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SIMULATION OF ASYNCRONOUS GENERATOR CONTROL WITH AC/DC/AC CONVERTER FED RLC SERIES CIRCUIT

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ABSTRACT: This paper describes the simulation studies of a 3-Ø self-excited asynchronous generator (SEASG) fed RL load in conjunction with an AC/DC/AC converter fed series RLC circuit. Self-excited asynchronous generator has emerged as a possible alternative for isolated power generation from renewable energy sources because of its low cost, less maintenance and rugged construction. However, it requires a suitable controller to regulate the voltage due to variation of consumer loads. From the characteristics of voltage generation in a SEASG (Self Excited Asynchronous Generator), it is essential to have a variable capacitance at the machine terminals to maintain constant voltage with variable load.

One of the solutions for this problem is the Linear Quadratic Regulator (LQR), whose principle is based in the synthesizing of a compensator from the formal establishment of a quadratic performance index. Since all state variables are available for measurement, the LQR can assure stability, performance, and robustness to the control system. The LQR can still be associated to an integral action in order to obtain a steady state null error considering reference steps and disturbances. This paper presents a discrete control system based on LQR with integral action for variable speed generation system connected to AC grid using an AC-DC-AC converter with VSI structure. A little variable speed asynchronous generation system connected to AC grid using an AC-DC-AC converter with VSI structure is developed using Matlab Simulink to verify the response of the proposed control scheme, which presents a satisfactory dynamic performance.

Key words: SEASG, AC/DC/AC converter, RLC series circuit, simulation

I. INTRODUCTION

The use of non-conventional energy sources has become eminent due to fast depletion of conventional energy sources. The recent trend to tap solar, wind and tidal energy are becoming popular amongst the renewable energy sources. At present, to decentralize the power generation system, attempts have been 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 crises. Self-excited asynchronous generator has emerged as a possible alternative for isolated power generation from renewable energy sources because of its low cost, less maintenance and rugged construction [1]-[3]. However, it requires a suitable controller to regulate the voltage due to variation of consumer loads. From the characteristics of voltage generation in a SEASG, it is essential to have a variable capacitance at the machine terminals to maintain constant voltage with variable load.

Although the variable speed is the more adequate solution for generation systems based on renewable energy, this operation mode presents a dilemma: How the operation at variable speed of the electrical generator can be adapted to the necessity to feed electrical loads that usually operate at fixed frequency; The more promising alternative to solve this dilemma is the use of an AC-DC-AC power converter, whose basic topology consists of two back-to-back power inverters connected by a DC bus. The VSI structure shown in fig. 1 is the most usual topology of AC-DC-AC converter, where a tank capacitor is connected to DC bus in order to store the necessary energy to support the power demand during the system transients [1]. The use of a tank capacitor with high capacitance allows decouple the AC-DC-AC structure, and each power converter can be independently controlled [2]. Inductances are used in order to filter the harmonic content in both AC sides. PWM techniques for the switching of the converter semiconductors also allow reduce the harmonic content in both AC sides.

Another advantage of this AC-DC-AC topology for variable speed generation are:-

- Operation in a large speed range;
- Fast response;
- Quasi-sinusoidal currents in both AC sides;
- Bidirectional and controllable flux of active and reactive power between both AC sides;
- Easy synchronization with the AC grid.

The control of the power converter connected to electrical generator must regulate the flux of active and reactive power to the electrical generator [6], [7]. The flux of active power determines the torque generator, which adjusts the operation point of the electrical machine according to the characteristics of the primary mechanical energy source in order to obtain the maximum efficiency on energy conversion. The torque control also improves the start-up, acceleration and deceleration processes of the generation system. The flux of reactive power must be controlled in order to regulate the magnetic field for the excitation of the electrical generator, which is required by the logic of torque control.

Since the power interchange between the AC generator and AC grid is reflected by the variations of the stored charge in the DC bus, the control of the power converter connected to AC grid must regulate the DC bus voltage in order to adjust the power demand of the AC grid according to generated energy [2].

Another aspect of the control of this power converter is the necessity to reduce the flux of reactive power to AC grid in order to assure an operation at high power factors, contributing to AC grid stability and minimizing the energy losses in the AC line [2]. The real problem of the multivariable control design is to synthesize a control law in order to assure both a good response as a minimum error signal for a feedback system within of specified tolerances in despite of the presence of uncertainties. One of the solutions for this problem is the Linear Quadratic Regulator (LQR), whose principle is based in the synthesizing of a compensator from the formal establishment of a quadratic performance index. Since all state variables are available for measurement, the LQR can assure stability, performance, and robustness to the control system [5]. The LQR can still be associated to an integral action in order to obtain a steady state null error considering reference steps and disturbances.

This paper presents a discrete control system based on LQR with integral action for variable speed generation system connected to AC grid using an AC-DC-AC converter with VSI structure. The proposal consists basically in two LQ current regulators with integral action for the control of the flux of active and reactive power in the AC generator and AC line, which provide a good stability margin and robustness to disturbance and parameter variations. The indirect field orientation principle is used in order to obtain an efficient and stable operation of the AC generator. An outer feedback loop with a PI controller and a feed-forward action realizes the voltage control in the DC bus. A little variable speed asynchronous generation system connected to AC grid using an AC-DC-AC converter with VSI structure is experimentally implemented in order to verify the response of the proposed control scheme, which presents a satisfactory dynamic performance.

II. AC/DC/AC CONVETER TOPOLOGY

In this way, the steady state effective impedance of the generator circuit has been controlled, hence called as impedance controller. S.S. Murthy et al [2] suggested a load controller (using 3-Ø rectifier with a d.c chopper circuit) in constant power operation of .induction generator. The rectifier and d.c chopper circuits are used as power balancers between the loads and dump load in such way that, the induction generator assumed to be fully loaded in all conditions. Hence, it is known as load balancer or power balancer in constant speed operations. The function of the load/power balancer is to balance the power consumed by loads and dump load. Bhim sigh et al [2] discussed about the design, analysis and modification of an electronic controller (ELC) in detail and the technique is successfully implemented in hydro power generation control.

Transient analysis of induction generator with ELC has been reported by same authors recently [2]. In view of this point, authors made an attempt to study the performances of SEASG conjoint with AC/DC/AC converter fed series RLC circuit. This work is basically an extension of electronic load controller circuit. In this paper, a Simulink model of AC/DC/AC converter fed RLC series circuit (connected at PCC of the SEASG) and SEASG fed RL are configured using power system tool box in Matlab / Simulink software. A single line diagram of the proposed system is shown in Fig.1. This model could emulate SEASG performances with and without AC/DC/AC converter fed Series RLC circuit.

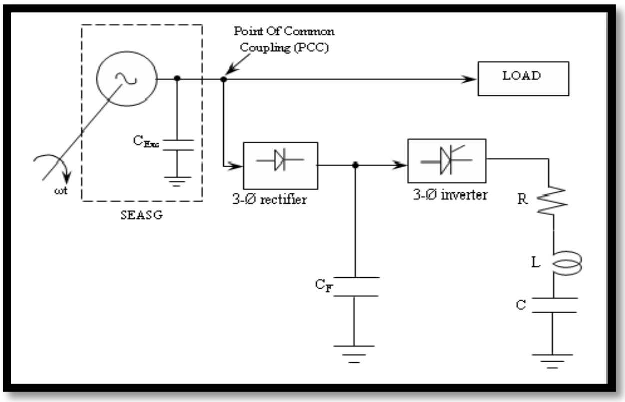

Fig. 1 Single line diagram of the proposed system

Functional model describes the relationship between the input and output signal of the system in form of mathematical function(s) and hence constituting elements of the system are not modelled separately. Simplicity and fast time-domain simulation are the main advantages of this kind of modelling with the penalty of losing accuracy. This has been a popular approach with regard to Generator modelling, where simulation of converters has been done based on expected response of controllers rather than actual modelling of Power Electronics devices. In fact, it is assumed that the converters are ideal and the DC-link voltage between them is constant. Consequently, depending on the converter control, a controllable voltage (current) source can be implemented to represent the operation of the rotor-side of the converter in the model. Physical model, on the other hand, models constituting elements of the system separately and also considers interrelationship among different elements within the system, where type and structure of the model is normally dictated by the particular requirements of the analysis, e.g. steady-state, fault studies, etc.

Indeed, due to the importance of more realistic production of the behaviour of Generator, it is intended to adopt physical model rather than functional model in order to accurately assess performance of DFIG in the event of fault particularly in determining whether or not the generator will trip following a fault. This paper proposes a graphic-oriented switch-by-switch representation of the back-to-back PWM converters with their modulators for both rotor- and stator-side converters, where both IGBT and reverse diode devices are represented as a two-state resistive switch. The two-state switch can take on two values, RON (close to zero) and ROFF (very high).

III. CONTROLLING OF SYSTEM CONFIGURATION

A brief explanation of the proposed system's configuration, principle of operation and basics of controller concept has been discussed in the following sub headings.

Proposed System

The circuit connection of the proposed system is shown in Fig.2. It consists of an induction motor coupled (mechanically) with an external drive (separately excited d.c motor) and an adequate 3-Ø capacitor bank (CE). The excitation capacitor bank, connected across the stator windings of the SEASG, supply power to the load. An RLC series circuit has been powered by a 3-Ø inverter and the inverter is configured with power electronic switches (S1 −S6). A 3-Ø uncontrolled bridge rectifier (D1 −D6) circuit with DC filter capacitor is connected to the generator terminals at the PCC shown in Fig.2

Principle of Operation

Initially, all main switches (TPST) are kept open. A 220V, 20A, 1500/1750 rpm separately excited D.C motor (prime mover) is started and allowed to run till the rotor of an induction motor reaches to a speed above the synchronous speed (Ns=(120*f) / P) of the rotating m.m.f. Where, Ns is the synchronous speed of the rotating m.m.f, f is the frequency in cycle per second and P is the number of poles. Since, adequate 3-Ø capacitor bank (calculated from the synchronous speed test) is connected across the stator terminals of the induction machine, an e.m.f is generated in the rotor circuit (provided with Permanent magnetism in the rotor circuit).

As rotor rotates consequently, voltage is induced across the stator terminals (say 415 volts) by induction principle. This process is known as self-excitation process and hence called as self-excited asynchronous generator (SEASG). Now the switch (TPST) has been closed and the load is connected to the generator terminals. The current, voltage and power drawn by the load have been measured. When the rectifier switch is closed, the d.c voltage builds up to its rated value. Then, the inverter circuit is triggered using the gate pulses (PWM based gate pulsed). The power switches are gated in such a way that the inverter current may resonate, lead or lag in the series connected passive elements of resistor, inductor and capacitor (shown in Fig.2).

The performance of SEASG has been changed with AC/DC/AC inverter fed RLC series circuit based on the change in effective impedance. A change of SEASG's performance has been studied at resonance frequency (50Hz); below the resonance frequency (25Hz) and above the resonance frequency (75Hz) of the inverter fed series RLC circuit in constant power operation.

Series resonance Circuit

To understand the basic concept of the proposed control technique, a well-known simple circuit of series connected resistance, inductance and capacitance is presented in Fig. 3. In most of the text books explained the characteristics behaviour of an RLC series circuit. The authors made an experimental attempt to implement this technique in SEASG power control application [1]. The circuit diagram and characteristic equations have been set forth here.

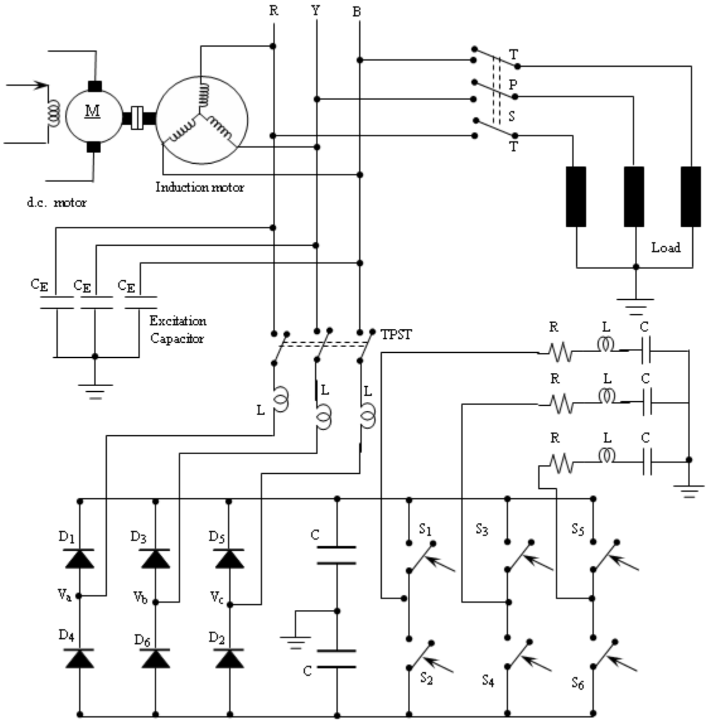

Fig. 2 Circuit connection of proposed system with controller

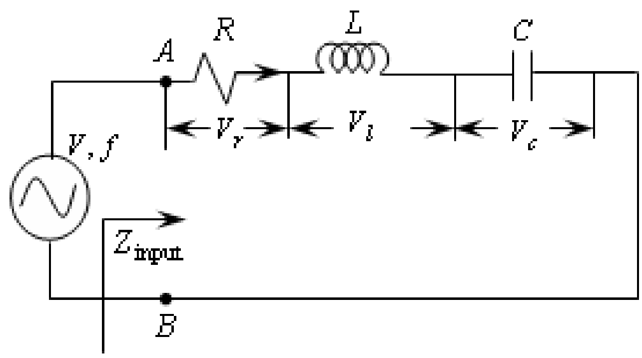

Fig. 3 Typical series RLC circuit

Fig.4. illustrates the RLC series circuit characteristics at different frequencies of operation.

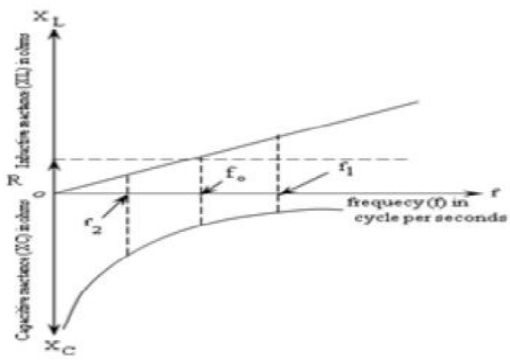

Fig. 4 Characteristics behaviour of RLC series circuit with frequency changes

These characteristics can also be obtained from equation (1) at different frequencies.

$$f_o = 1/2\pi\sqrt{LC} \quad \text{………. (1)}$$

Where,
Fo is the series resonant frequency in cycle per second;
L is the inductance of the inductor in henrys and
C is the capacitance of the capacitor in farads.

The effective reactance offered by this circuit depends on the operating frequency. Suppose, if the operating frequency of the network changes consequently, the effective impedance also changes. The changes in impedance can be characterized by a linear equation, which lies on the locus of the impedance shown in Fig.5.

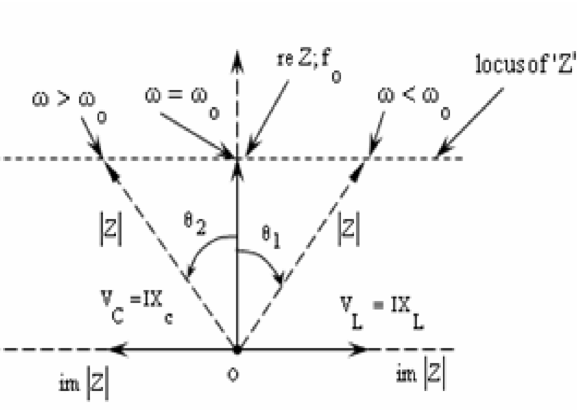

Fig. 5 Effective impedance changes with different frequency

IV. SYSTEM CONFIGURATION

The schematic arrangement of the proposed system is shown in Fig.6. It consists of an SEASG, rectifier – inverter fed RLC series circuit with RL load. SEASG is driven at a constant speed along with static capacitor at the stator terminals of the SEASG. The effect of changing load on the generated voltage was found to be drooping with an increase of load. To compensate this drooping voltage, an R L C series resonance circuit fed from an AC/DC/AC converter is connected at PCC.

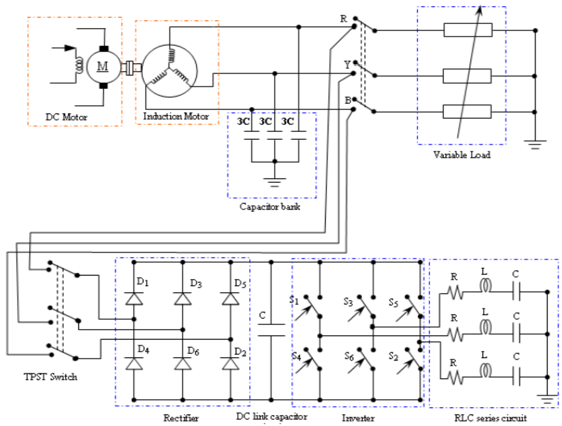

Fig. 6 Schematic arrangement of proposed standalone power system

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

V. SIMULATION AND RESULTS

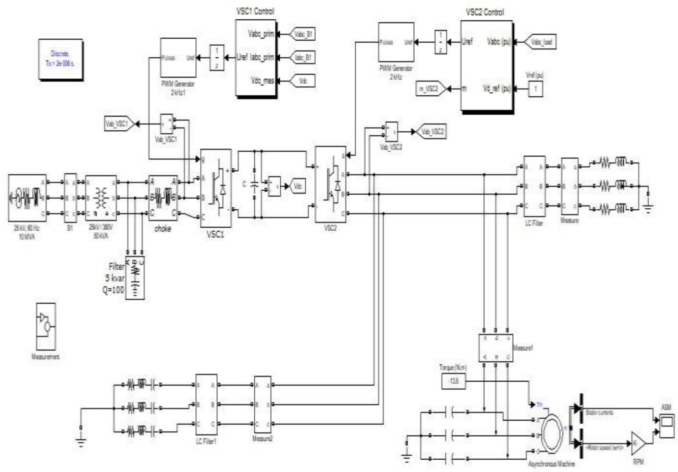

Fig 7- Matlab Simulation of AC/DC/AC converter with RLC fed SEASG

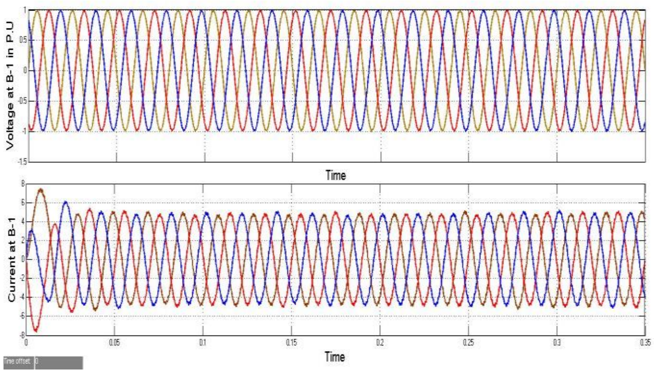

Fig 8- Bus-1 output voltage and current waveform

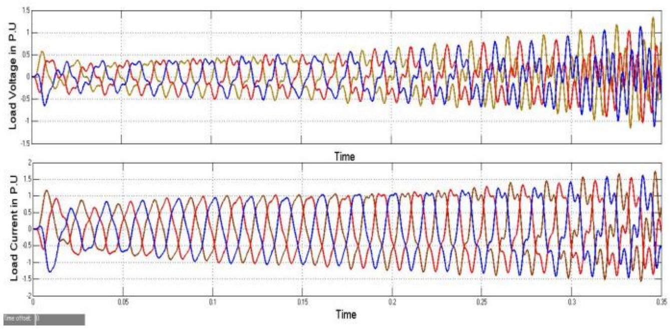

Fig 9- Load side output voltage and current waveform

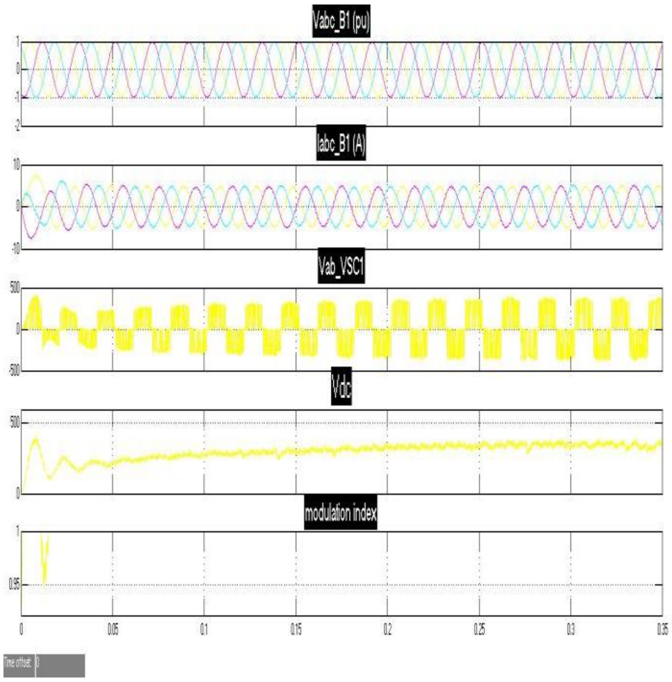

Fig 10- VSC-1 Sending side output parameters

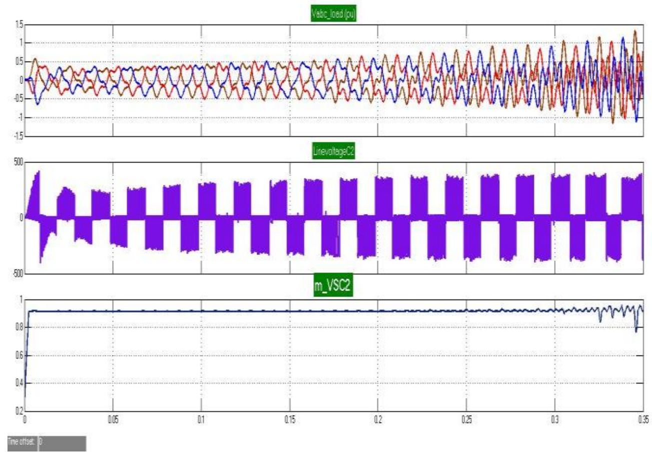

Fig 11- VSC-2 Receiving Side Output Parameters

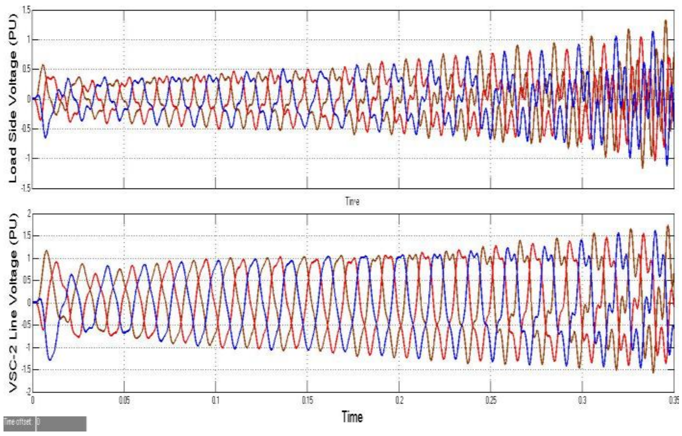

Fig 12- Load Side output voltage and Line Voltage in P.U

THD ANALYSIS

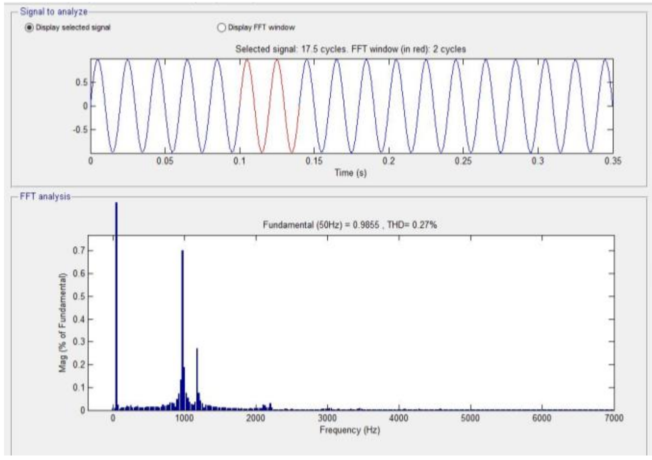

Fig 13- Source Side Voltage THD

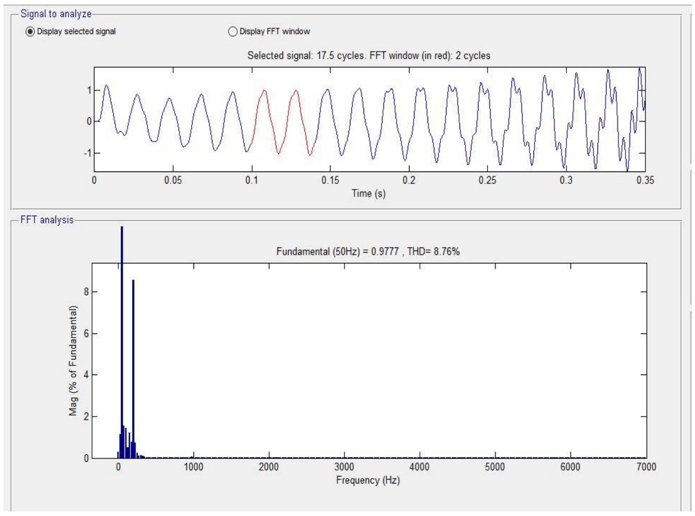

Fig 14- Load Side Voltage THD

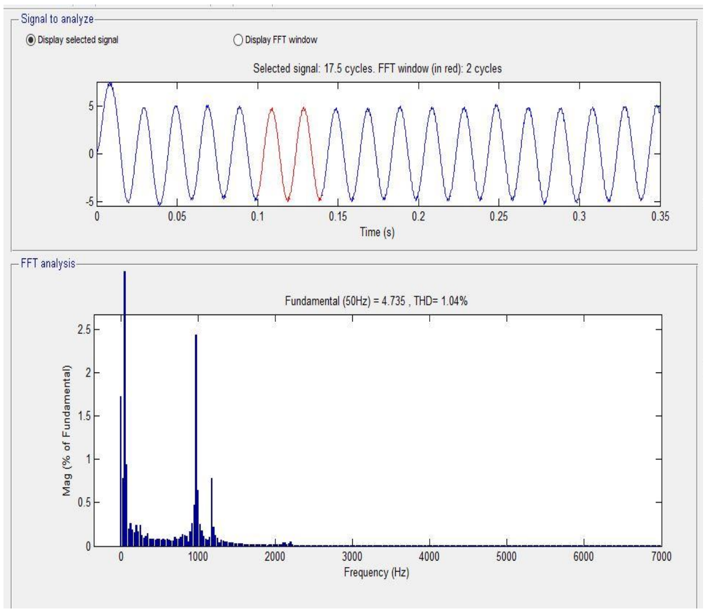

Fig 15- Source Side Current THD

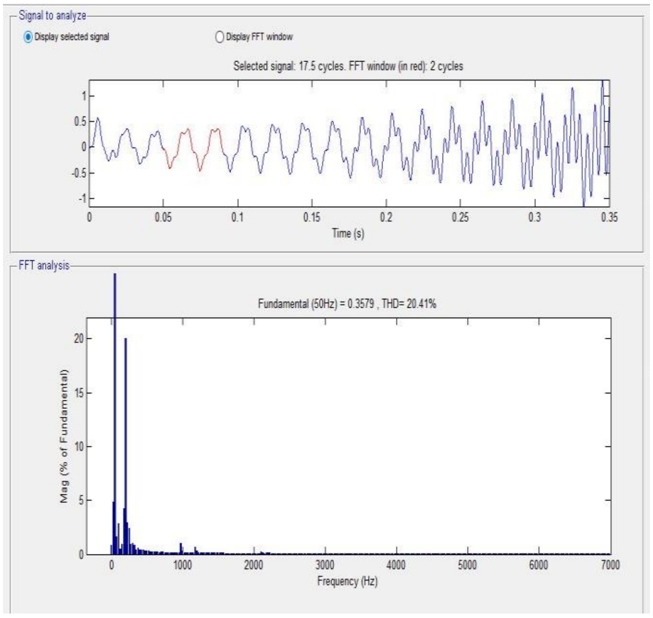

Fig 16- Load Side Current THD

Comparative Analysis of THD

Parameters	THD %
Source Side Voltage THD	0.27 %
Source Side Current THD	1.04 %
Load Side Voltage THD	8.76 %
Load Side Current THD	20.41 %

DTC CONTROL OF SEAG

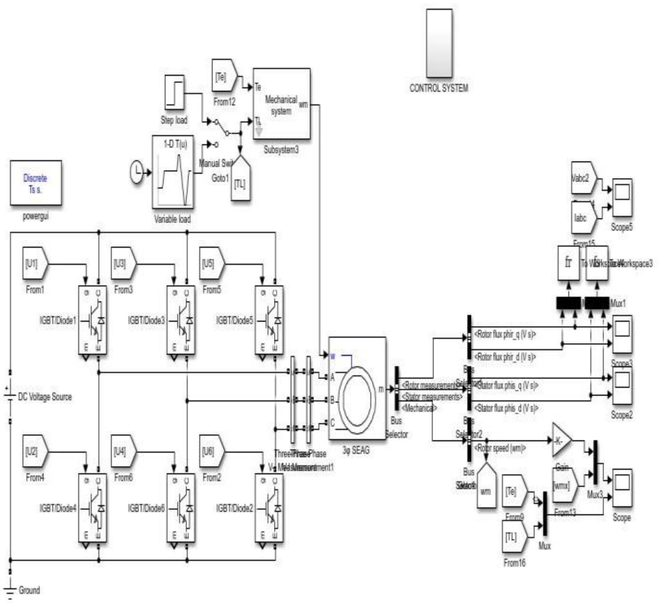

Fig 17- Matlab Simulation system of DTC control for SEAG

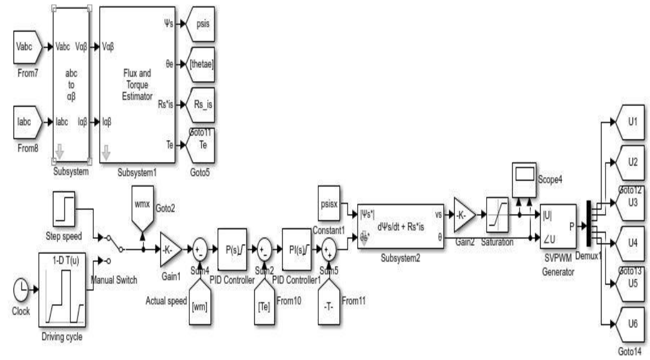

Fig 18- Controlling subsystem for DTC for variable load condition

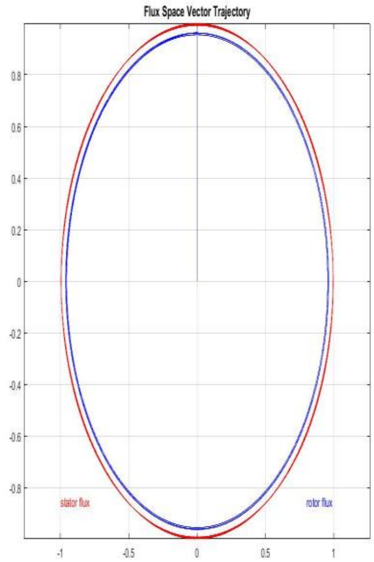

Fig 19-Flux Trajectory using DTC control for SEAG in variable load condition

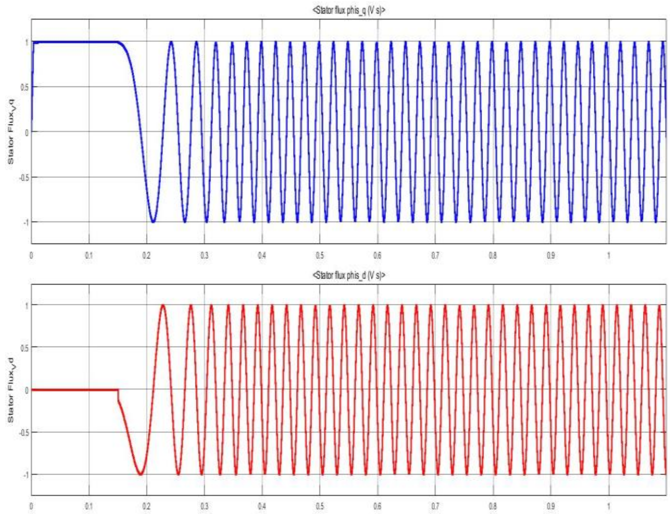

Fig 20- Stator Flux output parameters for direct axis and quadrature axis

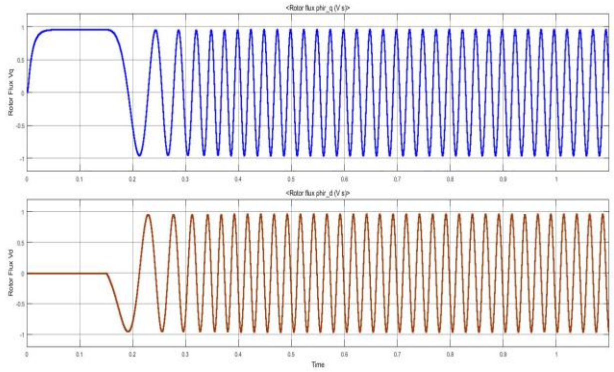

Fig 21- Rotor Flux output parameters for direct axis and quadrature axis

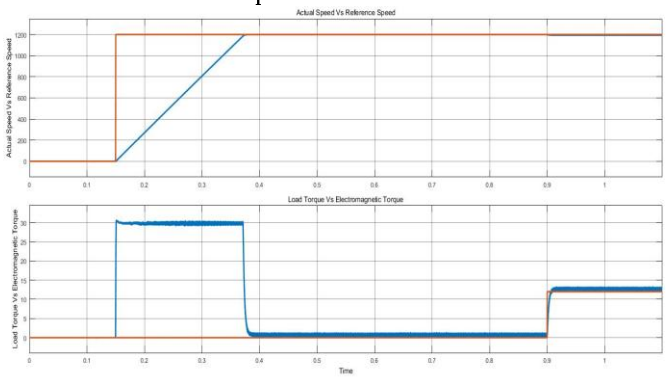

Fig 22-Torque and Speed controlling output waveforms in variable load condition

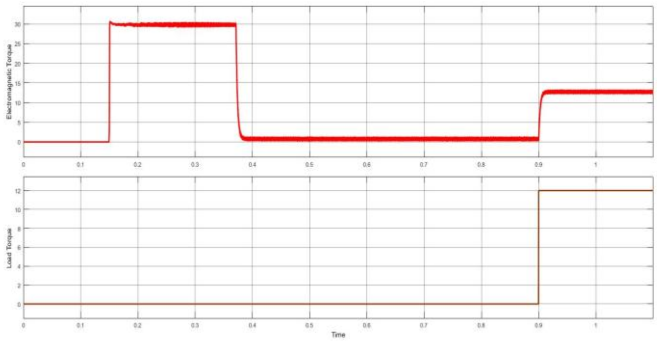

Fig 23- Torque Variation and control for variable load condition

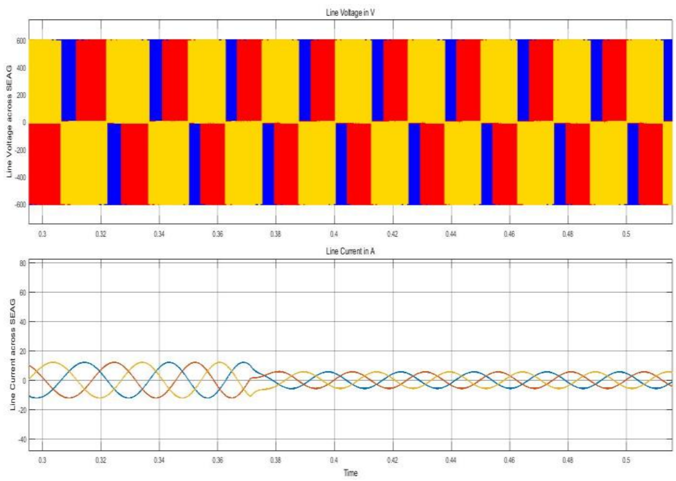

Fig 24- Line Voltage and Current waveforms

VII. CONCLUSION

This paper describes the simulation studies of a 3-Ø self-excited asynchronous generator (SEASG) fed RL load in conjunction with an AC/DC/AC converter fed series RLC circuit An attempt has been made to analyze the current, drawn by the rectifier circuit due to changes in the inverter frequency and their effects on the terminal voltage of the generator have been studied in open loop control. The frequency variation of the inverter fed series RLC circuit emulate the phenomenon of an inductive, capacitive reactance and resistive effect at the point of common coupling (PCC) of the generator terminal. Simulation of the proposed system with AC/DC/AC inverter fed RLC series circuit in open loop has been studied. This concludes that the characteristics impedances of series circuit changes due to frequency changes that reflect into the system at PCC.

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