 4.12 shows the active power P and reactive power Q which is fed to the load. The value of P is 280 watts and Q is 430 vars. The results are taken when the SEIG has resistive load of 500 watts and the reactive load is 300 vars. The speed of operation of SEIG is 159.08 rps. The shunt compensation provided is 4000 Vars to the system from the excitation capacitance.

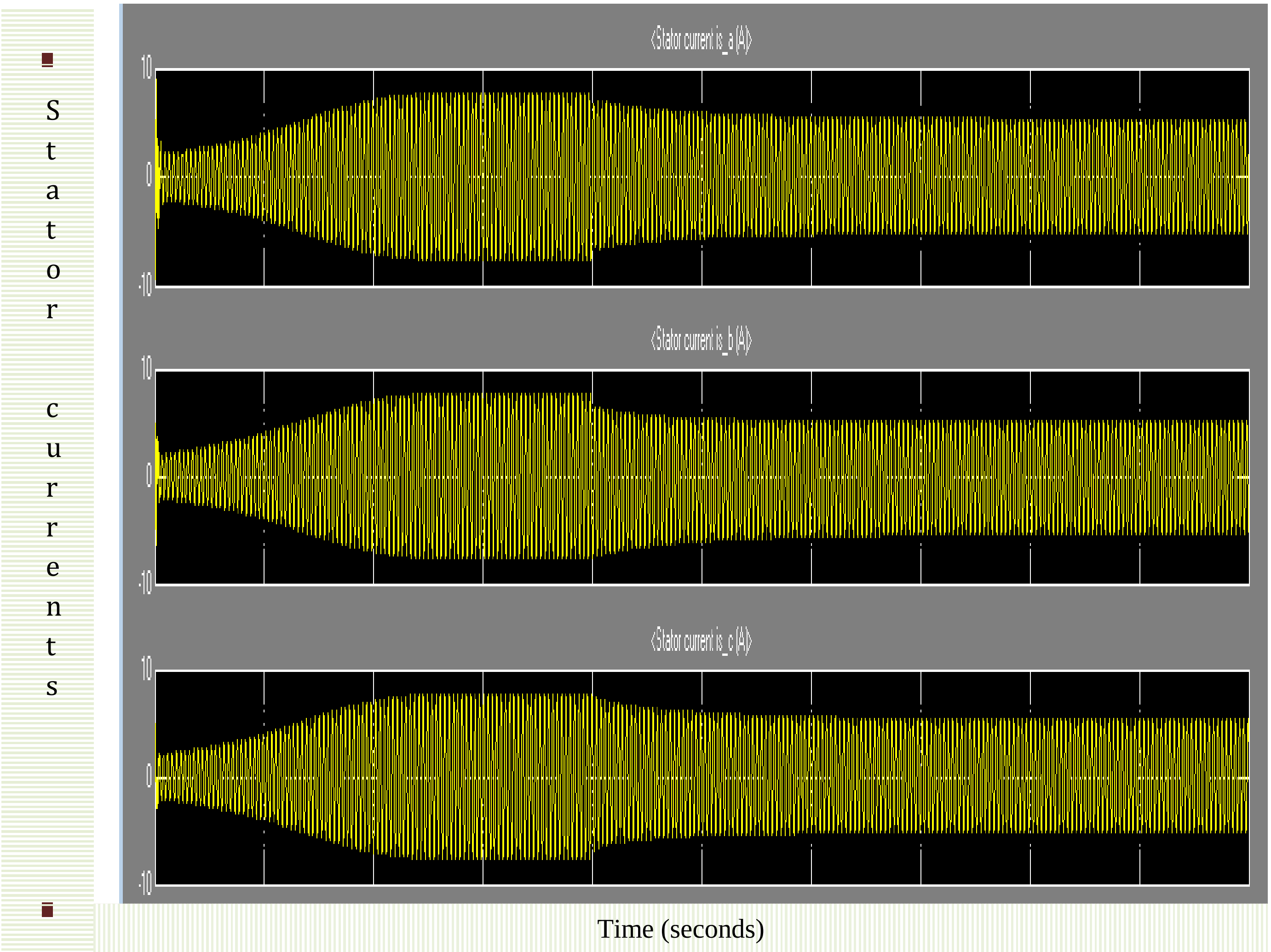

Fig 4.13 Variation of Is Vs Time

The fig 4.13 shows the current which is generated by the SEIG by all the three phase. The results are taken when the SEIG has resistive load of 500 watts and the reactive load is 300 vars. The speed of operation of SEIG is 159.08 rps. The shunt compensation provided is 4000 Vars to the system from the excitation capacitance. The current generated by SEIG is 5.3 amperes peak.

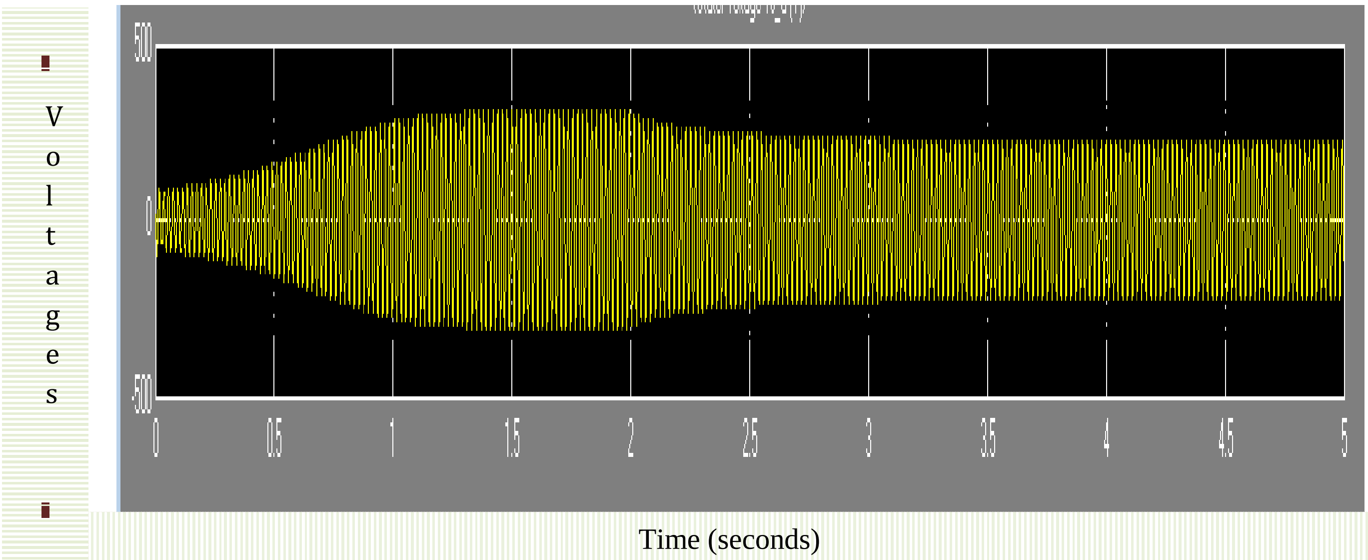

Fig 4.14 variation of Vs with Time

The fig 4.14 shows the voltage which is generated by the SEIG. The results are taken when the SEIG has resistive load of 500 watts and the reactive load is 300 vars. The speed of operation of SEIG is 159.08 rps. The shunt compensation provided is 4000 Vars to the system from the excitation capacitance. The voltage generated by SEIG is 385 volts.

Table 4.1 : Values of voltages and currents of SEIG

RL	XL	PL	QL	VL	IL	Is	Vs	PF
Watts	Vars	Watts	Vars	Volts	amperes	amperes	Volts	
500	100	450	550	472	1.10	7.00	277	0.770
500	200	420	470	430	1.00	6.20	254	0.750
500	300	280	430	385	0.95	5.30	224	0.840
500	400	170	350	310	0.85	4.40	191	0.898
500	500	30	80	150	0.40	3.20	140	0.936

The table 4.1 shows the values of the Load voltages and load currents when the speed of the rotor of the SEIG is kept constant at 159.08 rps and the excitation capacitance provides constant reactive vars of 4000 to the system. The load is kept changing. It can be seen from the table that as reactive load is increased from 100 vars to 500 vars there is a significant decrease in the voltage and current. At 500 vars load the SEIG voltage decays to zero after certain interval of time.

Table 4.2: Values of voltages and currents of SEIG when speed is changing

Wr	PL	QL	VL	IL	Is	Vs	PF
Rad/sec	watts	Vars	Volts	Amperes	Amperes	Volts	
159.08	280	430	385	0.950	5.300	224	0.84
159	230	400	380	0.750	5.200	220	0.867
158	185	337	350	0.770	4.900	208	0.876
157	145	265	310	0.600	4.400	204	0.877
156	85	155	240	0.500	3.500	186	0.8769
155	25	45	120	0.260	3.000	134	0.874
160	265	475	416	0.850	5.590	241	0.873
161	310	550	447	0.910	6.300	259	0.871
162	350	615	474	0.960	6.500	280	0.869
163	385	670	500	1.010	6.900	290	0.867
165	440	760	530	1.120	7.200	305	0.865
166	470	800	546	1.150	8.000	320	0.862
170	560	940	595	1.270	8.600	342	0.859

The table 4.2 shows the values of the Load voltages and load currents when the load is kept constant. The resistive load is kept 500 watts reactive load is kept 300 vars and the excitation capacitance provides constant reactive vars of 4000 to the system. The speed of the SEIG is kept changing. It can be seen from the table that as speed changes keeping all the parameters same then the voltage and current also changes. As the speed is increased the voltage increases and as speed is decreased the voltage also decreases and at certain speed the voltage decays to zero. At a speed of 155 the SEIG voltage decays to zero after certain interval of time.

Table 4.3: Values of voltages and currents of SEIG when capacitance is changing

Capacitive reactive power	PL	QL	VL	IL	Is	Vs	PF
Vars	watts	Vars	Volts	Amperes	amperes	Volts	
3800	80	140	230	0.500	3.200	140	0.868
4000	230	400	385	0.750	5.200	220	0.866
4200	350	625	478	0.990	6.800	275	0.873
4500	450	800	540	1.100	8.200	310	0.871
5000	550	970	590	1.160	10.000	340	0.869
5500	610	1100	630	1.300	12.000	360	0.874
6000	Overshoot						

The table 4.3 shows the values of the load voltages and load currents when the load is kept constant. The resistive load is kept 500 watts reactive load is kept 300 vars and the speed of the rotor of the SEIG is kept constant at 159.08 rps. The excitation capacitance is changed and performance is analysed. It can be seen from the table that as capacitance vars changes keeping all the parameters same then the voltage and current also changes. As the capacitance is increased the voltage increases rapidly and as capacitance is decreased the voltage also decreases. At a capacitance of 6000 vars the SEIG voltage overshoots by a very large amount.

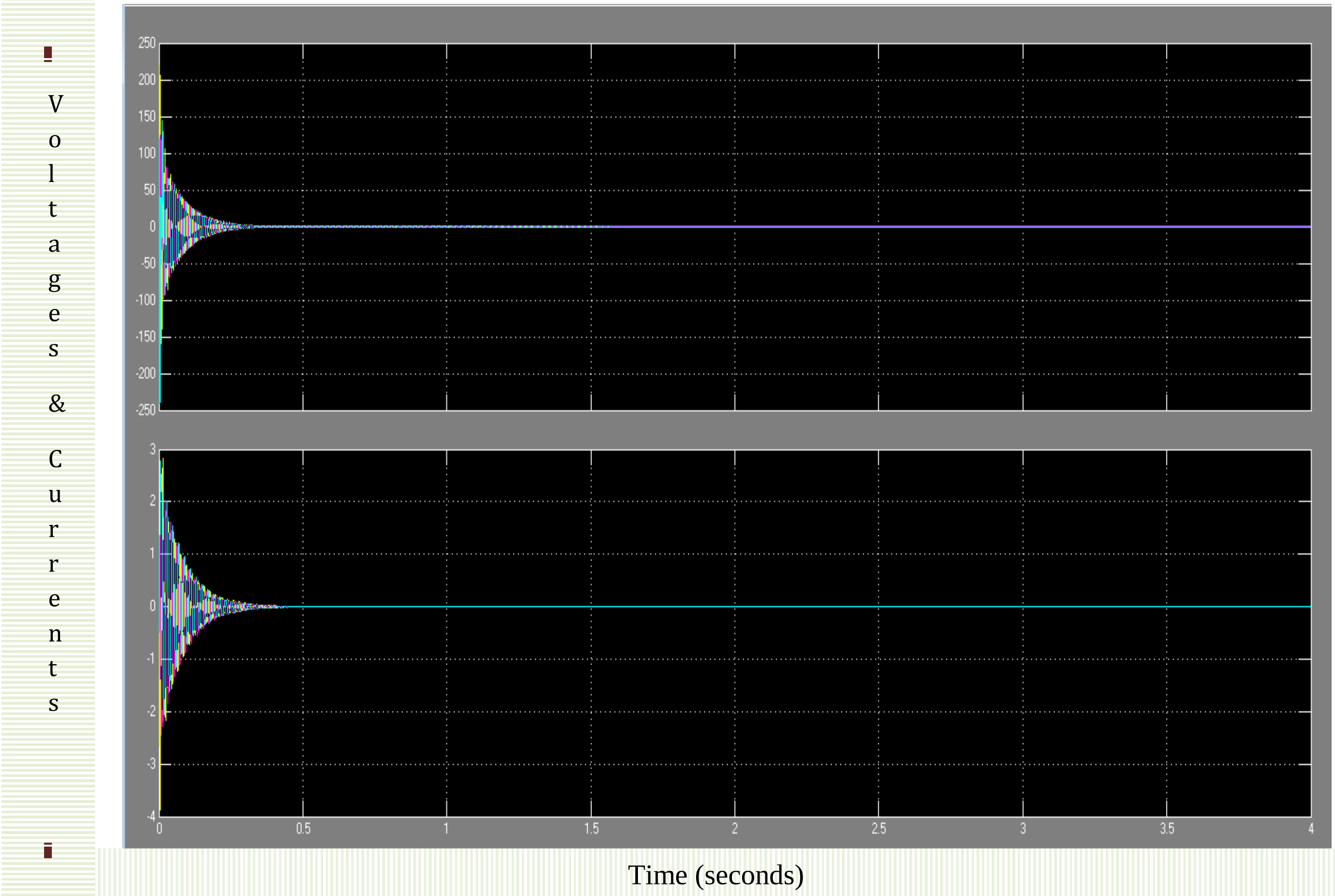

Fig 4.15 Variation of VL Vs Time and IL Vs Time

The Fig 4.15 shows variation of the load voltage and the load current with respect to time. The SEIG has resistive load of 100 watts and the Induction motor load of 1 hp. The speed of operation of SEIG is 159 rps. The shunt compensation provided is 4000 Vars to the system from the excitation capacitance. As seen from the graph the voltages and currents are zero which means that the induction generator is not able to build up voltage when induction motor load is connected.

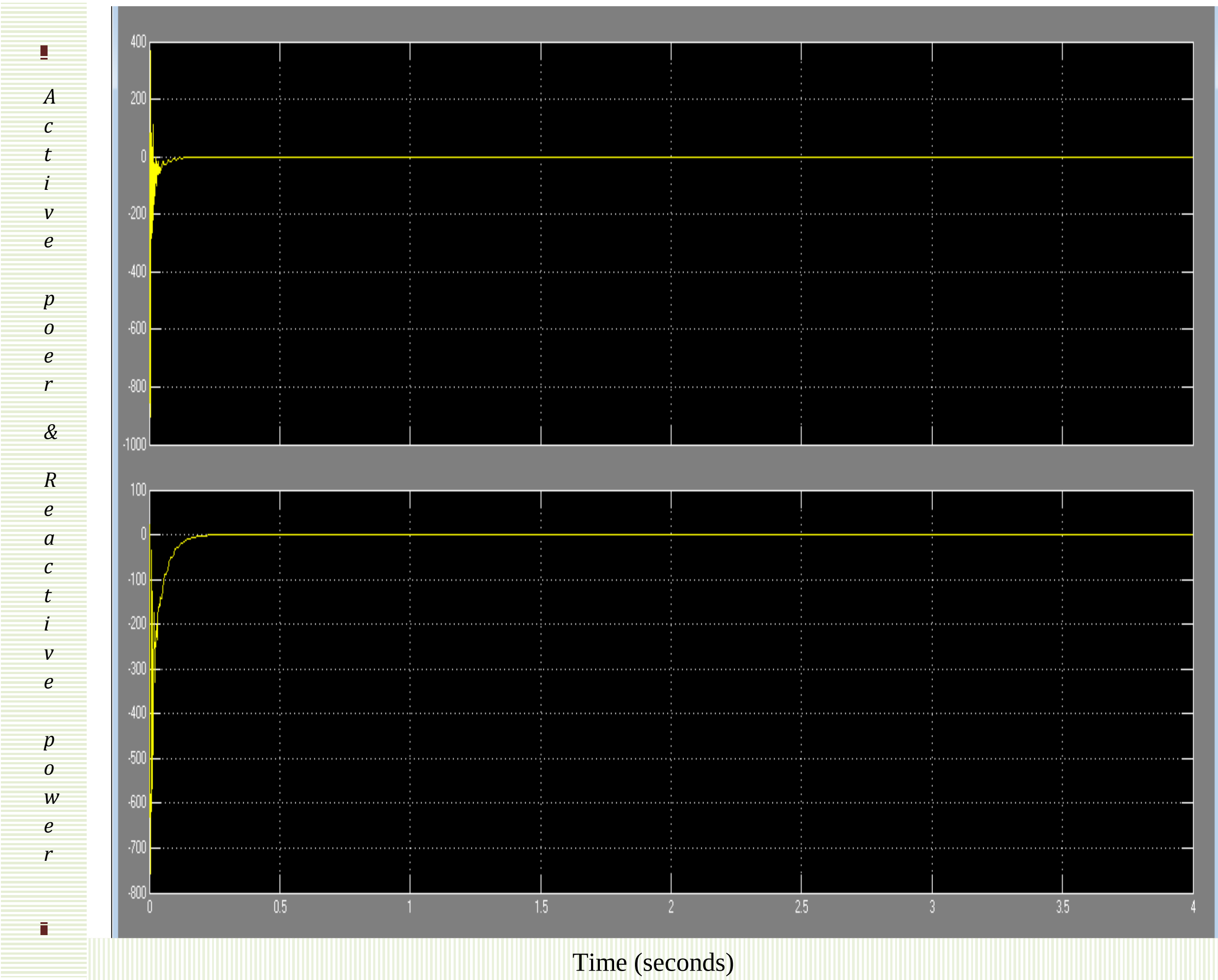

Fig 4.16 Variation of P and Q with Time

The Fig 4.16 shows variation of the active power P and the reactive power Q with respect to time. The SEIG has resistive load of 100 watts and the Induction motor load of 1 hp. The speed of operation of SEIG is 159 rps. The shunt compensation provided is 4000 Vars to the system from the excitation capacitance. As seen from the graph the active power P and the reactive power Q are zero which means that the induction motor is not drawing any power from the SEIG.

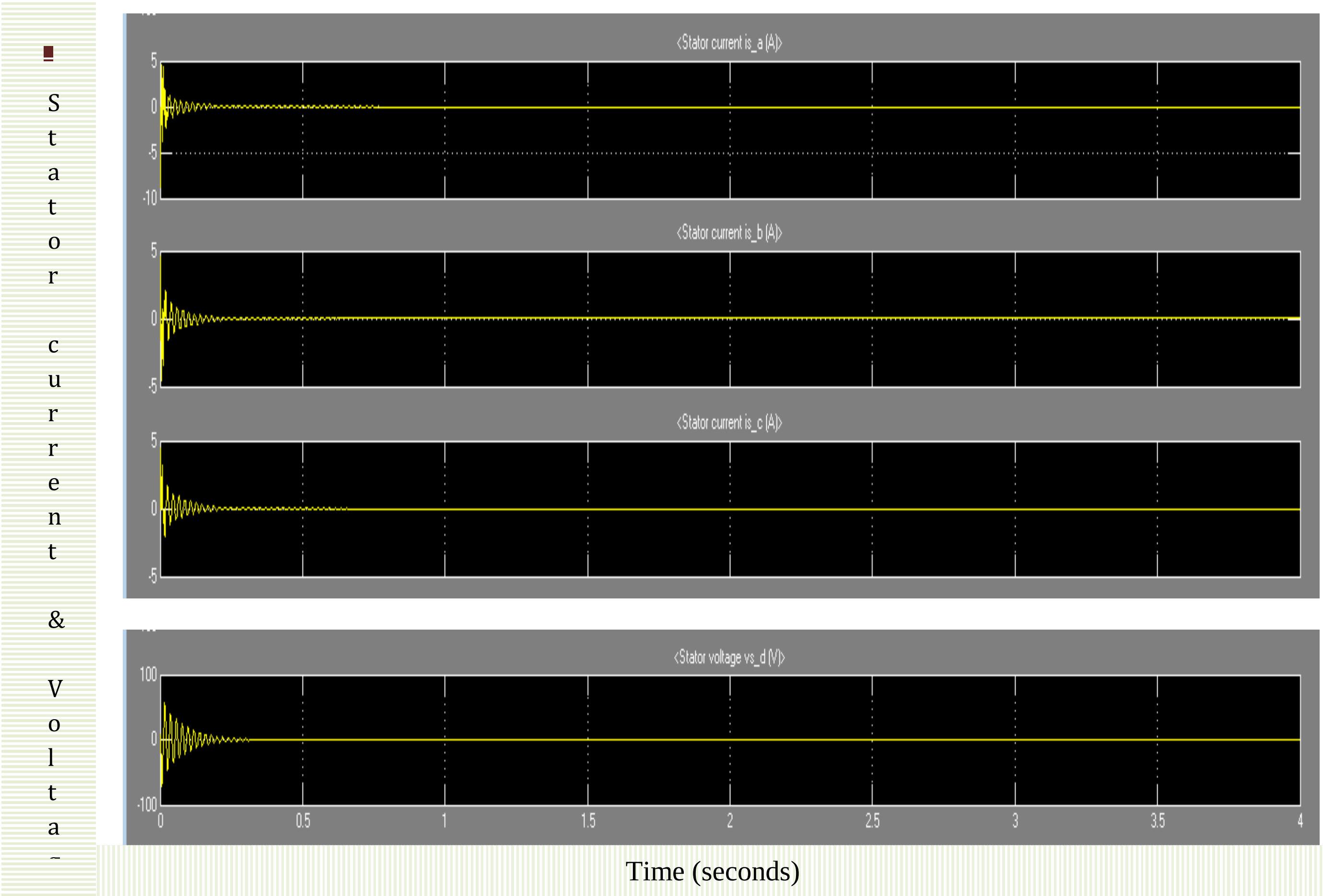

Fig 4.17 Plot of Is and Vs with time

The Fig 4.17 shows variation of the stator current and voltage with respect to time. The SEIG has resistive load of 100 watts and the Induction motor load of 1 hp. The speed of operation of SEIG is 159 rps. The shunt compensation provided is 4000 Vars to the system from the excitation capacitance. As seen from the graph the stator voltage and stator current is zero which means that the induction generator is not able to supply the load.

4.3.2 Results when three phase SEIG simulink model with three phase resistive load in short shunt configuration

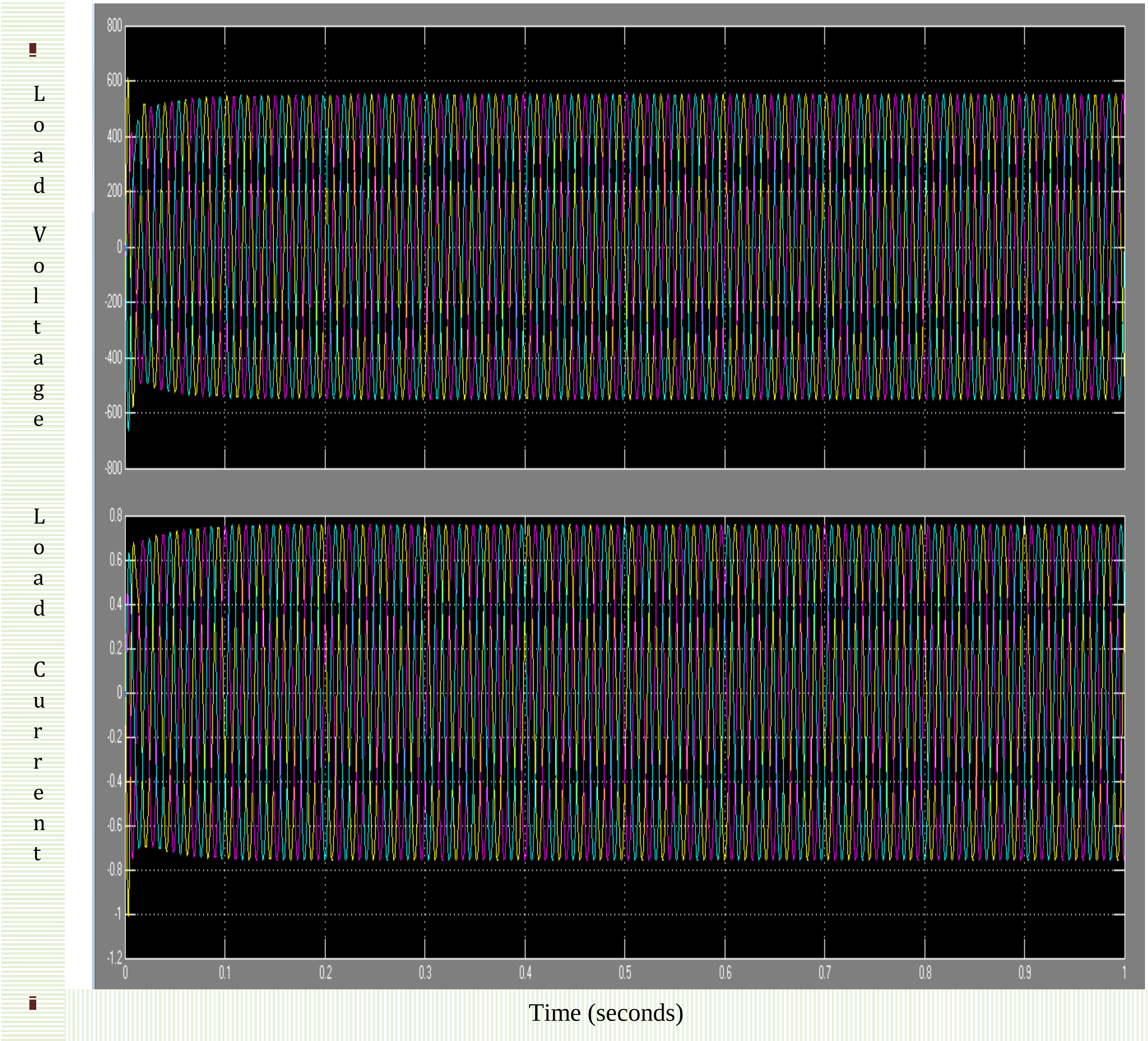

Fig 4.18 Variation of VL and IL with Time

The fig 4.18 shows variation of the load voltage and current when a load of 350Ω is applied with Csh=29µf. The rotor speed is maintained at a constant value of 0.9898 pu. The required series capacitance to maintain the rated voltage at load is 12µf.

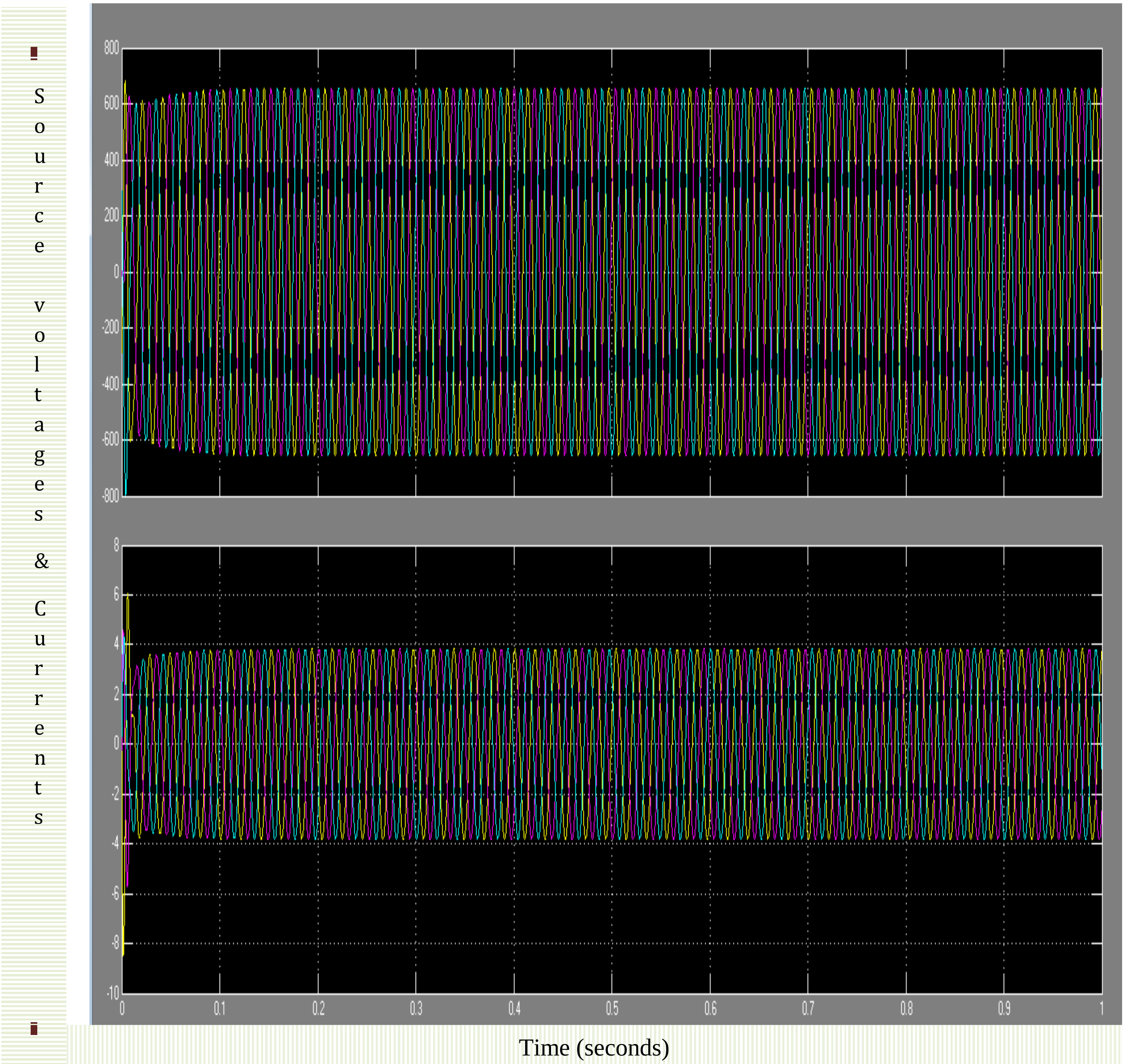

Fig 4.19 Variation of Vabc and Iabc Vs Time

The fig 4.19 shows voltage and current generated by the SEIG. It can be seen that the voltages and currents generated in all the three phases are balanced.

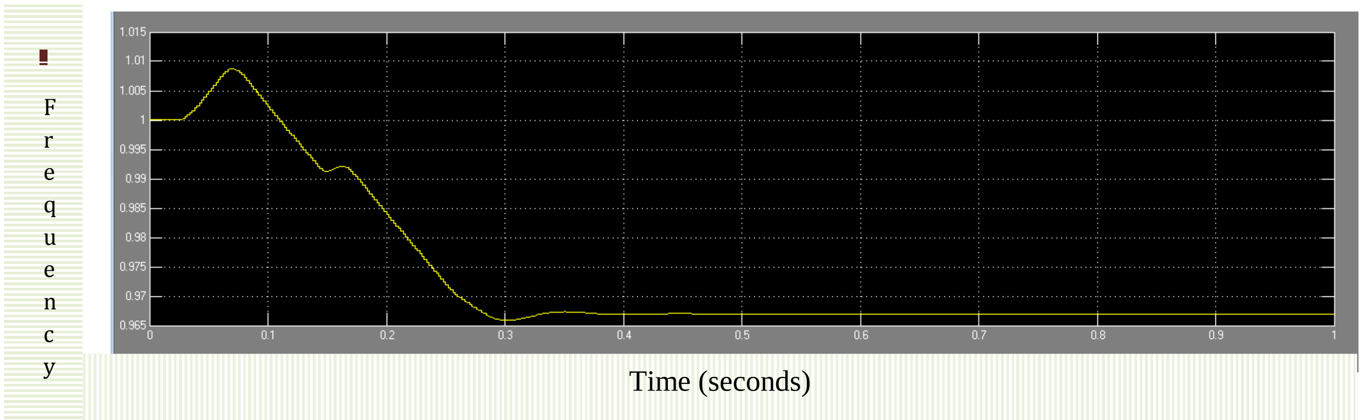

Fig 4.20 Variation of Freq with Time

The fig 4.20 shows the frequency which is maintained at 0.9767 pu for the same value of load.

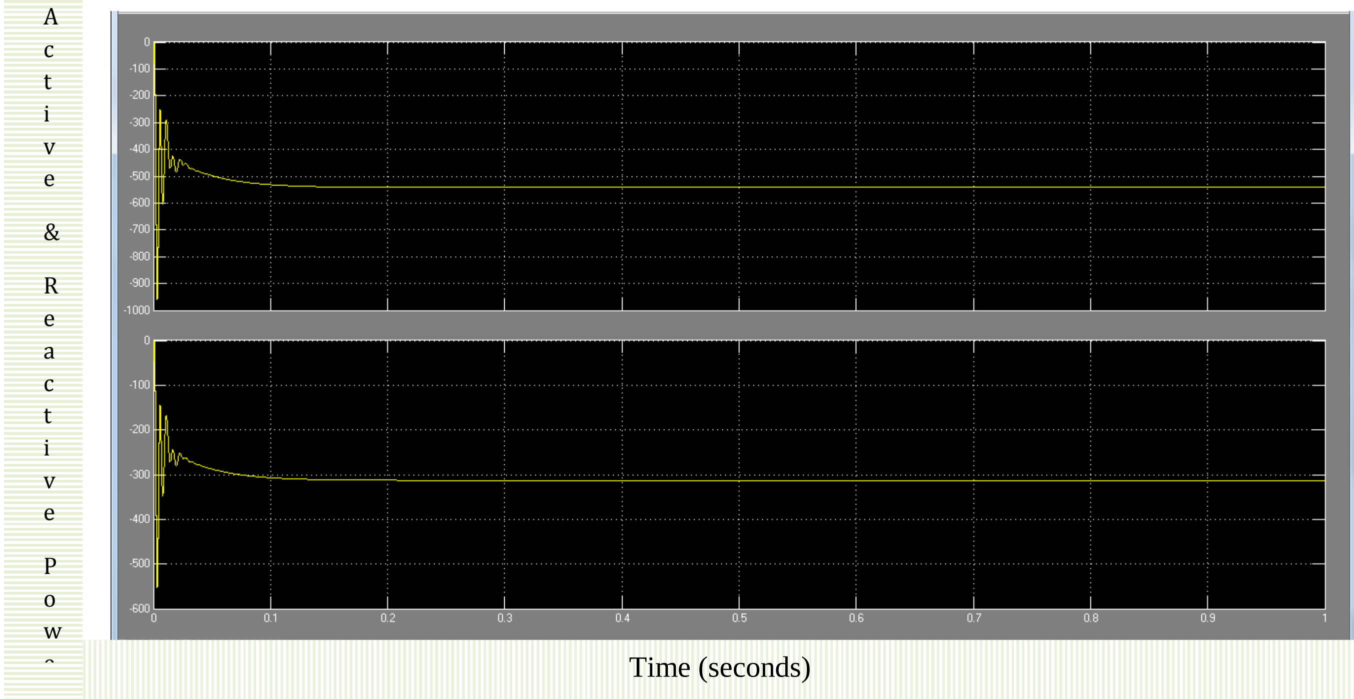

Fig 4.21 Variation of P and Q with Time

The fig 4.21 shows that Active Power P is equal to 542 Watts and Reactive Power is equal to 313 Watts.

Table 4.4.Comparisons for the various simulated results are listed in the table

S no	Csh pu	Cse pu	Load pu	Speed pu	frequency pu	Load Voltage pu	Load Current pu	Stator Voltage pu	Stator current pu	P pu	Q pu
1	1.0507	0.4348	0.8399	0.9898	0.9767	1.0010	0.2768	1.2323	1.4328	1.3007	0.7511
2	1.0507	0.5072	0.7199	0.9830	0.9580	1.0013	0.3242	1.2027	1.4179	1.4591	0.8399
3	1.0507	1.4493	0.9599	0.9458	0.9233	0.9990	0.2382	1.0001	1.0420	1.0559	0.6096
4	1.0507	1.0870	0.8399	0.9518	0.9270	0.9950	0.2754	1.0304	1.1165	1.2311	0.7103
5	1.0507	1.4130	0.7199	0.9585	0.9305	0.9980	0.3275	1.0499	1.1686	1.4639	0.8471
6	1.0507	0.4710	0.9599	0.9700	0.9488	1.0060	0.2441	1.1448	1.2765	1.1063	0.6383
7	1.0507	0.4891	0.8399	0.9750	0.9520	1.0040	0.2765	1.1672	1.3249	1.2479	0.7199
8	1.0507	0.4674	0.7199	0.9906	0.9658	1.0050	0.3237	1.2342	1.4700	1.4639	0.8399
9	0.9783	0.3080	0.9599	1.0180	0.9985	1.0010	0.2382	1.2659	1.3993	1.0799	0.6240
10	0.9783	0.3514	0.8399	1.0032	0.9967	1.0006	0.2754	1.2715	1.4291	1.2383	0.7151
11	0.9783	0.3659	0.7199	1.0314	1.0082	0.9997	0.3237	1.3292	1.5444	1.4519	0.8399
12	0.9275	0.3225	0.9599	1.0280	1.3397	1.0030	0.2430	1.303	1.2509	1.0943	0.6311
13	0.9275	0.3442	0.8399	1.0316	1.0103	1.0040	0.2783	1.269	1.3769	1.2599	0.7247
14	0.9275	0.3949	0.7199	1.0360	1.0125	1.0040	0.3237	1.2938	1.4365	1.4639	0.8399
15	0.8913	0.3442	0.9599	1.0434	1.0241	1.0048	0.2441	1.2658	1.3212	1.1039	0.6383
16	0.8913	0.3297	0.8399	1.0488	1.0280	1.0010	0.2791	1.2938	1.3769	1.2527	0.7247
17	0.8913	0.3986	0.7199	1.0436	1.0203	1.0010	0.3237	1.2779	1.3874	1.4543	0.8399
18	0.8913	0.3152	0.9599	1.0390	1.0198	1.0006	0.2423	1.2521	1.2988	1.0895	0.6287
19	0.8913	0.3514	0.8399	1.0412	1.0202	1.0011	0.2765	1.2659	1.3398	1.2479	0.7199
20	0.8913	0.4022	0.7199	1.0414	1.0180	0.9990	0.3215	1.2696	1.3769	1.4447	0.8351

21	0.8913	0.3442	0.9599	1.0306	1.0111	1.0004	0.2423	1.2193	1.2523	1.0895	0.6287
22	0.8913	0.3370	0.8399	1.0454	1.0246	1.0003	0.2765	1.2808	1.3584	1.2431	0.7199
23	0.8913	0.4094	0.7199	1.0420	1.0185	1.0050	0.3237	1.2696	1.3769	1.4639	0.8399
24	0.8913	0.3623	0.9599	1.0258	1.0061	0.9997	0.2419	1.1988	1.2281	1.0871	0.6263
25	0.8913	0.3986	0.8399	1.0288	1.0073	1.0006	0.2754	1.2118	1.2653	1.2407	0.7199
26	0.8913	0.4348	0.7199	1.0356	1.0117	1.0006	0.3260	1.2454	1.3398	1.4711	0.8471
27	0.9783	0.2754	0.9599	1.0306	1.0115	0.9997	0.2397	1.3180	1.4886	1.0775	0.6216
28	0.9783	0.3134	0.8399	1.0321	1.0112	1.0006	0.2769	1.3273	1.5109	1.2455	0.7199
29	0.9783	0.3514	0.7199	1.0365	1.0135	1.0007	0.3223	1.3478	1.5631	1.4495	0.8375
30	0.6522	0.2366	0.9599	1.155	1.1380	1.00005	0.2419	1.3459	1.1909	1.0919	0.6311
31	0.6522	0.0725	0.8399	1.598	0.7700	0.9990	0.2773	2.6155	2.9494	1.2431	0.7199
32	0.6522	0.0772	0.7199	1.655	0.8000	1.0015	0.3238	2.7552	3.2378	1.4567	0.8399

4.3.3 Results of three phase SEIG simulink model with three phase resistive load in long shunt configuration

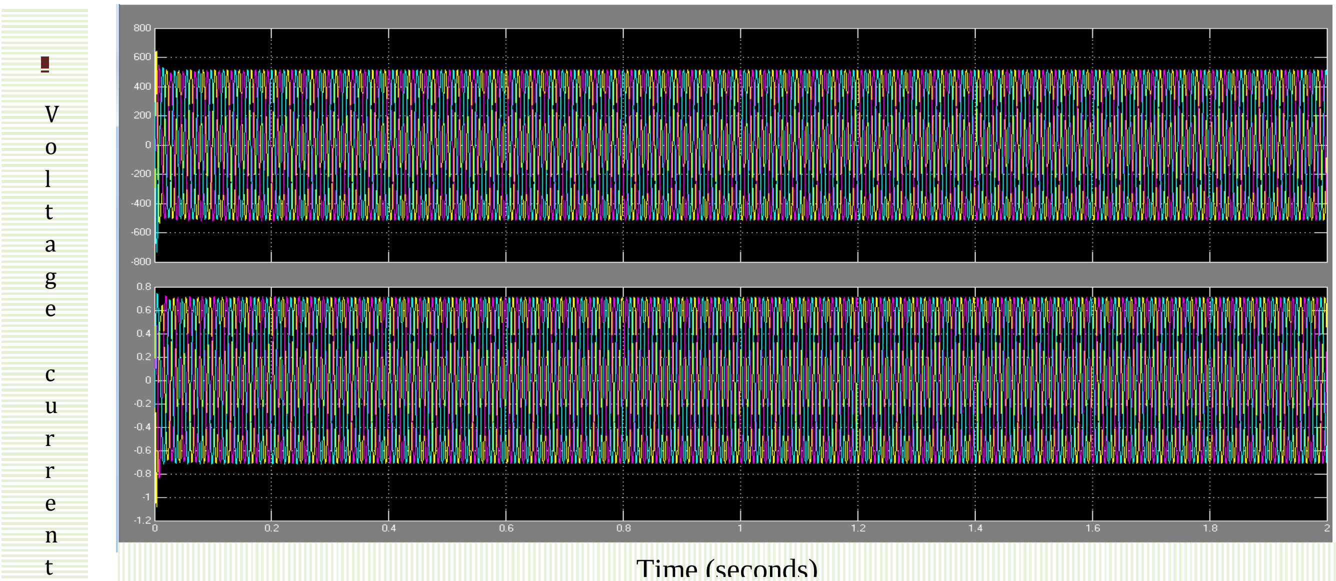

Fig 4.22. Variation of VL and IL with Time

The fig 4.22 shows the load voltage and current when a load of 350Ω is applied with Csh=29μf and Cse=268μf. The rotor speed is maintained at a constant value of 0.9898 pu.

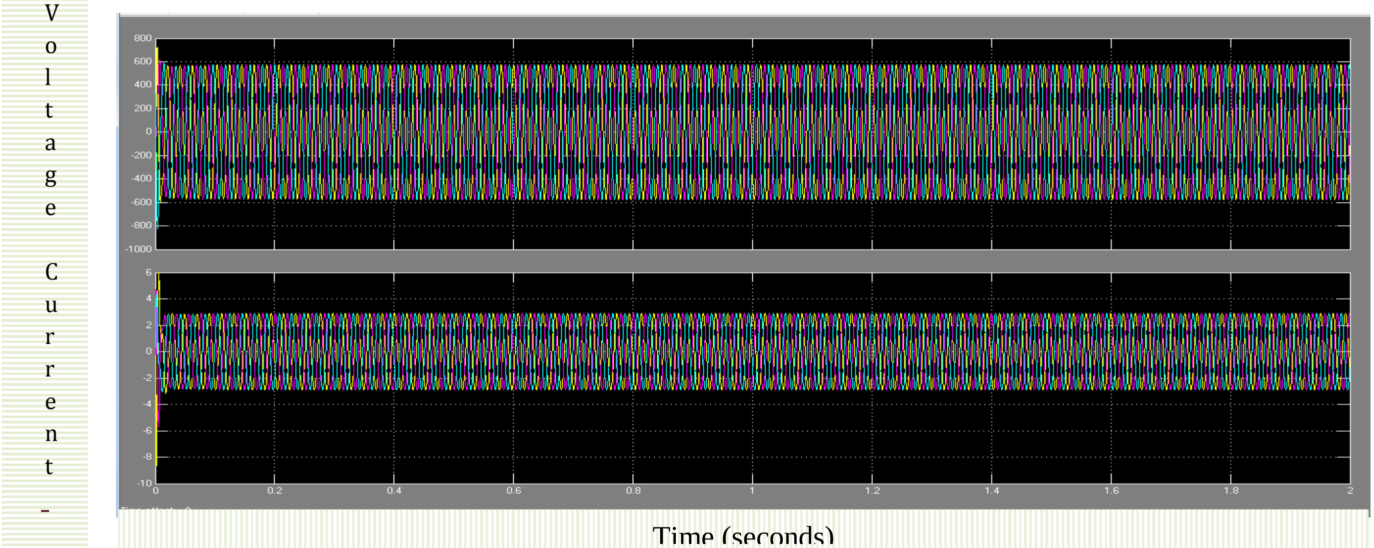

Fig 4.23 Variation of Vabc and Iabc with Time

The fig 4.23 shows voltage and current generated by the SEIG. It can be seen that the voltages and currents generated in all the three phases are balanced.

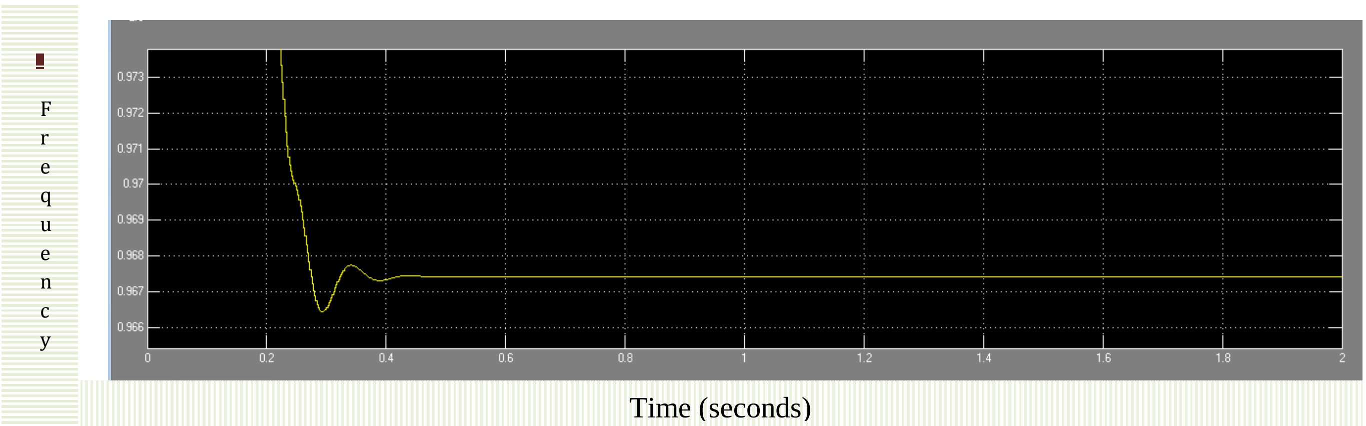

Fig 4.24 Variation of Freq with Time

The fig 4.24 shows the frequency which is maintained at 0.9675 pu for the same value of load.

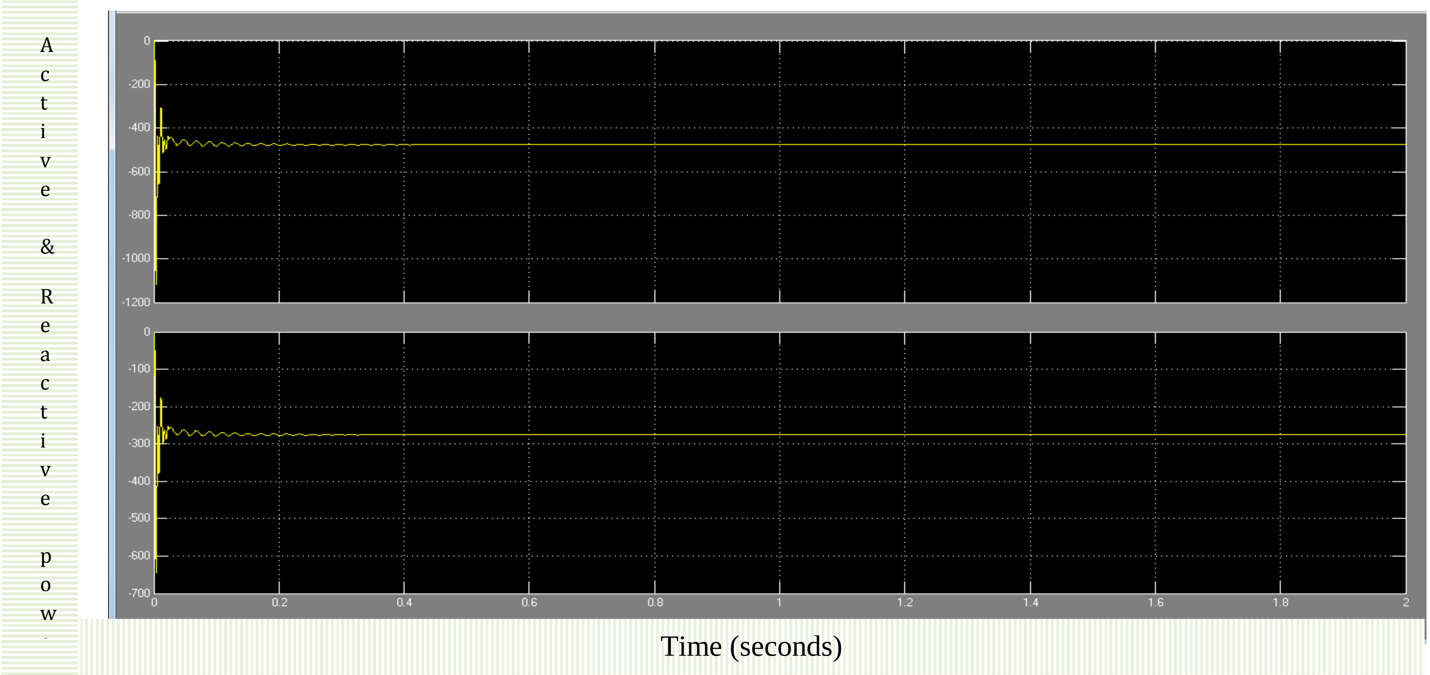

Fig 4.25 Variation of P and Q with Time

The fig 4.25 shows that Active Power P is equal to 476 Watts and Reactive Power is equal to 275 Watts.

Comparisons for the varoius experimental and simulated results are listed in the table mentioned below.

Table 4.5. Comparison for Load Voltages and Load currents

					Load Voltage pu		Load current pu	
	Csh pu	Cse pu	Load pu	Speed pu	Exp	Sim	Exp	Sim
1	1.0507	9.7101	0.9599	0.9760	1.0023	0.9354	0.2895	0.2266
2	1.0507	9.7101	0.8399	0.9898	1.0000	0.9592	0.3579	0.3643
3	1.0507	9.7101	0.7199	0.9830	1.0024	0.9252	0.2947	0.2977
4	1.0507	10.1449	0.9599	0.9458	1.0002	0.8703	0.3368	0.2103
5	1.0507	10.1449	0.8399	0.9518	1.0018	0.8749	0.2737	0.2419
6	1.0507	10.1449	0.7199	0.9585	1.0078	0.87495	0.3158	0.2902
7	1.0507	8.3333	0.9599	0.9700	1.0015	0.8936	0.3789	0.2169
8	1.0507	8.3333	0.8399	0.9750	0.9980	0.9122	0.2947	0.2456
9	1.0507	8.3333	0.7199	0.9906	1.0000	1.1076	0.3474	0.2977
10	0.9783	7.4638	0.9599	1.0180	0.9957	0.9606	0.3895	0.2326
11	0.9783	7.4638	0.8399	1.0032	0.9981	0.9122	0.2737	0.2512
12	0.9783	7.4638	0.7199	1.0314	1.0018	0.9680	0.3263	0.3126
13	0.9275	7.2464	0.9599	1.0280	1.0013	0.9494	0.3895	0.2307
14	0.9275	7.2464	0.8399	1.0316	1.0018	0.9494	0.2842	0.2624
15	0.9275	7.2464	0.7199	1.0360	1.0002	0.9429	0.3158	0.304
16	0.8913	7.2464	0.9599	1.0434	1.0031	0.9662	0.3895	0.2345
17	0.8913	7.2464	0.8399	1.0488	1.0026	0.9680	0.2737	0.2605
18	0.8913	7.2464	0.7199	1.0436	1.0005	0.9401	0.3263	0.3015

The Table 4.5 shows effect on Load Voltage and Load current as the value of Csh, Cse and speed is changed. The performance is checked by applying three set of loads.

Table 4.6 Comparison for Stator Voltages and Stator Currents

					Stator current pu		Stator voltage	
	Csh pu	Cse pu	Load pu	Speed pu	Exp	Sim	Exp	Sim
1	1.0507	9.7101	0.9599	0.9760	0.9474	1.0234	1.0526	1.0425
2	1.0507	9.7101	0.8399	0.9898	0.9737	1.0718	1.0789	1.0704
3	1.0507	9.7101	0.7199	0.9830	0.9474	1.0383	1.0658	1.0323
4	1.0507	10.1449	0.9599	0.9458	1.0000	0.9680	1.0526	0.9680
5	1.0507	10.1449	0.8399	0.9518	1.0000	0.9602	1.0395	0.9736
6	1.0507	10.1449	0.7199	0.9585	1.0000	0.9787	1.0789	0.9739
7	1.0507	8.3333	0.9599	0.9700	1.0000	0.9750	1.0211	1.0146
8	1.0507	8.3333	0.8399	0.9750	1.0000	0.9974	1.0263	1.01643
9	1.0507	8.3333	0.7199	0.9906	0.9474	1.0421	1.0263	1.04621
10	0.9783	7.4638	0.9599	1.0180	1.0000	1.0234	1.1316	1.0983
11	0.9783	7.4638	0.8399	1.0032	1.0526	0.9676	1.1053	1.0387
12	0.9783	7.4638	0.7199	1.0314	1.0526	1.0790	1.1053	1.1000
13	0.9275	7.2464	0.9599	1.0280	1.0526	0.9713	1.1053	1.0797
14	0.9275	7.2464	0.8399	1.0316	1.0000	1.1755	1.1184	1.0726
15	0.9275	7.2464	0.7199	1.0360	0.9474	0.9936	1.1184	1.0723
16	0.8913	7.2464	0.9599	1.0434	1.0000	0.9862	1.1184	1.0946
17	0.8913	7.2464	0.8399	1.0488	0.9474	0.9974	1.1289	1.0983
18	0.8913	7.2464	0.7199	1.0436	0.9474	0.9713	1.1184	1.0648

The Table 4.6 shows effect on Stator Voltage and Stator Current as the value of Csh, Cse and speed is changed.

Table 4.7 Comparison of Frequency

					frequency pu			
	Csh pu	Cse pu	Load pu	Speed pu	Exp	Sim	P pu	Q pu
1	1.0507	9.7101	0.9599	0.9760	0.9325	0.9560	0.9599	0.5472
2	1.0507	9.7101	0.8399	0.9898	0.9350	0.9675	1.1423	0.6599
3	1.0507	9.7101	0.7199	0.9830	0.9387	0.9580	1.2479	0.7199
4	1.0507	10.1449	0.9599	0.9458	0.9162	0.9220	0.8231	0.4800
5	1.0507	10.1449	0.8399	0.9518	0.9200	0.9300	0.9599	0.5280
6	1.0507	10.1449	0.7199	0.9585	0.9262	0.9341	1.1279	0.6479
7	1.0507	8.3333	0.9599	0.9700	0.9312	0.9510	0.8687	0.5040
8	1.0507	8.3333	0.8399	0.9750	0.9350	0.9520	0.9935	0.5760
9	1.0507	8.3333	0.7199	0.9906	0.9425	0.9650	1.2311	0.7199
10	0.9783	7.4638	0.9599	1.0180	0.9512	0.9981	0.9935	0.5760
11	0.9783	7.4638	0.8399	1.0032	0.9700	0.9820	1.0271	0.6000
12	0.9783	7.4638	0.7199	1.0314	0.9687	1.0050	1.3631	0.7799
13	0.9275	7.2464	0.9599	1.0280	0.9875	1.0080	0.9839	0.5688
14	0.9275	7.2464	0.8399	1.0316	0.9800	1.0100	1.1183	0.6455
15	0.9275	7.2464	0.7199	1.0360	0.9887	1.012	1.2887	0.7439
16	0.8913	7.2464	0.9599	1.0434	0.9925	1.0236	1.0199	0.5880
17	0.8913	7.2464	0.8399	1.0488	0.9900	1.0265	1.1711	0.6719
18	0.8913	7.2464	0.7199	1.0436	0.9950	1.0192	1.2815	0.7367

The Table 4.7 shows the changes in the frequency as the value of Csh, Cse and speed is changed.

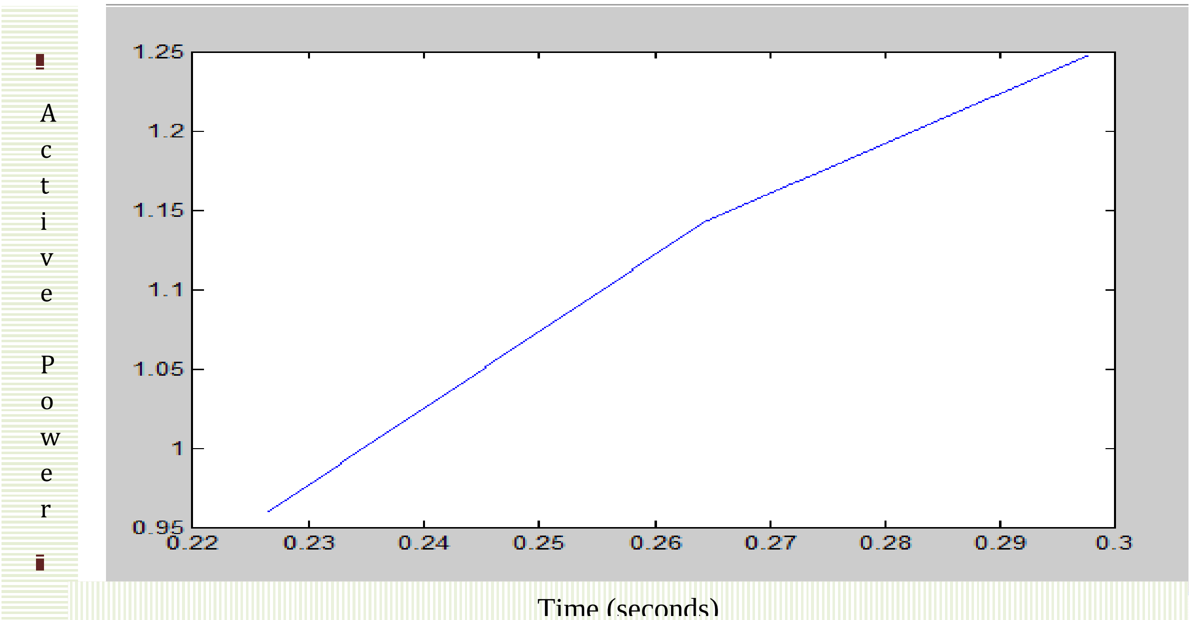

Fig 4.26 Variation of Active Power Vs Load Current

The fig 4.26 shows the changes in the Active Power P in Watts with respect to load current I in pu for the first three set of load values as mentioned in the Table 4.7. It is seen that the graph is linear.

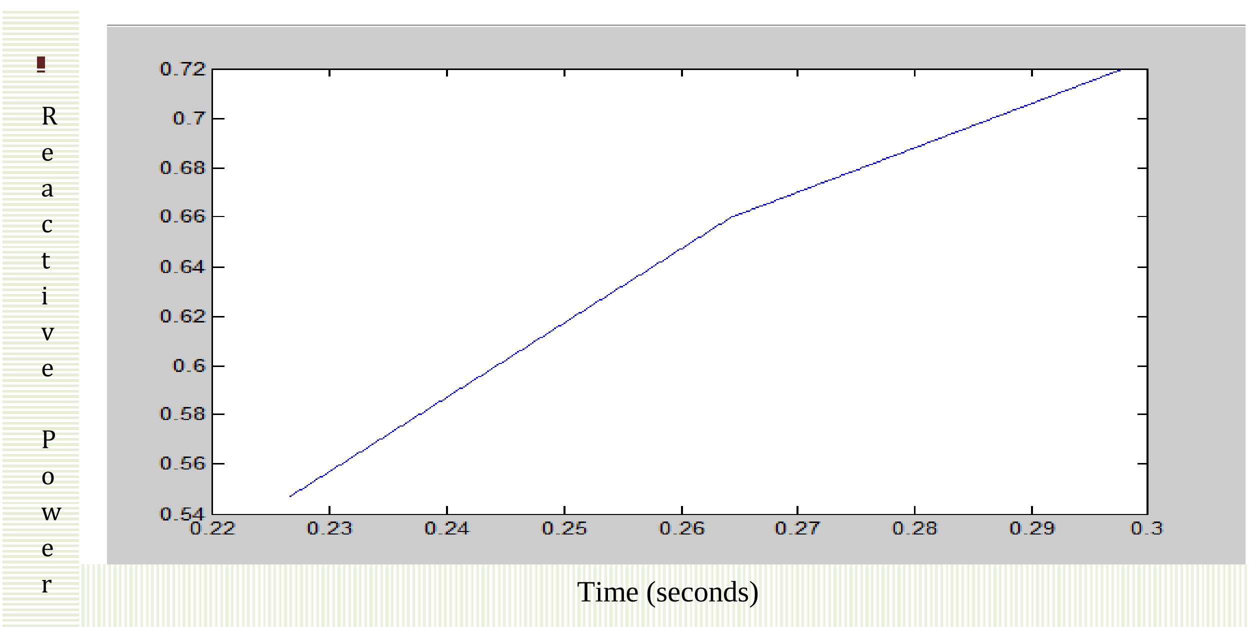

Fig 4.27 Variation of Reactive Power with Load Current

The fig 4.27 shows the variation in Reactive Power Q as the load is changed. This graph is also plotted for the first three set of values as mentioned in Table 4.7. This graph is also linear.

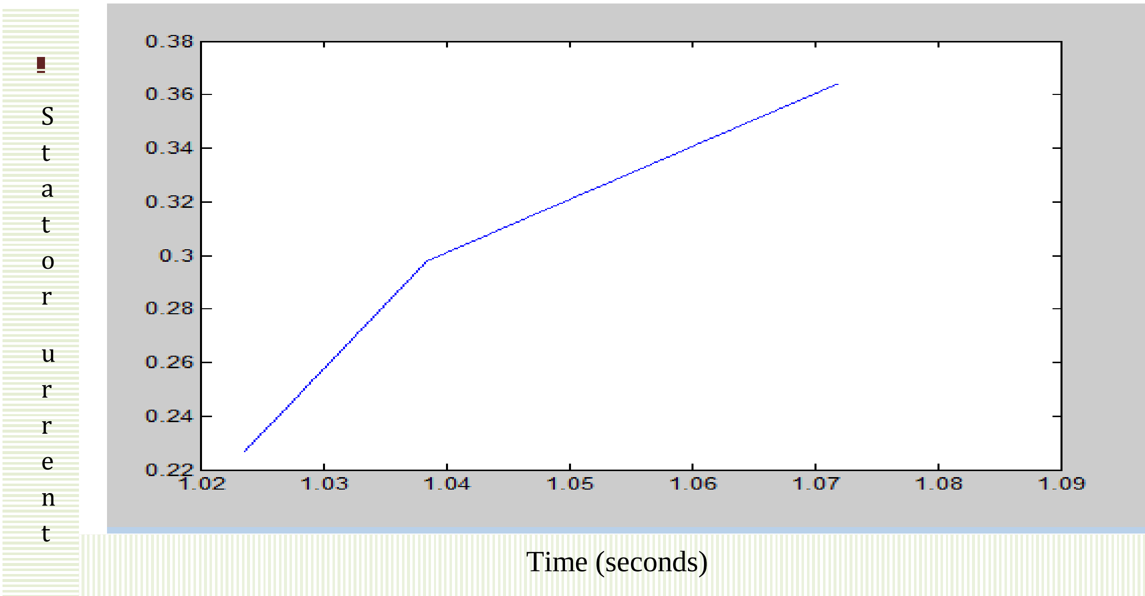

Fig 4.28 Variation of Stator Current with load Current

This fig 4.28 is plotted for as per the values mentioned in Table 4.5 and Table 4.6. The graph shown is linear as seen from fig 4.28.

4.3.4 Results for simulink model of SEIG feeding 3 phase induction motor

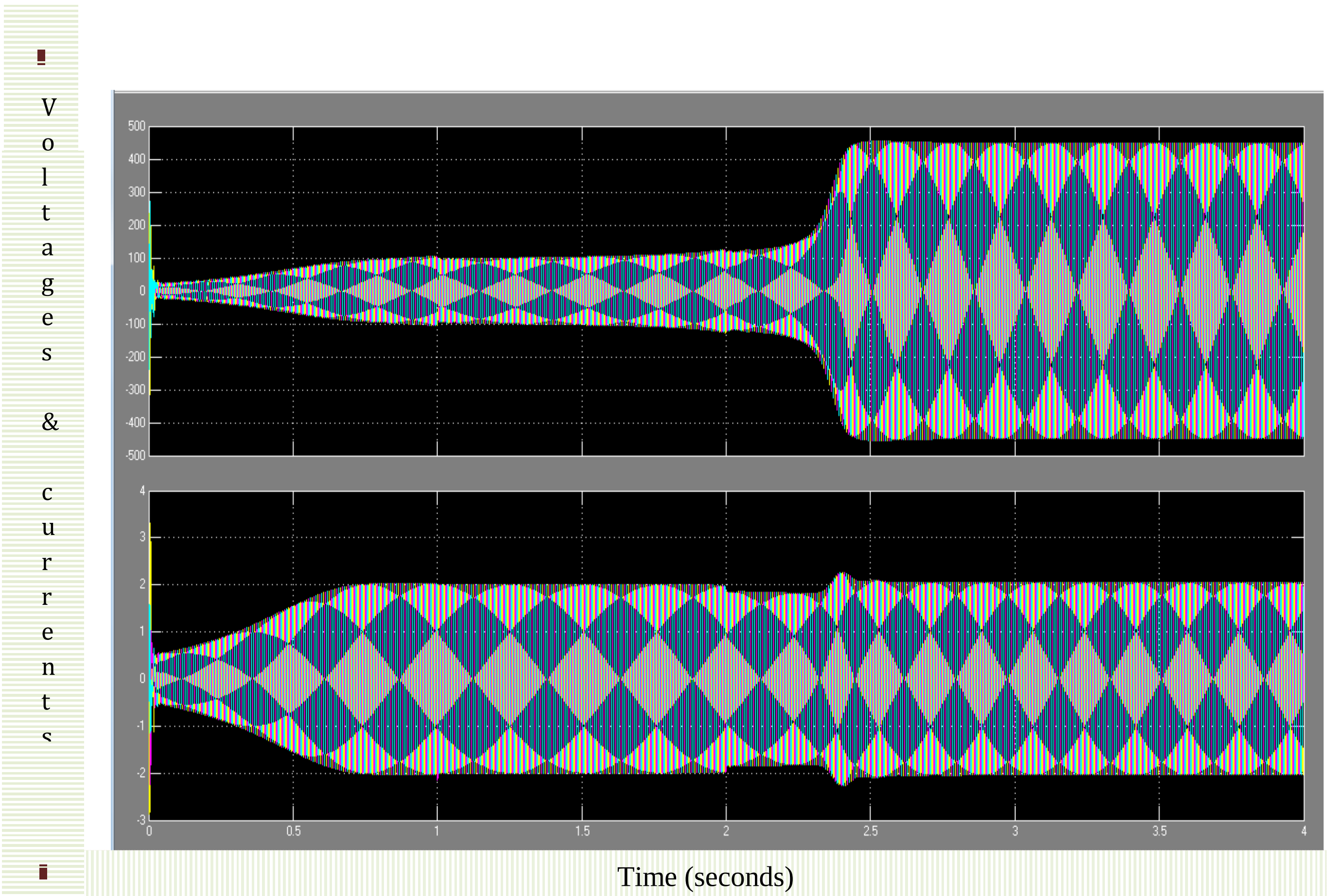

Fig 4.29 Variation of V2 and I2 Vs Time

The fig 4.29 shows the load voltage and current across resistive load of 500Watts and Induction motor load. The capacitive reactive power which is provided is 3400 Vars. The results are shown when rotor of SEIG is run at a constant value of 158 rps and the series capacitance is 18 microfarad. The graph shows that as the induction motor is connected the voltage is build up and sustained. The voltage build up in the induction motor takes place gradually as seen from the results. It can be seen that the voltages and currents are balanced throughout the entire operation. The voltage and current drops at 2 seconds as soon as the breaker 2 operates and load of 300 Watts is connected to the system. But the voltages and currents again maintain their position after few seconds. It can be seen that the dynamic system is stable throughout the operation.

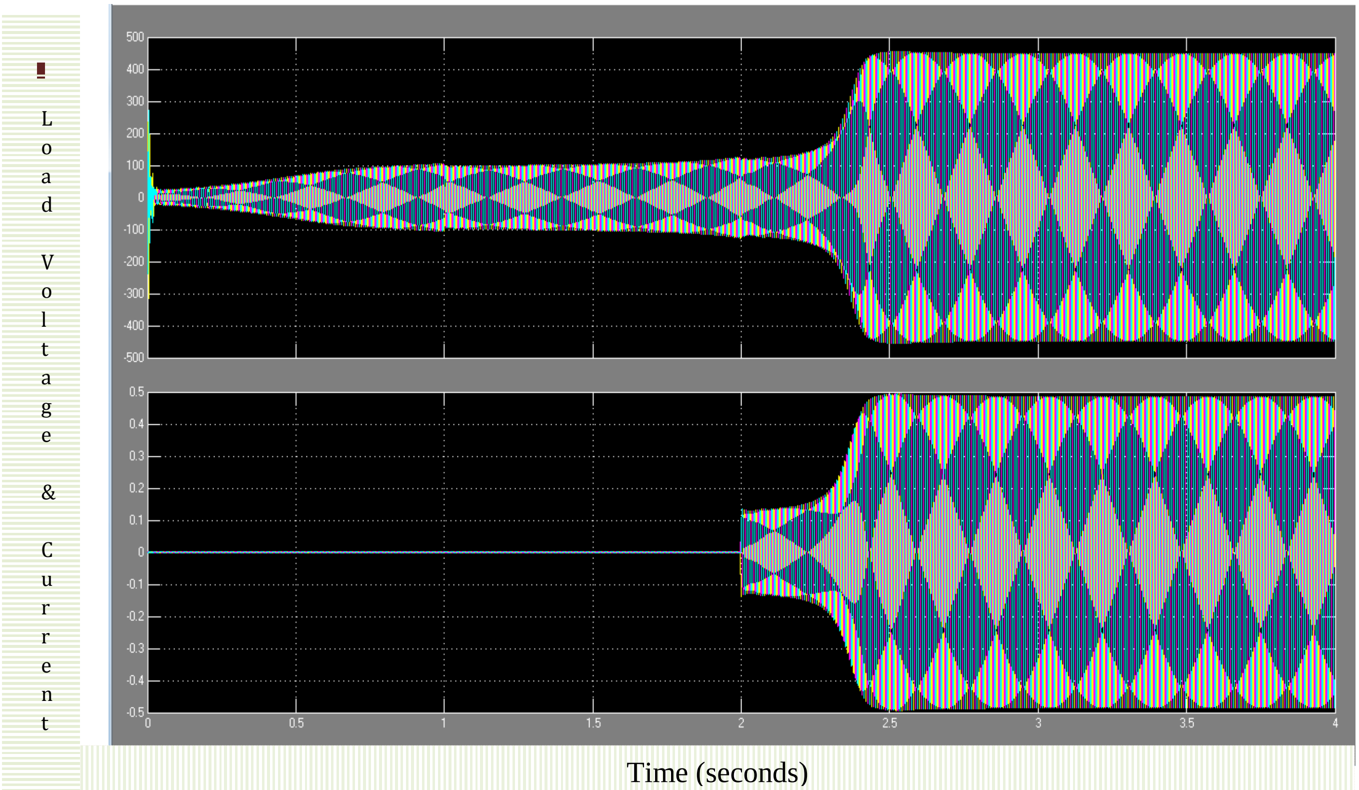

Fig 4.30 Variation of V1 and I1 with Time across load of 300 Watts

The fig 4.30 shows the voltage and current across the load of 300 Watts. The speed of SEIG is 158 rps and the series capacitance is 18 microfarad. The current in the load is zero for a duration of 2 seconds as the breaker is open initially and as soon as the load is connected after 2 seconds through the breaker the current in the breaker starts to flow. From the results it can be seen that the voltage and current rise gradually and at about 2.5 seconds the voltages and currents in all the three phases attain a constant and steady value with a balanced operation in the system. The drop in the voltage at the transition time of both the breakers is very well seen in the results. But as the system is compensated the voltage reach its steady value after very few cycles and maintains its voltage.

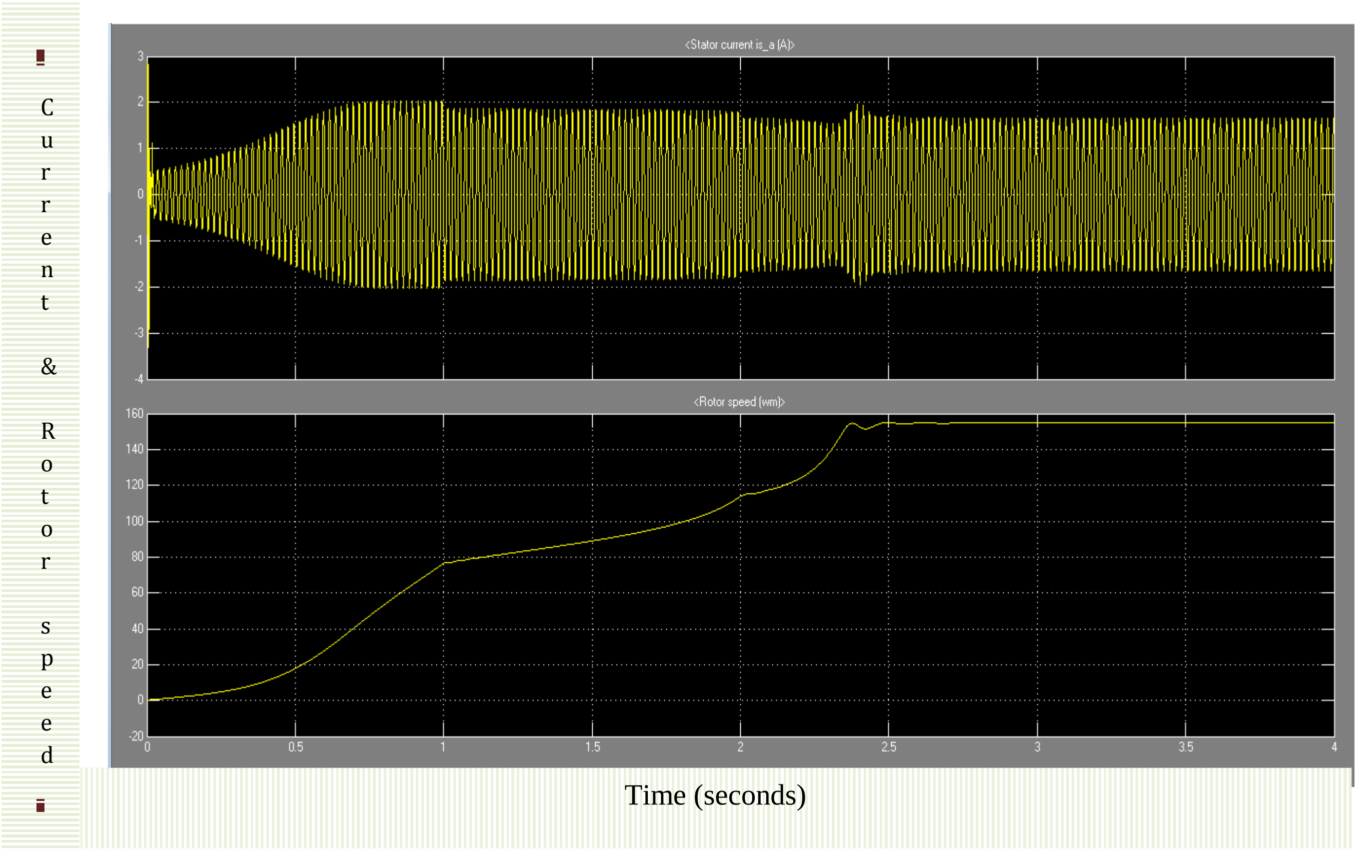

Fig 4.31 Variation of Im and Wim with Time

The fig 4.31 shows the currents flowing in the Induction motor as well as the rotor speed of the induction motor. The current which the Induction motor draws is highly balanced and stable. The speed of the induction motor starts rising gradually and at around 2.4 seconds reaches a constant value of 159 rps which suggests that the speed of the operation is stable. The induction motor is connected in the system throughout the period without any breaker. As the resistive loads are connected in the system through the breaker at 1 second and 2 seconds the currents in induction motor decreases slightly. But the system is stable and balanced and reaches steady state after few cycles.

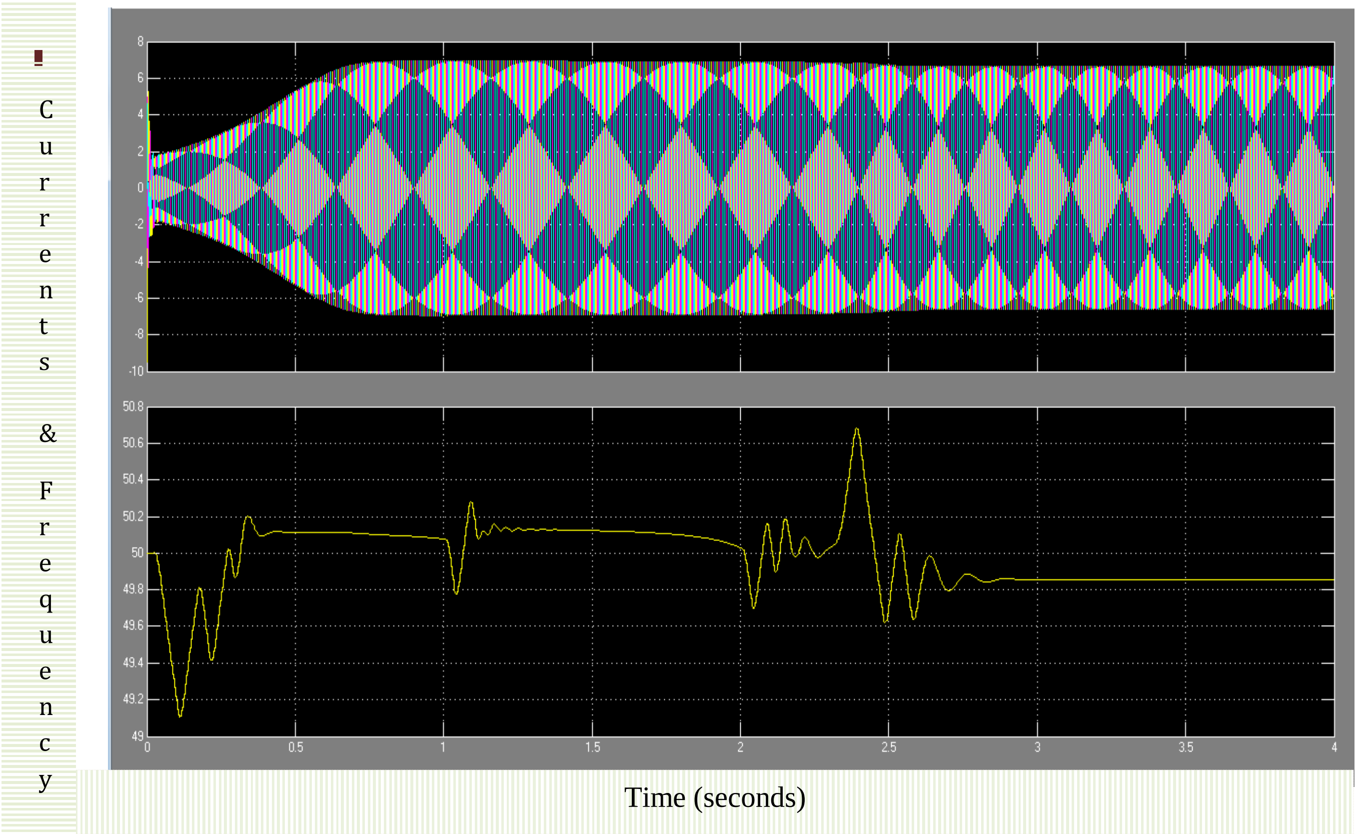

Fig 4.32 Variation of Ic and Freq with Time

The fig 4.32 shows the current drawn by the shunt capacitance Csh and the frequency throughout the entire operation. The current in all the three phases of the capacitor is balanced. All the three capacitors draw 7 amperes peak current to provide a total reactive power of 3400 vars to the system. This means each capacitor provides approximately 1133 vars of reactive power to the system. From the figure it can be seen that as the load is applied at 1 sec the frequency fluctuates for few cycles and attains constant value of 50.1 hertz. Again when load is applied at 2 sec then there is fluctuation in the frequency for few cycles and maintains constant value of 49.85 hertz at 2.8 sec which remains constant throughout the operation.

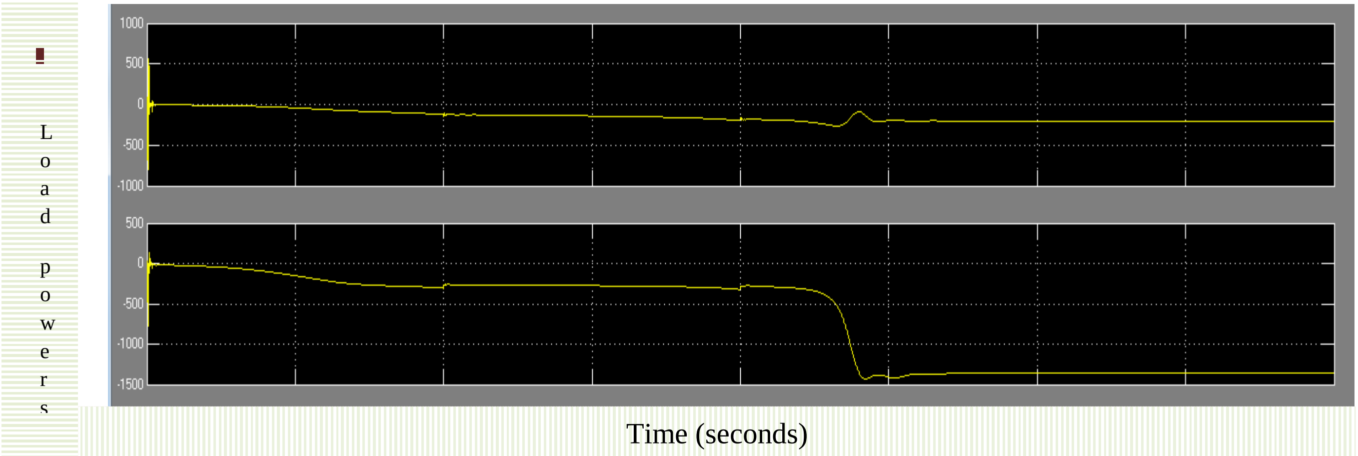

Fig 4.33 Variation of P2 and Q2 with Time

The fig 4.33 shows instantaneous active and reactive power which is drawn by the load 2 which is 500 watts and the induction motor collectively. The active power drawn is 202 watts and reactive power is 1362 Vars.

Table 4.8: Values of voltages and currents when Wr is changing

V2 Volts	I2 amperes	P2 watts	Q2 Vars	P1 watts	Q1 Vars	I im ampere	Wim rad/sec	Freq Hz	Wr rad/sec	Is ampere	Ic Ampere
86	1.87	97	226	106	232	1.75	63.00	49.99	157.50	8.80	6.85
449	2.00	202	1362	485	1525	1.65	155.00	49.85	158.00	8.50	6.61
457	2.00	200	1414	495	1585	1.70	155.00	50.01	158.50	8.70	6.70
465	2.10	200	1465	500	1640	1.73	155.60	50.16	159.00	8.85	6.79
474	2.15	200	1517	513	1700	1.77	156.20	50.31	159.50	8.90	6.87
481	2.19	200	1570	520	1760	1.81	156.50	50.46	160.00	9.08	6.95

The table 4.8 shows different values of voltage across induction motor load as the speed of SEIG changes. All the values of the table 4.8 are listed keeping all the parameters same except the SEIG speed. The series capacitance is fixed at 18 microfarad. The load W1 and W2 are kept constant throughout with values of 300 watts and 500 watts respectively. The active and reactive power across the induction motor load and load W2 is also stated in the table. The frequency variation with the speed changes of the system is also shown in the table 1. The capacitor current Ic as well as the current drawn by the source is also listed in the table. The table also shows the variation in the current drawn by Induction motor as well as its rotor speed Wim.

Table 4.9: Values of voltages and currents when Cse is changing

V2 volts	I2 ampere	P2 watts	Q2 vars	P1 watts	Q1 vars	Iim ampere	Wim rad/sec	Freq Hz	Cse µf	Is ampere	Ic ampere
78.5	1.77	77	200	86	200	1.66	49.8	50.16	17	8.75	6.85
449	2.05	202	1360	488	1525	1.66	154.60	49.85	18	8.50	6.6
490	2.26	171	1664	510	1860	1.90	154	49.80	19	8.85	6.67

The table 4.9 shows different values of voltage across induction motor load as the series capacitance changes. All the values of the table 4.2 are listed keeping all the parameters same except the series capacitance. The speed of the SEIG is fixed at 158 rps. The load W1 and W2 are kept constant throughout with values of 300 watts and 500 watts respectively. The active and reactive power across the induction motor load and load W2 is also stated in the table. The frequency variation with the changes of the series compensator capacitance of the system is also shown in the table 1. The capacitor current Ic as well as the current drawn by the source is also listed in the table. The table also shows the variation in the current drawn by Induction motor as well as its rotor speed Wim.

4.3.5 Results for simulink model of long shunt SEIG feeding an Induction motor

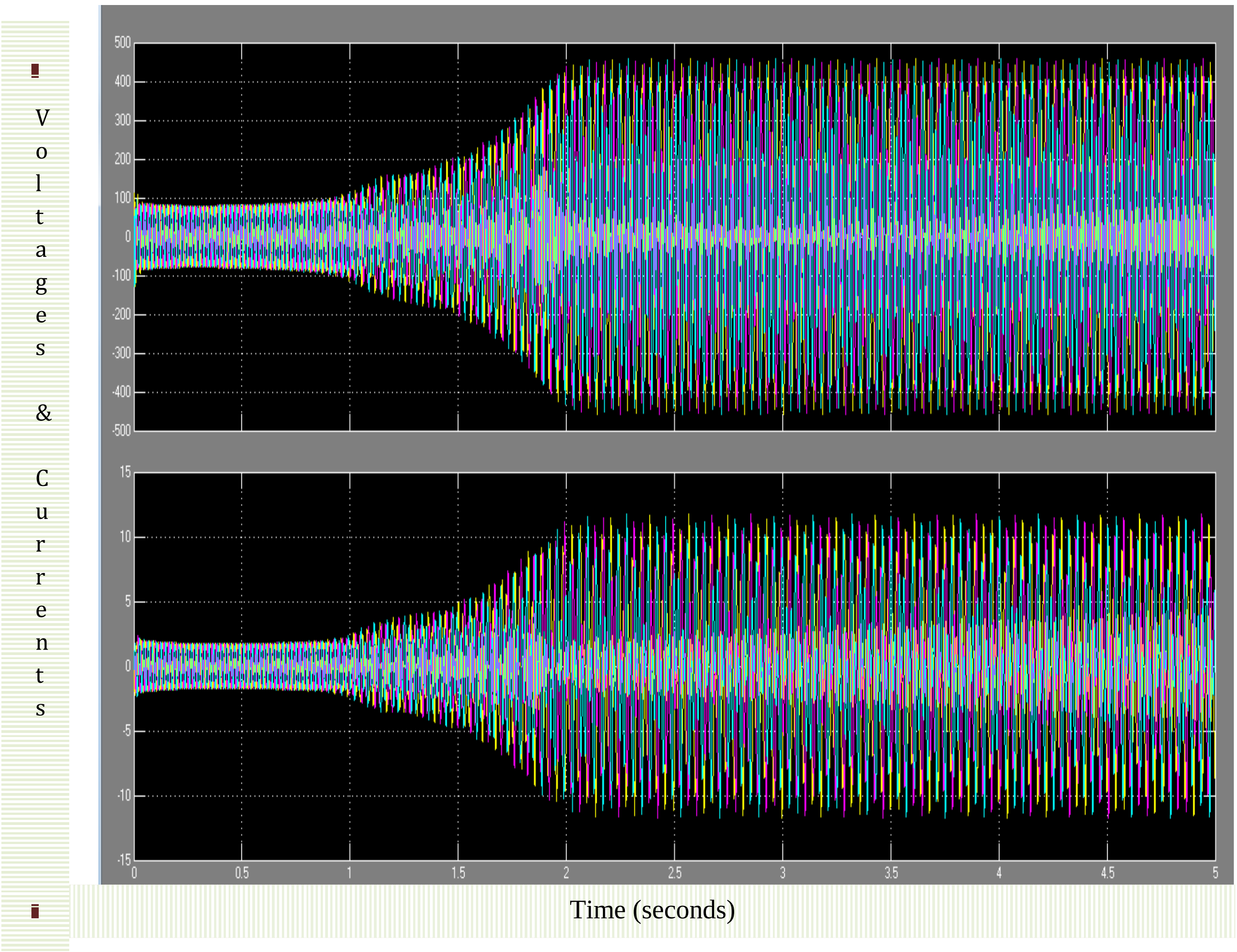

Fig 4.34 Variation of V2 and I2 Vs Time

The fig 4.34 shows the load voltage and current across load of 500Watt and Induction motor. The capacitive reactive power which is provided is 9000 Vars. The rotor speed is maintained at a constant value of 159.5 rps. The graph shows that as the induction motor is connected the voltage is build up and sustained. But the voltages are not balanced. These unbalanced waveforms generated shows that the system is unstable.

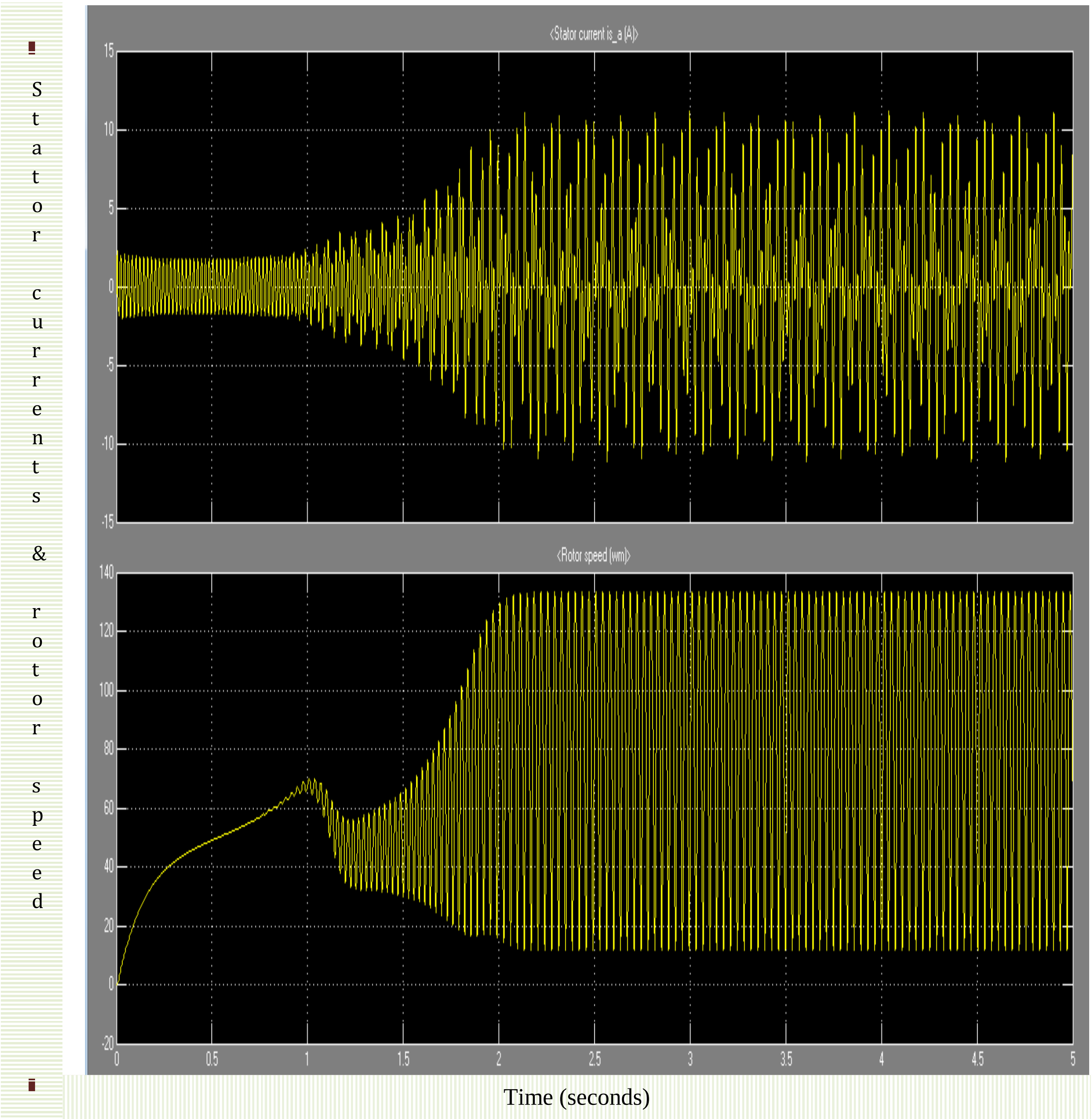

Fig 4.35 Variation of Iim and Wim with Time

The fig 4.35 shows the currents flowing in the Induction motor as well as the rotor speed of the induction motor. The current which the Induction motor draws is highly unbalanced and unstable. The speed of the induction motor is also varying which suggests that the speed of the operation is not stable.

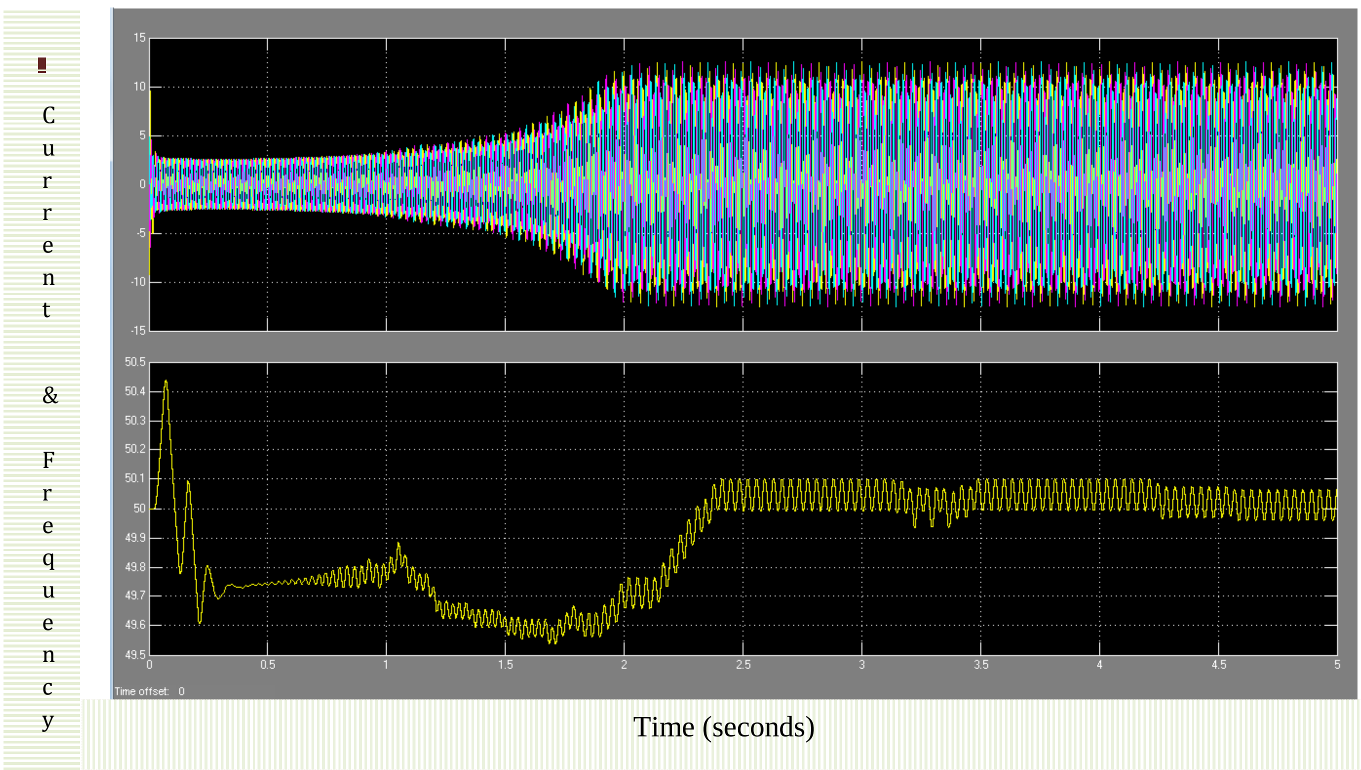

Fig 4.36 Variation of Ic and Freq with Time

The fig 4.36 shows the current drawn by the shunt capacitance Csh and the frequency throughout the entire operation. The current in all the three phases of the capacitor is unbalanced due to induction motor load. The frequency is also fluctuating

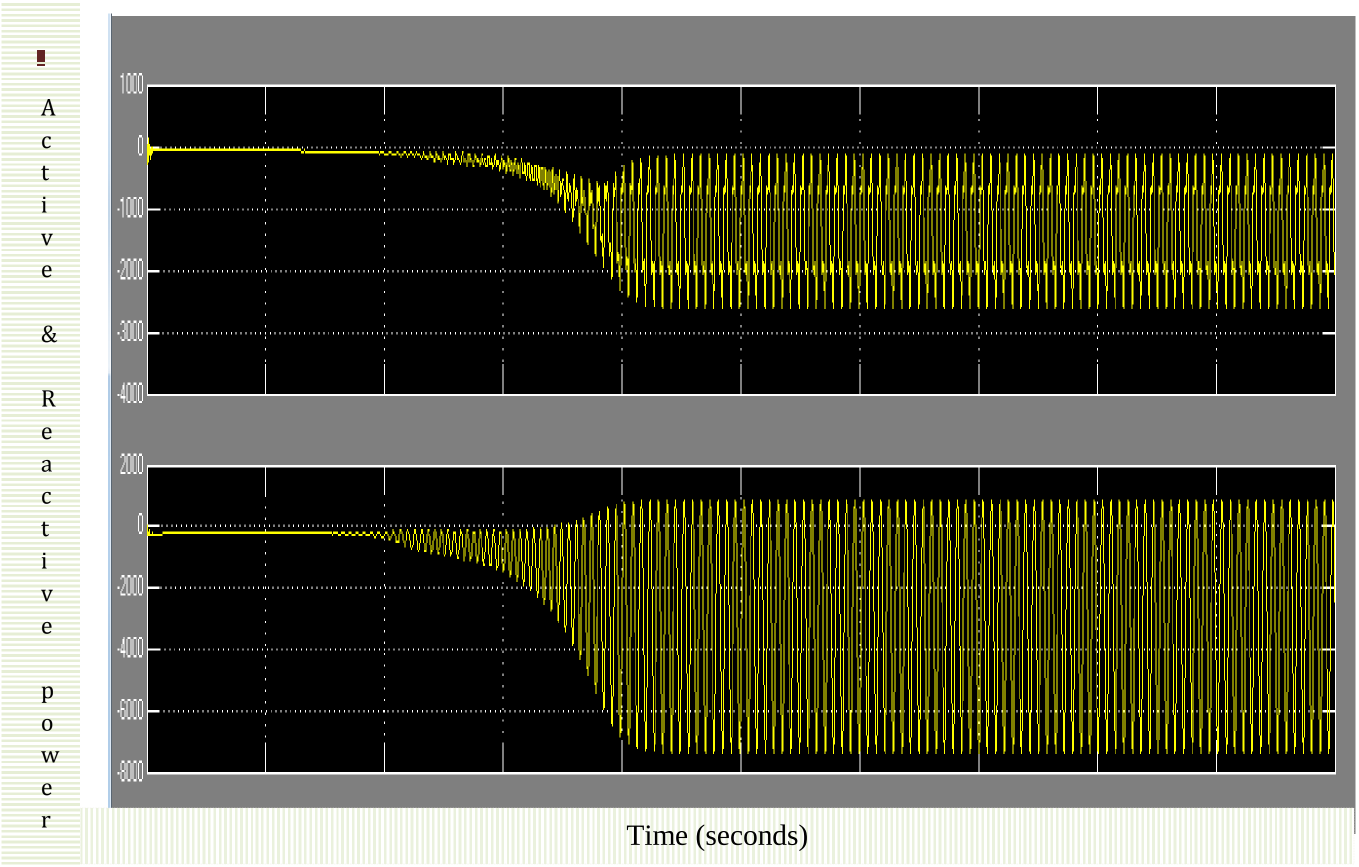

Fig 4.37 Variation of P2 and Q2 with Time

The fig 4.37 shows instantaneous active and reactive power which is drawn by the load 2 which is 500 watts and the induction motor collectively. The active power drawn and reactive power is highly fluctuating.

4.3.6 Results for three phase Induction generator feeding Single phase induction motor in short shunt configuration

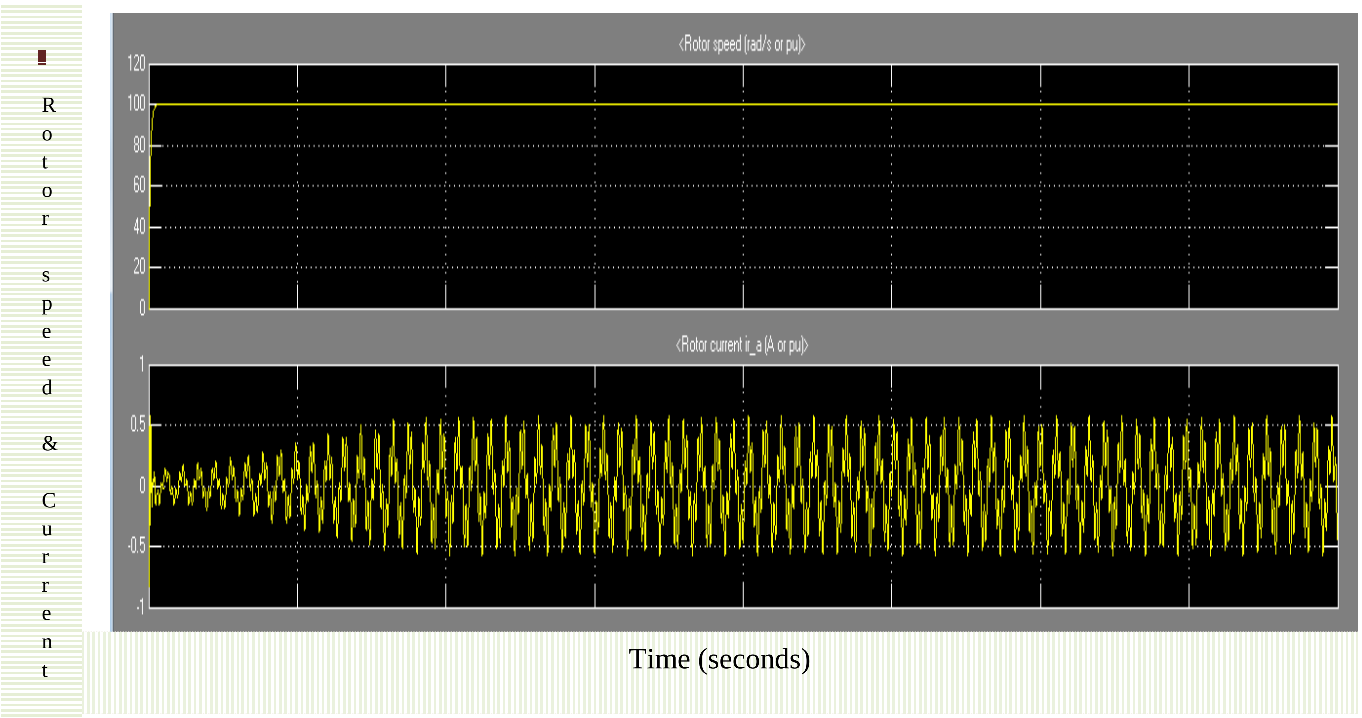

Fig 4.38 Variation of single phase IM Rotor speed wr and Rotor current Ir with time

The fig 4.38 shows the rotor speed of the single phase IM load which is 100 rad per sec. the running time for the model is 4 seconds. The speed of the rotor is constant throughout the operation. It also shows the rotor currents which is drawn by the single phase induction motor. The fig shows that the rotor currents are balanced. The induction motor is single winding split phase induction motor. The rotor current comes out to be 0.5 amperes.

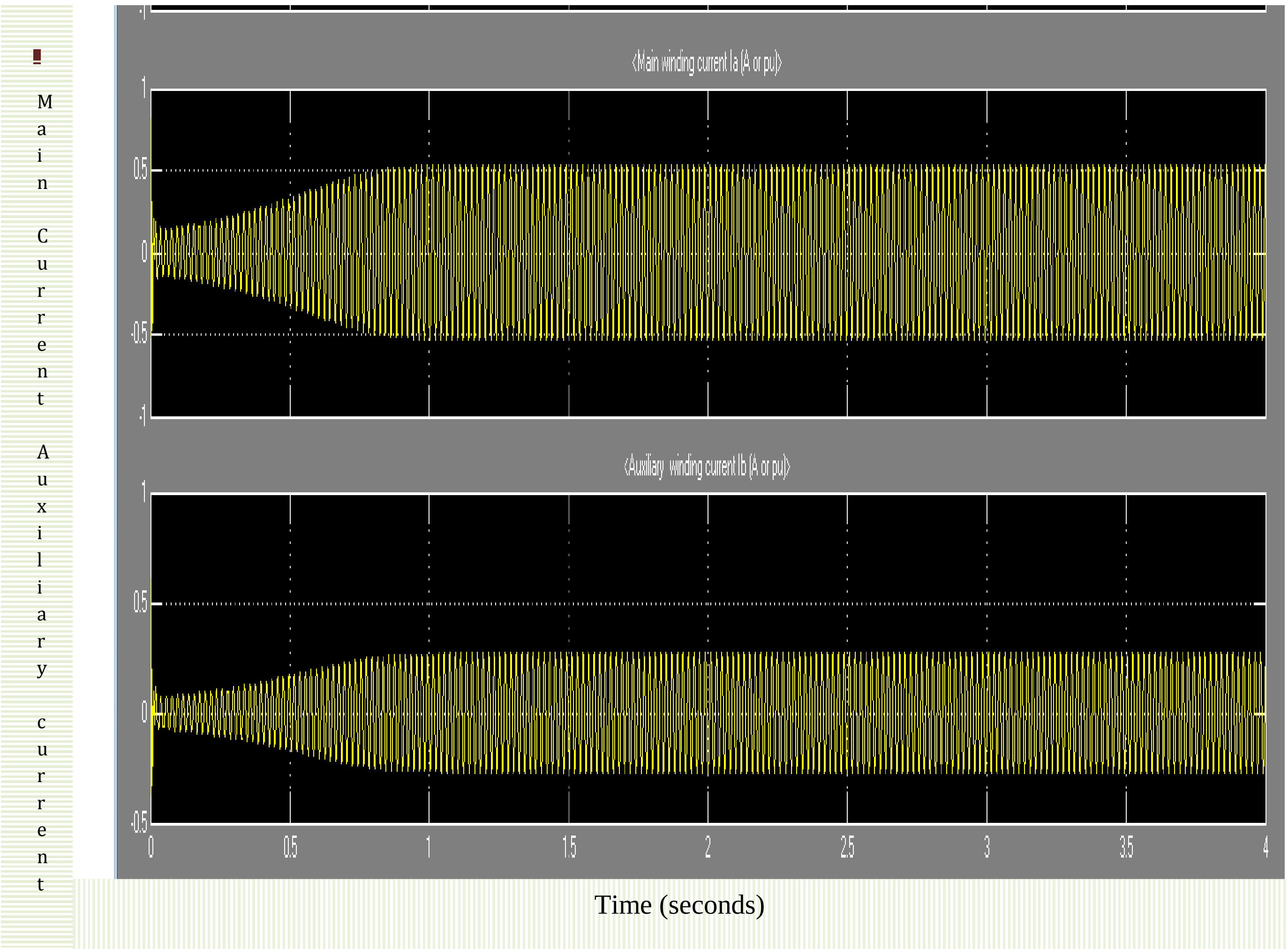

Fig 4.39 Variation of Main winding current Im and Auxiliary winding current Ib with Time

The fig 4.39 shows that current in the main and auxiliary winding is balanced. The value of the main winding current is 0.5 amperes and that for the auxiliary current is 0.6 amperes.

4.3.7 Results for three phase Induction generator feeding Single phase induction motor in long shunt configuration

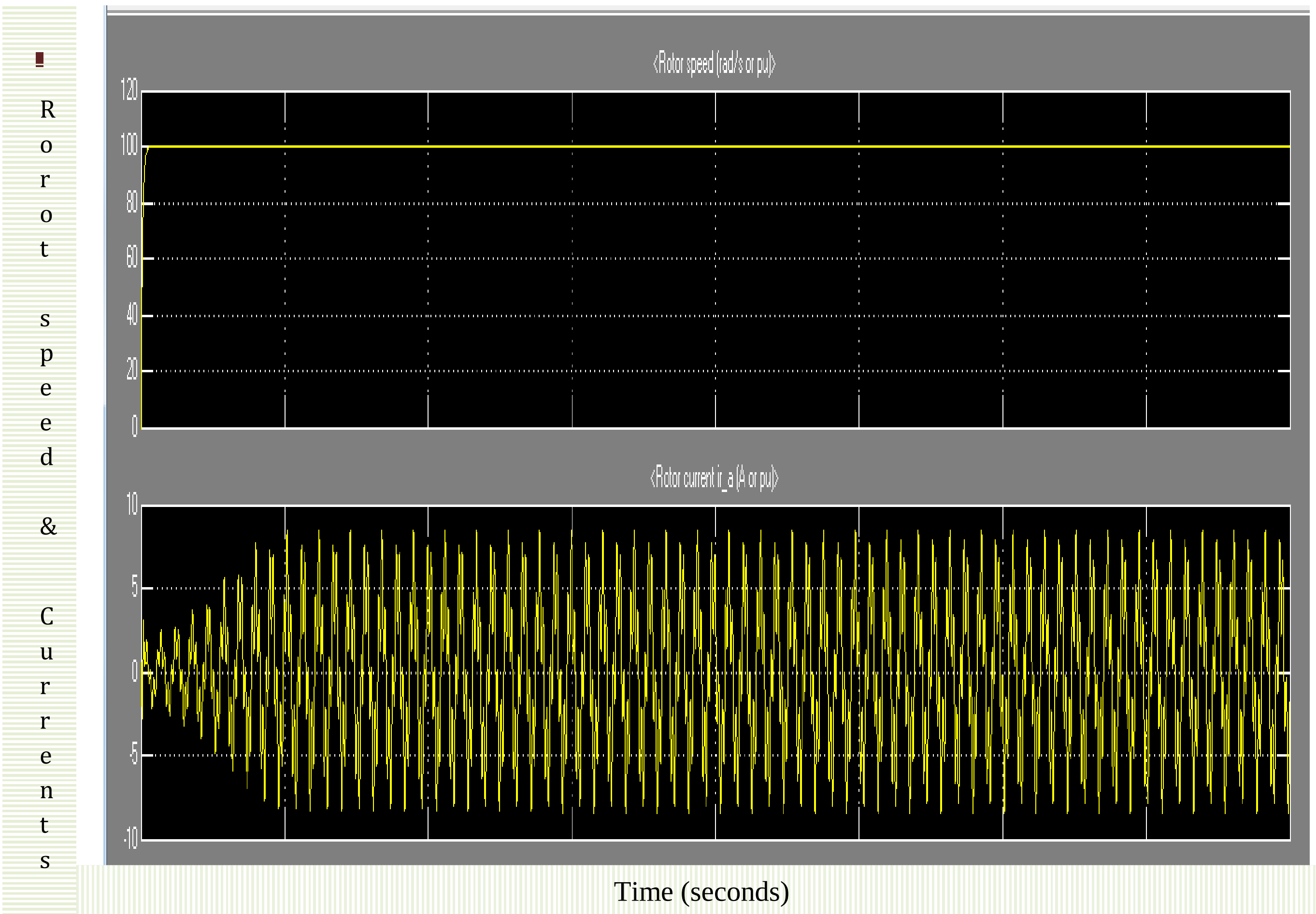

Fig 4.40 Variation of single phase IM Rotor speed Wr and Rotor current Ir with time

The fig 4.40 shows the rotor speed of the single phase IM load which is 100 rad per sec. The running time for the model is 4 seconds. The speed of the rotor is constant throughout the operation. It also shows the rotor currents which is drawn by the single phase induction motor. The fig shows that the rotor currents are balanced. The induction motor is single winding split phase induction motor. The rotor current comes out to be 8 amperes.

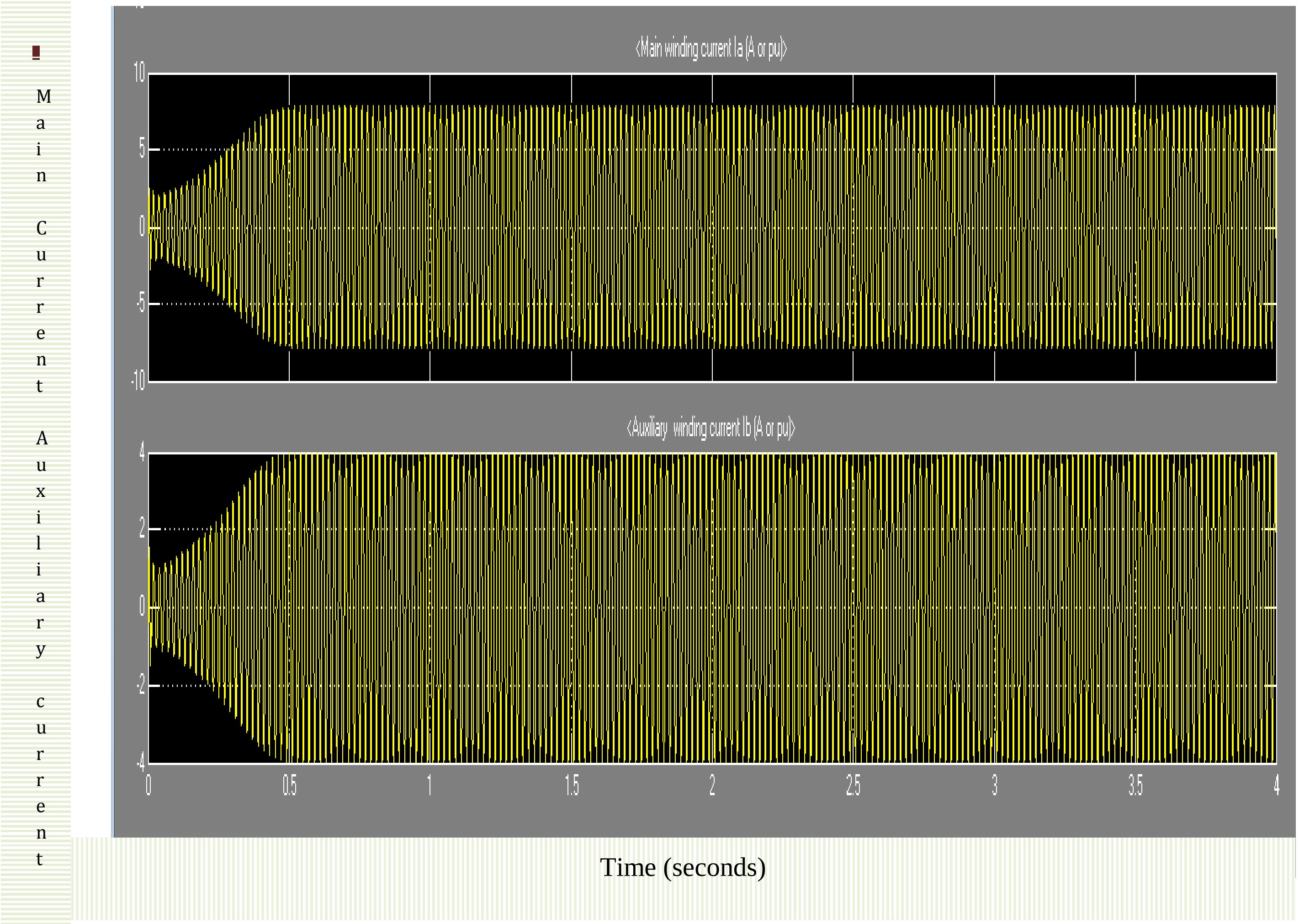

Fig 4.41 Variation of Main winding current Im and Auxiliary Current Ib with Time

The fig 4.41 shows that current in the main and auxiliary winding is balanced. The value of the main winding current is 8 amperes peak and that for the auxiliary current is 4 amperes. All the currents are balanced which shows that the operation is stable.

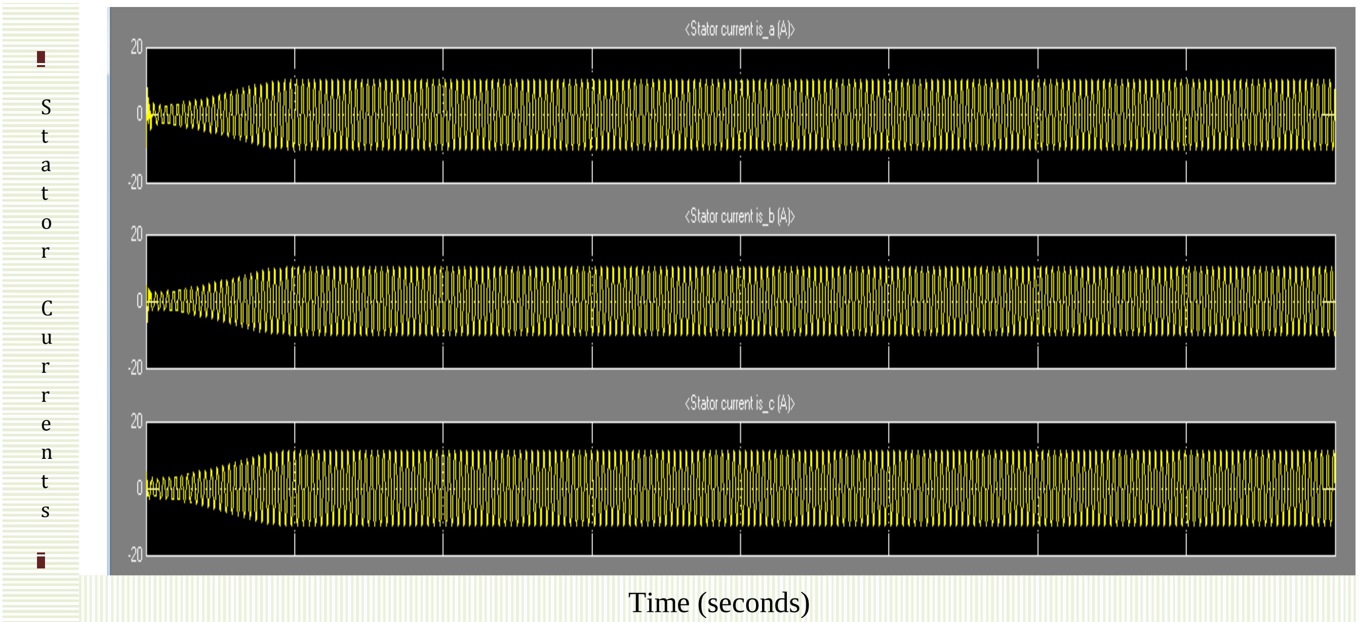

Fig 4.42 Variation of SEIG current Is with Time

The fig 4.42 shows the variation of all the currents in the three phases of the induction generator. The peak values of the current in all the phases are 10 ampere.

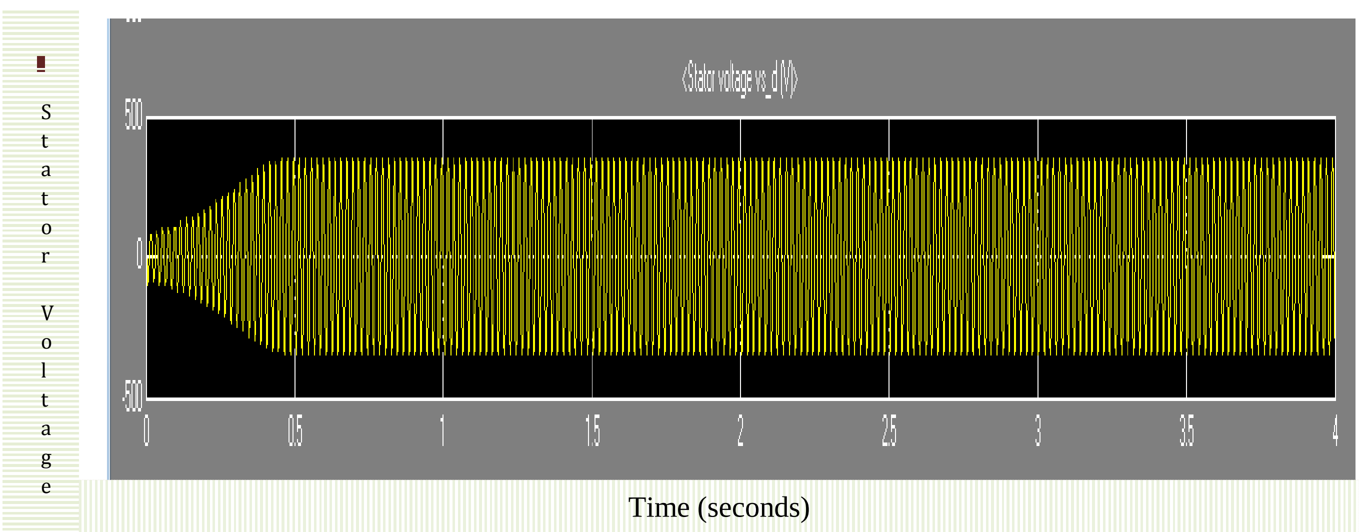

Fig 4.43 Variation of stator voltage Vs with Time

The fig 4.43 shows the voltage across the stator of the induction generator. The voltages are balanced which suggests a stable operation.

CHAPTER 5

CLOSED LOOP CONTROL OF LONG SHUNT INDUCTION GENERATOR FEEDING INDUCTION MOTOR LOAD

5.1 INTRODUCTION

The long shunt configuration of the SEIG has been studied in earlier chapters. In this chapter the closed loop control of the long shunt SEIG is carried out. The main aim is to control the load voltage and maintain it at the rated value. The compensator is used for this purpose. The model used for the long shunt configuration feeding induction motor load is same as discussed in the previous chapters. This is done to compare the performance of the SEIG with the compensator. The values of the excitation capacitance provide 9000 vars and the series capacitance has same values of 213 microfarad. The SEIG rating is 5 Hp. Two induction motors of 1 Hp are connected to the system as loads. At different interval of time different reactive loads are applied to the system and the performance of the SEIG under closed loop operation is carried out. It will be seen that there is no fluctuation in system voltage as different loads are applied.

For the single phase load the same compensator is used to control the SEIG voltage. The split phase motor is used as load in long shunt configuration. The values of the compensator are arranged so that it is able to maintain the required voltage.

5.2 SIMULINK MODEL

5.2.1 Three phase SEIG feeding induction motor load

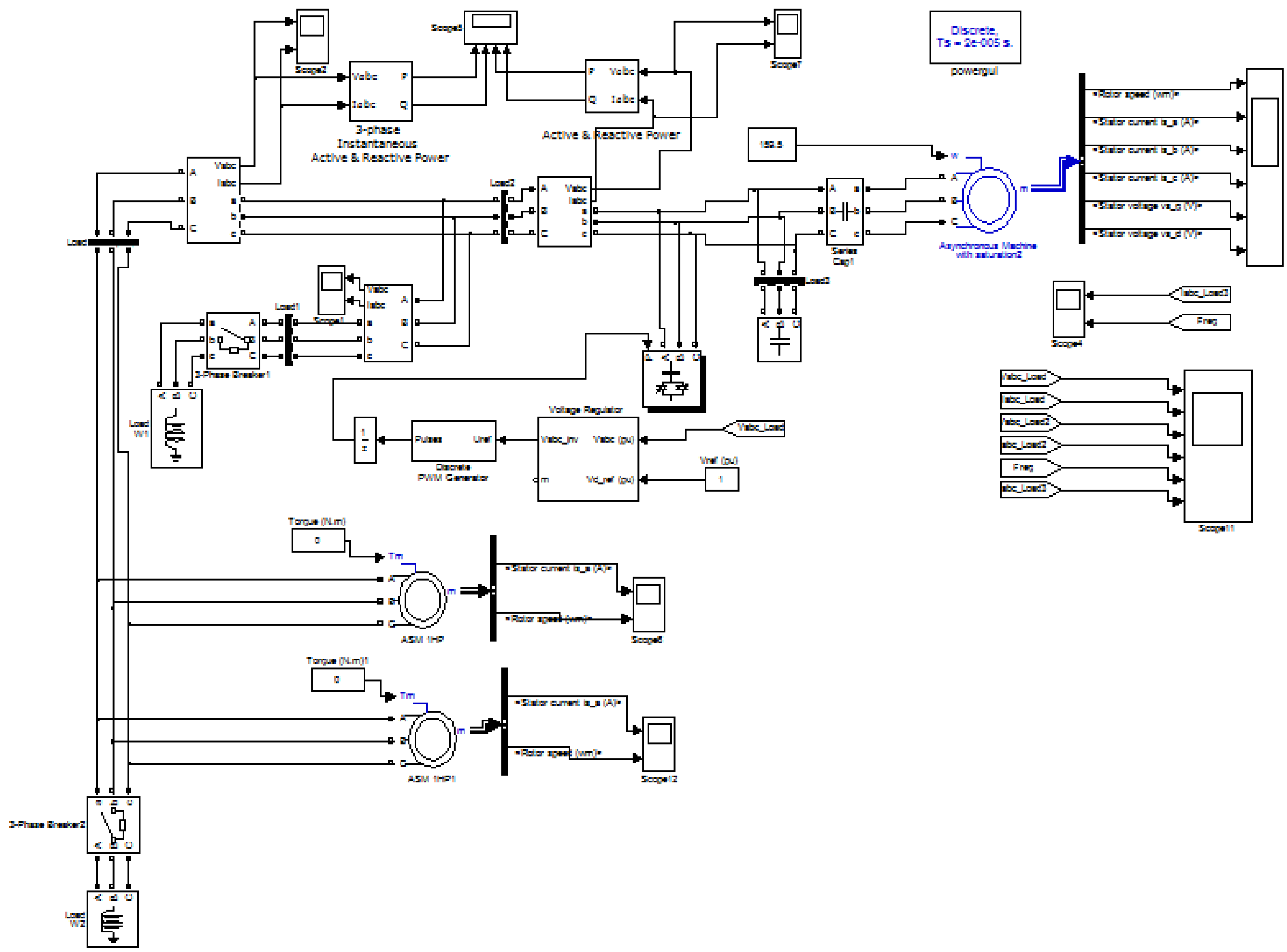

Fig 5.1 Simulink model of long shunt SEIG with voltage controller

The fig 5.1 shows the simulink model of the long shunt SEIG with voltage control loop. The voltage at the induction motor load side is controlled . Two induction motor of same rating is connected to the SEIG. The induction motor rating is 1 hp. Two reactive loads are also connected using breaker in the circuit. The speed of the SEIG is maintained at 158.5 rps.

5.2.2 Three phase SEIG feeding Split phase motor as load

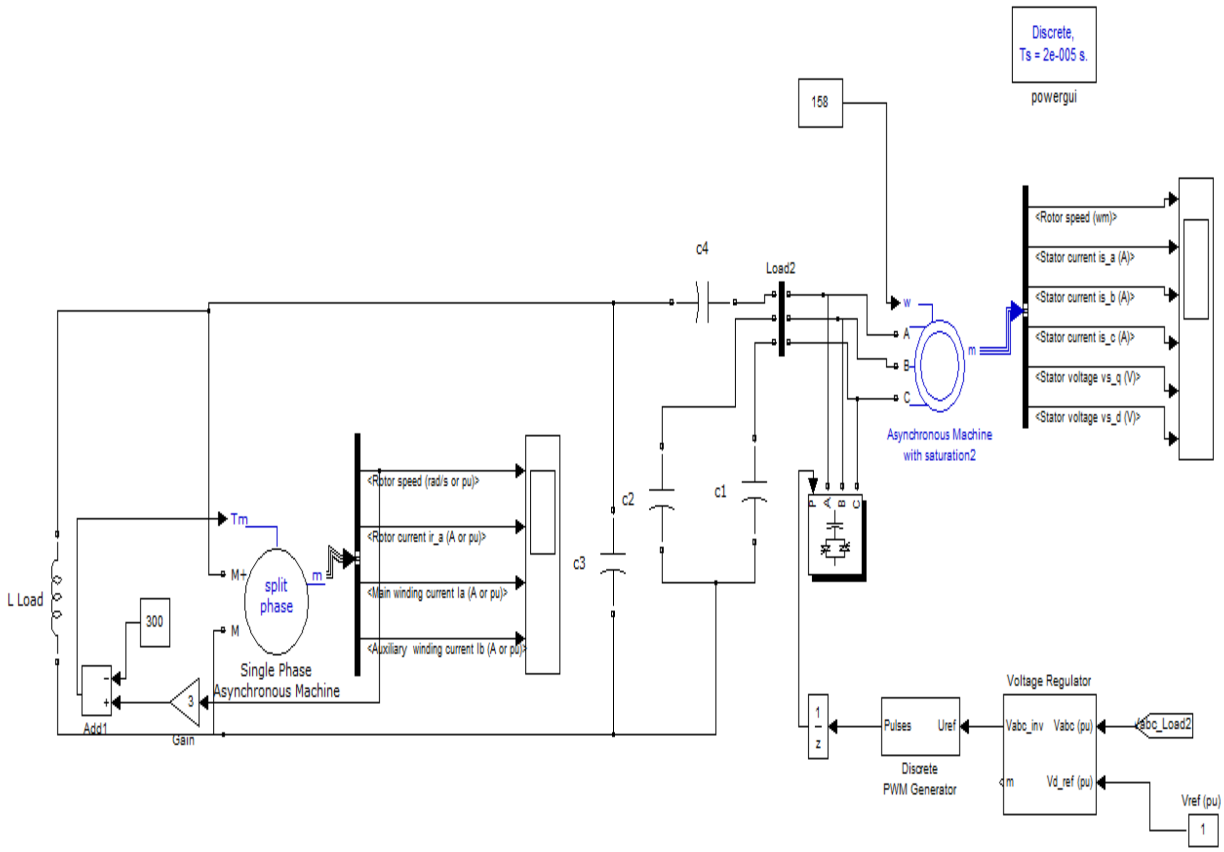

Fig 5.2 Simulink model of Single phase long shunt SEIG with voltage controller

The fig 5.2 shows the simulink model of the long shunt SEIG feeding single phase load with voltage control loop. The voltage at the SEIG is controlled . Split phase induction motor is connected to the SEIG. The induction motor rating is 0.25 hp. A reactive load of 100 vars is also added to check the performance of the controller. The speed is maintained constant at 158 rps. The value of C4 is 100 microfarad. The capacitors C1 and C2 are used for phase balancing having equal values of 100 microfarad. The capacitor C3 has a value of 500 microfarad.

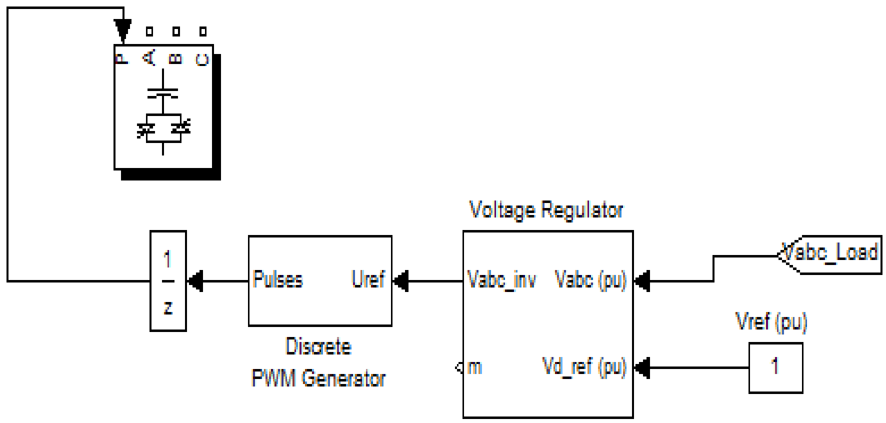

Fig 5.3 Simulink model of Voltage controller

The voltage controller of fig 5.3 consists of voltage regulator and PWM generator. The voltage regulates the voltage to maintain a constant voltage profile. The output voltage or load voltage is converted in pu values and is compared with reference voltage which is 1 pu. The voltage regulator then sends signal to the PWM generator which generates the firing pulses for the gate of the thyristor compensator. The compensator is a VAr compensator. The compensator provides the necessary reactive power to the system with the help of thyristor firing circuit control.

5.3 RESULTS AND DISCUSSIONS

5.3.1 Results for SEIG feeding three phase induction motor load

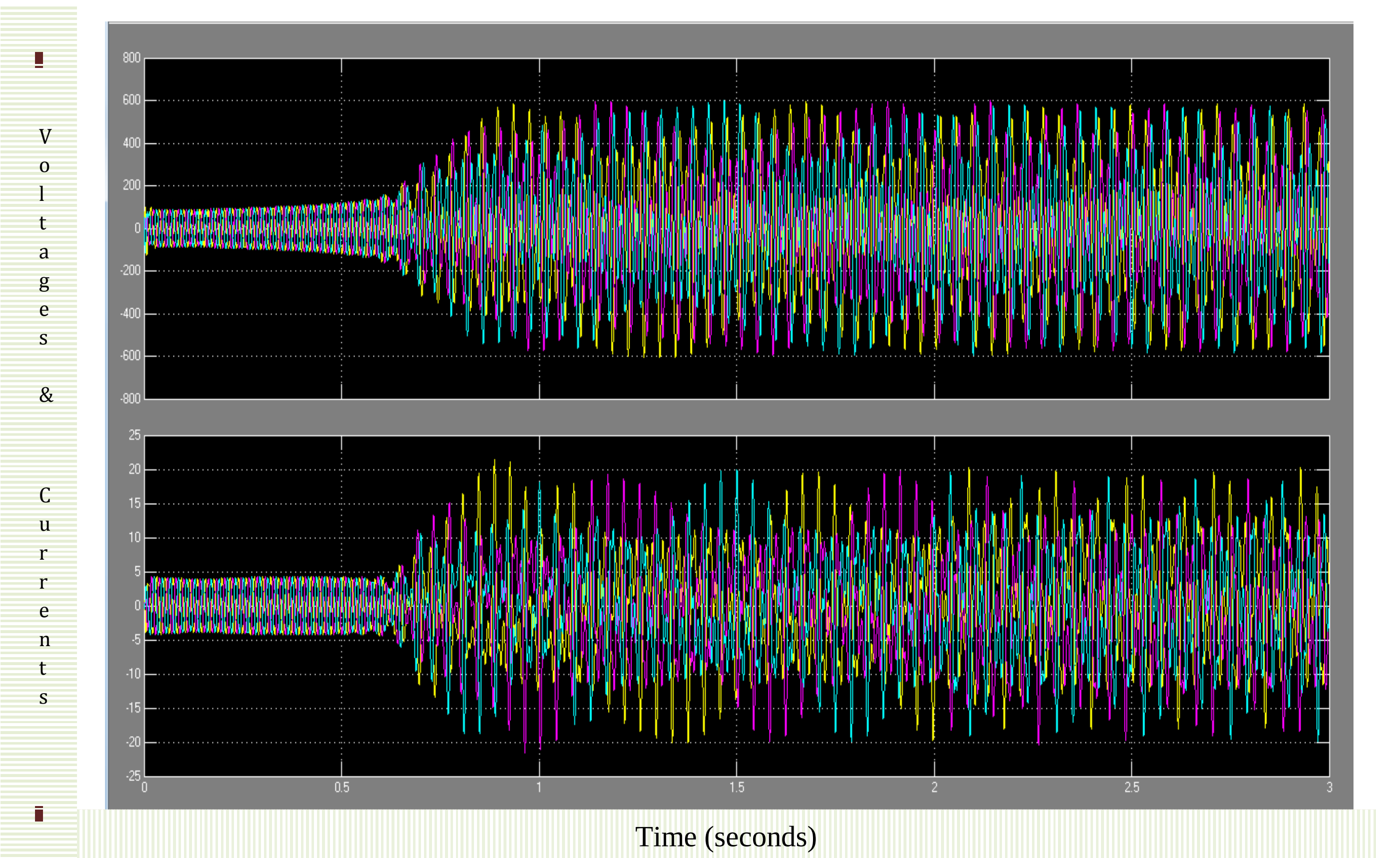

Fig 5.4 Variation of V2 and I2 with Time

The fig 5.4 shows the plot of voltage and the current across the induction motor load. As seen from the plot the voltage is constant throughout the operation and is maintained at the rated value. With the help of two breakers load is applied at different interval of time. Both the breakers are initially open. The transition time of the breaker 1 is 1 sec which is connected to a load W1 of 1000 Vars. The transition time of the breaker 2 is 2 sec which is also connected to a load W2 of 1000 Vars. As seen from result there is no voltage drop after load is applied to the system. The compensator maintains the rated voltage throughout the operation.

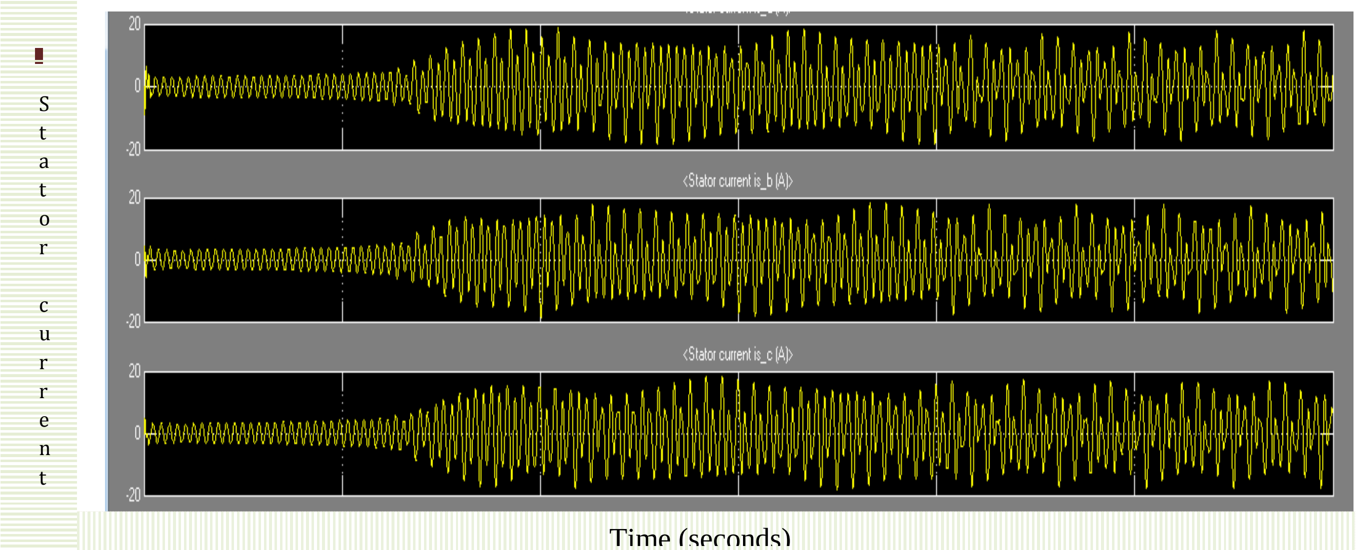

Fig 5.5 Variation of Is With Time

The fig 5.5 shows the source current generated by the SEIG in all the three phases. The currents in all the three phases have rms value of 10 amperes.

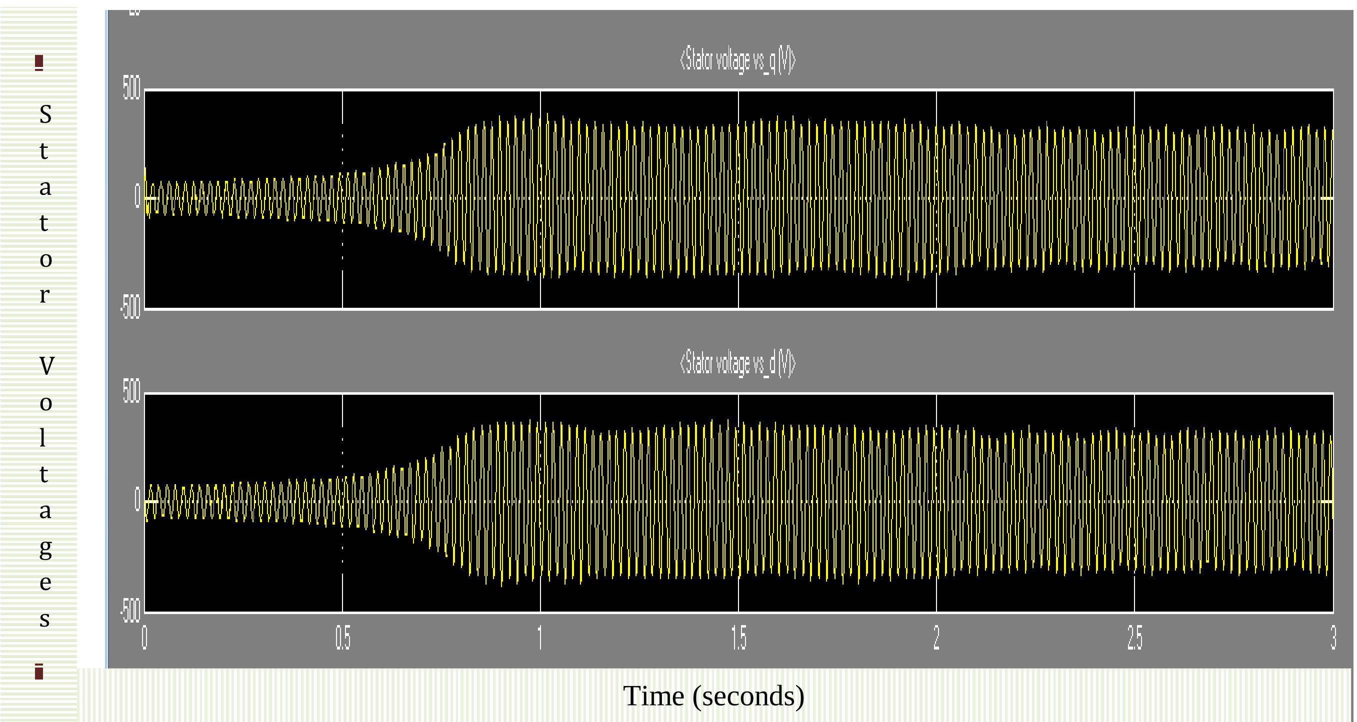

Fig 5.6 Variation of Vs with Time

The fig 5.6 shows the plot of source voltage generated by the SEIG. The voltage generated is rated voltage of the SEIG.

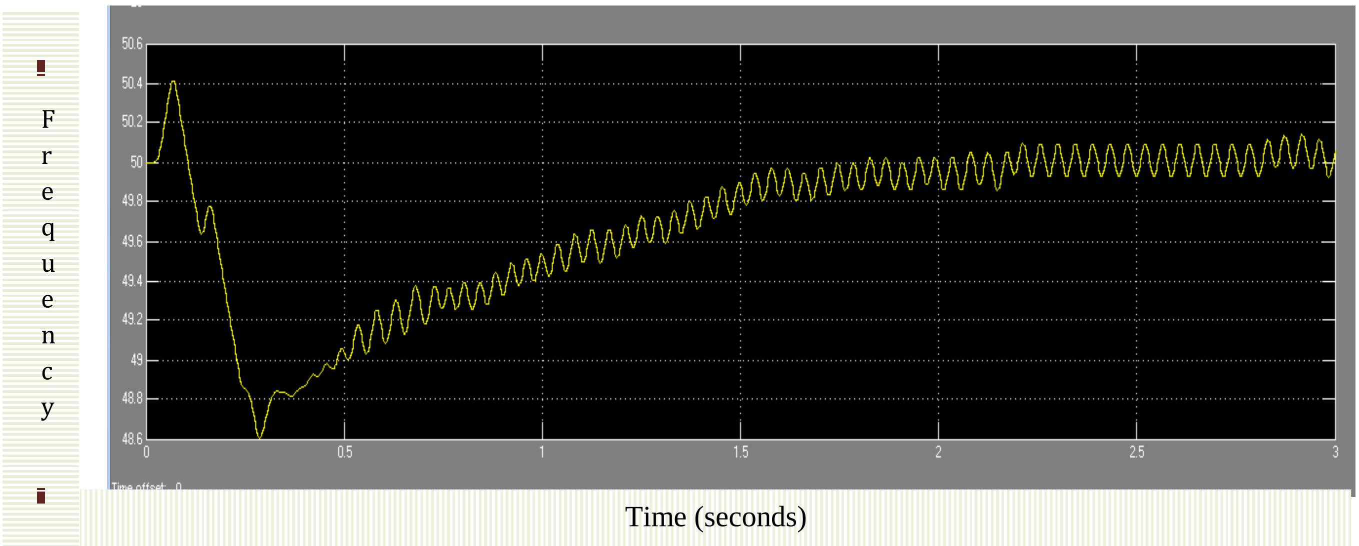

Fig 5.7 Variation of frequency with time

The fig 5.7 shows the frequency of the system. The reactive loads are applied at 1 sec and 2 sec . As the steady state is reached the frequency of the system fluctuates at 50 hertz.

5.3.2 Results for SEIG feeding split phase motor load

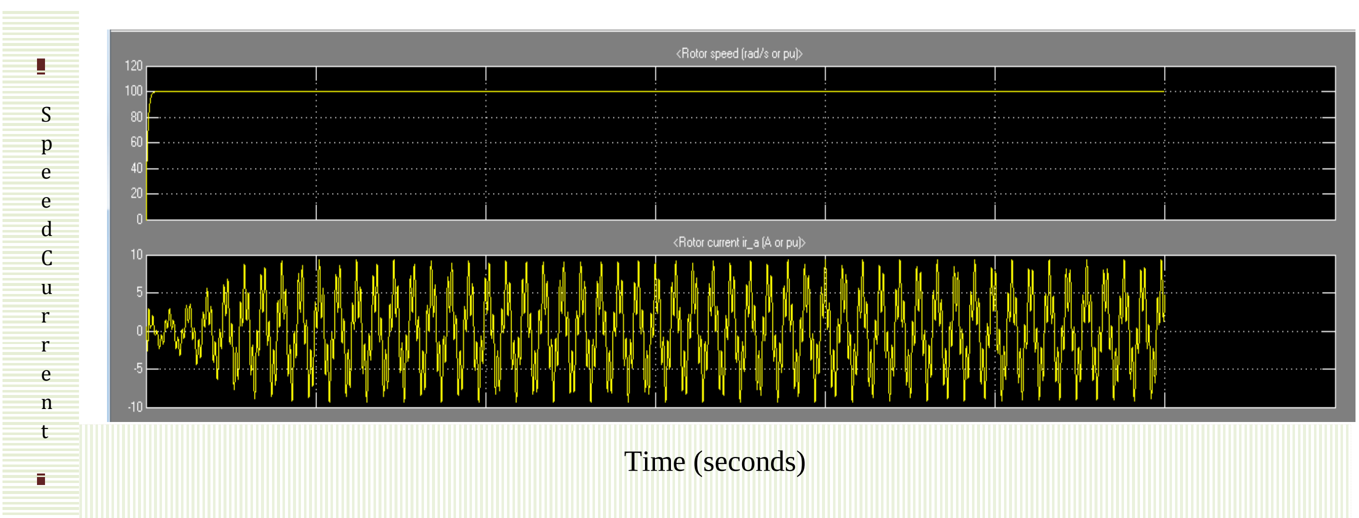

Fig 5.8 Variation of single phase IM Rotor speed Wr and Rotor current Ir with time

The fig 5.8 shows the rotor speed of the single phase IM load which is 100 rad per sec. The running time for the model is 4 seconds. The speed of the rotor is constant throughout the operation. It also shows the rotor currents which is drawn by the single phase induction motor. The fig shows that the rotor currents are balanced. The induction motor is single winding split phase induction motor. The rotor current comes out to be 9 amperes.

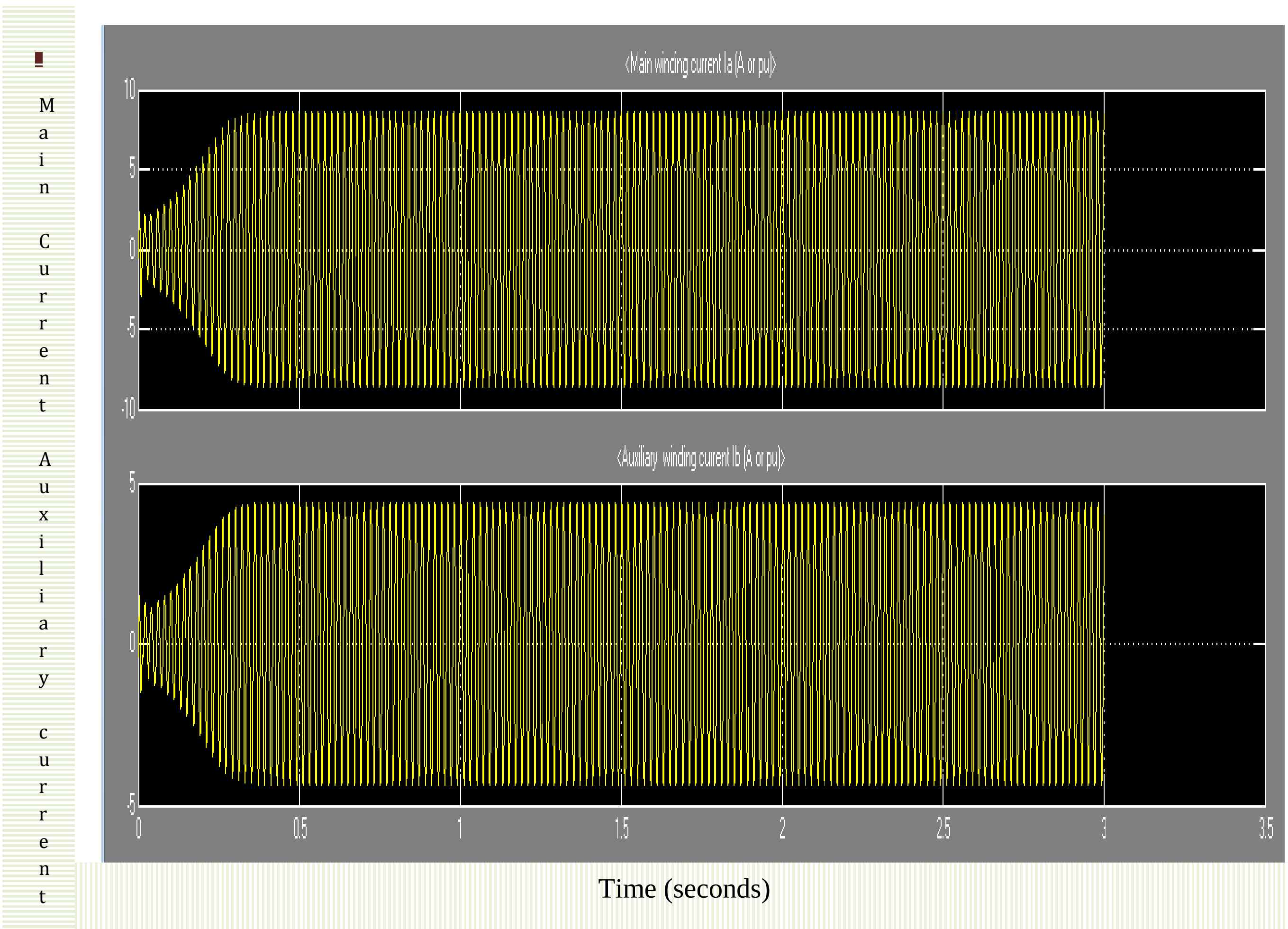

Fig 5.9 Variation of Main winding current Im and Auxiliary Current Ib Vs Time

The fig 5.9 shows that current in the main and auxiliary winding is balanced. The value of the main winding current is 8.65 amperes peak and that for the auxiliary current is 4.4 amperes. All the currents are balanced which shows that the operation is stable.

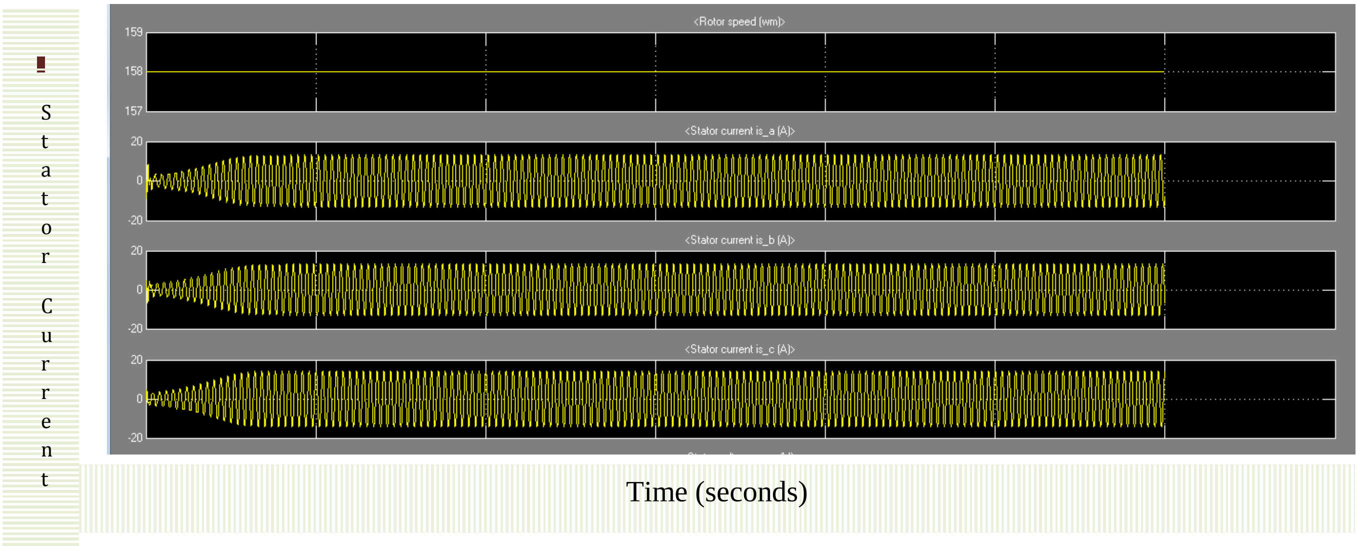

Fig 5.10 Variation of SEIG current Is Vs Time

The fig 5.10 shows the plot of all the currents in the three phases of the induction generator. The peak values of the current in all the phases are 13.1 amperes.

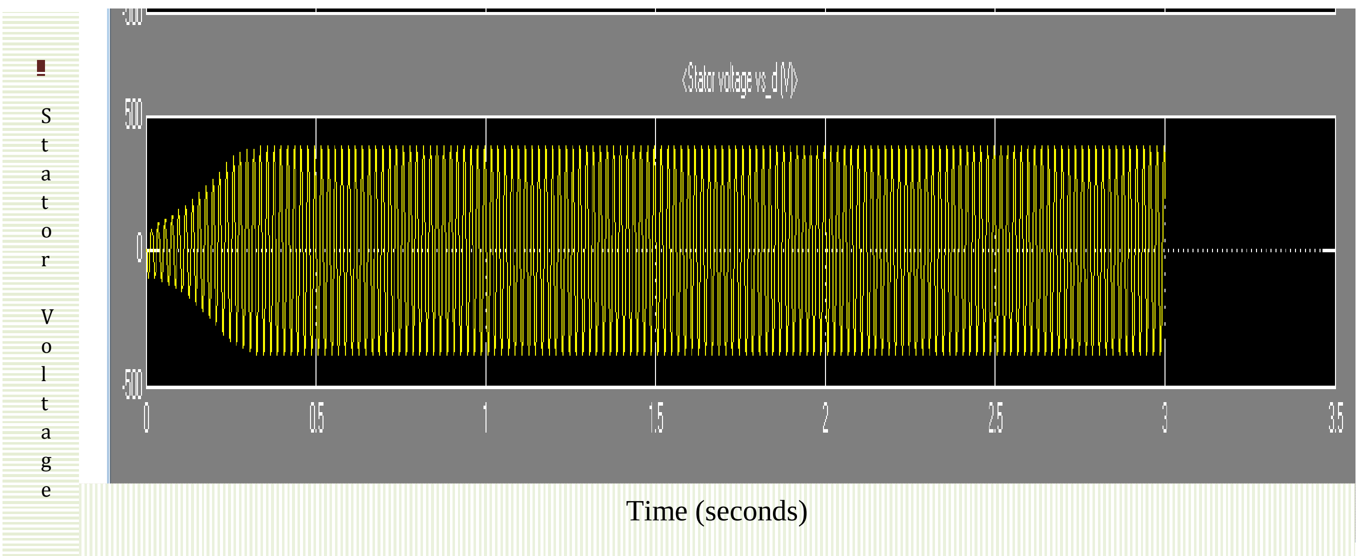

Fig 5.11 Variation of stator voltage Vs Vs Time

The fig 5.11 shows the voltage across the stator of the induction generator which is 390V. The voltages are balanced which suggests a stable operation.

5.4 CONCLUSION

The performance analysis of long shunt self excited induction generators are studied when closed loop operation is carried out. As seen from the results that the voltage of the shunt configuration can be regulated widely. If the reactive load of the induction generator is increased by a large value, the compensator is successful in maintaining the rated voltage at the load.

CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1 CONCLUSION

The simulink results of the SEIG are discussed in this chapter for reactive load and induction motor load. When the reactive load and the resistive load is connected to the system the voltage is build up to the rated value by very large value of capacitance. Beyond that value the voltage rises rapidly to overshoot the voltage. It is also affected by the speed of the system. From the results of the tables stated it can be concluded that the voltage regulation of induction motor is very poor.

When induction motor is connected to the SEIG then it is not able to build voltage in any case when shunt only compensation is used for SEIG. As seen from the result the 5 hp SEIG is not able to run the 1 hp motor even if speed and capacitance is increased to a sufficiently large value.

To maintain a good voltage regulation and to run the induction motor a series compensation is required along with the shunt compensation. The series compensation provides avery good voltage regulation to the SEIG. There are two types of series compensation long shunt and short shunt configurations which is discussed further in the chapters.

The experimental result and simulated results for the SEIG are compared. The series compensation for the resistive load connected to the SEIG gives a better performance as compared to shunt only connection. The speed of the SEIG can be varied widely with wide range of voltage stability. From the table 1 it can be seen that the series compensated SEIG is very effective to provide a better operating performance to the system. Further in short shunt connection there is no problem of voltage instability but this is not the case in the long shunt connection. The long shunt connection will be studied later in the chapters.

In this chapter the analysis for the long shunt configuration is carried out. Due to the series compensation the voltage of SEIG can be regulated for a wide range. The results are verified by changing simultaneously the value of load, Csh, W and the value of Cse changes correspondingly. Experimental results and simulated results are verified

We know that an induction motor can work as an induction generator when the stator terminals are connected with proper value of excitation capacitance.The series compensation is required when three phase Induction motor load is connected to the SEIG. From the results of the table 1 it can be concluded that the voltage of the system fluctuates widely as the speed is slightly varied for fixed series and shunt capacitance. When the speed of the SEIG is decreased then the voltage of the system also decreases and as the speed increases the system voltage also increases. The speed of the induction motor also changes with the speed of the SEIG. But for a slight decrease in the speed of SEIG both the voltage and the induction motor speed decreases by a large value. From the table 2 it is concluded that as the series capacitance changes there is a considerable change in the system voltage. The speed of the induction motor also decreases by a large amount when the series capacitance is decreased beyond a certain value. If all the parameters are kept constant and only the value of shunt capacitance is changed then only the voltage of the resistive load is affected. There is no change in the induction motor current and speed for balanced operation. But as the series capacitance is changed all the parameters of the system are affected like all the voltages across loads, induction motor current and speed.

For the single phase IM load the steinmetz connection for the short shunt configuration is described with the help of the simulink model in matlab. The shunt capacitor C3 and the series capacitor C4 helps the induction generator in self excitation. The balanced supply is obtained by changing the values of C1 and C2. These capacitors are used for the phase balancing purpose. The capacitor C1, C2, C3 and C4 can be used to control the performance of the system. With proper selection of these values single phase induction motor can be run using three phase induction generator with the system being balanced and stable.

With the help of simulink results it is shown that the long shunt configuration of the SEIG feeding an induction motor is highly unstable. All the parameters are fluctuating in nature. The voltages and currents are highly unbalanced. This is not the case in short shunt configuration in which all the parameters are balanced and the system is stable. According to Li Wang [21] starting resistance has to be included in the induction motor for long shunt otherwise voltage will be distorted but no such provision is needed in SEIG under short shunt configuration.

6.2 SCOPE FOR FUTURE WORK

For better performance of the SEIG under different conditions power electronic devices and facts devices (STATCOM, BESS, SSSC) can be used which has wide range of applications. Parallel operation as well as use of hybrid systems with SEIG is very efficient and enhances its scope.

APPENDIX:

Induction machine specification

The specification of the 1 hp machine are taken from [8] SEIG
3-phase, 4-pole, 50 Hz, Star connected, squirrel cage induction machine 750W/1HP, 380V, 1.9A

Parameters
$R_1 = 0.0823, R_2 = 0.0696, X_1 = X_2 = 0.0766$

Base values:
Base voltage =219.3V
Base current =1.9A
Base impedence =115.4Ω
Base frequency =50 Hz
Base speed =1500rpm
The variation of magnetizing reactance with air gap voltage at rated frequency for the induction machine is given below.

$X_m < 169.2 \quad E_1 = 512.69 - 2.13X_m$
$179.42 > X_m \geq 169.20 \quad E_1 = 891.66 - 4.37X_m$
$184.46 > X_m \geq 179.42 \quad E_1 = 785.79 - 3.78X_m$
$X_m \geq 184.46 \quad E_1 = 0$

The specification of the 5 hp machine are taken from [26] SEIG 3-phase, 4-pole, 50 Hz, Star connected, squirrel cage induction machine
The parameters of the 5HP, 400 volts, 3 phase, 50 Hz, 4-pole SEIG are:

Stator Resistance = 1.405Ω, Rotor Resistance = 1.39Ω, Stator Leakage Inductance =0.0078H, Rotor Leakage Inductance = 0.0078H, Inertia =0.138 kg/m2

Single phase induction motor parameters:

0.25 hp, 110 V, 4 pole, 50 Hz , split phase single phase induction motor

Main winding parameters
Stator Resistance = 2.02 Ω, Rotor Resistance = 4.12Ω, Stator Leakage Inductance =7.4e-3H, Rotor Leakage Inductance = 5.6e-3H, Inertia =0.0146 kg/m2
Mutual inductance= 0.1772H

Auxiliary winding parameters
Stator Resistance = 7.14 Ω
Stator leakage Inductance = 8.5e-3H

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