Current Control of Self-Excited Induction Generator using Shunt Active Filter

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DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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CERTIFICATE

This is to certify that the thesis entitled, **“CURRENT CONTROL OF A SELF-EXCITED INDUCTION GENERATOR USING A SHUNT ACTIVE POWER FILTER”** submitted by Sri **Gour Sunder Garain** bearing roll no. 212EE4244 in partial fulfillment of the requirements for the award of MASTER of Technology Degree in **Electrical Engineering** with specialization in **“Power Electronics and Drives”** during section of 2012-2014 at the National Institute of Technology, Rourkela is an authentic work carried out by him/her under my/our 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

Self-energized impelling generators are great applicants for wind controlled power era, particularly in remote territories, in light of the fact that they needn't bother with an outside force supply to process the excitation attractive field. A three-stage actuation machine could be made to fill in as a self-energized instigation generator where a three-stage capacitor bank is joined over the stator terminals to supply the touchy force necessity of a heap and generator. A standout amongst the most well-known issues when uniting little renewable vitality frameworks to the electric burden is it can infuse symphonious parts that may fall apart the force quality. In the late decades, the world has seen a development in the utilization of non-direct loads. The sounds causes issues in force frameworks and in customer items, for example, gear overheating, capacitor blowing, engine vibration, unnecessary nonpartisan momentums and low power variable.

Shunt active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the grid. This paper presents a new control strategy based on shunt active power filter for controlling the current of self-excited induction generator when generator is connected to a nonlinear load. This paper also represents the analysis and modelling of dynamic model of SEIG in MATLAB/ SIMULINK. Basically a strategy based on an active power filter (APF) for controlling the current and power quality of the self-excited induction generator (SEIG) have been presented in this paper. The shunt active power filter was implemented using a three phase PWM current controlled voltage source inverter (VSI) and connected to the wind generator and loads in order to compensate the current harmonics and reactive power.

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CHAPTER

1

INTRODUCTION

1.1 INTRODUCTION

Today, the main source of electricity generated is fossil fuels like coal, oil, and natural gas and these are a non-renewable energy source. These fossil fuels have limited reserves and will run out in the future. Apart from that another drawbacks of this non-renewable energy source are it produces pollutant gases when fuels are burned and increases cost of generation. However more attention is being given to renewable energy such as wind, micro-hydro, solar, tidal wave, bio-fuel etc. Out of these renewable energy source wind energy seems to be important and promising source because it is clean and abundant resource that can produce electricity with no emission of pollutant gas and economically viable.

Induction generators are commonly used for wind powered electric generation, especially in remote and isolated areas, because of their relative advantages over conventional synchronous generator such as brush-less rugged construction , low cost, less maintenance, simple operation, self-protection against faults, good dynamic response and capability to generate power at varying speed.

A three-phase induction machine can be made to work as a self-excited induction generator where a three-phase capacitor bank is connected across the stator terminals to supply the reactive power requirement of a load and generator. In a grid connected induction generator driven by a wind turbine the magnetic field is produced by excitation current drawn from the grid.

The increasing use of solid-state power-conversion equipment and other power electronic-type devices on distribution systems is causing utilities to become much more concerned about voltage and current harmonic levels. The harmonics causes problems in power systems and in consumer products such as equipment overheating, capacitor blowing, motor vibration, excessive neutral currents and low power factor. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase-shifted by 180°.

Shunt active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the grid. This principle is applicable to any type of load considered as harmonic source.

1.2 MOTIVATION:-

A three-phase induction machine can be made to work as a self-excited induction generator where a three-phase capacitor bank is connected across the stator terminals to supply the reactive power requirement of a load and generator. Self-excited induction generator is best suitable for generating electricity from wind, especially in remote areas, because of their relative advantages over conventional synchronous generator such as brush-less rugged construction, low cost, less maintenance, simple operation, and self-protection against faults, good dynamic response and capability to generate power at varying speed.

The main methods of representing a SEIG are the steady state model and the dynamic model. The d-q reference frame model, impedance based model, admittance based model, operational circuit based model, and power equations based models are frequently used for analysis of SEIG. The main drawback of using the per-phase steady state equivalent circuit model is that it cannot be used to solve transient dynamics because the model was derived from the steady state conditions of the induction machine. The advantage of D-Q axes model or dynamic model is that it is powerful for analyzing the transient and steady state conditions, giving the complete solution of any dynamics.

One of the most common problems when connecting small renewable energy systems to the electric load is it can inject harmonic components that may deteriorate the power quality. Shunt active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the grid.

It motivates to first develop the dynamic model of stand-alone SEIG and analyzed the whole system with different conditions and then develop an instantaneous reactive and active theory based Shunt Active Power Filter to compensate the current harmonics.

1.3 OBJECTIVE:-

The main objectives of this project is

1. To analysis and modeling of dynamic model of SEIG in MATLAB/SIMULINK.
2. To analyse the dynamic response and voltage build up process of SEIG under different loading conditions, variable speed of rotor and different capacitance value.
3. To design and simulate a shunt active filter based on p-q theory to compensate harmonics and reactive power requirement while a nonlinear loads is connected to the generator.

1.4 Literature Review:-

In 1935 **basset et. Al**[1] have discovered the possibility of using induction machine a self-excited induction generator in isolated mode by using external capacitor across stator terminal. The main methods of representing SEIG are the steady state model and the dynamic model. The main drawback of the using per-phase steady state equivalent circuit model is that it cannot be used to solve transient dynamics because the model was derived from the steady state conditions of the induction machine. The dynamics model of SEIG is based on d-q axes equivalent circuit or the unified machine theory. **Maliket. Al**[2] described that the value of the excitation capacitance must be in the range $C_{min} \leq C \leq C_{max}$ and the numerical method used in finding out the capacitance requirement for the self-excited generator is the trial and error method. The SEIG represented in d-q axes by Wang et. Al[3]reported that the dynamics generated voltage an varies with applied load., but there is no result that show what happen to the dynamic speed of the rotor when the generator is loaded. **Seyomet. al [4]** described the effect of magnetizing inductance of the self-excitation and loading analysis of an isolated induction generator and how the operating frequency and generated voltage are affected by taking resistive load only. So to improve the performance of SEIG, many researchers have proposed different control strategies and application in different power electronic controllers. The smooth control of SEIG may be achieved by the use of static VAR compensators (SVC) reported by **Brennetet. Al**. [5] but it require large size capacitors and inductors and also inject harmonics currents in SEIG system. Singh et. al [6] described that current controlled voltage source inverter (CC-VSI) with self-supporting dc bus can be used as astatic synchronous compensators (STATCOM) for voltage regulation under varying static load but not for frequency regulation. Electronic load controllers(ELCs) [7]-[9] have been proposed in the application of self-excited induction generator with constant power prime movers like micro hydro turbines ,the magnitude and the frequency of the generated voltage are varying with different load conditions. Voltage controlled by balancing the generator output power, the active power is controlled.

1.5 OVERVIEW

1.5.1 SELF EXCITED INDUCTION GENETATOR:

The advantages of using an induction generator instead of a synchronous generator are reduced unit cost and size, brush-less rugged construction (in squirrel cage construction), absence of separate dc source, ease of maintenance, self-protection against severe overloads and short circuits, etc. Induction generators are two types (on the basis of rotor construction)

i) Squirrel cage induction generator;
ii) Wound rotor induction generator.

Depending upon speed and frequency of prime mover induction generator schemes can be classified into:-

i) Constant Speed Constant Frequency [CSCF]
ii) Variable Speed Variable Frequency [VSCF]
iii) Variable Speed Constant Frequency [VSCF]

Mainly the generators which are used for Wind power generation are:-

I. Permanent Magnate Synchronous Generator:-

Low speed, weight, power loss, regular maintenance, noise generation are the main disadvantages of PMSG type generator.

II. Self-Excited Induction Generator :-

In isolated systems, squirrel cage induction generators with capacitor excitation, known as self-excited induction generators (SEIGs), are very popular. It has poor voltage and frequency regulation.

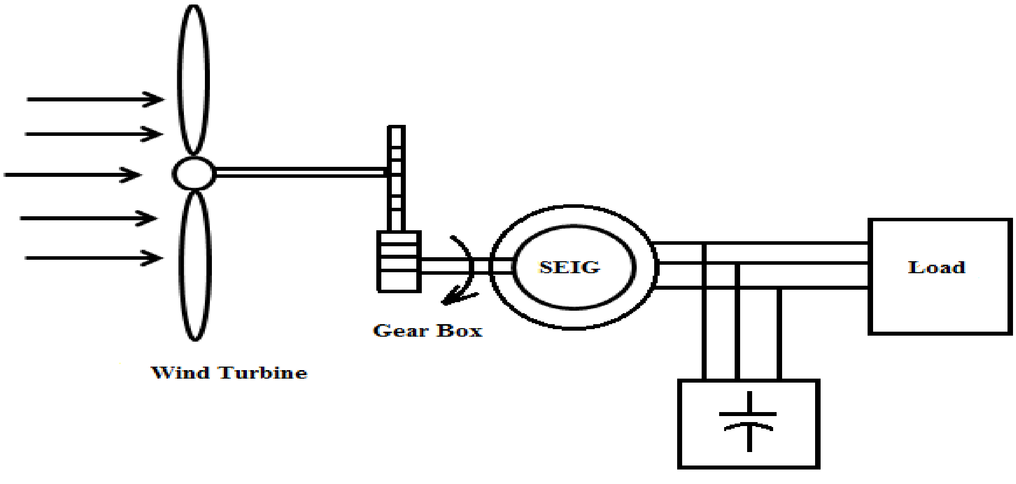

Fig. 1. Schematic diagram of Wind-Driven SEIG

III. Double Fed Induction Generator :-

Doubly-fed electric machines are essentially electric machines that are fed a momentums into both the stator and the rotor windings. The essential preference of doubly-fed induction generators when utilized as a part of wind turbines is that they permit the amplitude and frequency of their yield voltages to be kept up at a consistent quality, regardless of the velocity of the wind blowing on the wind turbine rotor. Due to this, doubly-fed induction generators might be specifically joined with the air conditioner power system and stay synchronized at all times with the air conditioner power system. Different points of interest incorporate the capability to control the power factor (e.g., to keep up the power factor at unity), while keeping the power.

Using a doubly-fed induction generator in wind turbines offers the accompanying preferences:

i) Can be operated at constant amplitude and frequency of the generated voltages rotor speed are variable.
ii) Generated power can be optimized as it is a function of the nominal output power of the wind turbine generator.
iii) Sudden variations in generator output power the rotor torque can be virtually eliminated.

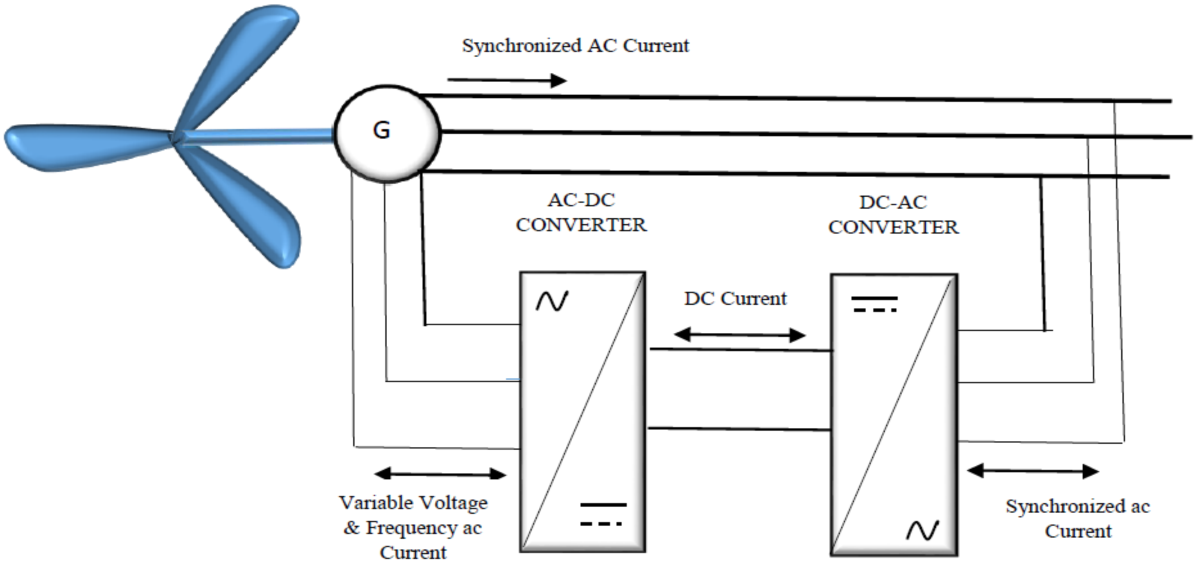

Fig1.2: - Double Fed Induction Generator

1.5.2 Process of self-excitation :-

The residual magnetism present in the rotor iron generates a small iron generates a small terminal voltage op, when rotor is run at the required speed and this voltage produces a magnetizing current ox. This current increases residual flux therefore more generated voltage ‘xq’. A current ‘oy’ again is sent due to this voltage xp and eventually generates voltage yr. This cumulative process of voltage buildup continue till the saturation curve intersects with the capacitor load line which is shown in below figure at point ‘m’ and that time slop of load line is $\tan^{-1}(\frac{1}{\omega C})$. To present residual flux in the rotor induction machine is run as a motor.

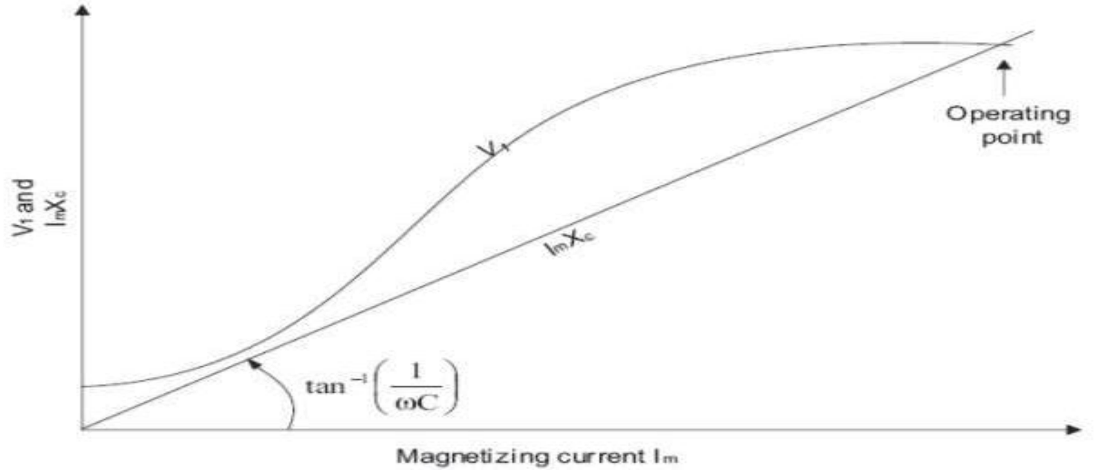

Fig 1.3:- The Magnetization Characteristic of SEIG

From the figure 1.3 it is cleared that this voltage buildup depends upon the value of capacitor and it is also shown that for capacitor C_4 voltage build up does not occur because capacitor load line does not intersects with the magnetizing curve of induction generator.

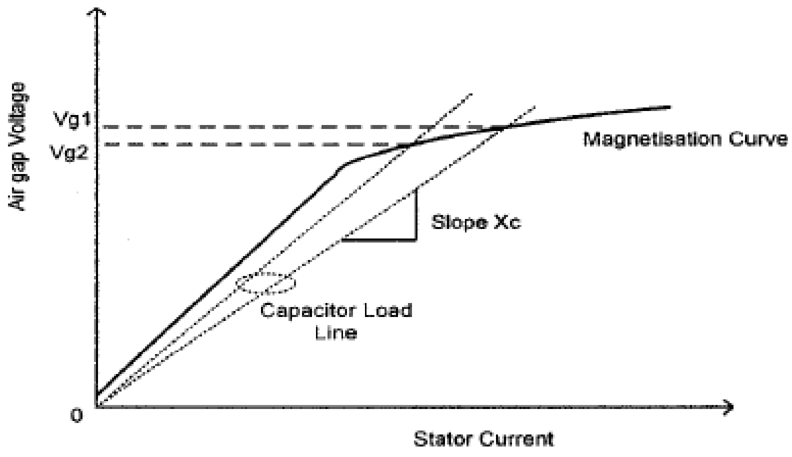

Fig1.4:- Magnetizing Curve and Capacitor Load Line

1.5.3 Representation of Magnetizing Inductance :-

Magnetizing Inductance is one of the main factor of voltage buildup and stabilization of SEIG. Magnetizing reactance (*Xm*) is a non-linear function of Magnetizing current (I_m) and are represented as polynomial equitation of I_m. To determine the coefficient value of this polynomial equation:-

i) We perform the Synchronous Speed Test where we run the given induction machine at synchronous speed at no load by a DC motor

ii) After that magnetizing characteristic i'e L_m verses I_m is plotted.

iii) In this study, a fifth degree polynomial estimate is decided to yield correct results and scientifically spoke to by as takes after:

$$L_m = a_5 i_m^5 + a_4 i_m^4 + a_3 i_m^3 + a_2 i_m^2 + a_1 i_m + a_0$$

iv) The coefficient of that polynomial equation is obtained by applying curve fit technique in matlab Simulink using a function 'polyfit' to the relationship between "Lm" and "im".

Since Xm is subject to frequency it is bad for transient element dissection, rather Lm ought to be utilized. The value of magnetizing inductance begins at a given unsaturated esteem, expands and then at long last reductions as the magnetizing current builds from zero. The other representation is Xm as a magnetizing current or Lm as a function of Vg/f.

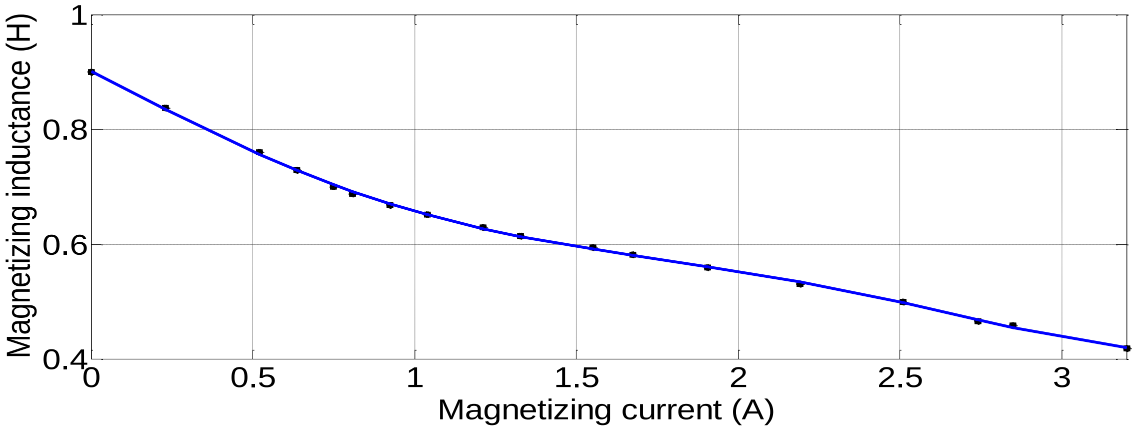

Fig1.5:- Variation of the Magnetizing Inductance with Magnetizing Current

1.5.4 SHUNT ACTIVE POWER FILTER:-

Recently the use of nonlinear loads such as any power electronic equipment, adjustable speed drives, static power supplies and UPS etc. an increase of the harmonic disturbances in the power systems. This type of loads draw harmonic and reactive power components of current from ac mains. The harmonics causes problems in power systems, such as :-

i) Overheating of consumer equipment;
ii) Motor vibration;
iii) Capacitor blowing;
iv) Excessive neutral currents;
v) Low power factor.

In order to face the problem of harmonics, many solutions have been proposed. Use of Shunt Active Power Filters (SAPF) is a very efficient technique to eliminate harmonic currents as well as to compensate for reactive power. The shunt active power filter (APF) is a device that is connected in parallel to the load to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line.

Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase-shifted by 180°.

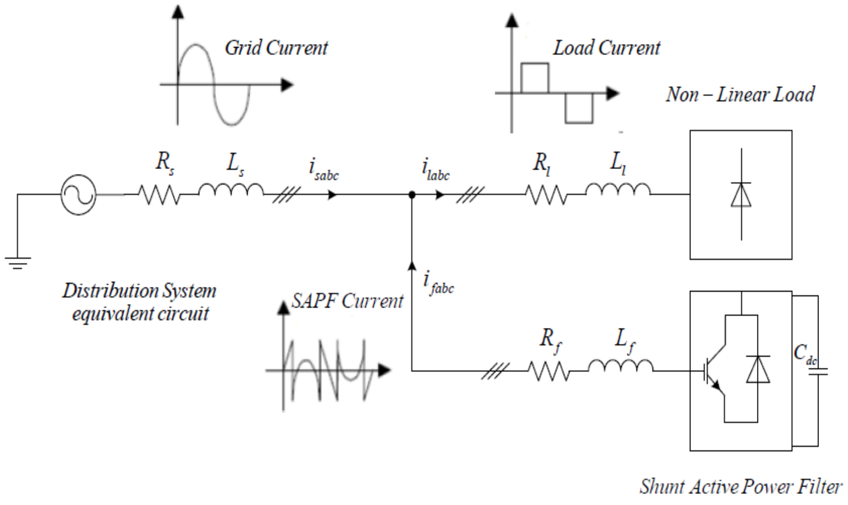

Fig1.6:- Basic Block Diagram of the Active Filter

The complete schematic diagram of the shunt active power filter is shown in fig 1.5. A Shunt Active Filters generally consists of following Blocks:-

i) A IGBT based voltage source inverter (VSI);

ii) A DC energy storage;

iii) The active controller;

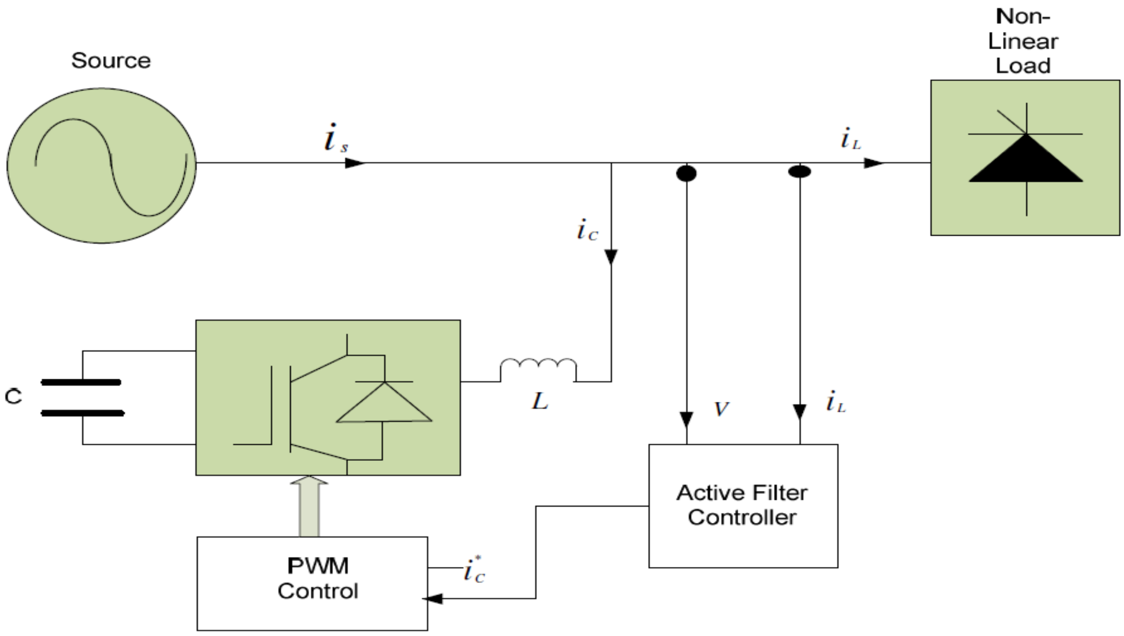

Fig 1.7: - Schematic diagram of a SHUNT ACTIVE POWER FILTER (SAPF)

Design of a power circuit includes three main parameters:

1. Selection of filter inductor, *Lc*
2. Selection of dc side capacitor, *Cdc*, and
3. Selection of reference value of dc side capacitor voltage, *Vdc*.

SUMMARY:-

This chapter represents the introduction to the operation and control of voltage source shunt active filter**.** In this chapter Instantaneous active reactive power theory control algorithm have been used for Shunt active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the system. A complete modelling of shunt active power filter based on P-Q theory have been designer in this chapter

CHAPTER

2

MODELlING OF STANDALONE WIND-DRIVEN SEIG SYSTEM

2.1 INTRODUCTION:

In this chapter, the dynamic model of the Self Excited Induction Generator with no load, resistive load, Inductive Load is derived and, based on this model; its steady-state operating conditions are obtained. The dynamic model of an IM considers the instantaneous effects of varying voltages, currents, frequency, and torque disturbances. The dynamic model of the three phase IM is very complex, because the three-phase rotor windings move with respect to the three-phase stator windings.

First, the transformation techniques are applied to eliminate the presence of □□in the equations. Resulting model is obtained in a synchronously rotating reference frame.

Second, the current variables are replaced by equivalent flux linkage variables and the terminal equations corresponding to the excitation capacitors and the load, together with the torque-balance equation, are included to obtain the complete mathematical model of the system.

Finally, the equilibrium conditions of the state variables are derived to determine the steady-state operating conditions of the model with the varying wind speed and load disturbances.

2.2 MODELING:-

Different models and their requisitions [3], [4], [5] [6], [7] have been displayed to break down the steady-state and transient performance of SEIG operating with either a controlled or unregulated prime mover. The primary systems for speaking to a SEIG are the steady state model and the element model. The steady state investigation of SEIG is focused around the steady state per-phase proportional circuit of an induction machine with the slip and angular frequency communicated regarding per unit frequency and per unit angular velocity. The principle impediment of utilizing the per-phase steady state proportional circuit model is that it can't be utilized to comprehend transient progress in light of the fact that the model was determined from the steady state states of the induction machine. The accompanying classifications are the distinctive models utilized.

2.2.1 STEADY STATE MODEL :-

i) Loop Impedance-Based Model:-

The performance of the SEIG utilizing an analytical model focused around an accepted single-phase equivalent circuit with per-unit (p.u.) parameter is carried out. The sort of model is utilized within for the assessment of different steady-state performance attributes of stand-alone generators, for example, the impact of shaft variety change in generator pole number, and parallel operation, and so forth. Raina et al. [10] have incorporated the injected harmonic currents because of the electronic controller on generator losses in the steady-state model of SEIG. Rajakaruna et al. [11] have incorporated the unregulated prime mover trademark in the steady-state model of a three-phase-balanced induction generator.

The loop-impedance method is focused around setting the aggregate impedance of the SEIG, i.e. counting the exciting capacitance, equivalent to zero and after that to discover the steady state operating voltage and frequency utilizing a irritation process.

ii) Loop Admittance-Based Model:-

An admittance-based model of SEIG utilizing a single-phase equivalent circuit model with a balanced three-phase burden is utilized for the determination of operating frequency and magnetizing reactance, true and nonexistent parts of the entirety of admittance of the rotor, magnetizing, and stator limbs are likened to zero. This method gives a mathematical interpretation for magnetizing reactance regarding generator frequency and different machines parameters and given pace. This model is additionally utilized an admittance-based model for a given yield frequency, where the performance comparison gets quadratic regarding speed and other machine parameters. In the nodal admittance method the real and imaginary parts of the general admittance of the SEIG are likened to zero.

iii) Operational Circuit-Based Model:-

Operational Circuit-Based Model is an option methodology to the steady-state performance analysis of a stand-alone SEIG. An operational equivalent circuit as far as operator $(1/\omega)$ d/dt supplanting f in an impedance based model is produced, where $\omega=2\pi f$. The result of a fifth-request polynomial for slacking burden gives the estimations of f and Xm.

2.2.2 DYNAMIC MODEL:-

The dynamic model of a SEIG is based on the D-Q axes equivalent circuit. D-Q –axis reference model was initially propounded by Krause et al [2]. For investigation the induction machine in three axes is changed to two axes, D and Q, and all the dissection is carried out in the D-Q axes model. The results are then changed again to the real three axes representation. In the D-Q tomahawks if the time fluctuating terms are overlooked the comparisons speak to just the steady state conditions. The playing point of D-Q axes model is that it is compelling for investigating the transient and steady state conditions, giving the complete result of any dynamics.

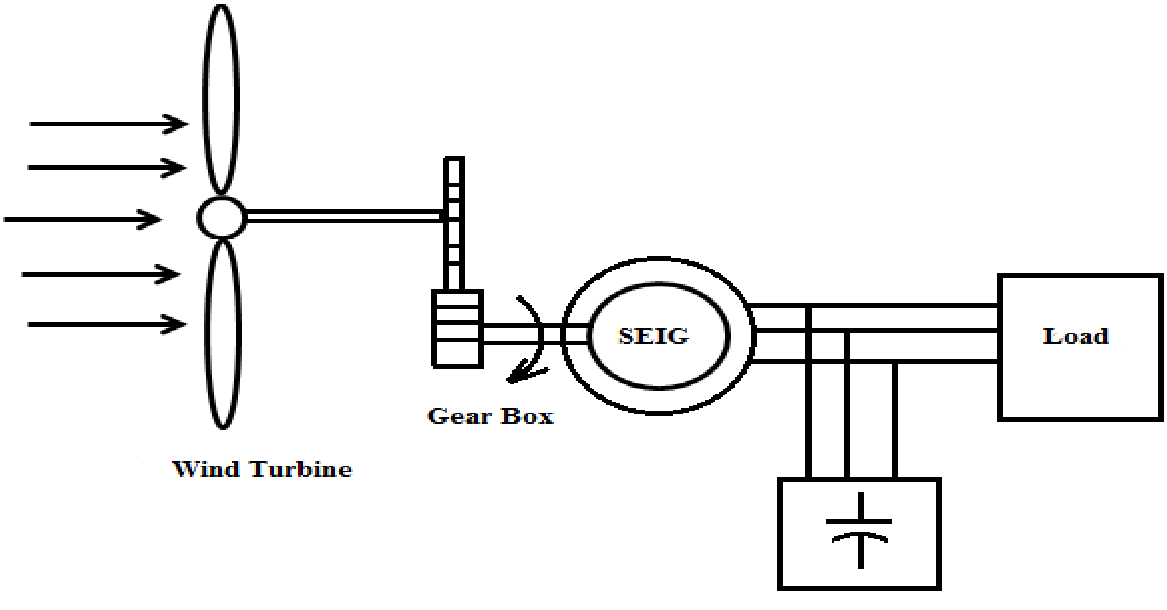

Fig. 1. Schematic diagram of Wind-Driven SEIG

Fig. 1 consists of a SEIG with load, bank of excitation capacitors which is generally delta connected and prime mover. For the improvement of an induction machine model [8] in stationary frame, the d-q discretionary reference frame model of machine is changed into stationary reference outline. Fig3.1 shows the structural d-q axes chart of SEIG.

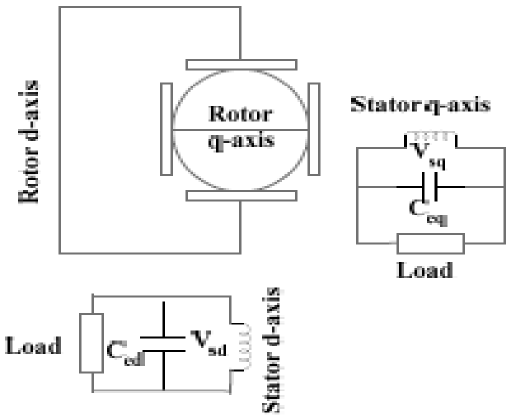

Fig 2.2 :- Structural d-q axes diagram of SEIG

Equivalent circuit of the induction generator with capacitor connected across stator terminal is shown in Fig 3.2 (a) and (b); the reference directions of currents and voltages are indicated. Using d-q components of stator current (isd and isq) and rotor current (ird and irq) as state variables [20], the above differential equations are derived from the equivalent circuit shown in Fig. 3.2.

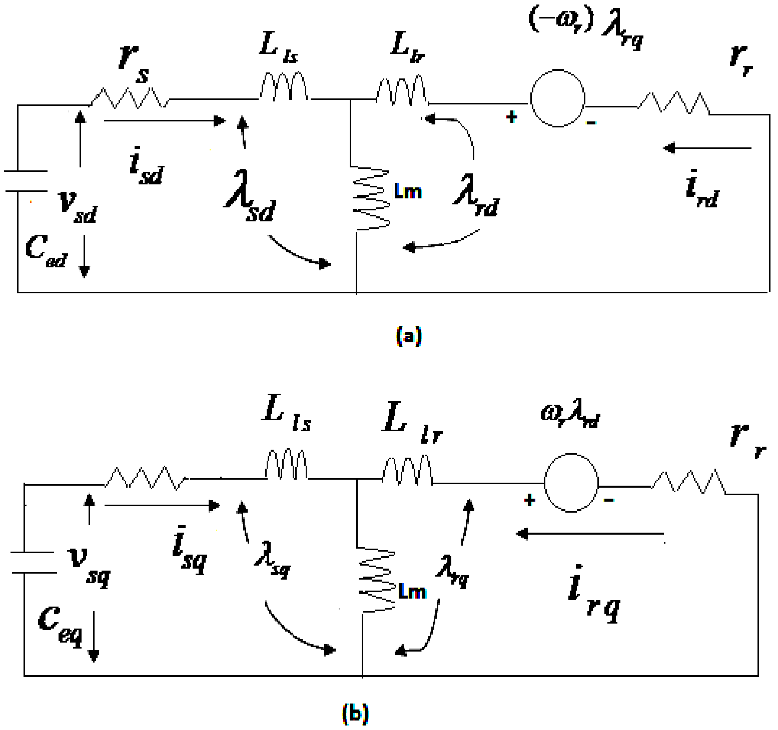

Fig 2.3:- d-q model of SEIG in stationary reference frame

(a) d-axis reference frame;

(b) q axis reference frame

The dynamic machine model in stationary reference frame can be inferred by substituting $\omega_e = 0$ in synchronously rotating reference frame d-q model equations.
By applying kvl law in above circuit we can find:

$v_{qs} = R_s i_{sq} + (d\lambda_{sq}/dt)$

$v_{ds} = R_s i_{sd} + (d\lambda_{sd}/dt)$

$0 = R_r i_{rq} + (d\lambda_{rq}/dt) - \omega_r \lambda_{rq}$

$0 = R_r i_{rd} + (d\lambda_{rd}/dt) + \omega_r \lambda_{rd}$

Where rotor voltage $V_{rd} = V_{rq} = 0$ as in squirrel cage type induction machine rotor are short circuited.

The flux linkage can be written as

$$\lambda_{sq} = L_s i_{sq} + L_m i_{rq}$$

$$\lambda_{sd} = L_s i_{sd} + L_m i_{rd}$$

$$\lambda_{rq} = L_r i_{rq} + L_m i_{sq}$$

$$\lambda_{rd} = L_r i_{rd} + L_m i_{sd}$$

Where inductance

$$L_s = L_{ls} + L_m$$

$$L_r = L_{lr} + L_m$$

Using above equations we can derive differential equations of stator and rotor current as follows

$$\frac{di_{sq}}{dt} = \frac{1}{L_s L_r - L_m{}^2}\left[-L_r r_s i_{sq} - w_r L_m{}^2 i_{sd} + L_m r_r i_{sq} - w_r L_m L_r i_{rd} + L_r v_{sq}\right]$$

$$\frac{di_{sd}}{dt} = \frac{1}{L_s L_r - L_m{}^2}\left[w_r L_m{}^2 i_{sq} - L_r r_s i_{sd} + w_r L_m L_r i_{rq} + L_m r_r i_{rd} + L_r v_{sd}\right]$$

$$\frac{di_{rq}}{dt} = \frac{1}{L_s L_r - L_m{}^2}\left[r_s L_m i_{sq} + w_r L_m L_s i_{sd} - L_s r_r i_{rq} + w_r L_s L_r i_{rd} - L_m v_{sq} \right]$$

$$\frac{di_{rd}}{dt} = \frac{1}{L_s L_r - L_m{}^2}\left[-w_r L_m L_s i_{sq} + r_s L_m i_{sd} - w_r L_s L_r i_{rq} - r_r L_{sr} i_{rd} - L_m v_{sd} \right]$$

The electromagnetic torque can be represented as

$$T_e = \left(\frac{3}{2}\right)\left(\frac{p}{2}\right) L_m \left[i_{sq} i_{rd} - i_{sd} i_{rq} \right]$$

Torque balance equation is

$$T_{shaft} = T_e + J\left(\frac{2}{P}\right)\frac{dw_r}{dt}$$

$$\frac{dw_r}{dt} = \left(\frac{P}{2J}\right)(T_e - T_{shaft})$$

2.2.2 MAGNETIZING INDUCTION (L_m) OBTINATATION:-

The magnetizing inductance "Lm" is not a consistent yet a capacity relies on upon the immediate benefit of magnetizing current "im" given by Lm= f(im).And

$$i_m = \sqrt{\left(i_{sd} + i_{rd}\right)^2 + \left(i_{sq} + i_{rq}\right)^2}$$

The magnetizing inductance "L_m" is calculated from the magnetizing characteristics fourth order polynomial for the test machine "i_m". The 5th order polynomial is arrived at, by applying curve fit technique to the relationship between "L_m" and "i_m", obtained by performing synchronous speed test on the test induction machine. In this study, a fifth degree polynomial estimate is decided to yield correct results and scientifically spoke to by as takes after.

$$L_m = a_5 i_m^5 + a_4 i_m^4 + a_3 i_m^3 + a_2 i_m^2 + a_1 i_m + a_0$$

The coefficient of that polynomial equation is obtained by applying curve fit technique in matlab Simulink using a function 'polyfit' to the relationship between "Lm" and "im".

Where

λ =flux linkage;

i_m = magnetizing current;

L_m =magnetizing inductance;

r =resistance;

L =inductance;

P=number of poles;

? = electrical rotor speed;

And T_e =electromagnetic torque.

2.2.3 EXCITATION MODELLING:-

The excitation system deals with the differential form of d-q components of stator voltage as follows

$$\frac{dv_{sq}}{dt} = \frac{i_{cq}}{C_{eq}}$$

$$\frac{dv_{sd}}{dt} = \frac{i_{cd}}{C_{ed}}$$

Where C_{eq} = Capacitor value along q axes

C_{ed} = Capacitor value along d axes.

2.2.4 LOAD MODELLING :-

For resistive load the d and q axes of current are

$$i_{Rq} = \frac{v_{sq}}{R_L}$$

$$i_{Rd} = \frac{v_{sd}}{R_L}$$

For balance R-L load the current state equitation are

$$i_{RLq} = \frac{v_{sq} - R_L i_{RLq}}{L_L}$$

$$i_{RLd} = \frac{v_{sd} - R_L i_{RLd}}{R_L}$$

Where ‘R_L’ = Load Resistance and ‘L_L’ = Load Inductance.

For Capacitive Load the capacitance is added to excitation capacitance.

Thus with help of above equitations the dynamic model of SEIG system is find by the eight first order differential equitations for an passive load.

State-space matrix of SEIG having R-L load is given by equations.

$$\frac{d}{dt}\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \\ v_{sd} \\ v_{sq} \\ i_{RLd} \\ i_{RLq} \end{bmatrix} = K\left\{\begin{bmatrix} R_sL_r & -\omega L_m^2 & -R_rL_m & -\omega L_mL_r & L_r & 0 & 0 & 0 \\ \omega L_m^2 & R_sL_r & \omega L_mL_r & -R_rL_m & 0 & L_r & 0 & 0 \\ -R_sL_m & \omega L_mL_s & R_rL_s & \omega L_sL_r & -L_m & 0 & 0 & 0 \\ -\omega L_mL_s & -R_sL_m & -\omega L_sL_r & R_rL_s & 0 & -L_m & 0 & 0 \\ 1/C_{ed}K & 0 & 0 & 0 & 0 & 0 & -1/C_{ed}K & 0 \\ 0 & 1/C_{eq}K & 0 & 0 & 0 & 0 & 0 & -1/C_{eq}K \\ 0 & 0 & 0 & 0 & 1/L_LK & 0 & -R_L/L_LK & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/L_LK & 0 & -R_L/L_LK \end{bmatrix}\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \\ v_{sd} \\ v_{sq} \\ i_{RLd} \\ i_{RLq} \end{bmatrix} + \begin{bmatrix} -L_r & 0 & L_m & 0 \\ 0 & -L_r & 0 & L_m \\ L_m & 0 & -L_s & 0 \\ 0 & L_m & 0 & -L_s \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{rd} \\ v_{rq} \end{bmatrix}\right\}$$

Where $$K = \frac{1}{L_m^2 - L_sL_r}$$

By applying d-q to abc transformation the three phase voltage and current can be calculated and the peak value of voltage per phase are obtained.

2.3 SIMMULINK MODEL:-

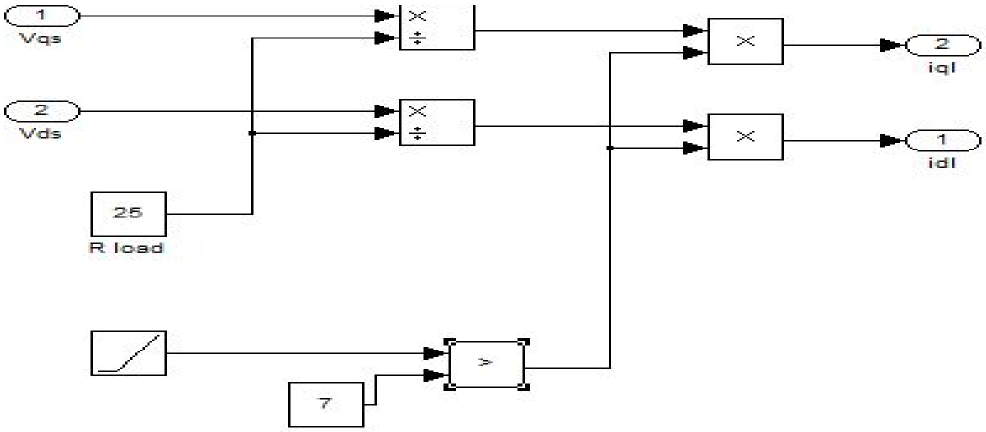

Fig2.4:- MATLAB Simulink Implementation of Load

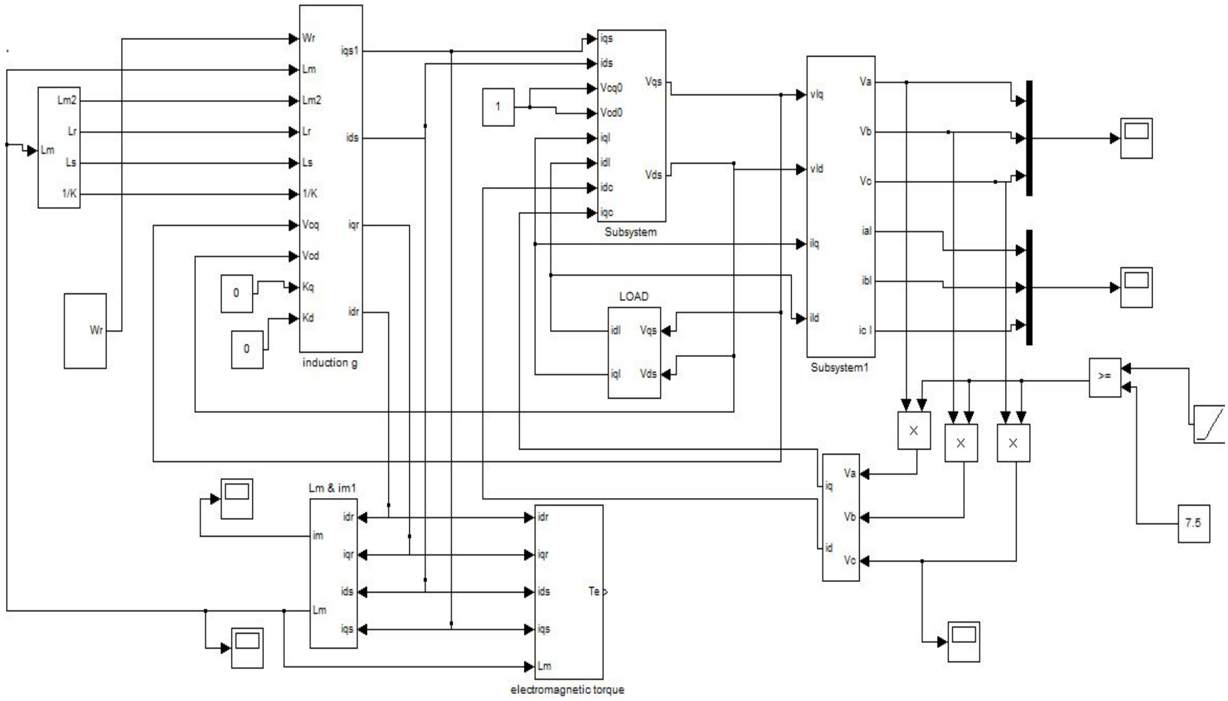

Fig 2.4:- MATLAB Simulink implementation of SEIG

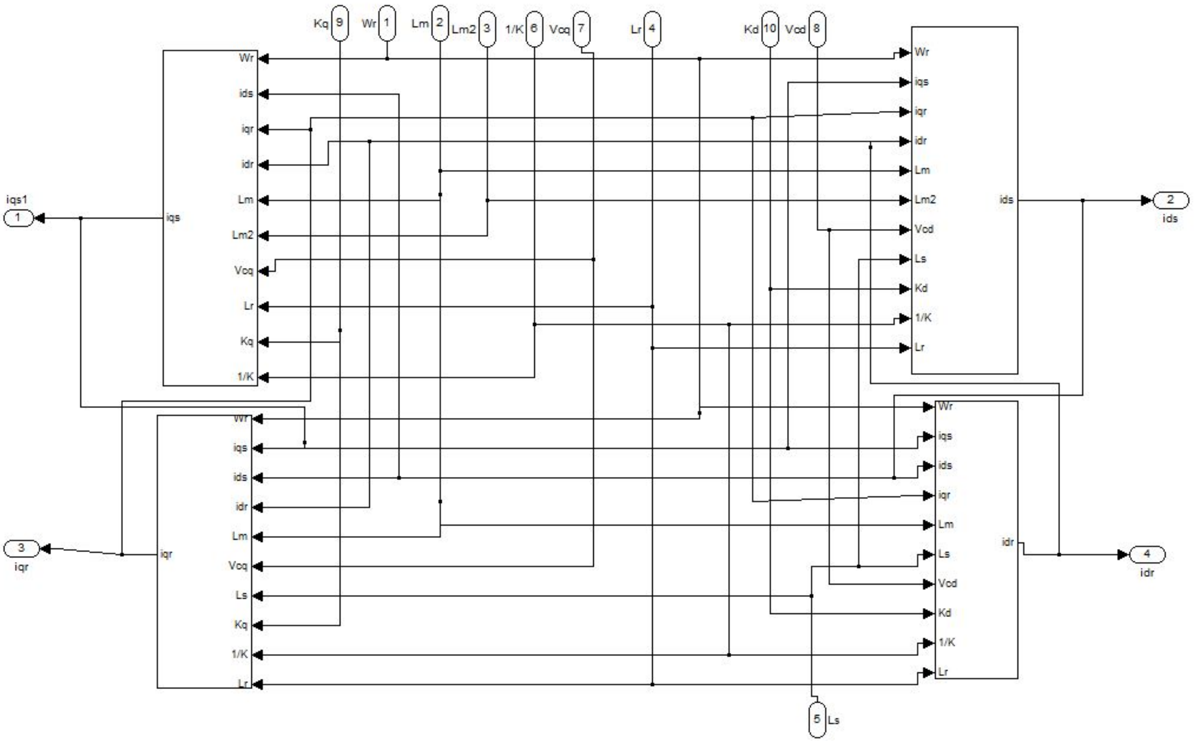

Fig 2.5:-MATLAB implementation of Induction Motor Modelling

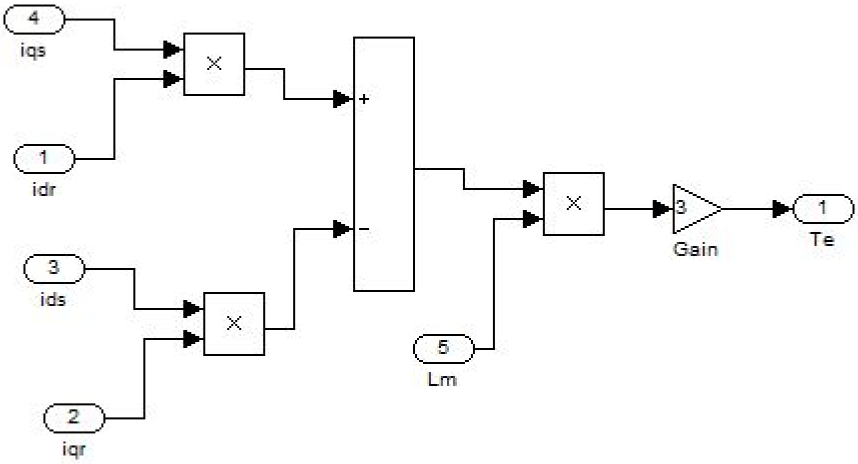

Fig 2.6:- MATLAB Simulink Implementation of Torque Calculation

2.4 SUMMARY:-

This chapter presents the analysis and modelling of Self-Excited Induction Generator. An AC capacitor is connected in stator terminal of an induction machine to supply the magnetizing current required for voltage build up process. This chapter mainly includes the mathematical modeling equations for different parameters self-excited induction generator, excitation capacitor and load impedance. By using these equations in MATLAB/Simulink a self-excited induction generator have been implemented.

CHAPTER

3

MODELLING OF SHUNT ACTIVE POWER FILTER

3.1 INTRODUCTION:-

This chapter represents the introduction to the operation and control of voltage source shunt active filter**.** This chapter presents the Instantaneous active reactive power theory control algorithm have been used for Shunt active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the grid. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180°. In this way, the power distribution system sees the nonlinear load and the active power filter as an ideal resistor. Various topologies of the shunt active filter have been proposed so far.

The operation of shunt APF is based on injection of compensating current which is equivalent to the distorted current. This is achieved by "shaping" the compensation current waveform (i_{fabc}), using the VSI switches. The shape of compensation current is obtained by measuring the load current (i_{labc}), and subtracting it from a sinusoidal reference. The aim of shunt APF is to obtain a sinusoidal source current (i_{sabc}) using the relationship: $i_{sabc} = i_{labc} - i_{fabc}$. Which only contains the fundamental component of the nonlinear load current and thus free from harmonics.

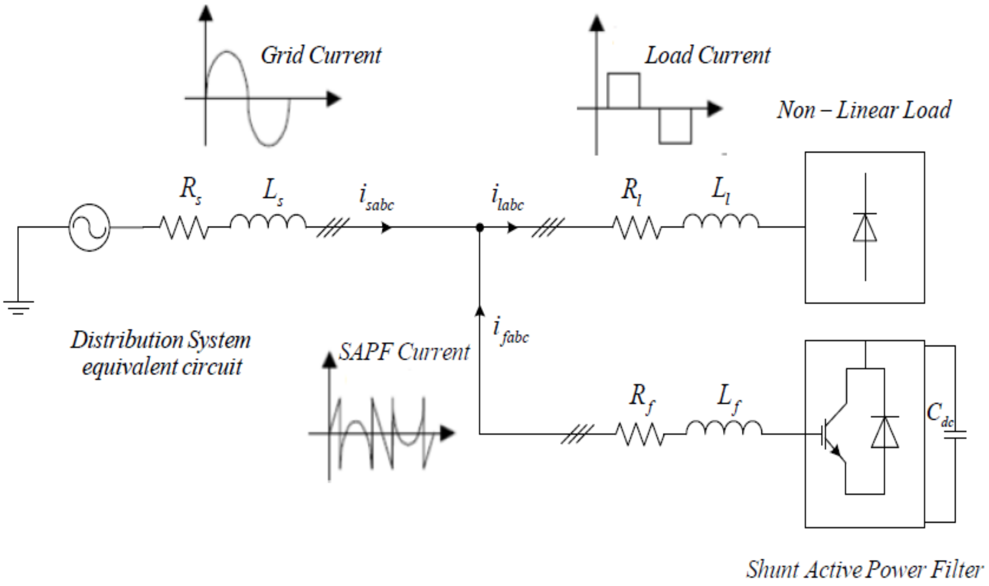

Fig 3.1: - Single line diagram and basic compensation principal of APF with current waveform.

The complete schematic diagram of the shunt active power filter is shown in fig 1.5. A Shunt Active Filters generally consists of following Blocks:-

i) A IGBT based voltage source inverter (VSI);

ii) A DC energy storage;

iii) The active controller;

The voltage source inverter consists of six controllable IGBTs switches with antiparallel diodes. The purpose of VSI is to produce ac voltage with the help of DC capacitor so that desired compensating current can be drawn by through the active filter.

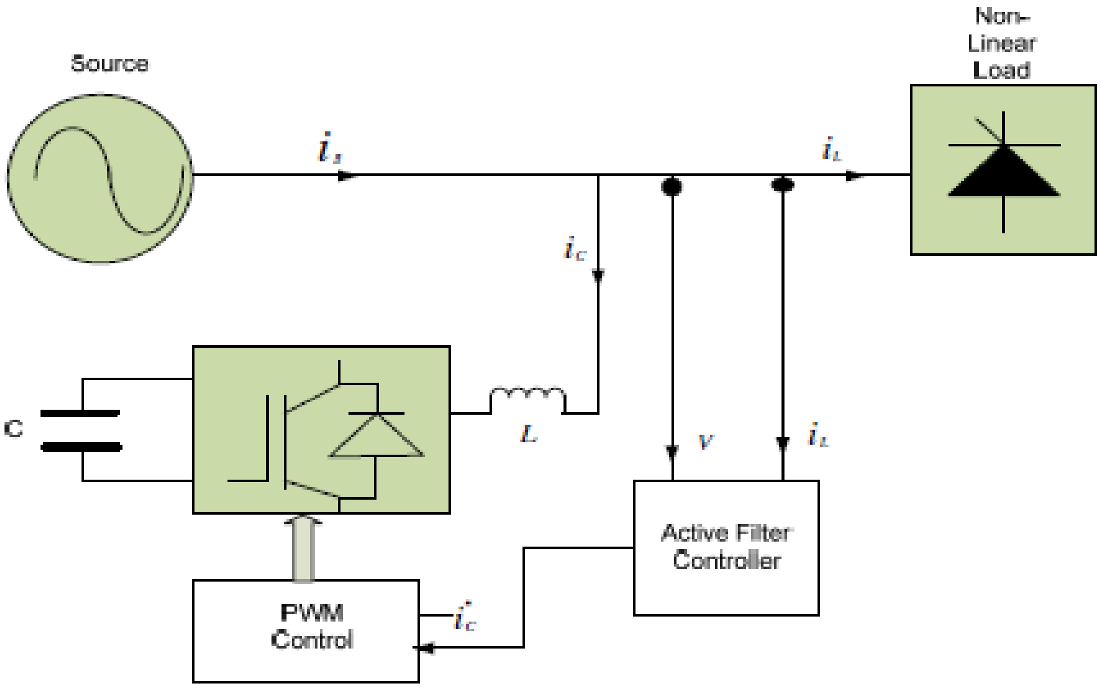

Fig3.2: - Schematic diagram of a SHUNT ACTIVE POWER FILTER

So many control strategy have been proposed but still instantaneous active reactive power theory is always preferable. The p-q theory or instantaneous power theory is based on time-domain; it makes operation in steady-state or transient state, as well as for generic voltage and current waveforms, allowing to control the active power filters in real-time. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation.

3.1.1 THE *p–q* THEORY BASED CONTROL STRATEGY:-

The p-q theory, or “Instantaneous Power Theory”, was developed by *Akagi et al in 1983* with the objective of applying it to the control of active power filters. This is achieved by transforming main voltage and load current into two axis $\alpha-\beta$ co-ordinates by:-

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

The instantaneous active and reactive P_L and q_L can be expressed as:-

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}$$

These instantaneous active and reactive power can be decomposed into oscillatory and average terms as:-

$$p_L = \overline{P} + p \quad \text{and} \quad q_L = \overline{Q} + q$$

Where,

$\overline{P}$ = Mean value of the instantaneous real power. It is the only the desired power component and corresponds to power transfer between source to load.

p =Alternated value of the instantaneous real power. Is to be compensate because it does not involve any energy transfer from the source to the load.

$\overline{Q}$ =The mean value of the instantaneous imaginary power. It corresponds to the power exchanges between the phases of the load and is responsible for the existence of undesired current. It must be compensated.

q =Alternated value of the instantaneous real power. It corresponds to the conventional reactive power. It can be compensated by the APF.

Since in the p-q theory the voltages are assumed sinusoidal, the power components must be computed using sinusoidal voltages.

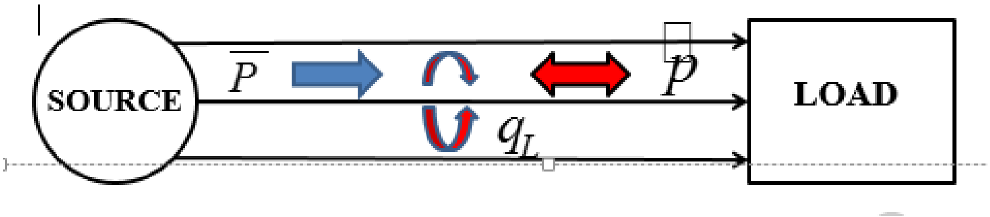

Fig 3.3:- p-q theory power components

So the powers to be compensated are

$$p_c = -p + p_{loss}$$

$$q_c = -q_L$$

Where p_{loss} = the active power needed to cover the filter loss and to maintained the desired voltage in the dc link.

The reference compensation currents are obtained by inverting the matrix

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{{v_\alpha}^2 + {v_\beta}^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -p + p_{loss} \\ -q_L \end{bmatrix}$$

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix}$$

- In order to separate the direct term of the instantaneous power from the alternating one. A Low Pass Filter (LPF) with feed-forward effect are used.

- DC-link voltage regulator is designed to give both good compensation and an excellent transient response. The actual DC-link capacitor voltage is compared by a reference value and the error is processed in a PI controller.

3.2 CONTROL BLOCK DIAGRAM:-

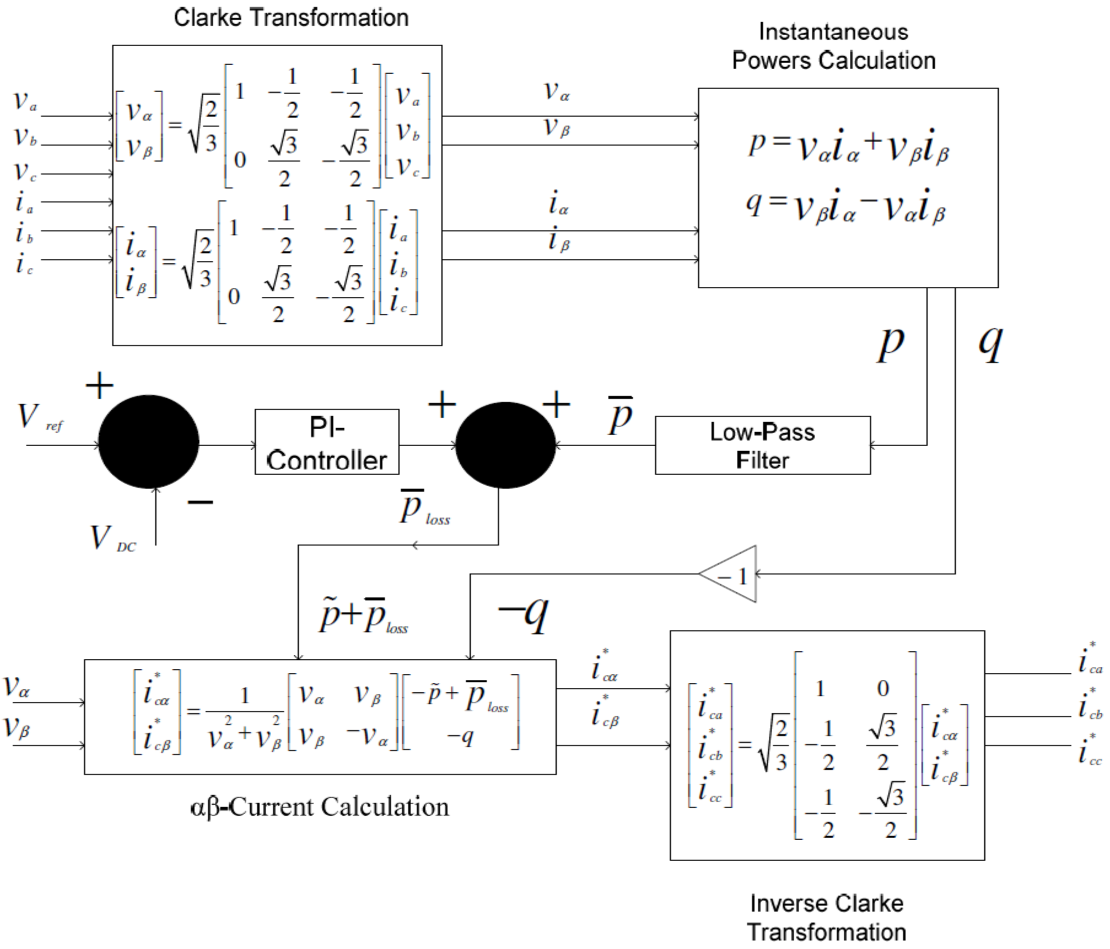

Fig3.4:- :- Control block for the instantaneous active reactive power control strategy

3.3 CONTROL METHODS OF VSI:-

Hysteresis current control is a method of controlling a voltage source inverter so that an output current is generated which follows a reference current waveform. After calculating source ref. currents $(i^*_{ca}\ i^*_{cb}\ i^*_{cc})$ are compared with actual APF line current $(i_{ca}\ i_{cb}\ i_{cc})$ with by using a **Hysteresis Current Controller** to generate the switching pattern of the VSI.

Hysteresis current control is one of the simplest technique to implement; it's developed by Brod and Novotny in 1985. One disadvantage is that there is no limit to the switching frequency. But additional circuitry can be used to limit the maximum switching frequency.

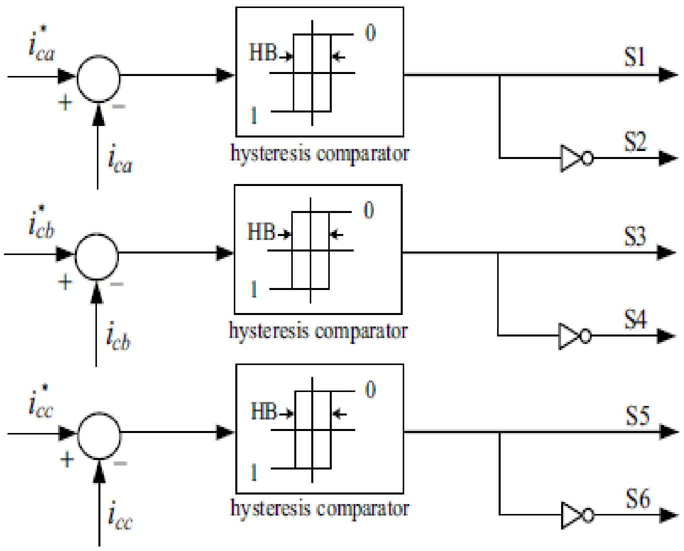

Fig3.5.:- Hysteresis band current controller

If $i_{ca} < (i^*_{ca} - HB)$ upper switch is OFF and lower switch is ON for phase a and S1=0 & S2 =1.

If $i_{ca} > (i^*_{ca} + HB)$ upper switch is ON and lower switch is OFF for phase a and S1=1 & S2 =0.

The switching functions SB and SC for phases "b" and "c" are determined similarly, using corresponding reference and measured currents and hysteresis bandwidth (HB).

3.4 CONTROL LOOP DESIGN:-

Voltage control of the dc bus is performed by adjusting the small power flowing in to dc capacitor, thus compensating conduction and switching losses. Proportional Integral controller is used In order to eliminate the steady state error and reduce the ripple voltage. It's defined as

$$H(S) = K_P + {}^{Ki}/_{s}$$

The proportional and integral gains are set such way that actual Vdc across capacitor is equal to the reference value of Vdc . The ripple voltage of the PWM current controlled voltage source inverter is reduced by the Proportional Integrated controller.

3.5 Roll of DC Capacitor:-

The purposes of DC link capacitor is mainly:-

i) It maintains almost a constant DC voltage.

ii) It serves as an energy storage element to supply real power difference between load and source during transients.

3.6 SIMMULINK DIAGRAM:-

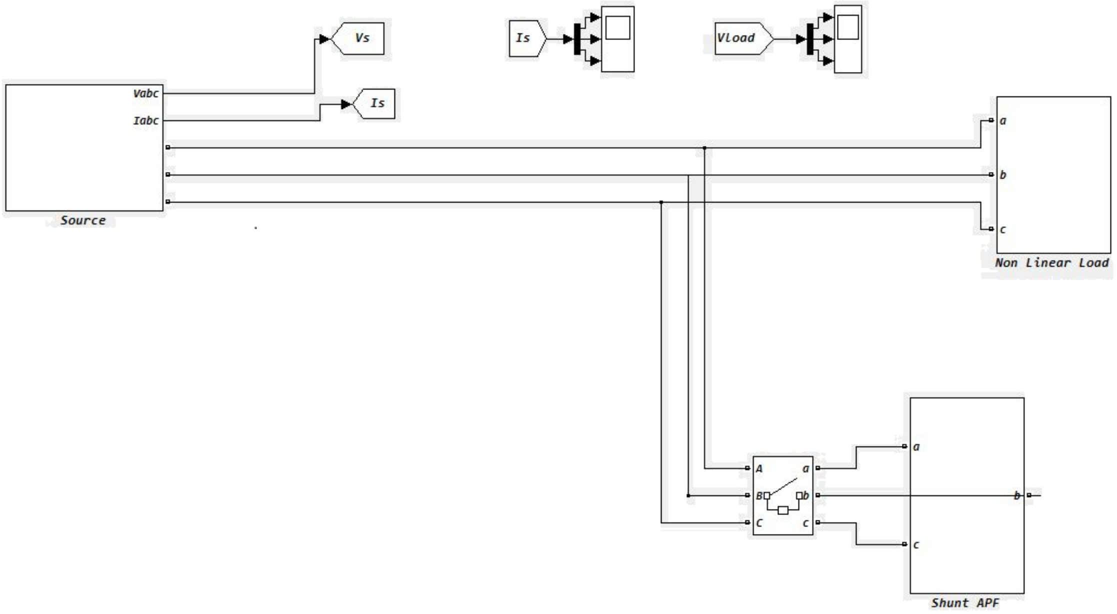

Fig 3.6:-MATLAB implementation of Current Control Scheme

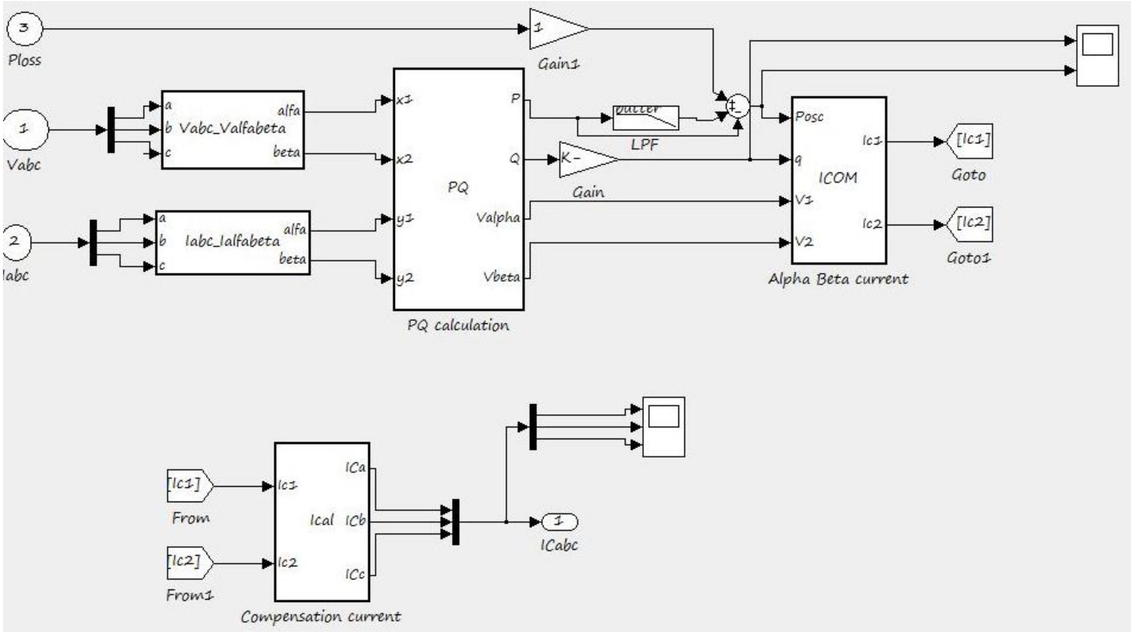

Fig 3.7:-MATLAB implementation of Compensation current calculation

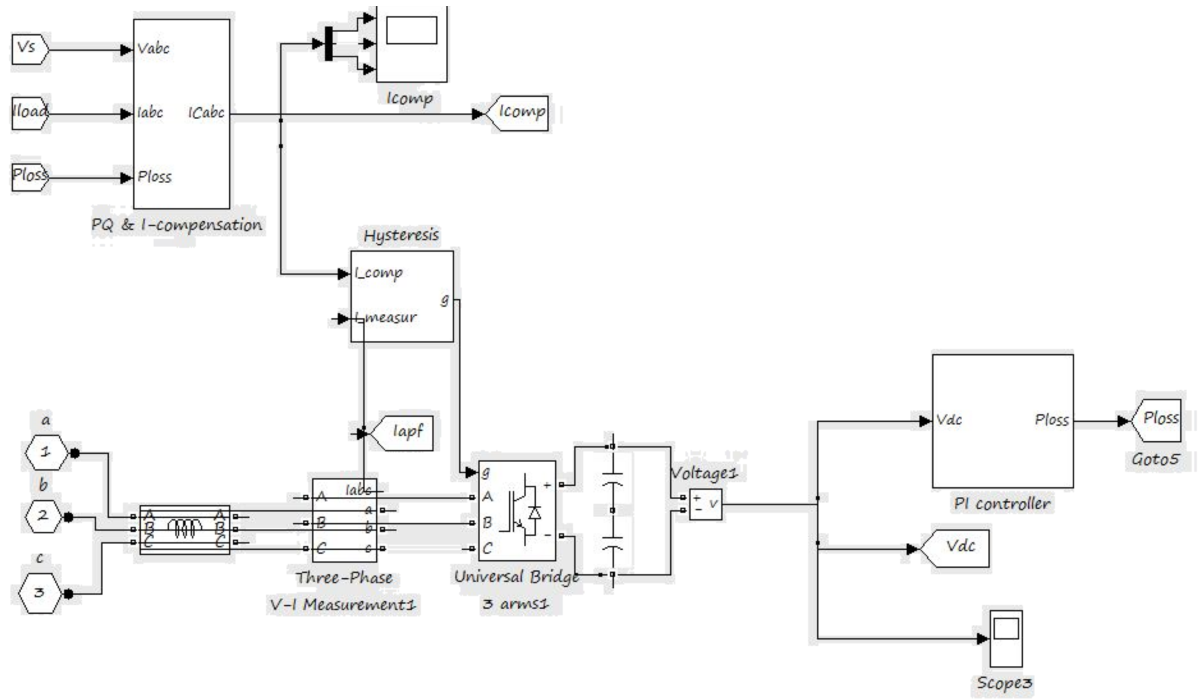

Fig 3.8:-MATLAB implementation of Active Filter

3.7 SUMMARY:-

This chapter represents the introduction to the operation and control of voltage source shunt active filter**.** In this chapter Instantaneous active reactive power theory control algorithm have been used for Shunt active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the system. A complete modelling of shunt active power filter based on P-Q theory have been designer in this chapter.

CHAPTER

4

RESULTS & DISCUSSION

SIMULATION RESULTS

A simulation is developed to model the control strategy based on p-q theory for controlling the current of a Self-Excited Induction Generator. The complete system mainly consists a SEIG and a shunt active power filter to compensate the harmonic current and a nonlinear load.

Table 1 shows the the specification of Self-Excited Induction Generator taken for Simulink modelling

SEIG Parameters:- (22 kW; 4 Pole Star connected ,415 V,50 Hz)

Rs(Ω)	**Rr(Ω)**	**Ls(H)**	**Lr(H)**	**ω (rad/s)**	**C (µF)**
0.2511	0.2489	0.00139	0.00139	356	152

Table 2 shows the variation of Magnetizing Inductance of given Machine with Magnetizing Current.

Magnetizing Inductance Vs. Magnetizing Current:-

Im (A)	**Lm (H)**
<=8	0.075
8-13	0.075-0.003(im-8)
13-23	0.06-.002(im-13)
>=23	0.041

SHUNT ACTIVE POWER FILTER PARAMETER:

	PARAMETER	**VALUE**
ASF	DC Link Voltage (V_{dc})	850 V
	DC Capacitor (C_f)	20 µF
	Coupling Inductor (L_f)	1.2 mH
	Unbalance Load (R_1, R_2, R_3)	(20, 40, 60 ohm)
	Diode Load (R)	25 ohm

The Results can be divide into two parts. One that is to analyze the dynamic behavior of self-Excited Induction Generator and other is to analyze the behavior of SEIG when the controller is connected harmonics compensation and a non-linear load is connected at load side. The system shown in fig 2.4, fig 2.5, fig 2.6, fig. 3.5; 3.6; 3.7 is simulated in in MATLAB/SIMULINK.

To analyzed the dynamic behavior of given SEIG it is shown below that the generated voltage, load current, variation of magnetizing inductance, change in output at different condition such as

i) At No Load
ii) With R load
iii) With RL Load
iv) At Variable rotor Speed
v) At change in capacitance Value

For the simulation purpose residual magnetism in terms of V_{sd} ,V_{sq} is chosen as 1 volt to induced rated voltage of 415 Volt. A 152 µF delta connected capacitance is selected to produce a lagging magnetizing current in stator winding. At no load the rotor speed of 1725 r.p.m is chosen to get rated voltage.

To investigate the dynamic performance of proposed algorithm under dynamic condition various waveform is shown to verify the effectiveness of this approach.

4.1 NO LOAD:-

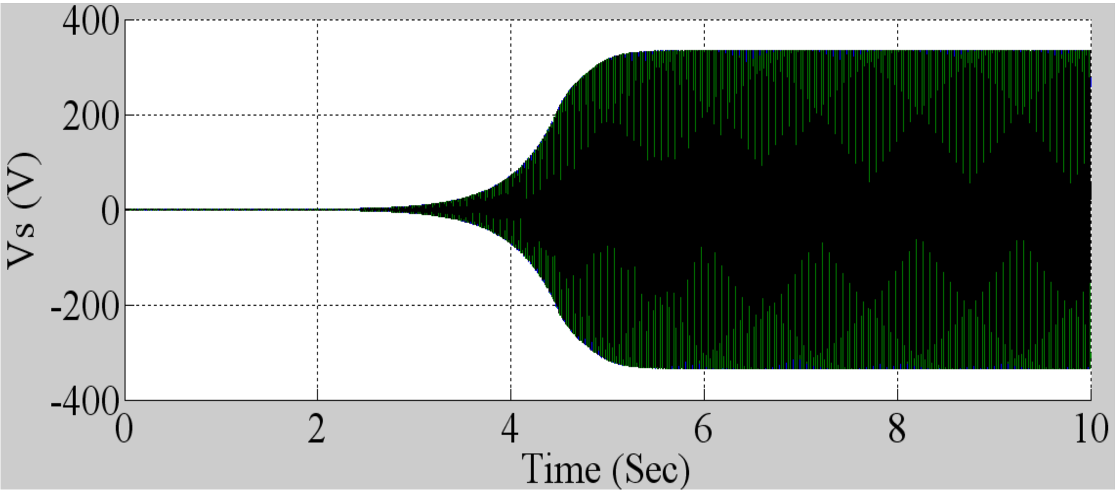

Fig4.1:- Stator Terminal Voltage at no load

From the stator terminal voltage wave form of seig in Fig4.1 shows that the steady state condition is coming within 7 sec and the magnitude of stator voltage is 340 Volt. Fig 4.2 shows the Magnetizing inductance characteristics.

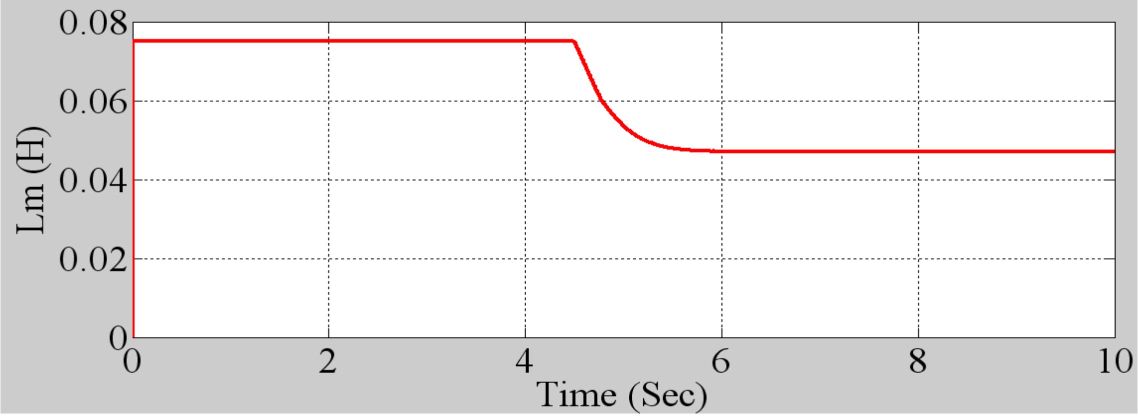

Fig4.2:- Variation of Lm Vs. Time

4.2 With R Load:-

A resistive load of 25 ohm, 7.5 kw is connected at time t=7 sec.

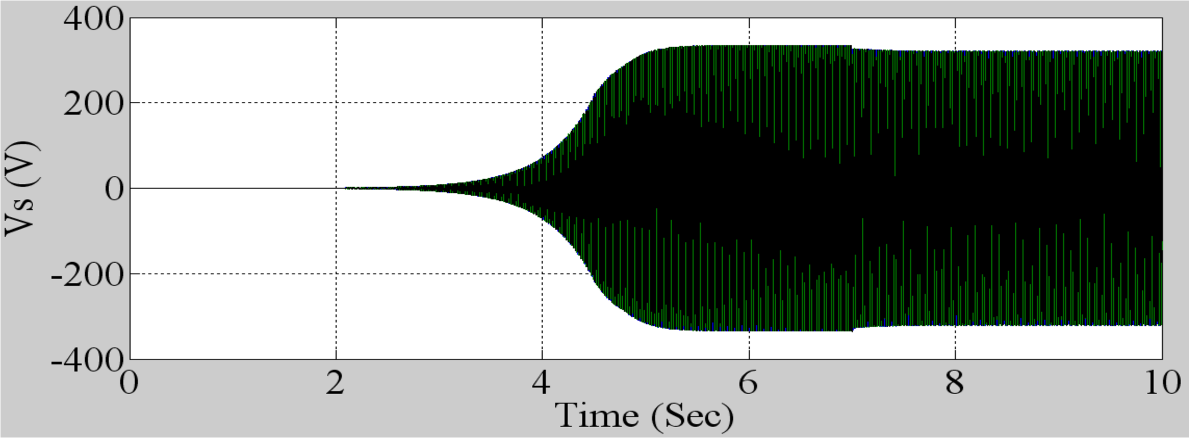

Fig4.3:- Stator Terminal Voltage with insertion of R load

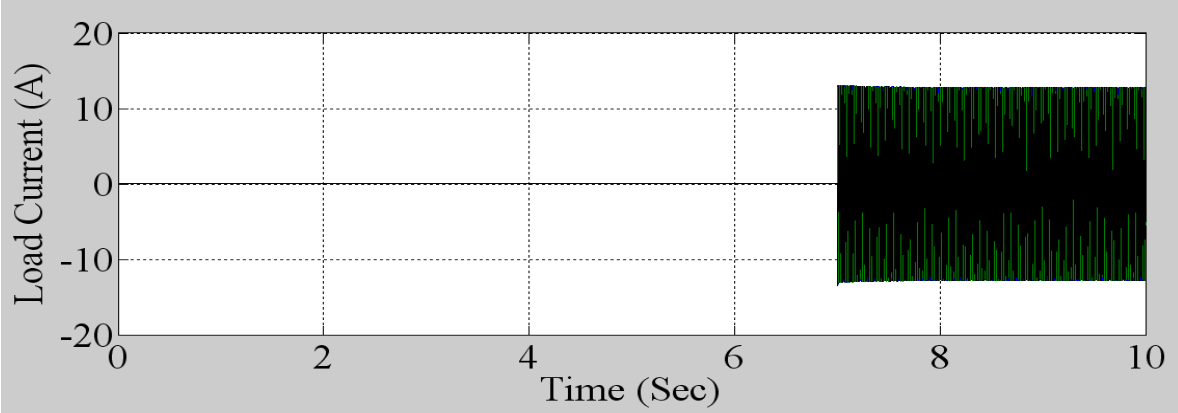

Fig4.4:- Load current with insertion of R load

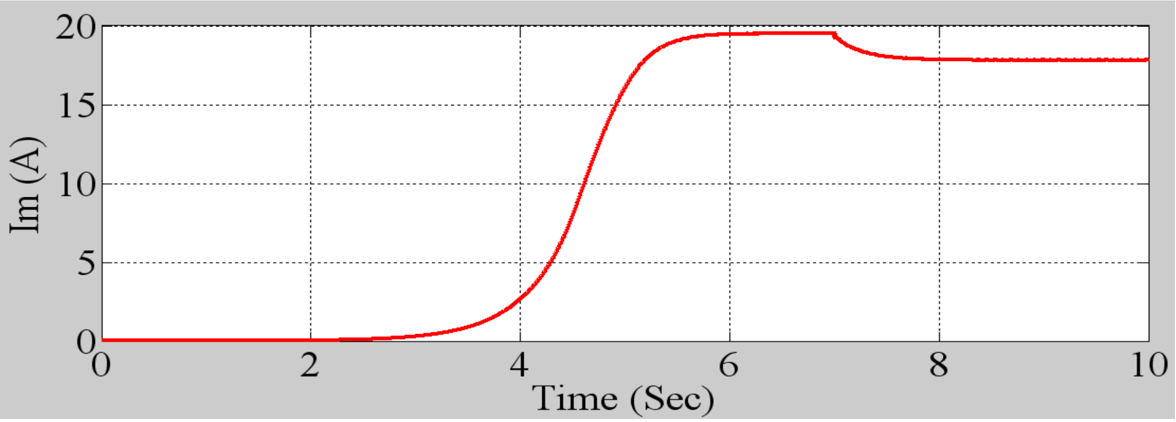

Fig 4.5 :- Im variation with load

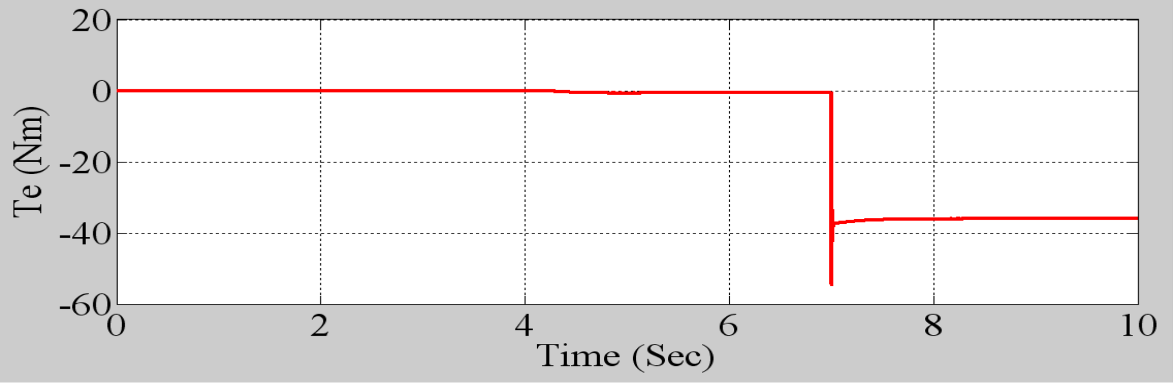

Fig 4.6:- Torque variation with load

It is observed that by applying load, terminal voltage reduces to 300 Volt. It is also observed that magnetizing current is decreasing when load is connected at time t=7 sec.

4.3 With RL Load:-

Appling R=25 Ω and L= 0.05971 H and p.f=0.8 Load at time 7 sec.

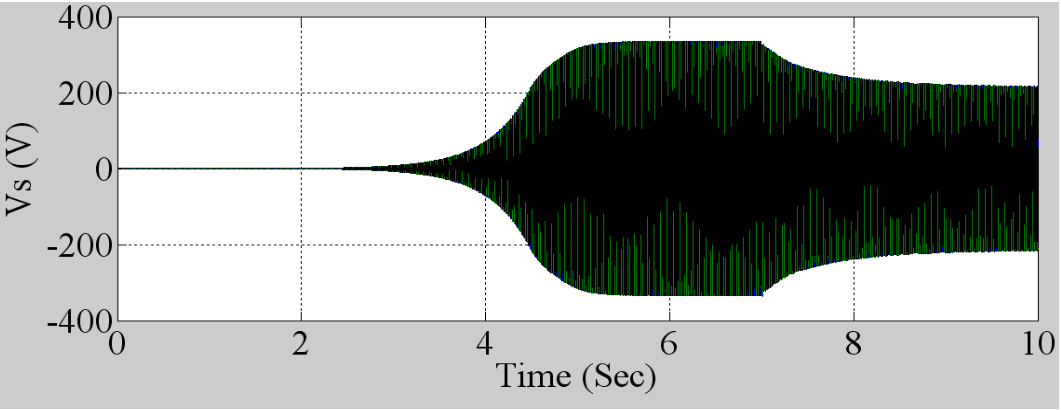

Fig 4.7:- Stator Terminal Voltage with insertion of RL load

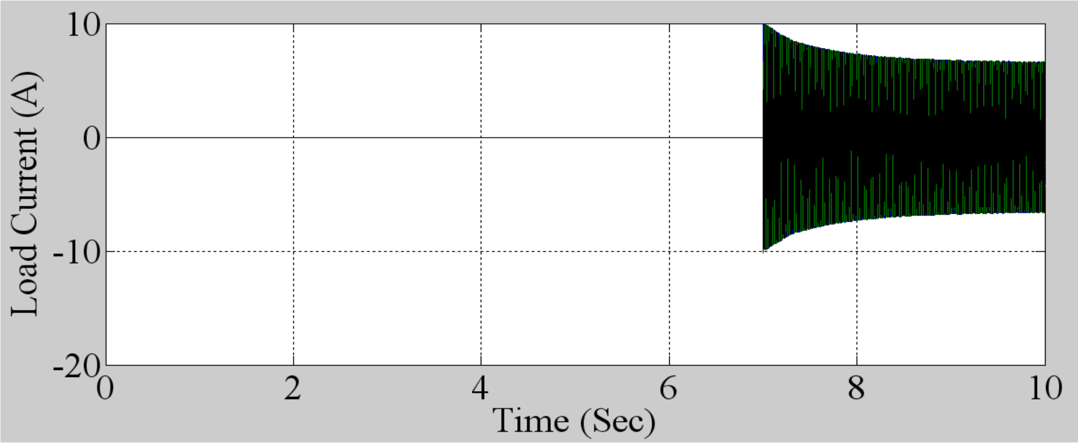

Fig 4.8:- Load current with insertion of RL load

4.4 At Variable Rotor Speed:-

Speed reduced to 293 rad/s from 356 rad/s at time t=6 sec.

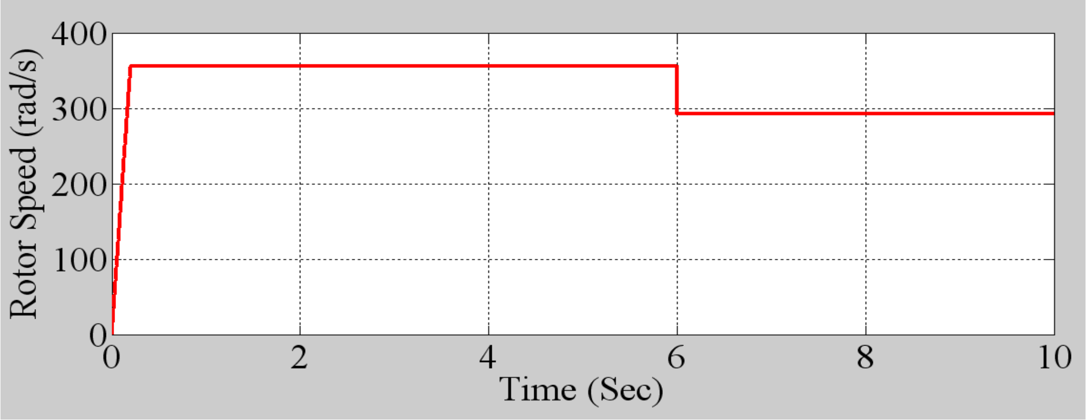

Fig4.9:- Variation in rotor speed

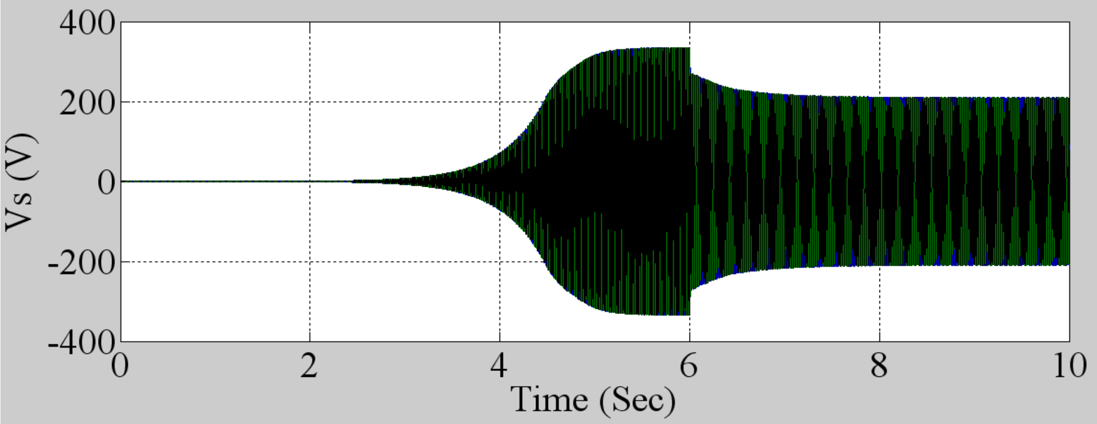

Fig4.10:- Stator Terminal Voltage

4.5 NON LINEAR LOAD:-

A DIODE based nonlinear load of 25 ohm is applied at time t=6.4 sec and the SAPF is switched on time t= 7 sec. To verify the effectiveness of propose method several performance waveform are shown below.

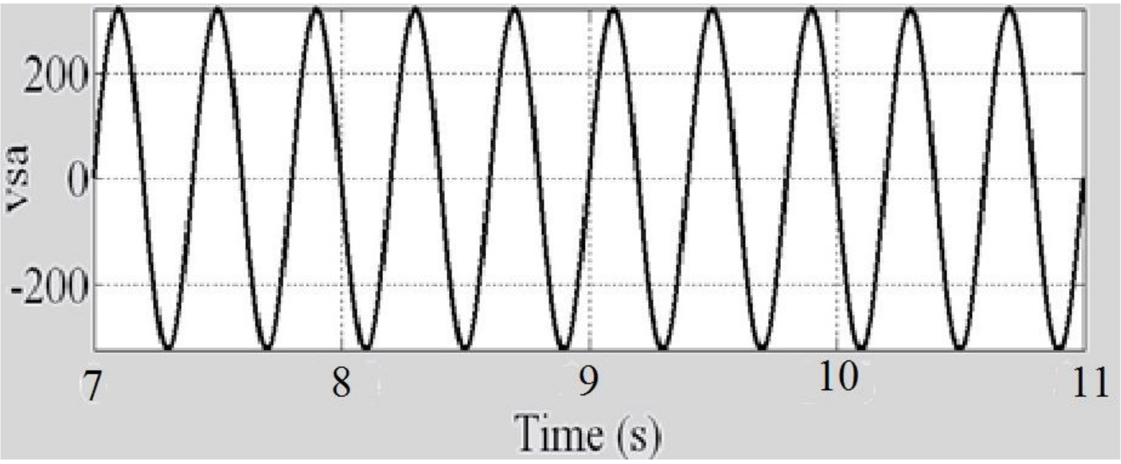

Fig4.11:- Source Voltage

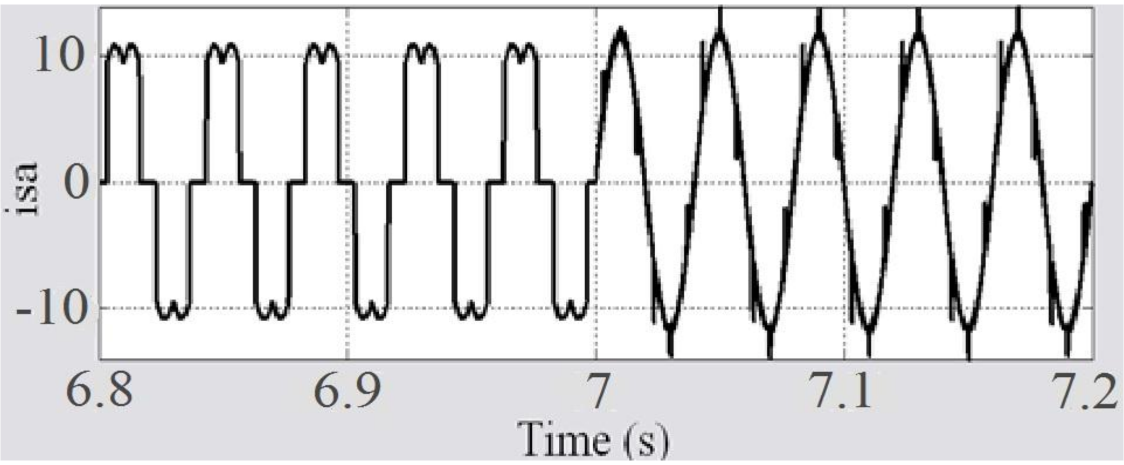

Fig4.12:- Source Current

The waveform shows the source voltage and source current i,e the output voltage and current of SEIG. The waveform shown in fig.4.12 demonstrates that source current before time t=7 when filter is connected i,e before compensation and after compensation it is almost sinusoidal with reduced harmonic content.

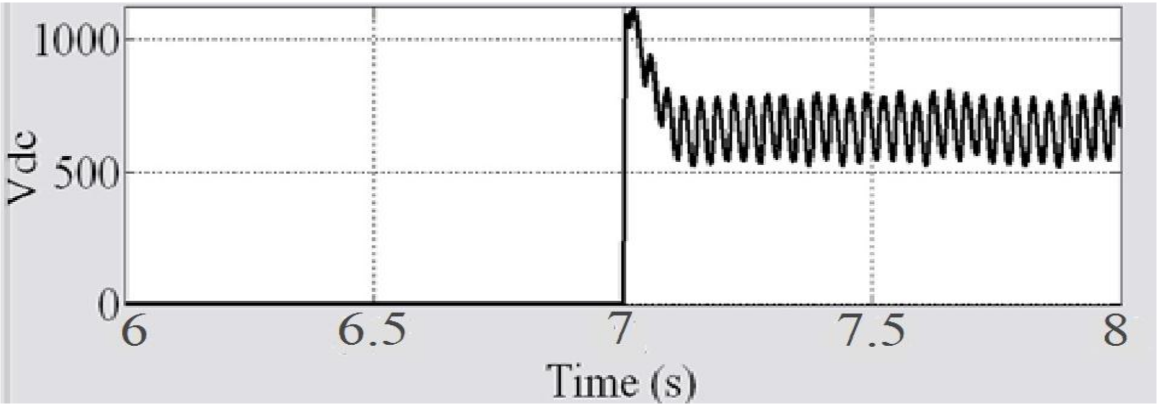

Fig 4.13:- Capacitor Voltage

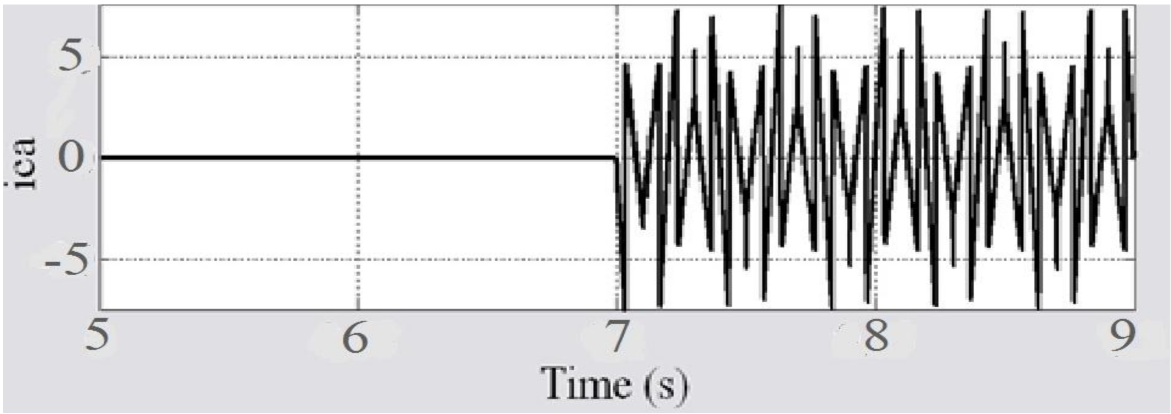

Fig4.14:- Reference current

From the waveform in fig4.14 it is very clear that capacitor voltage settled at value of $V_{dc,ref}$ which is 850 volt.

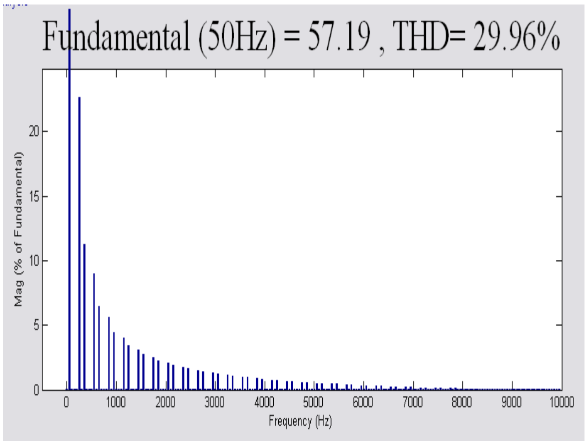

Fig4.15:- THD of Load Current

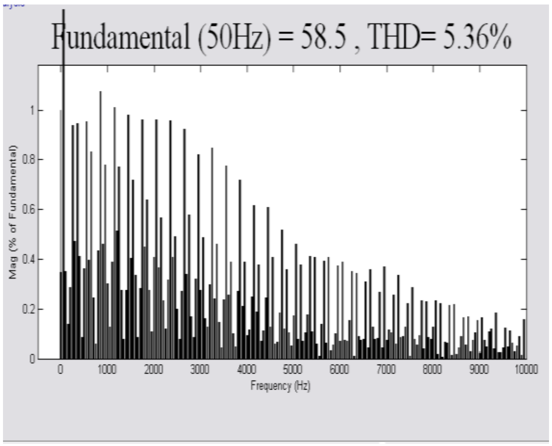

Fig4.16:- THD of Source Current

It is noticed from the fig4.15 and fig 4.16 that Total Harmonic Distortion of source current is reduced to 5.36 % from 29.96 %.

4.6 Summary:-

This chapter contains two part. **First part** represents dynamic behavior of SEIG at various conditions. This chapter shown the open loop behavior of self-excited induction generator at different loading condition, with no load, R load, RL load. Voltage build up process under change in rotor speed, change in capacitance value are examined. **Second part** represents the dynamic performance of proposed algorithm under dynamic condition various waveform is shown to verify the effectiveness of this approach.

CHAPTER

5

CONCLUSIONS

Conclusions:-

My first objective is to investigate the dynamic performance of SEIG at different transient condition. From the above discussion we can conclude that Voltage developed depends upon

- i) Value of capacitor,
- ii) Speed of the rotor.
- iii) Value of Excitation Capacitance,
- iv) Load connected

The main objective of this work is proposed a method to control current by compensating harmonics of load current. From the simulation result we can conclude that an active power filter connected in PCC can eliminate harmonics and reactive current from the load current and make load current sinusoidal.

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