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Control Of DFIG Based Wind Turbine For Optimal Power Output

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***Abstract* — Variable-speed wind turbine (VSWT) with doubly-fed induction generator (DFIG) is one type of wind power that capable of producing electrical energy efficiently, capable of controlling real and reactive power generator, and improves the power quality. This paper deals with the analysis of a doubly-fed induction generator (DFIG) driven by the wind turbine.The variation of Output generated power with respect to variable input is to be studied. Inveter is designed with PID controller, which is used for the converter operation in RSC(Rotor Side Converter) & GSC(Grid Side Converter).Proper Control Technique For RSC & GSC is Used.Voltage Oriented Control For GSC & Stator Flux Oriented Control Technique For RSC is To be Implemented.The output power at different wind speed is to be studied in simulation.**

Keywords- Introduction to Doubly-Fed Induction Generator (DFIG), Wind Turbine Modeling, Inverter,Introduction to RSC(Rotor Side Converter) & GSC(Grid Side Converter),Control Techniques For Both Converters

I. INTRODUCTION

In recent years, renewable energy systems have attracted the great interest because conventional sources of energy are limited and a number of problems associated with their use, like environment pollution, large grid requirements etc. The variable speed system with a DFIG to improve the efficiency, power rating, cost benefit effectiveness etc. Wind is highly variable in nature, so variable speed DFIG based WECS offers many advantages compared to the fixed speed squirrel cage induction generators, such as reduced converter rating, cost and losses in result of that an improved efficiency.

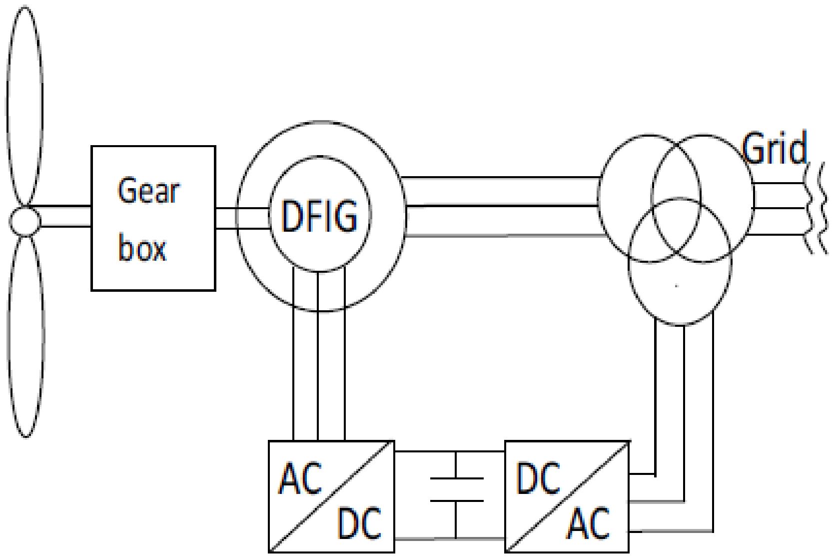

Fig.1 Block Diagram Of DFIG

II Modeling Of DFIG

The modeling of DFIG is done through the Clarke and Park transformations in the synchronously rotating reference frames. Decoupled control of active and reactive power can be easily implemented. Following space-space equations in synchronous reference frame represents the dynamic modeling of DFIG.

$$V_{qs} = R_s\, i_{qs} + \frac{d}{dt}\varphi_{qs} + \omega_e \varphi_{ds} \quad (1)$$

$$V_{ds} = R_s\, i_{ds} + \frac{d}{dt}\varphi_{ds} - \omega_e \varphi_{qs} \quad (2)$$

$$V_{qr} = R_r\, i_{qr} + \frac{d}{dt}\varphi_{qr} + \omega_e \varphi_{dr} \quad (3)$$

$$V_{dr} = R_r\, i_{dr} + \frac{d}{dt}\varphi_{dr} - \omega_e \varphi_{qr} \quad (4)$$

$$\varphi_{qs} = L_{ls}\, i_{qs} + L_m(i_{qs}+i_{qr}) = L_s i_{qs} + L_m\, i_{qr} \quad (5)$$

$$\varphi_{ds} = L_{ls}\, i_{ds} + L_m(i_{ds}+i_{dr}) = L_s i_{ds} + L_m\, i_{dr} \quad (6)$$

$$\varphi_{qr} = L_{lr} i_{qr} + L_m(i_{qs}+i_{qr}) = L_r i_{qr} + L_m i_{qs} \quad (7)$$
$$\varphi_{dr} = L_{lr} i_{dr} + L_m(i_{ds}+i_{dr}) = L_r i_{dr} + L_m i_{ds} \quad (8)$$

III Wind Turbine Modeling

The wind turbine is described in terms of the power it generates, which depends on the wind velocity, air density, turbine radius and the power coefficient for the turbine. The turbine radius plays an important role in energy capture from the wind. If the radius of the turbine is large, then it will capture large amount of energy from the wind [4]. The power P_t that is produced by the wind turbine is given by Equation

$$P_t = \frac{1}{2}\rho A V^3 C_p(\lambda,\theta) \quad (9)$$

where, Cp is the power coefficient of the wind turbine is the pitch angle of the turbine blade is the air density is the turbine radius, and V is the wind velocity. The turbine is normally coupled to shaft of the generator through a gearbox whose gear ratio G is chosen to maintain the speed of the generator shaft within a desired speed range.

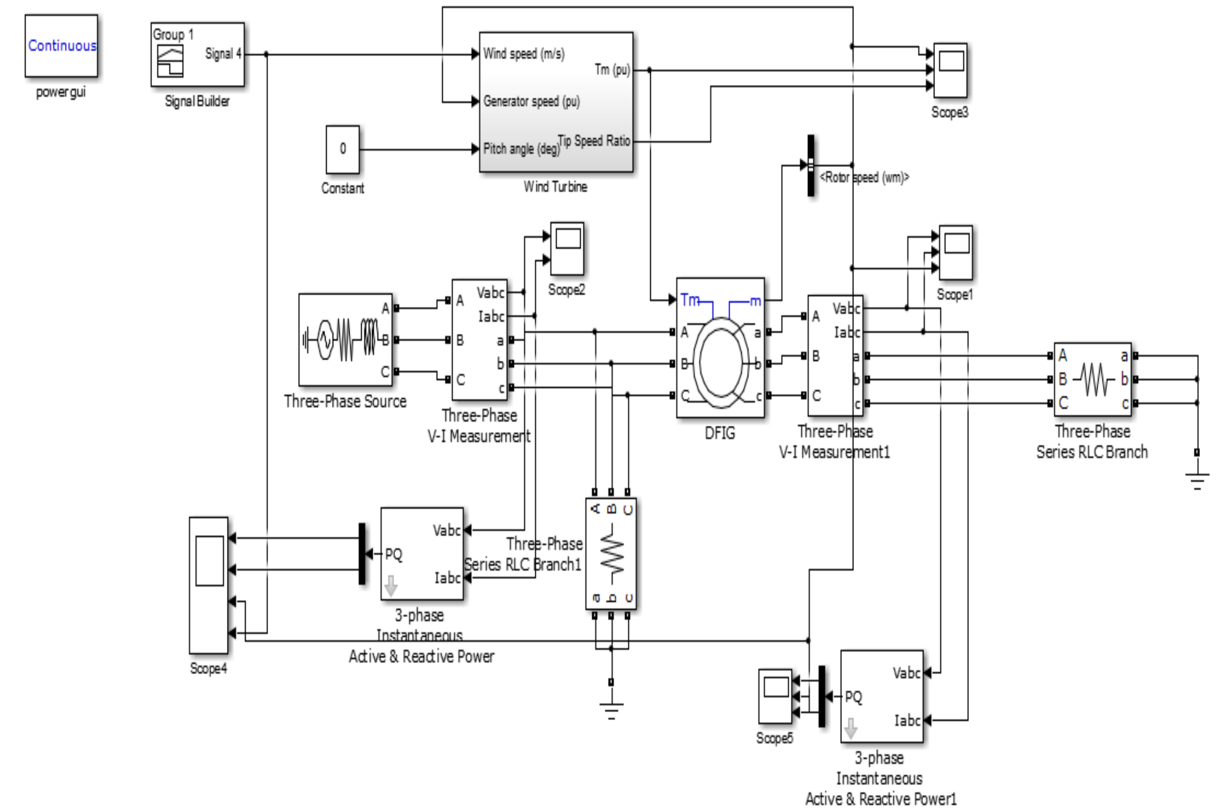

Fig.2 Matlab Open Loop Simlation

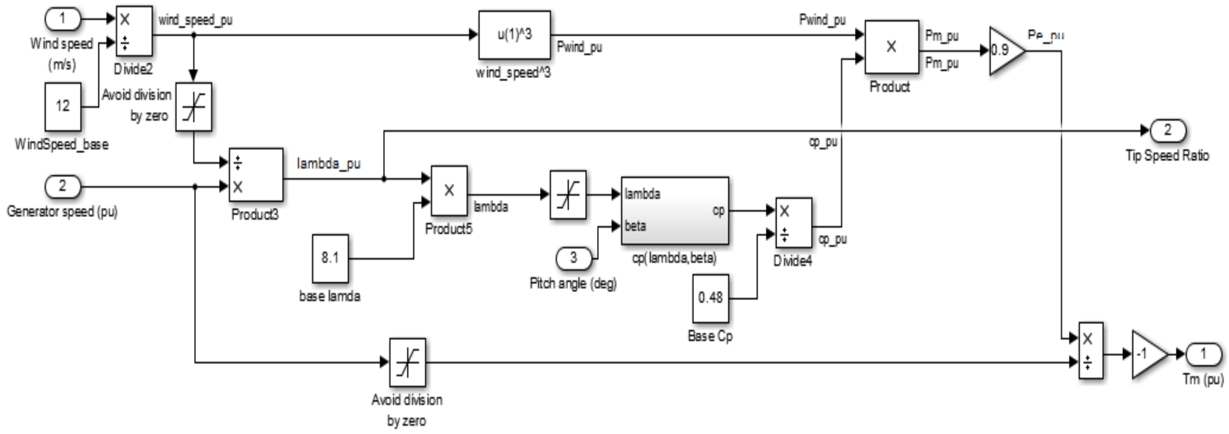

Fig.3 Sub system of wind turbine

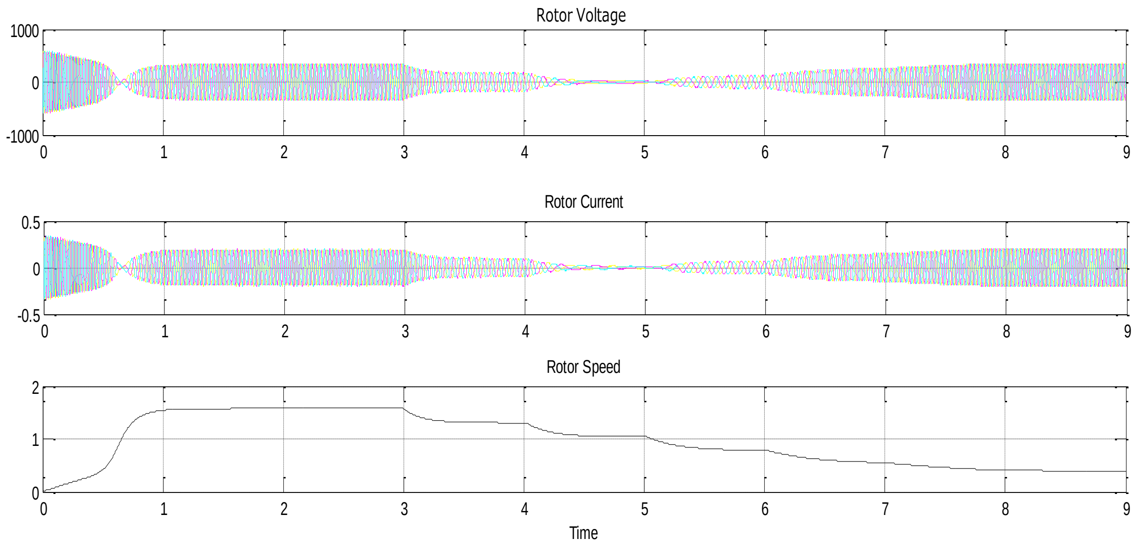

Fig.4 Waveform for rotor voltage ,current and speed

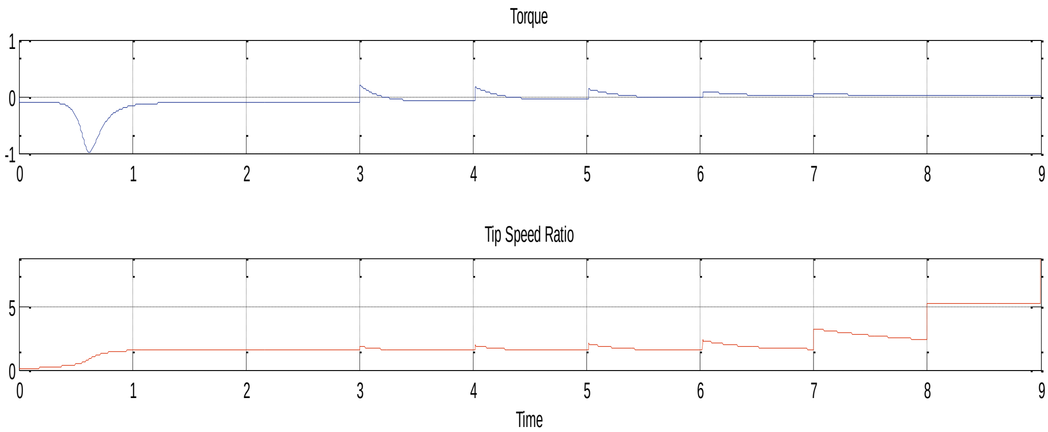

Fig.5 waveform for rotor Torque and Tip speed ratio

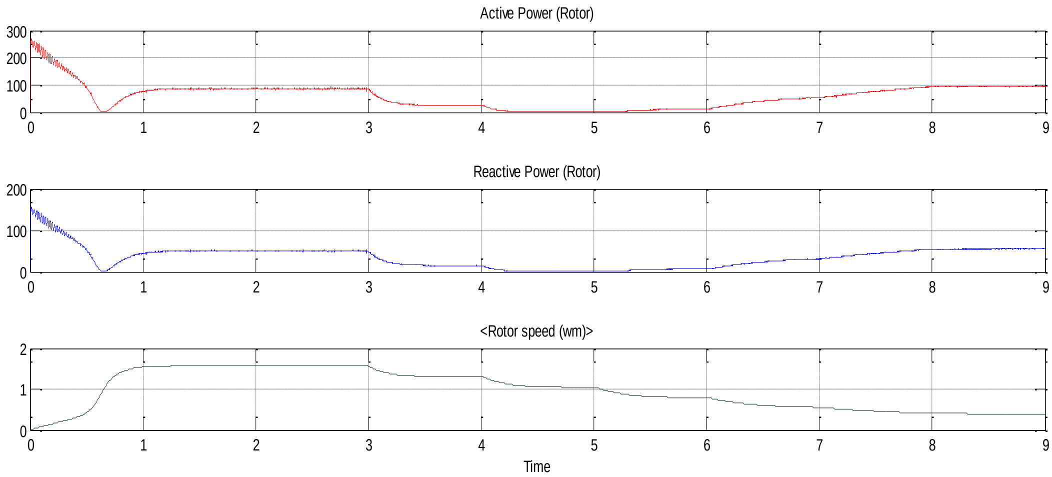

Fig.6 Active Power & Reactive Power of Rotor

IV Rotor Side Converter

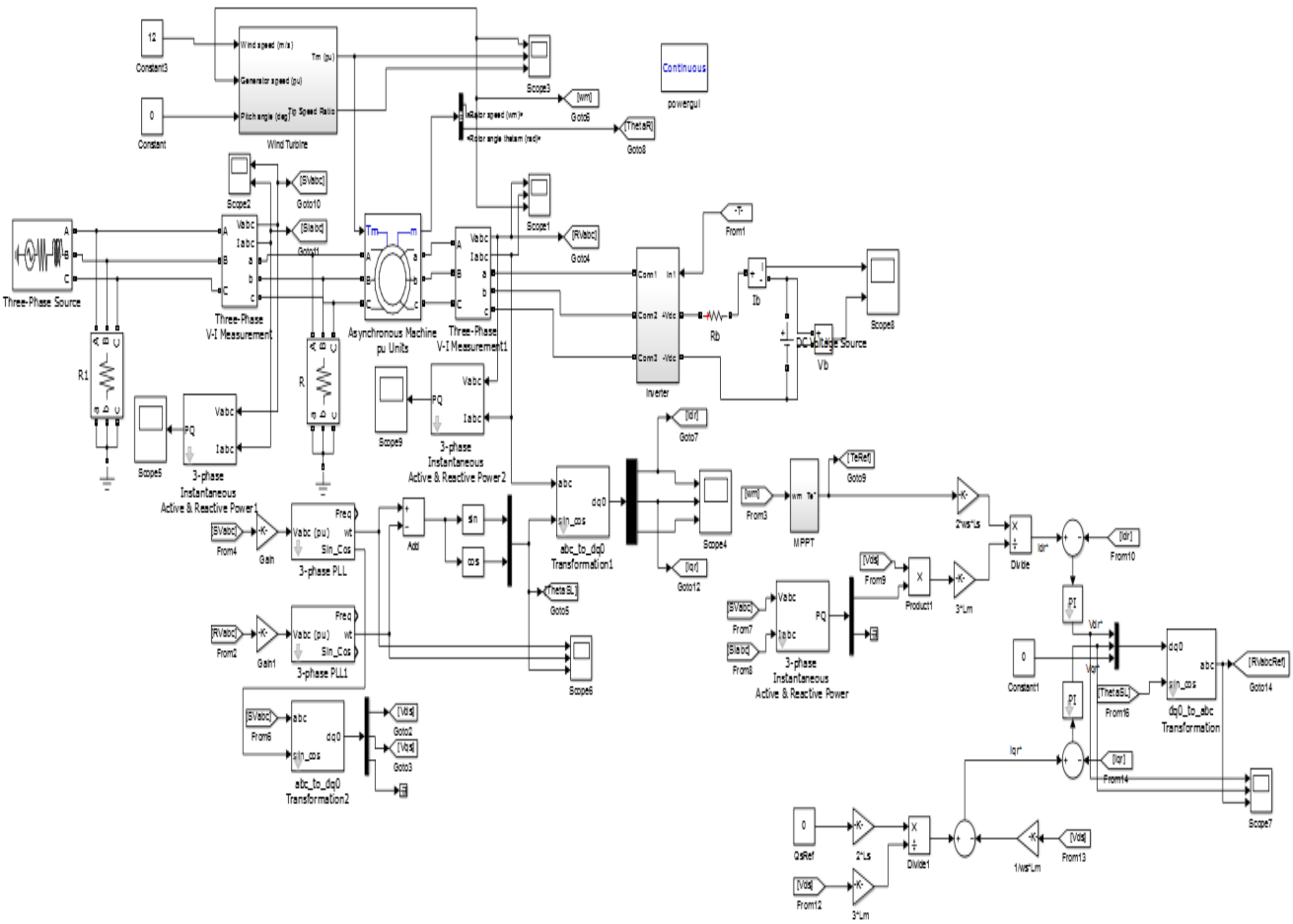

Fig.7 Simulation of Rotor Side Converter

The rotor-side converter (RSC) applies the voltage to the rotor windings of the doubly-fed induction generator. The purpose of the rotor-side converter is to control the rotor currents such that the rotor flux position is optimally oriented with respect to the stator flux in order that the desired torque is developed at the shaft of the machine. The rotor-side converter uses a torque controller to regulate the wind turbine output power and the voltage (or reactive power) measured at the machine stator terminals.

V Stator Flux Oriented Control

The Stator of the Generator is Directly connected to the grid, and its voltage and frequency can be considered constant under normal operating condition . It is therefore, convenient to use stator voltage oriented control for DFIG. The stator voltage oriented control is achived by aligning the d-axes of the synchronous reference frame with the stator voltage vector .The resultant d & q axws stator voltages are Vqs=0 and Vds=Vs.The Rotor rotates at speed ω_r.The angle between the stator voltage vector and the rotor is the slip angle defined by $\theta_{sl} = \theta_s - \theta_r$.Since the DFIG operates with unity power factor, the stator current vector i_s aligned with $v_s$which are controlled by the converter in the rotor circuit. The DFIG wind energy system can be controlled by the electromagnetic torque for speed control or active power. Electromagnetic torque Te of the Generator ,Active and Reactive power Ps & Qs of Stator are controlled by the rotor side converter . Therefore it is worthwile to investigate the controllability of Te,Ps and Qs by the rotor voltage and current .The investigation also facilitate the analysis of stator voltage oriented control.

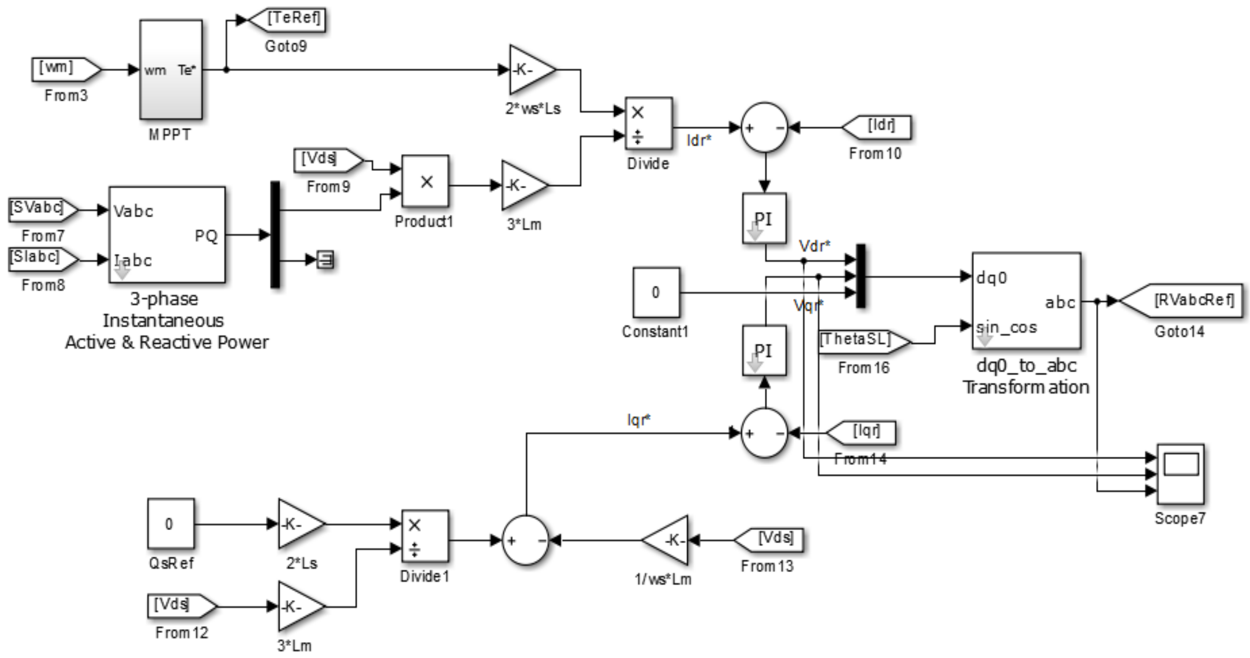

Fig.8 Sub System Of RSC

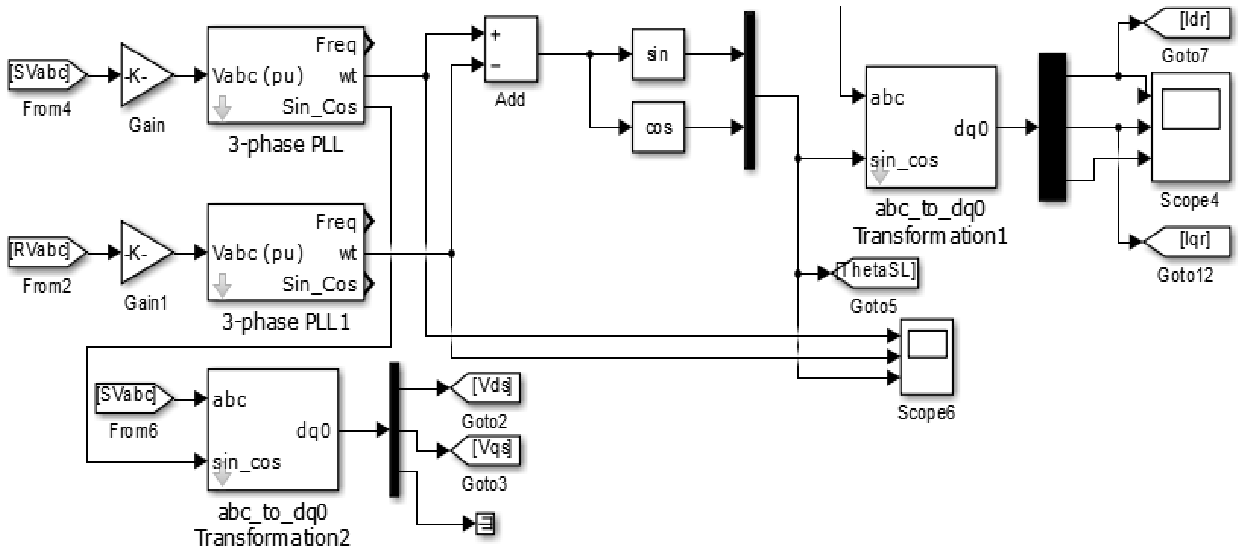

Fig.9 Sub System Of RSC

VI Grid Side Converter

The grid-side converter aims to regulate the voltage of the dc bus capacitor. Moreover, it is allowed to generate or absorb reactive power for voltage support requirements. The function is realized with two control loops as well: an outer regulation loop consisting of a dc voltage regulator. The output of the dc voltage regulator is the reference current for the current regulator. The grid side system is composed by the grid side converter, the grid side filter, and the grid voltage.The grid side converter is modeled with ideal bidirectional switches. It converts voltage and currents from DC to AC, while the exchange of power can be in both directions from AC to DC (rectifier mode) and from DC to AC (inverter mode).

VII VOLTAGE ORIENTED CONTROL (VOC) TECHNIQUE

The grid connected inverter can be controlled with various schemes. One of the schemes is known as voltage oriented control (VOC),as shown in figure. This scheme is based on transformation between the abc stationary reference frame and dq synchronous frame. The control algorithm is implemented in the grid-voltage synchronous reference frame, where all the variables are of DC components in steady state.This facilitates the design and control of the inverter. To realise the VOC, the grid voltage is measured and its angle θgis detected for the voltage orientation. This angle is used for the transformation of variables from the abc stationary frame to the dq synchronous frame through the abc/dq transformation or from the synchronous frame back to the stationary frame through the dq/abc transformation as shown in fig. Various methods are available to detect the grid voltage angle θg. Assuming that the grid voltages, vag, vbg, vcg are three phase balanced sinusoidal waveforms, θg. Can be obtained by,

θg = tan-1 vβ/vα

The above equation indicates that there is no need to measure the phase-c grid voltage vcgas shown in fig.In practice, the grid voltage may contain harmonics and be distorted, so digital filters or phase- locked loops(PLLs) may be used for the detection of grid voltage angle θg. where Q* g is the reference for the reactive power, which can be set zero for unity power factor operation, a negative value for leading power factor operation, or a positive value for lagging power factor operation.

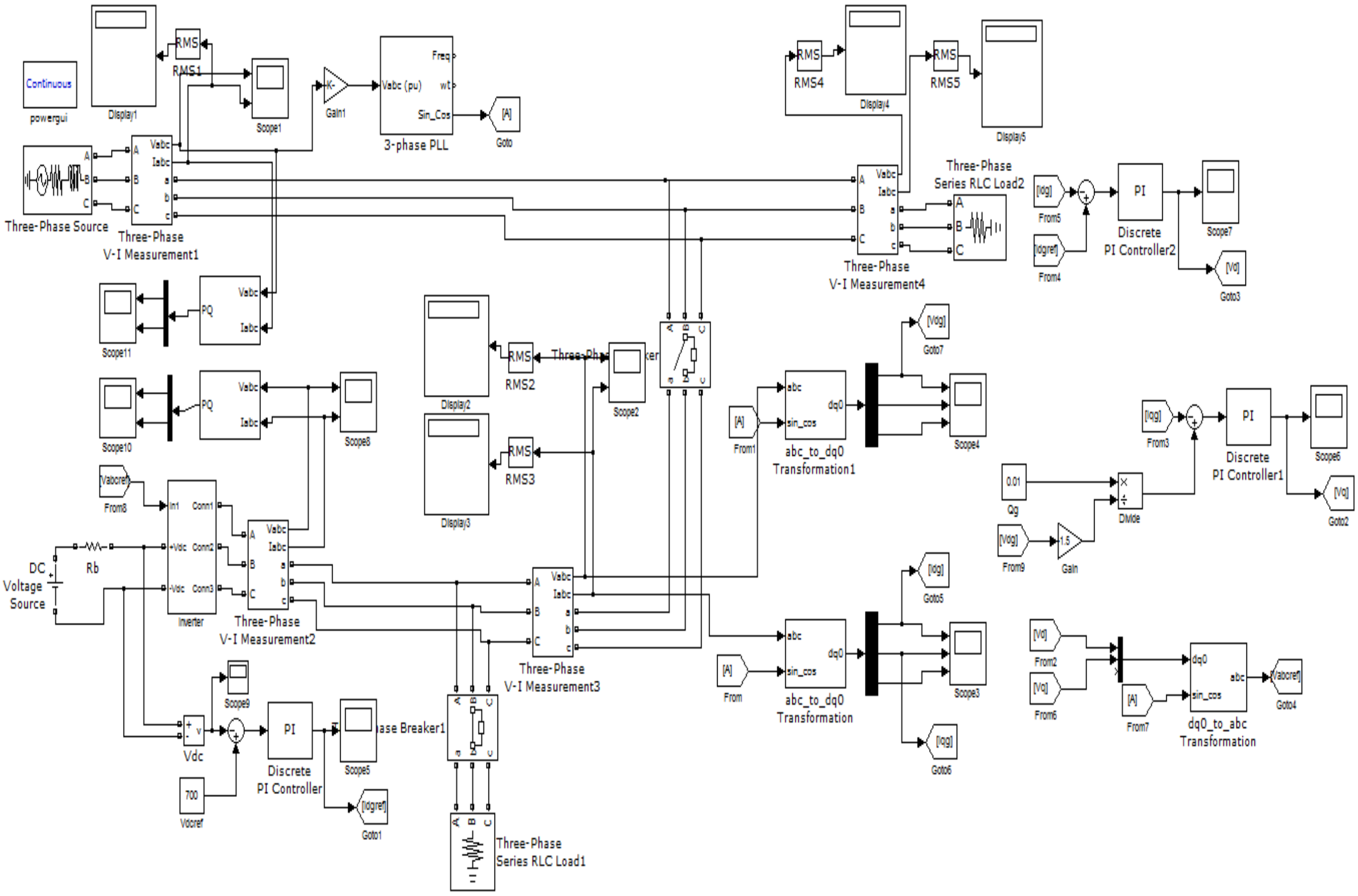

Fig.10 Simulation of Grid Side Converter

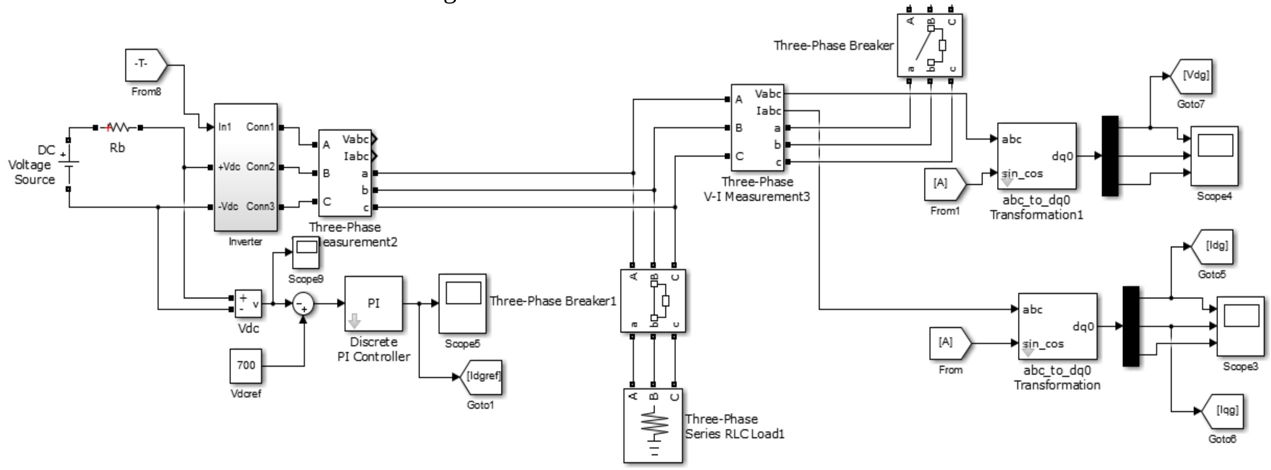

Fig.11 Sub System Of GSC

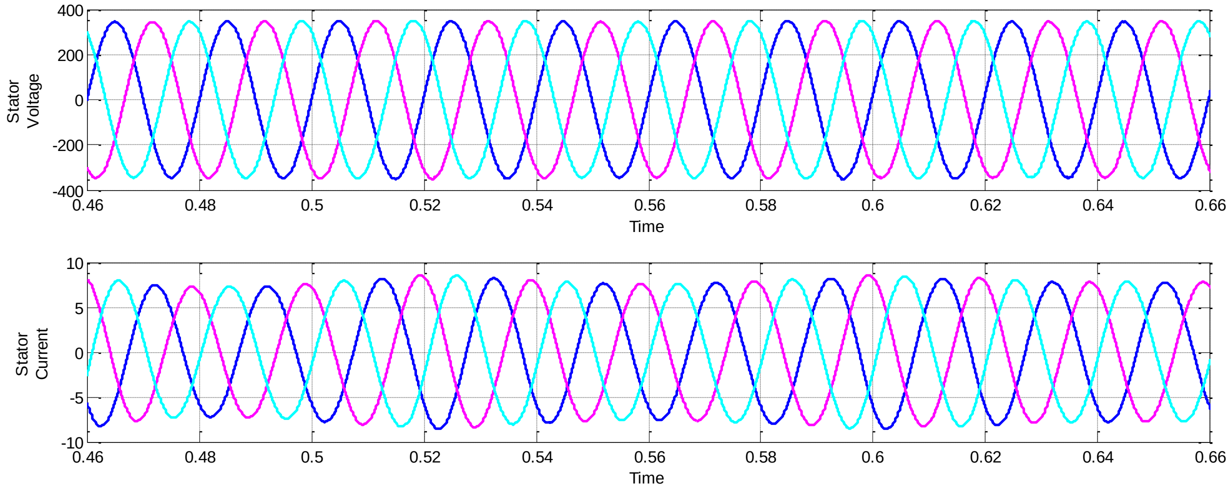

Fig.12 Stator Voltage& Stator Current

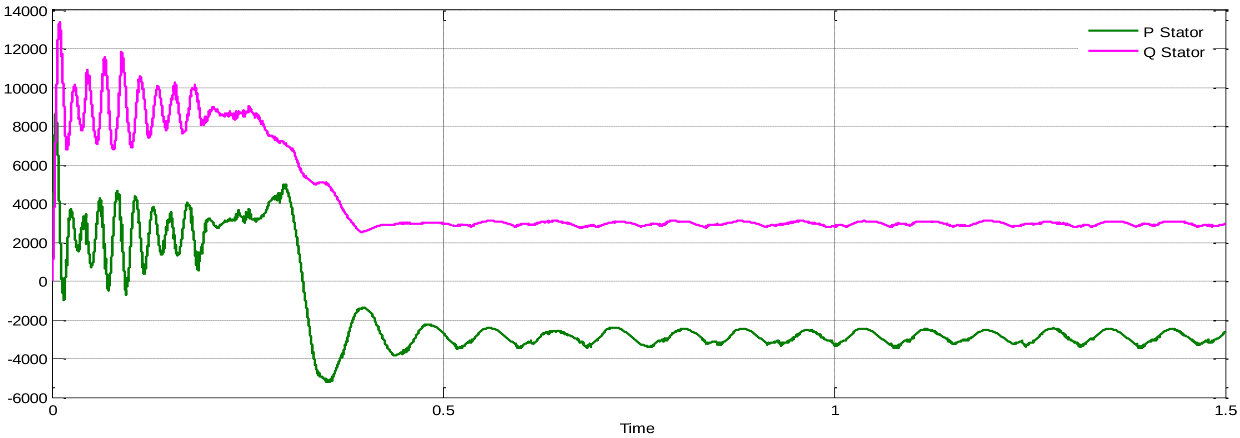

Fig 13 Stator Active and Reactive Power

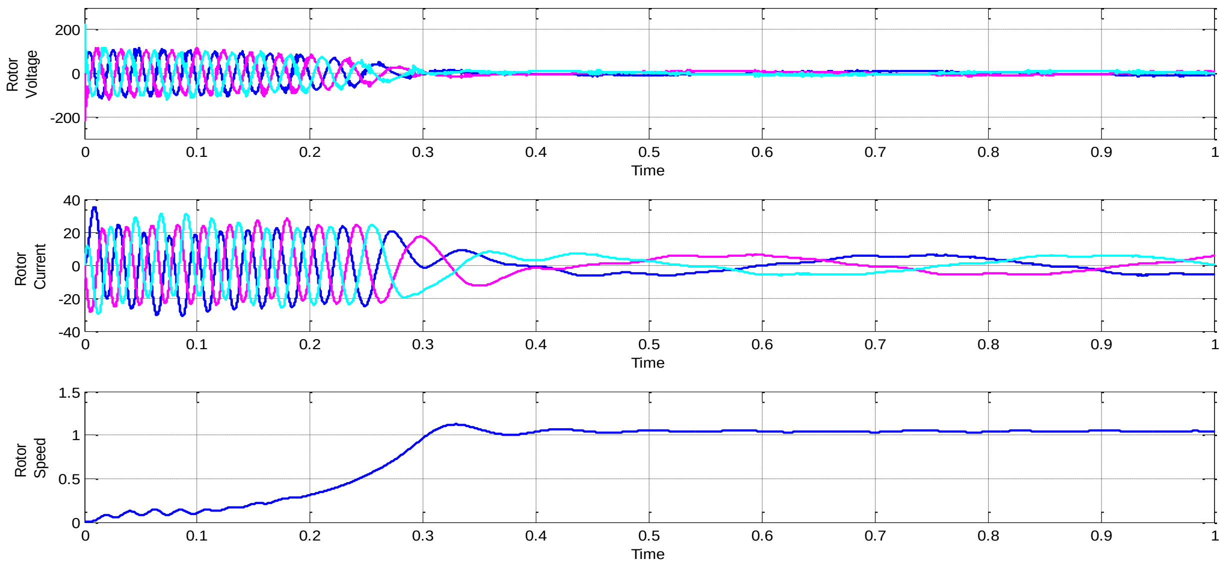

Fig 14 Rotor Voltage, Current and Swpeed

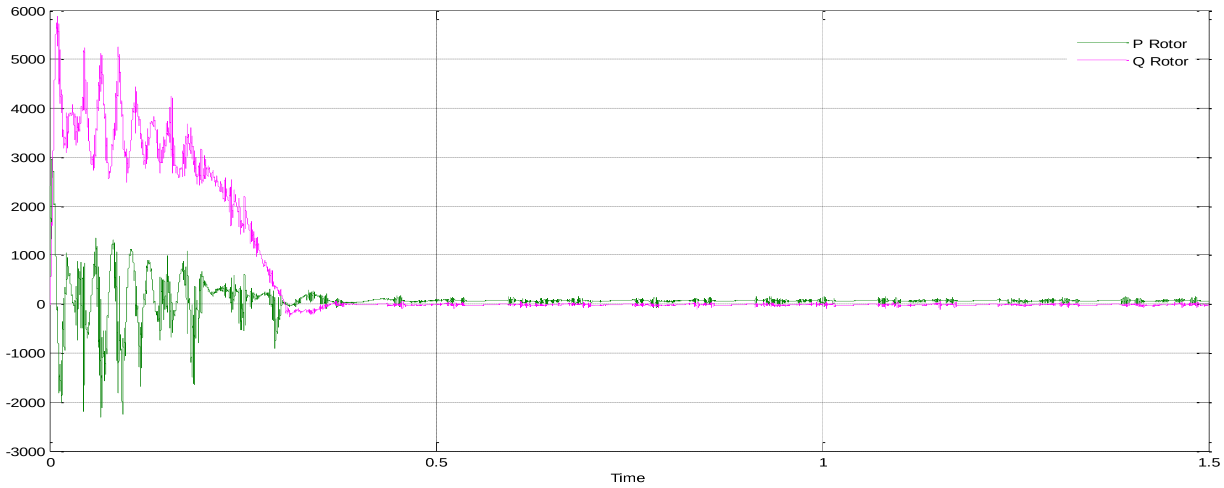

Fig 15 Active and Reactive Power Of Rotor

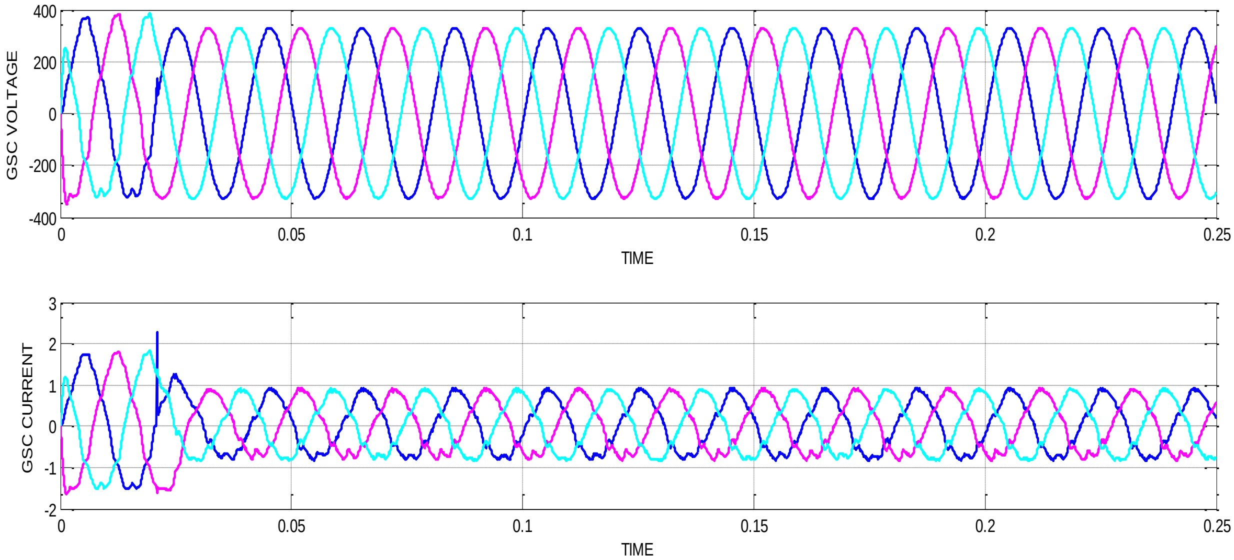

Fig 16 GSC voltage & GSC current

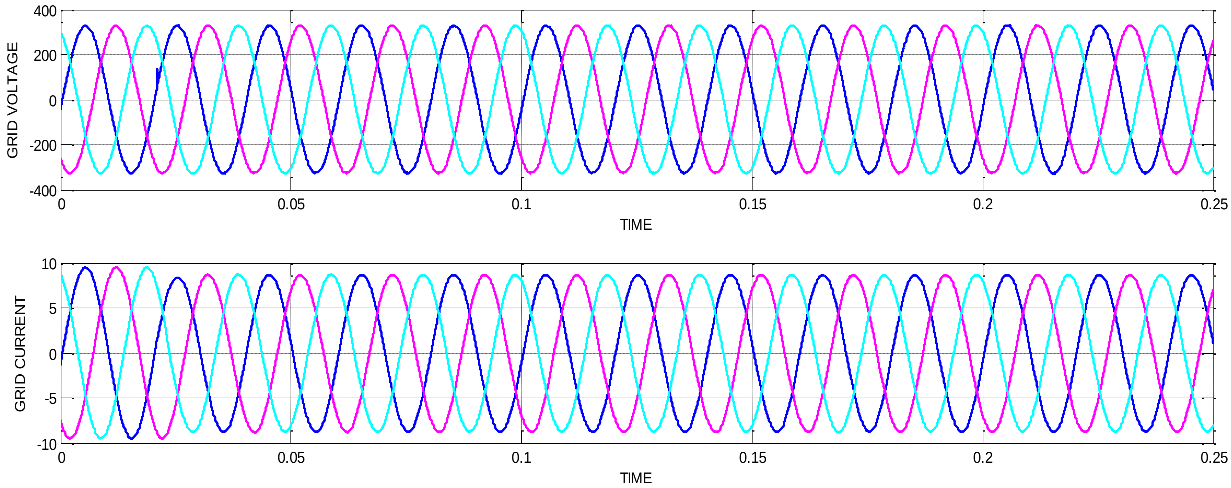

Fig 17 Grid Voltage & Grid Current

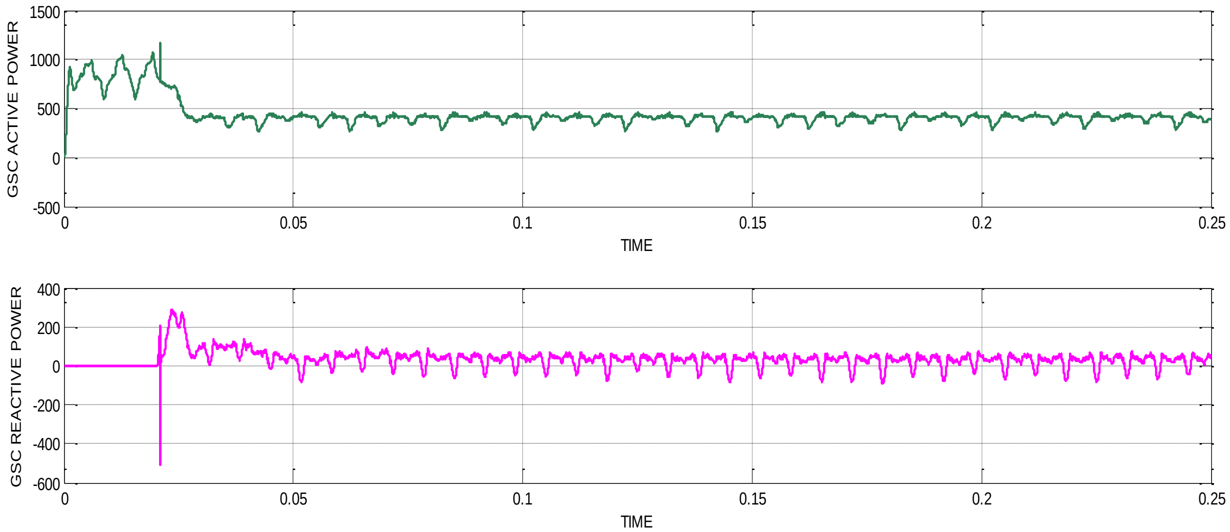

Fig 18 GSC Active and Reactive Power

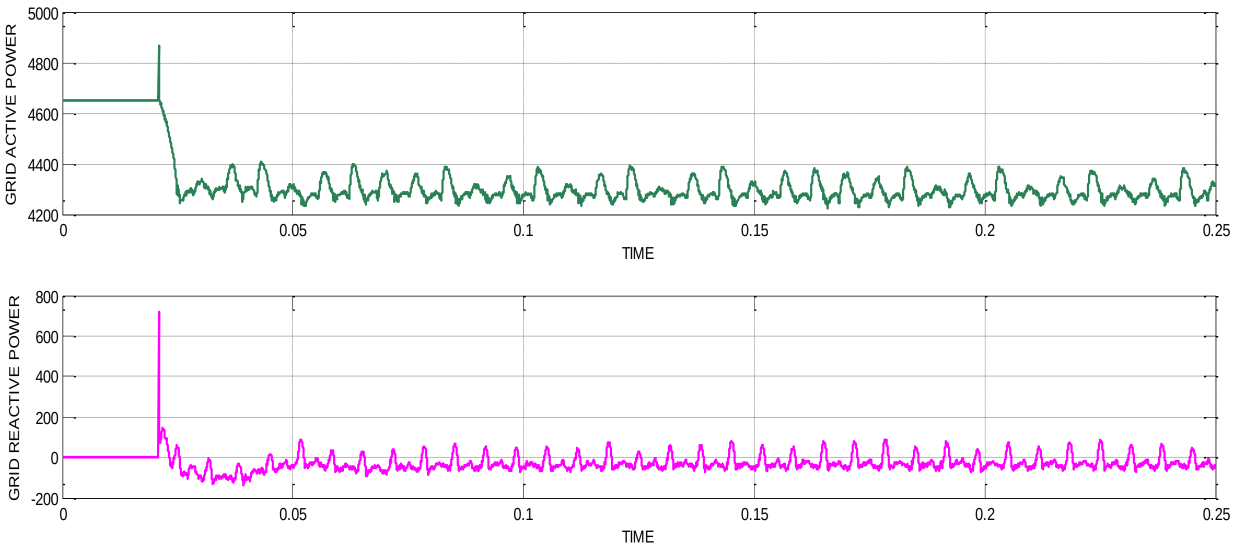

Fig 19 Grid Active and Reactive Power

APPENDIX

Pn (Nominal power)	3730 VA
V_{rms} (Supply Voltage r.m.s)	460V
f(Supply Frequency)	50Hz
Rs((Rotor Resistance)	0.01965 pu
L_{ls}(Stator Inductance)	0.0397 pu
Rr'(Rotor Resistance)	0.01965 pu
$L_{lr}{}'$(Rotor Inductance)	0.0397 pu
Lm(Mutual Inductance)	1.345 pu
H(s) Inertia constant	0.09526pu
F(pu) friction factor	0.05479pu
pole pairs(p)	2

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