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ANALYSIS OF 3 PHASE SELF-EXCITED INDUCTION GENERATOR WITH RECTIFIER LOAD

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Abstract:** Use of self-excited induction generator is becoming popular for the harnessing the renewable energy resources such as small hydro and wind. A capacitor self-excited induction generators are being well thought-out as an unusual choice to the sophisticated synchronous generators for the reason of reduced unit cost, brushless rotor (squirrel cage construction), absence of separate D.C source and ease of maintenance. In this Thesis, the steady-state analysis of self excited induction generator is presented and a method to calculate the capacitance value of a 3 phase squirrel cage induction motor working as a generator in the self-excited mode of operation. The capacitor value is determined from the manufacturer data. The performance analysis of self-excited induction generator fed rectifier load in steady state condition. It is well known that, harmonics are generated at the input side of the induction generator due to the presence of rectifier circuit which is non linear. In this thesis, the various rectifier loads (both controlled and uncontrolled) connected with the Self Excited Induction Generator are simulated and evaluated. The Fast Fourier transformation algorithm is used to analyze the harmonic currents and voltages under steady-state conditions. Finally, the main objective of this thesis is to perform the steady state analysis of the proposed system. The simulation is done using MATLAB/SIMULINK software power system tools and the harmonics are calculated. The entire test like D.C test, No Load test, Block rotor test are also performed in MATLAB software. Results are discussed and presented.

***Keywords:** Induction generator, isolated system, self-excited induction generator, steady-state analysis*

I. INTRODUCTION

A device that converts the mechanical energy of rotation into electrical based on electromagnetic induction. An electro motive force is induced in a conducting loop or coil when there is a change in the number of magnetic field lines or magnetic flux passing through the loop. When the loop is closed by connecting the ends through an external load, the induced voltage will cause an electric current to flow through the loop and load. Thus rotational energy is converted in to electrical energy. Similar to an induction motor, Induction generators produce electrical power when their shaft is rotated faster than the synchronous speed of the equivalent induction motor. When an induction machine is driven at a speed greater than the synchronous speed (negative slip) by means of an external prime mover, the direction of induced torque is reversed and theoretically it starts working as an induction generator. From the circle diagram of the induction machine in the negative slip region, it is seen that the machine draws a current, which lags the voltage by more than 90. This means that real power flows out of the machine but the machine needs the reactive power. To build up voltage across the generator terminals, excitations must be provided by some means; therefore, the induction generator can work in two modes (grid connected and isolated mode).

The process of voltage buildup in an induction generator is very much similar to that of a dc generator. There must be a suitable value of residual magnetism present in the rotor. In the absence of a proper value of residual magnetism, the voltage will not build up. So it is desirable to maintain a high level of residual magnetism, as it does ease the process of machine excitation. When an induction generator first starts to run, the residual magnetism in the rotor circuit produces a small voltage. This small voltage produces a capacitor current flow, which increases the voltage and so forth until the voltage is fully built up. To achieve a given voltage level in an induction generator, an external capacitor must be able to supply the magnetizing current of that level.

II. CLASSIFICATION OF INDUCTION GENERATORS

Based on different ways such as rotor construction, excitation process and prime movers induction generators can be classified into Fig. 3.1.

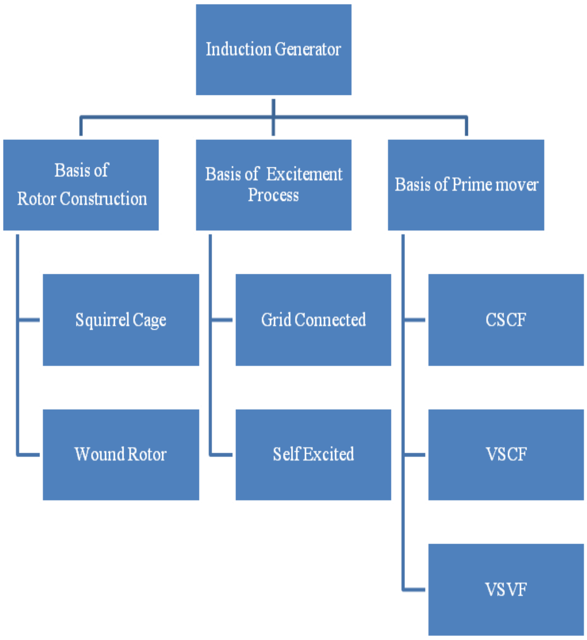

Fig 1 Classification of Induction Generator

A. Classification on the basis of their Rotor Construction

- Squirrel cage induction generator
- Wound rotor induction generator

B. Squirrel Cage Induction Generator

For the squirrel cage type induction generator, the rotor winding consists of un-insulated conductors, in the form of copper and aluminium bars embedded in the semi closed slots. These solid bars are short circuited at both ends by end rings of the same material. Without the rotor core, the rotor bars and end rings look like the cage of a squirrel. The rotor bars form a uniformly distributed winding in the rotor slots are shown in Fig. 3.2.

Fig 3.2 Squirrel Cage Rotor

C. Wound Rotor or Slip Ring Induction Generator

In the wound rotor type induction generator, the rotor slots accommodate an insulated distributed winding similar to that used on the stator. The wound rotor type of induction generator costs more and requires increased maintenance. The wound rotor or slip ring rotor is shown in Fig. 3.3.

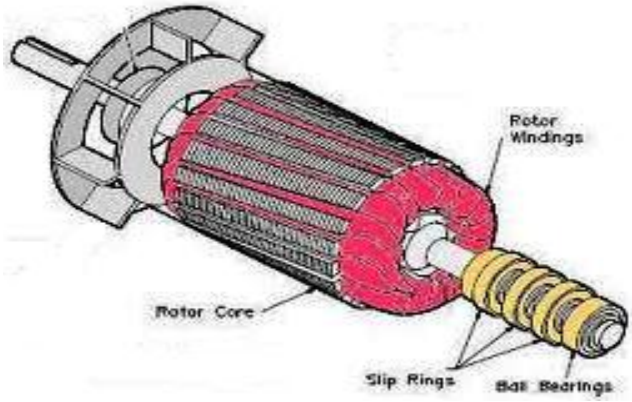

Fig 3.3 Slip Ring Rotor

D. Classification on the basis of their Excitement Process

- Grid connected induction generator
- Self-excited induction generator

E. Grid Connected Induction Generator

In grid connected mode induction generators receive their excitation from the grid, and generate real power via slip control when driven above the synchronous speed, so it is called grid connected induction generator. It is also called autonomous system or electric utility and they have no means of producing or generating voltage until such time the generator is connected to the grid. Induction generators are direct drive. The frequency and voltage of the power generated with induction generators are governed by the frequency and voltage of the incoming utility line. Induction generators can only be run in parallel with the grid, which means when the electric grid goes down, or there is a blackout, all generator sets, cogeneration and tri generation power plants within the grid that has the blackout, also goes down. This is why customers seeking greater power reliability should only consider cogeneration and tri generation power systems that have synchronous generators. Fig. 3.4 shows a grid connected induction generator.

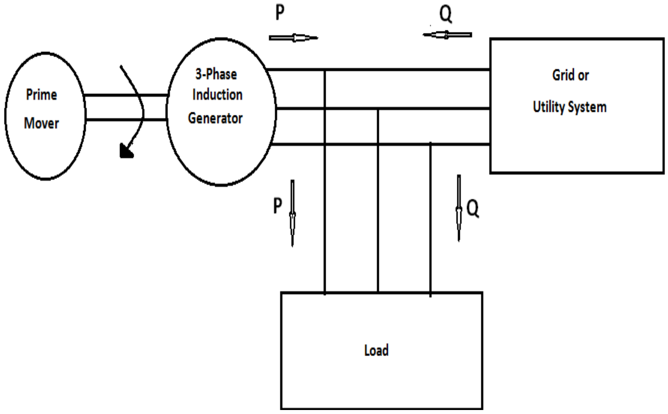

Fig 3.4 Grid Connected Induction Generator

The GCIG results in large inrush and voltage drop at the time of connection, and its operation makes the grid weak. The excessive VAR drain from the grid can be compensated by the shunt capacitors, but it cause large over voltage during disconnection. Therefore, the operation of GCIG should be carefully chalked out from the planning stage itself. The performance of the GCIG under balanced and unbalanced faults should be thoroughly investigated to ensure good quality and reliable power supply.

F. Self-Excited Induction Generator (SEIG)

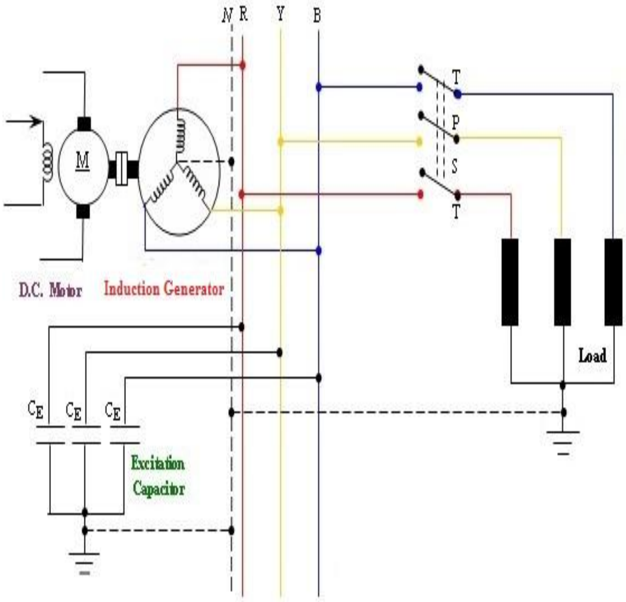

Fig 3.5 Self-Excited Induction Generator (SEIG)

The self excited induction generator takes the power for excitation process from a capacitor bank, connected across the stator terminals of the induction generator. This capacitor bank also supplies the reactive power to the load. These capacitors are shown in Fig. 3.5.

The excitation capacitance serves a dual purpose for stand-alone induction generator: first ringing with the machine inductance in a negatively damped, resonant circuit to build up the terminal voltage from zero using only the permanent magnetism of the machine, and then correcting the power factor of the machine by supplying the generator reactive power.

G. Classification on the basis of Prime Movers used, and their Locations

- Constant speed constant frequency (CSCF)
- Variable speed constant frequency (VSCF)
- Variable speed variable frequency (VSVF)

Constant-Speed Constant Frequency: - In this scheme, the prime mover speed is held constant by continuously adjusting the blade pitch. An induction generator can operate on an infinite bus bar at a slip of 1% to 5% above the synchronous speed. Induction generators are simpler than synchronous generators. They are easier to operate, control, and maintain, do not have any synchronization problems, and are economical.

Variable-Speed Constant Frequency: - Variable speed constant frequency energy conversion schemes generally use synchronous or wound rotor induction machines to obtain constant frequency power generation, even in presence of prime mover speed fluctuations [6].Further, on account of its simplicity, ease of implementation, and low cost, the self-excited induction generator finds wide application in power generation using nonconventional energy sources such as wind. The variable-speed operation of wind electric system yields higher output for both low and high wind speeds. This results in higher annual energy yields per rated installed capacity. Both horizontal and vertical axis wind turbines exhibit this gain under variable speed operation. There are two popular schemes to obtain constant frequency output from variable speed.

H. AC–DC–AC Link

With the advent of high-powered thyristors, the ac output of the three-phase alternator is rectified by using a bridge rectifier and then converted back to ac using line commutated inverters. Since the frequency is automatically fixed by the power line, they are also known as synchronous inverters.

I. Double Output Induction Generator

The DOIG consists of a three-phase wound rotor induction machine, mechanically coupled to either a wind or hydro turbine, whose stator terminals are connected to a constant voltage and constant frequency utility grid. The variable frequency output is fed into the ac supply by an ac–dc–ac link converter consisting of either a full-wave diode bridge rectifier and thyristor inverter combination or current source inverter-thyristor converter link. One of the outstanding advantages of DOIG in wind energy conversion systems is that it is the only scheme in which the generated power is more than the rating of the machine. However, due to operational disadvantages, the DOIG scheme could not be used extensively. The high maintenance requirements, low power factor, and poor reliability are the few disadvantages due to the sliding mechanical contacts in the rotor. This scheme is not suitable for isolated power generations because it needs grid supply to maintain excitation.

Variable-Speed Variable Frequency: - This scheme is the only one known where the generator gives more than its rated power without being overheated. Since the proposed concept is to be used for heating purposes, a constant voltage and a constant frequency is irrelevant. Thus, the model will be of interest for frequency and voltage insensitive applications especially in remote areas. With variable prime mover speed, the performance of synchronous generators can be affected. For variable speed corresponding to the changing derived speed, SEIG can be conveniently used for resistive heating loads.

J. Induction Generator Configurations

The configurations of induction generator are shown in Table 3.1.

Table 3.1 Configuration of Induction Generator

IG Type	Speed		Grid Connected	Isolated	Frequency		Voltage	
	Constant	Variable			Constant	Variable	Constant	Variable
Wound Rotor	-	*	*	-	*	-	*	-
Cage Rotor	*	*	*	*	*	*	*	*

- Impractical; * Practical;

III. STEADY STATE ANALYSIS OF SEIG

Steady-state analysis of SEIG is of interest, both from the design and operational point of view. The terminal voltage and frequency are unknown and Have to be computed for a given speed, capacitance and load impedance. The analysis is complicated owing to the magnetic saturation in the machine and the need to choose suitable parameters corresponding to this saturated condition. For the Steady-state analysis, the following assumptions are made: (a) Only the magnetizing reactance is assumed to be affected by magnetic saturation, and all other parameters of the equivalent circuit are assumed to be constant. (b) Leakage reactance of stator and rotor, in per unit, are taken to be equal. This assumption is normally valid in induction-machine analysis. (c) Core loss in the machine is neglected, although the analysis can be easily extended to account for core loss.

IV. STEADY STATE MODEL OF INDUCTION MACHINE

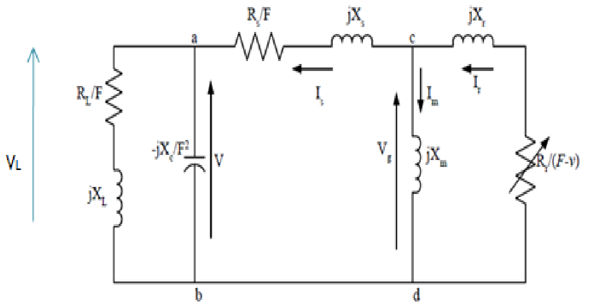

Fig: - 1.4 per phase equivalent circuit

Following two solution techniques based on the steady-state equivalent circuit are:

- Nodal Admittance Method
- Loop Impedance Method

V. DETERMINATION OF EQUIVELENT CIRCUIT PARAMETERS

- No Load Test
- Blocked Rotor Test
- D. C Test

No-Load Test The no-load test on a Squirrel cage induction motor is conducted to measure the rotational losses of the motor and to determine some of its equivalent circuit parameters. In this test, a rated, balanced ac voltage at a rated frequency is applied to the stator while it is running at no load, and input power, voltage, and phase currents are measured at the no-load condition.

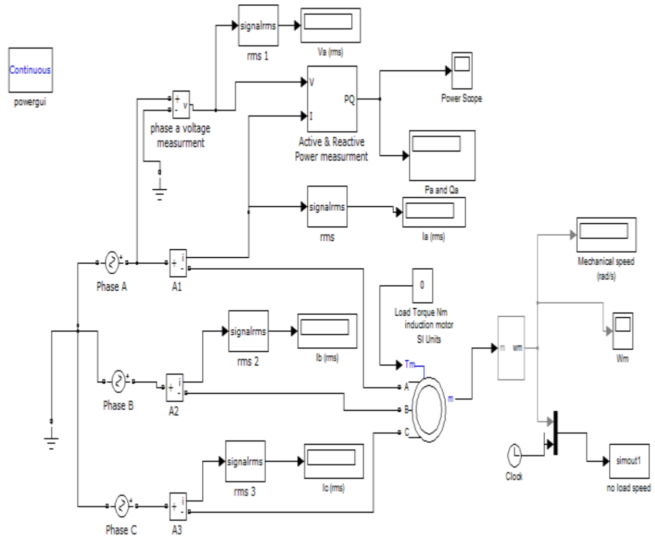

Fig: -1.5 simulink diagram of no load test

Blocked Rotor Test The blocked-rotor test on an induction motor is performed to determine some of its equivalent circuit parameters. In this test, the rotor of the induction motor is blocked, and a reduced voltage is applied to the stator terminals so that the rated current flows through the stator windings. The input power, voltage, and current are measured

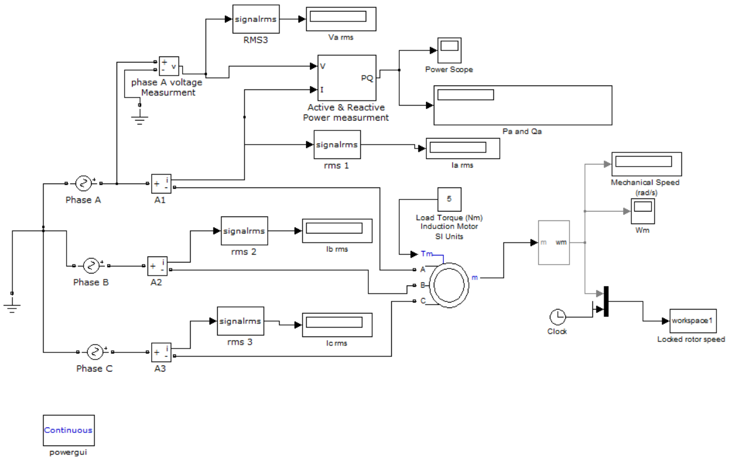

Fig. 5.2 Block Rotor Test

Measurement of Stator Resistance (D.C Test) The dc test is performed to compute the stator winding resistance$R1$. A dc voltage is applied to the stator windings of an induction motor. The resulting current flowing through the stator windings is a dc current; thus, no voltage is induced in the rotor circuit, and the motor reactance is zero. The stator resistance is the only circuit parameter limiting current flow. [4]

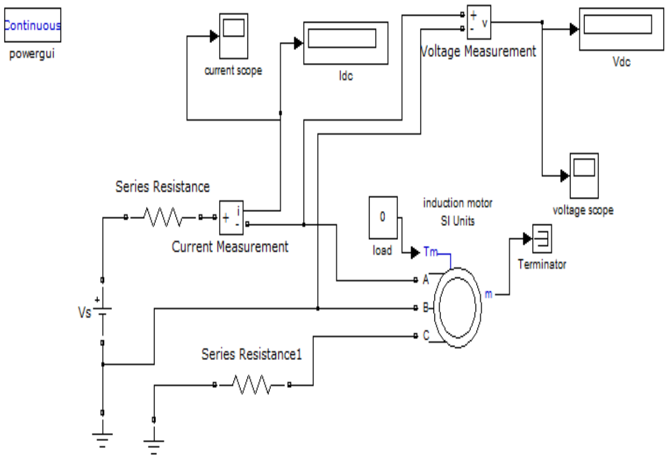

Fig 5.3 D.C Resistance Test

VI. MATLAB/SIMULINK MODELS

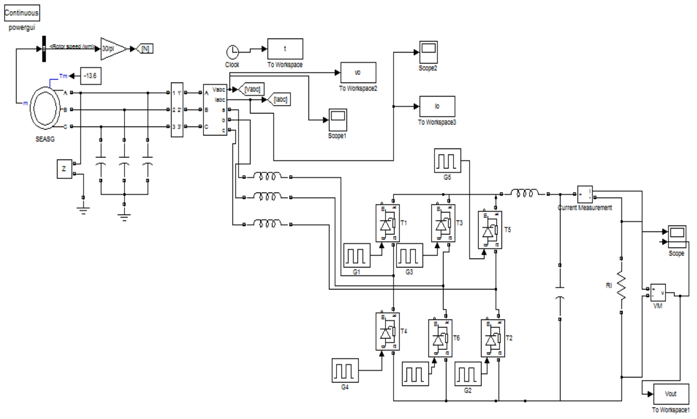

Fig:-1.8 SEIG with controlled rectifier load

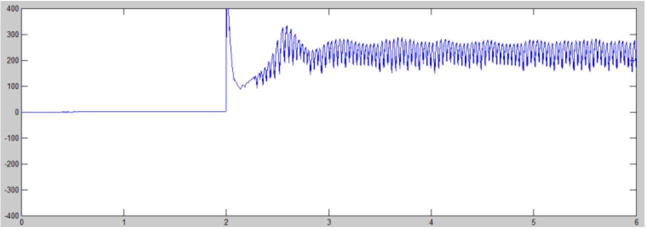

Fig: - 1.9 SEIG fed controlled rectifier output voltage.

VII. HARMONIC ANALSYS

When the non linear (rectifier) load is connected to the terminals of a SEIG the undesired problems, due to harmonic currents, such as additional power losses, high-frequency pulsating torque, the output capacity etc. To evaluate the harmonic components that are present in the generated voltages, stator currents, and load currents under the steady state conditions is analysed. The quality of the generated output voltage is evaluated by the total harmonic distortion (THD). The THD is an index of the closeness in shape between the waveform and its fundamental component and is defined as$THD = \left[\left(\frac{v}{v1}\right)^2 - 1\right]^{\frac{1}{2}}$

Where, V1 is the fundamental R.M.S component

$$HF = \left[\left(\frac{I}{I1}\right)^2 - 1\right]^{\frac{1}{2}}$$

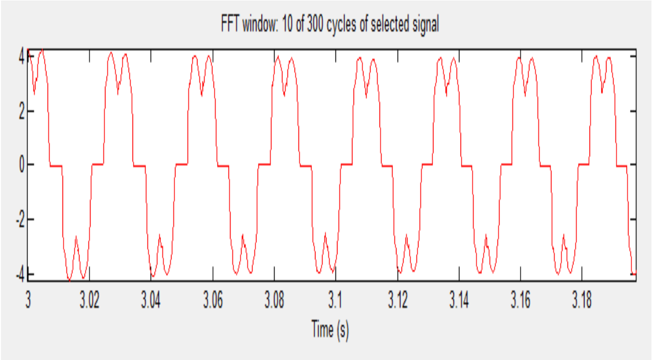

Fig:-1.10 SEIG line current due to diode rectifier harmonics

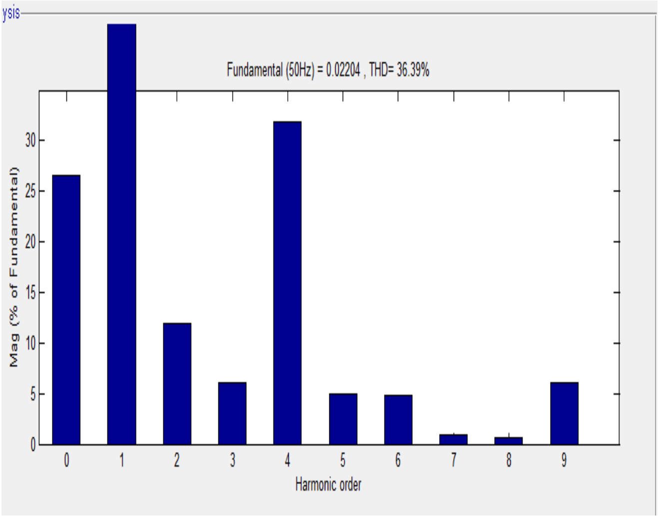

Fig:-1.11 SEIG line current harmonic order at 50hz.

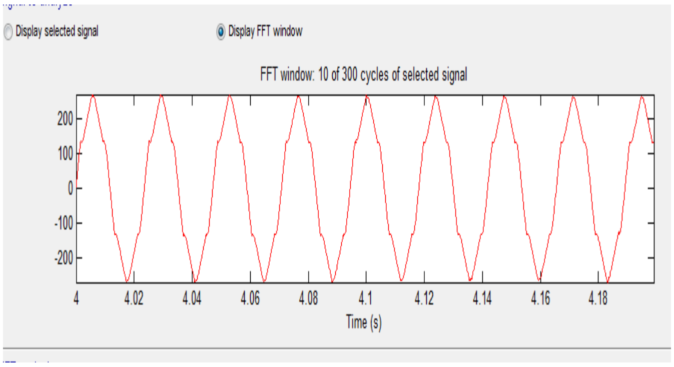

Fig:-1.12 SEIG phase voltage due to diode rectifier harmonics

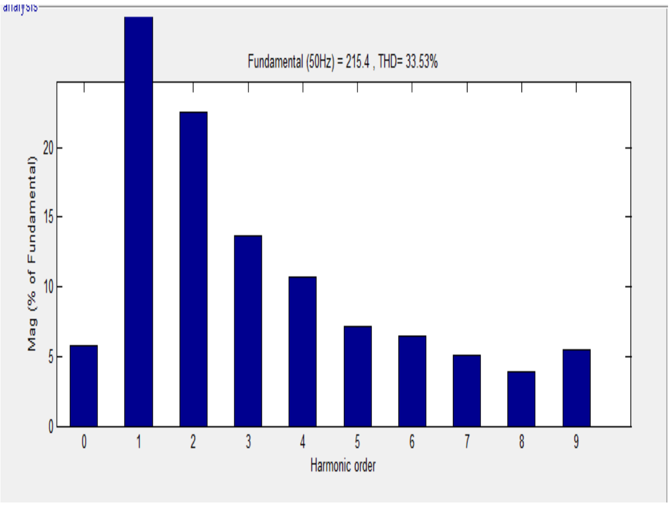

Fig:-1.13 SEIG phase voltage harmonic order at 50hz

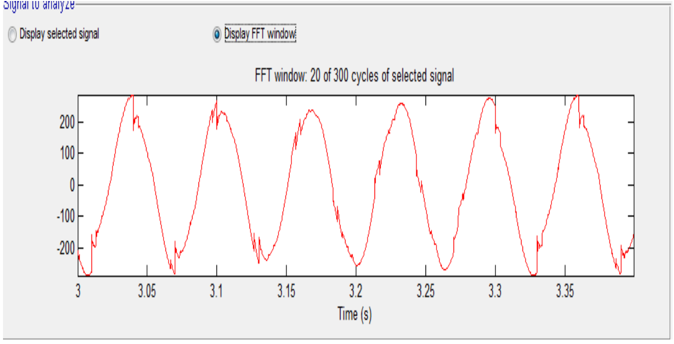

Fig:-1.14 SEIG phase voltege due controlled nonlinear(rectifier) load

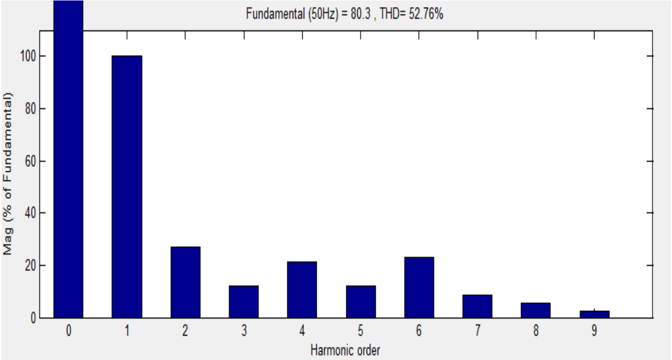

Fig:-1.15 SEIG phase voltage harmonic order at 50hz

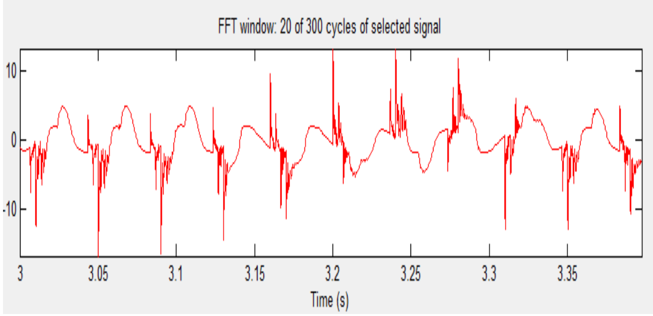

Fig:-1.16 .SEIG line current due to controlled rectifier load

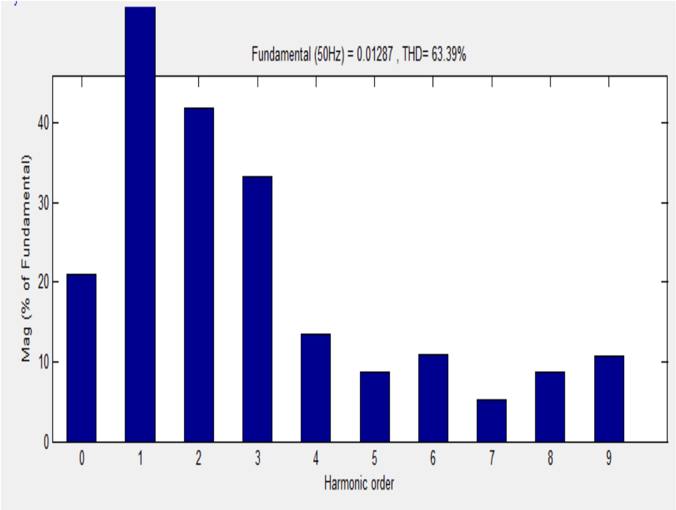

Fig:-1.17. SEIG line current harmonic order at 50hz.

At different loads the THD and HF are calculated.

VIII. CONCLUSIONS

This paper has presented the performance of an isolated self-excited induction generator (SEIG) feeding a nonlinear (rectifier) load. The steady-state performances are investigated by using the hybrid induction machine model. The models of the multi-phase both un-controlled and controlled rectifiers are also formulated by using MATLAB/SIMULINK software. It has been shown that the developed models can work very well. Harmonic content caused by the nonlinear rectifier load are estimated with the FFT algorithm. Static DC loads as well as a dynamic DC motor load including the effect of the filter under steady-state conditions have been included. The harmonics of single stage and multi-phase rectifiers is analyzed.

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