Matlab Simulation of an Induction Generator Based Ac/Dc Hybrid Electric Power Generation System

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Abstract – In more electric aircraft (MEA) system, both AC and DC electric power with multiple voltage levels are required for various aircraft loads. This paper presents an induction generator based AC/DC hybrid electric power generation system for MEA. In the proposed system architecture, a high speed induction starter/generator and a low speed induction generator are installed on the high pressure (HP) and low pressure (LP) spools of the engine, respectively. In generating mode of operation, all of the constant voltage variable frequency AC power is generated by the HP generator while the DC power demand is shared by both HP and LP generators. A control scheme is developed to regulate the AC load voltage and coordinate DC power generation between the two generators. The proposed induction generator based AC/DC hybrid generation system results in reduced hardware requirement compared to both AC and DC primary generation systems.

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INTRODUCTION

According to the statistics and the forecasts from the International Civil Aviation Organization (ICAO), the revenue passenger-kilometers (RPK) of global air transport has grown at an average yearly rate of 6.2% since 2003, and will continue to grow at an average rate of 4.5% until the year 2030 (Haitham, et. al., 2014). The electrical power produced at the generating station is delivered to the consumers through a network of transmission and distribution systems. It is difficult to draw a line between the transmission and distribution systems of large power system. The transmission and distribution systems are similar to man's circulatory systems. The transmission systems may be compared with in the human body and distribution systems with capillaries. They serve the same purpose of supplying the ultimate consumer in the city with life giving blood of civilization electricity. The electrical power is almost exclusive generated, transmitted and distributed in the form of alternating current. Most of the load are inductive in nature and hence have now lagging power factor. The low power factor is highly as it causes an increase in current, resulting in additional losses of real power in all the elements of power system from power generator to the utilization device.

These days the most utilized charging devices for EV/HEV are regulation, that implies they permit having power spill circuit of lattice to the vehicle battery, however many research establishments are attempting to apply bi regulation charging device, with battery to network control stream. A several arrangements have the battery, or some other vitality source, similar to super capacitors or flywheels, included linear forwardly in the charging stations or UPS system. Over the last thirty years, remarkable progress has been achieved in the aircraft development moving toward MEA, where many hydraulic, mechanical, and pneumatic powered subsystems have been fully or partially replaced by electrical systems (Haitham, et. al., 2014). However, the magnitude of the benefits and negative consequences for adopting MEA initiative varies from different technical approaches which includes new electrical power system architectures and different generator types. In this paper the control scheme with constant power and sinusoidal current compensation is clarify by the creators. This paper shows a changed control scheme to compensate a distribution feeder loading with non-linear loads. The compensation comprises of three principle destinations that are:-

i) Regulation of real power deliver to loads

ii) Regulation of DC connection voltage to ensure PWM converter operation and

iii) Correction of power factor.

CURRENT TRENDS AND CHALLENGES OF MORE ELECTRIC AIRCRAFT ARCHITECTURE

Over the past forty years, considerable amount of research has made remarkable progress to move towards more electric aircraft systems. In recent MEA systems, numerous mechanically, hydraulically, or pneumatically powered subsystems are partially or even completely replaced by electrical counterparts. Power quality is defined as a capability of system or an equipment to function satisfactorily in its electromagnetic environment with circuit introducing intolerable electromagnetic disturbance to anything in that environment.

Power quality is the combination of voltage quality and current quality. This power quality is concerned with deviations of voltage and current from the ideal.

Power quality is a set of electrical boundaries that allows a piece of equipment to function in its manner with circuit significant loss of performance. They were probably susceptible to whatever power quality anomalies existed at the time but the effects were not readily discernible due to the robustness of the machines and lack of effective ways to measure power quality parameters.

3.1 Conventional and more electric aircraft architectures

A basic schematic of the non-propulsive power distribution of conventional aircraft is shown in Figure 3.1. In conventional aircraft, the jet fuel is consumed by the gas turbine engine to generate power. Most of this power is used for propulsion of the aircraft, whereas the remainder is converted into pneumatic, hydraulic, mechanical and electrical power, where:-

- Pneumatic power is obtained from the high pressure compressors of the gas turbine engine. This form of power is used to supply high pressure bleed air for the environmental control system (ECS) and wing anti-icing system. For a 300 passenger civil aircraft with 40 MW equivalent propulsion thrust, the pneumatic power needed is about 1.2 MW.

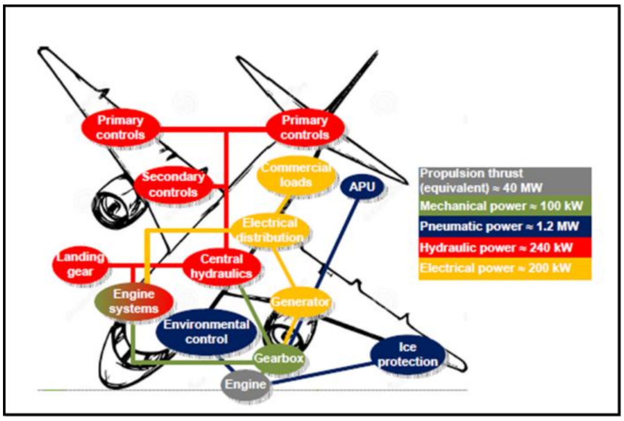

Figure 3.1. Non-propulsive power distribution of conventional aircraft

The performance of the hybrid non-propulsive power system of aircraft has been improved over the years, yet its complexity has grown even faster. Presently, the conventional non- propulsive power system still represents a major factor in aircraft malfunctions and failures. Furthermore, because of the inflexible infrastructure of the pneumatic and hydraulic systems, the leakage of the systems is generally difficult to locate or accessed, resulting in a great number of aircraft maintenance \down-times" and even flight delays.

Optimizing the hybrid non-propulsive power system with incremental changes to existing products individually has become increasingly difficult The AC and DC variable speed drives used on board holder cranes are critical supporters of aggregate harmonic current and voltage distortion. While SCR phase control makes the attractive normal power factor, DC SCR drives work at not as much as this. What's more, line notching happens when SCR's commutate, making transient peak recovery voltages that can be 3 to 4 times the ostensible line voltage depending on the system impedance and the speed of the drives. The frequency and severity of these power system disturbance differs with the speed of the drive. Harmonic current injection by AC and DC drives will be highest when the drives are working at slow speed. Power factor will be most reduced when DC drives are working at slow speed or during acceleration and deceleration periods, increase to its greatest value when the SCR's are phased on to deliver evaluated or base speed. Above base speed, the power factor basically stays constant. Through the work of researchers and engineers all over the world, the list of mechanical, pneumatic and hydraulic loads to be replaced by electrical counterparts are growing progressively over time. Presently, novel means of generating, distributing, storing and using non-propulsive power on board are investigated and examined at aircraft level. A possible non-propulsive power system concept of MEA is shown in Figure 3.2.

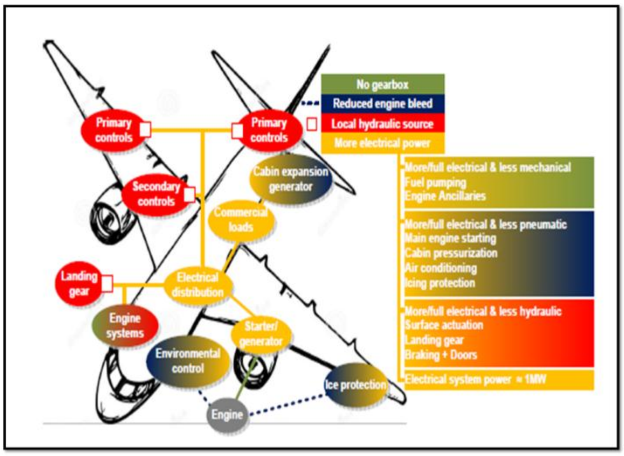

Figure 3.2. A possible non-propulsive power system concept of more electric aircraft

In aircraft systems, the effect of electrical power off take can sometimes have significant impact on the dynamics and control of the aircraft engine. For instance, during the transition from cruise to descent phase, the aircraft engine power is transiently reduced while maintaining high electrical power demand. This transition creates a possibility of engine instability and may require substantial electric load shedding. Furthermore, with the increasing electric power consumption in MEA, the above effect will be more severe if the electric power is solely extracted from the HP spool of the gas turbine engine. This issue can be resolved by installing an extra generator on the LP spool of the engine and sharing the power extraction between the HP and LP spools.

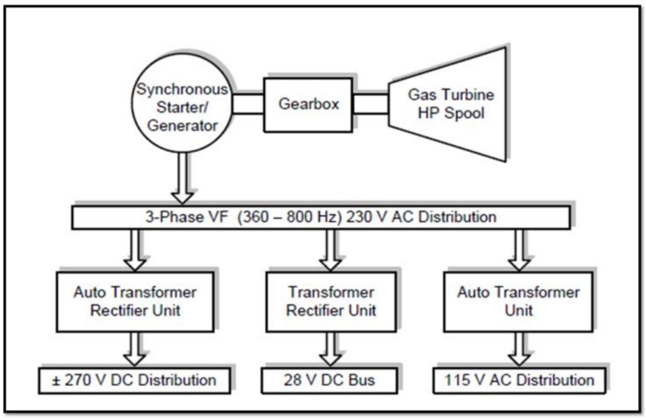

Figure 3.3. System configuration of a wound field synchronous generator based AC primary generation system

The idea of adding a fan-shaft generator on the low pressure spool has been widely accepted with the concept of MEE. In a twin-spool aircraft engine, the generators on HP and LP spool operate at different frequencies. In order to parallel the two generators with enhanced efficiency and reduced size and weight, a DC primary generation system with power electronic converters is preferred as an advanced more electric architecture. PM generator has been investigated for this twin-spool twin-generator architecture due to its high power density and self-excited capability. As shown in Figure 3.4, a high speed starter/generator and a low speed generator are placed directly on the HP and LP spool of the engine, respectively. In the engine starting process, the PM starter/generator on HP spool can operate as a motor to start the engine using ground power supply.

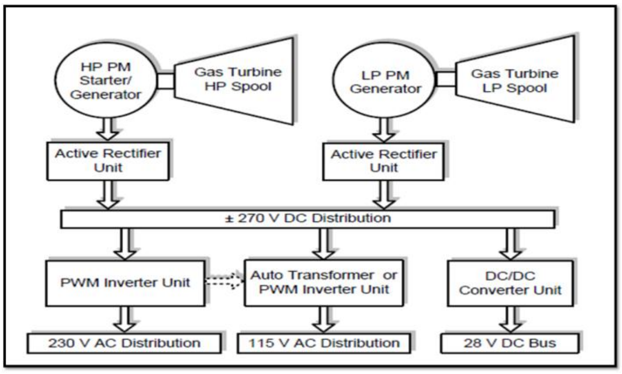

Figure 3.5 a potential system configuration of a DC primary generation system

In AC primary generation system, the frequency insensitive loads are powered directly from the synchronous generator terminals, where the AC load voltage is regulated by adjusting the excitation of the field winding of WFSG according to the shaft speed variation. A new approach of generating CVVF AC power directly from the generator terminals without external excitation is required in the new power generation system under MEE concept.

PROPOSED SYSTEM

The proposed induction generator based AC/DC hybrid generation system is shown in Fig. 4.1. In the proposed system, a high speed open-end winding squirrel-cage induction starter/generator and a low speed conventional wye-connected squirrel-cage induction generator are attached to the high pressure (HP) and low pressure (LP) spools of the engine, respectively. In generating mode of operation, the HP generator is in charge of generating all of the CVVF power, while the DC power demand is shared by both HP and LP generators. The proposed AC/DC hybrid generation architecture can supply CVVF power directly from one side of the generator winding terminals without external exciter, and generate DC power on the other side of the generator winding terminals through an inverter/rectifier unit.

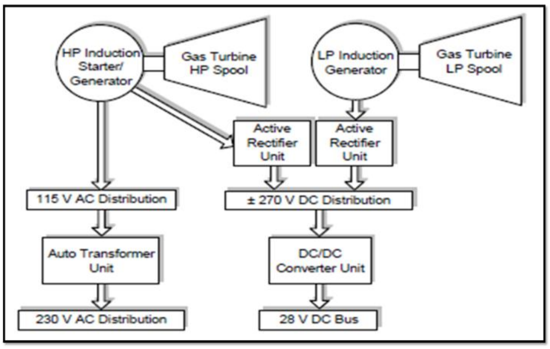

Fig. 4.1. System configuration of the induction generator based AC/DC hybrid generation system

As compared to the AC primary generation system in Fig. 1, the application of induction generator removes the external exciter, while the twin-spool twin-generator architecture improves the overall generation performance.

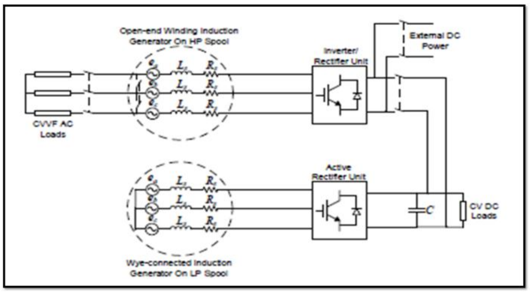

Fig. 4.2. Electrical system diagram of the induction generator based AC/DC hybrid generation system

A more detailed electrical system configuration is shown in Fig. 4.2. An inverter/rectifier unit and frequency insensitive AC loads are connected to each end of the HP spool open-end winding induction generator terminals. An active rectifier unit is connected to the LP spool wye-connected induction generator. The DC output end of the inverter/rectifier unit and the active rectifier unit are paralleled to the DC bus.

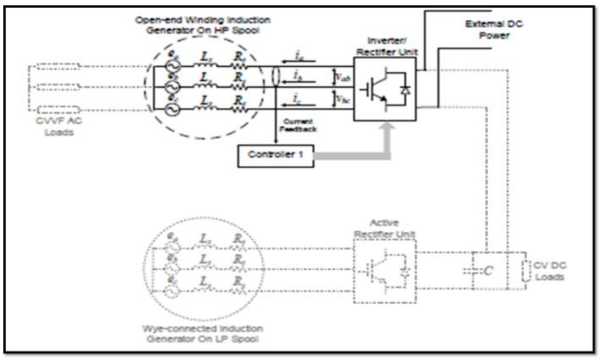

Fig. 4.3. Starter mode of operation of the induction generator based AC/DC hybrid generation system

In most of the MEA applications, besides generating electric power, the main engine generator is also used as a starter for starting the aircraft engine. A DC power supply from the APU generation system or ground power supply is usually available for this process. As is shown in Fig. 4.3, in the engine starting mode of operation, the entire LP spool generation subsystem is deactivated.

MODELLING AND SIMULATION

Matlab Simulation of Grid connected Induction Generator

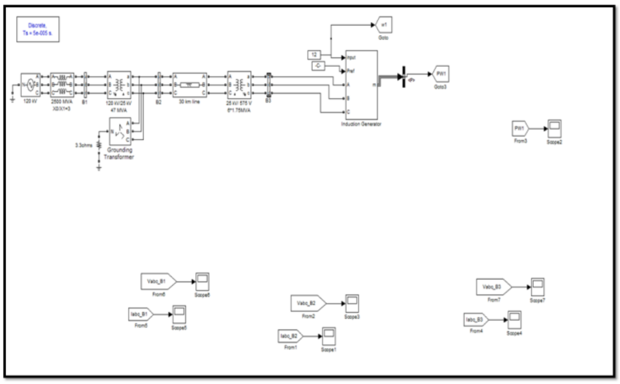

Fig 5.1 Matlab Model of Grid Connected Induction generator

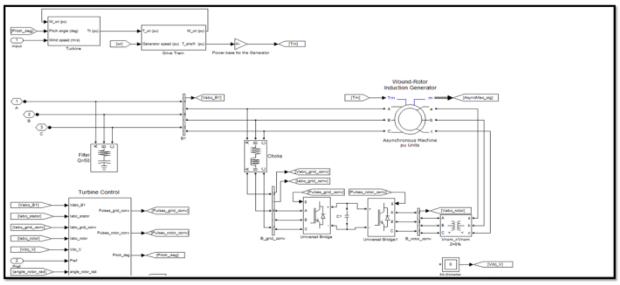

Fig 5.2 Subsystem of Induction generator

Simulation Results:-

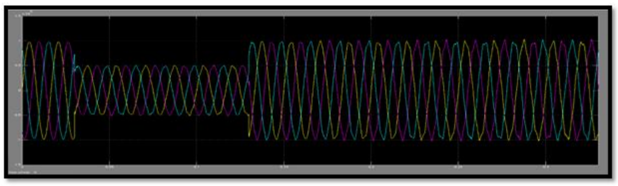

Fig 5.3- Bus-1 Voltage waveform

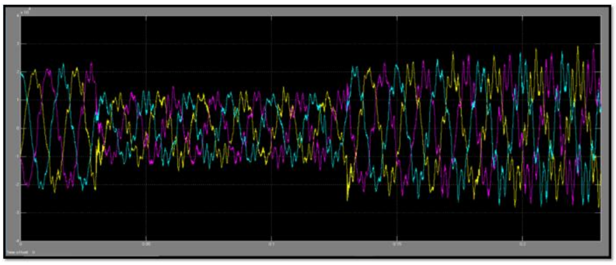

Fig 5.5- Bus-2 Voltage waveform

Matlab Simulation of AC/DC/AC Converter

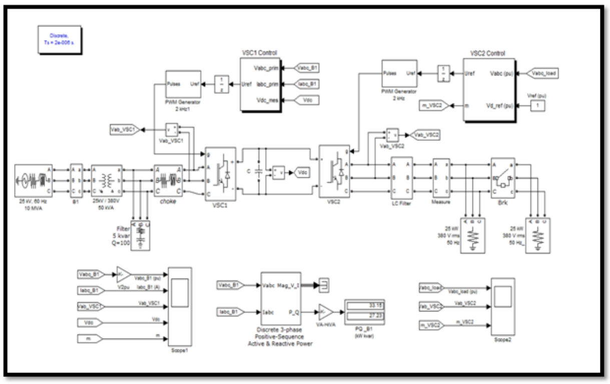

Fig 5.7- Matlab Model of AC/DC/AC Converter

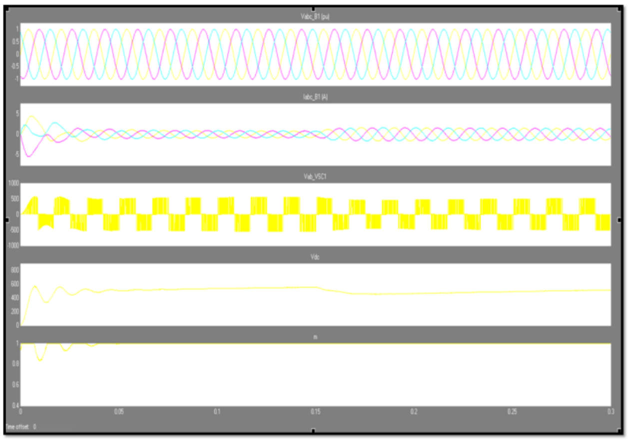

Fig 5.8- VSC-1 output parameters waveform

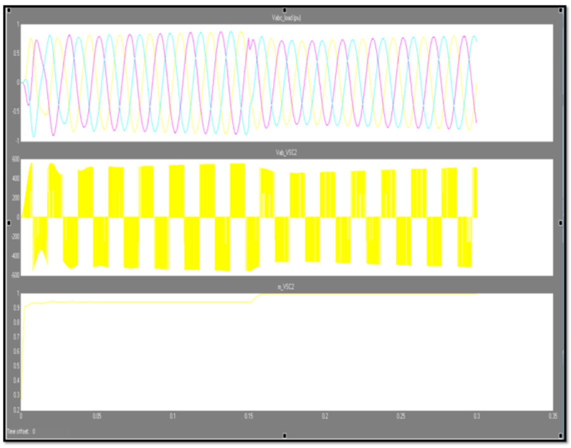

Fig 5.9- VSC-2 output parameters waveform

Matlab Simulation of Proposed System for Induction Generator

Among the three generator parameters which have impact to the DC power output regulation precision of the HP spool generation subsystem, the stator resistance $Rs1$ and rotor leakage inductance $Llr1$ are relatively small, and contribute minor effect to the regulation robustness degradation. A parameter sensitivity test for DC power output in terms of HP generator stator resistance and rotor leakage inductance is performed using MATLAB. The results of the test are shown in Fig. below section.

The DC power output regulation precision of the HP spool generation subsystem depends greatly on the estimation accuracy of the magnetizing inductance $Lm1$ of HP generator. Since the DC bus voltage regulated in a master-slave strategy, as the master control output, the DC power output error from the HP spool generation subsystem can be compensated by the slave DC voltage controller in LP spool generation subsystem in normal operation. If the HP generator is operated in deep saturation region, saturated magnetizing inductance estimation methods can be used to improve the DC power output regulation precision of the HP spool generation subsystem.

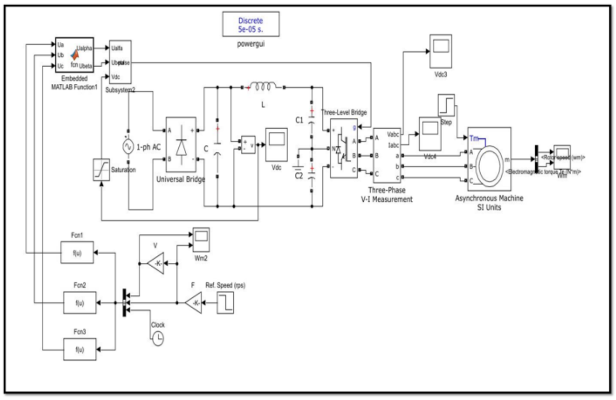

Fig 5.10- Proposed System with AC/DC/AC converter for Induction Generator

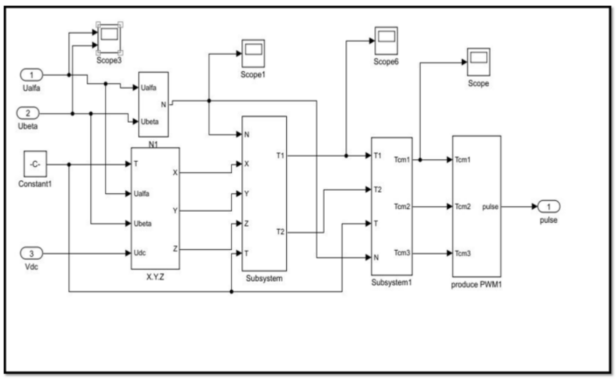

Fig 5.11- Inverter Controlling Subsystem

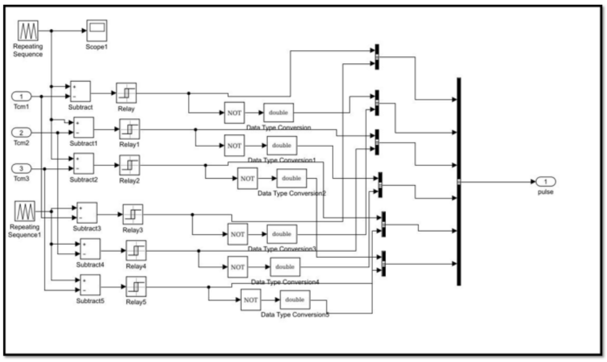

Fig 5.12- Triggering Pulse generation control system

Simulation Results: - Case-I Step signal of 3

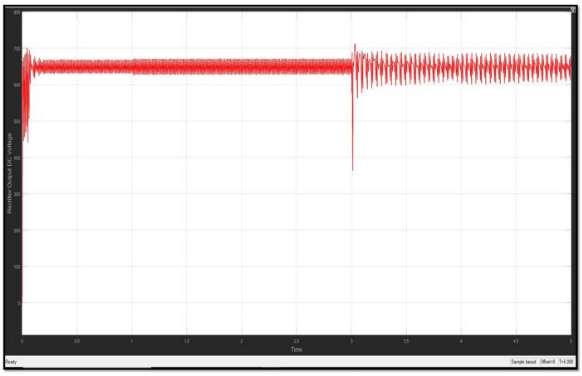

Fig 5.13 Rectifier Output DC Voltage

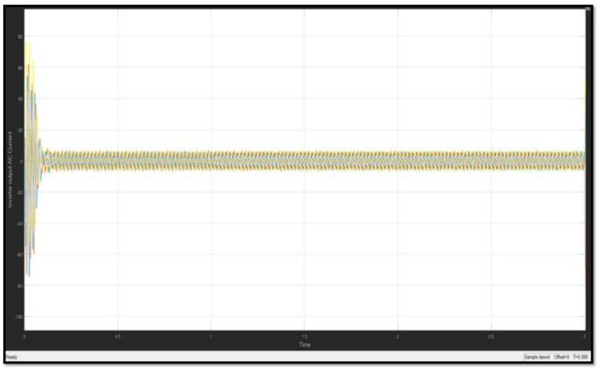

Fig 5.14- Inverter output AC Current

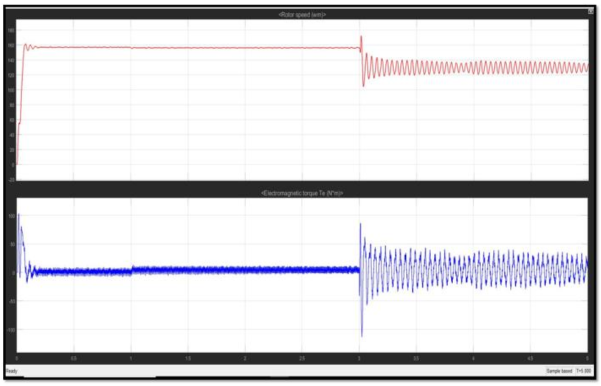

Fig 5.15- Induction Generator Output Parameters

Simulation Results:- Case-II Step signal of 5

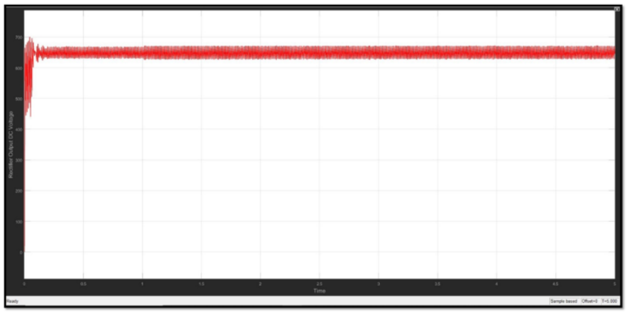

Fig 5.16-Rectifier Output DC Voltage

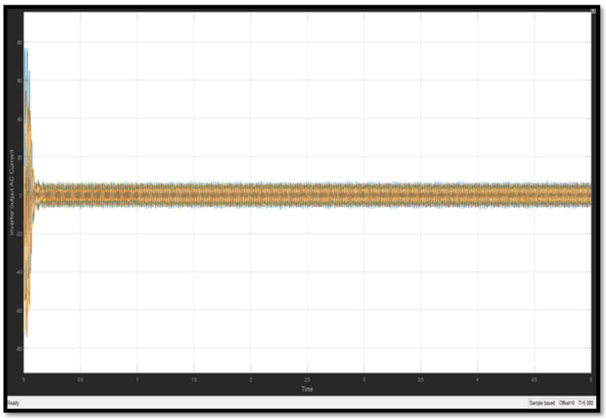

Fig 5.17- Inverter output AC current

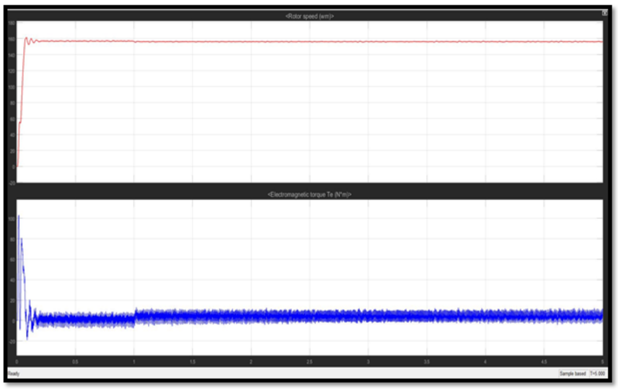

Fig 5.18- Induction Generator Output parameters

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 analyse 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. In this paper an induction generator based AC/DC hybrid generation system for MEA is presented. The application of induction generator addresses the problem of excessive fault current due to the PM excitation in PM generator based generation system. The proposed AC/DC hybrid generation architecture supplies CVVF power directly from generator terminals without external exciter. The Simulation results of AC/DC/AC converter for Induction generator is successfully done in Matlab Simulation, for different step

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