Dynamic modeling of DFIG for improvement in power quality issues of wind farms

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***Abstract*— This paper describes the incorporation of wind farms with a grid-connected system in advance power quality problems of voltage sag, voltage swell & harmonics and its severe impact due to nonlinear & unbalanced loads fed by doubly fed induction generator (DFIG) integrated to a grid. Due to these power quality issues sometimes equipment should be shut down, a data error occurs and harmonics generate heat leading to reduced equipment lifespan, misfiring in variable speed drive. These are the most important power quality problems that influence the performance of the DFIG interconnected to the grid. A control strategy of unified power quality conditioner (UPQC) is proposed which mitigate voltage sag, voltage swell & harmonics of DFIG to stay connected to the grid. Simulation is carried out using MATLAB SIMULINK to ensure the use of the proposed converter in enhancing the overall system performance and maintaining the system stability. The results are discussed in detail in the paper.**

Keywords: Power quality, Voltage sag, Voltage swell, Harmonics, DFIG, Grid.

I. INTRODUCTION

Nowadays utilization of electricity increases due to this penetration of renewable energy sources are increases. Renewable energy sources are emerging sources that has immense potential compared to conventional energy sources furthermore renewable energy is sustainable, reusable, clean & eco-friendly. Among the available renewable energy sources wind energy is fact rapid growth worldwide has led to a large penetration of wind energy into the power grid and it is promising due to economic viability. In India the total installed capacity of wind power generation is 25.1GW as 2016 mainly spread across South, West & North regions. According to ministry of new & renewable energy (MNRE) the potential of wind resource in India as around 30GW assessed at 100m hub height. The MNRE has set the target for wind power generation capacity at 60GW within 2022[1][2]. There are four types of wind turbine generators are available in market, out of which, DFIG is more popular [3]. It is lead to development of a highly efficient variable speed wind turbines with voltage source converter which is more advantageous than the fixed speed wind turbines. DFIG is variable speed wind turbine with back to back converter. The stator is directly connected to the grid while the rotor is connected through back to back converter.

The rotor side converter uses a high frequency switching pulse width modulation converter to achieve high control performance such as fast dynamic response with low harmonic distortion. The power electronic converters need only be rated to handle a fraction of the total power. The rotor power typically about 30% nominal generator of the total power. Therefore, the losses in the power electronic converter can be reduced, compared to a system where the converter has to handle the entire power and the system cost is lower due to partially rated power electronics [4]. The main drawback of DFIG wind turbine is integrated to the grid it's generates power quality issues [5]. Whenever fault occurs at grid side, the current through the rotor rise and if proper protection is not given it will be damaged. Fig.1 shows detailed configuration of DFIG.

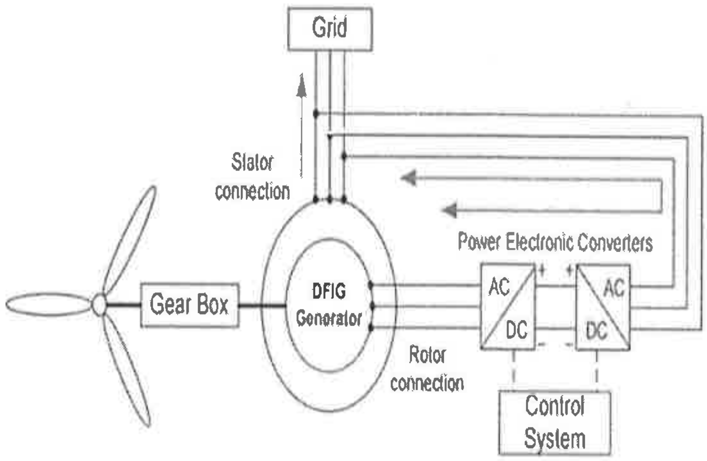

Fig.1 The configuration of DFIG interconnected with grid

II. DYNAMIC MODELING OF DFIG

The energy in the wind pole have two or three propeller around a rotor. The rotor converts kinetic energy to mechanical energy. The rotor is connected to a shaft and spins generator to generate electricity. The power developed in the wind turbine is given by following equations.

$$P_T = 0.5\ C_P\ A\ \rho_A W^3 \text{ watts} \qquad (1)$$

Where C_P is the power coefficient of wind turbine it is range between 0.25 to 0.45, A is the swept area of rotor in m^2, ρ_A is the Air density in kg/m^3 and W is the Wind speed in m/s.

The understanding of the operation of DFIG during steady state conditions and transient state conditions are necessary to discuss about the control techniques to improve power quality. The stator of DFIG wind turbine is connected directly to the grid and rotor is connected to the grid via slip rings through the rotor side converter (RSC) and grid side converter (GSC). The power transfer in these two converters constitutes only up to 30-35% of the total capacity of the machine.Fig.2 shows equivalent circuit of the DFIG.

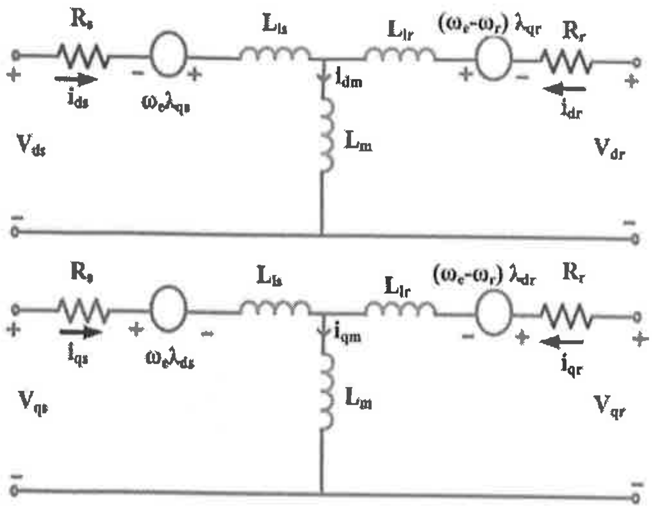

Fig.2 Equivalent circuit of DFIG.

The stator and the rotor voltage in the synchronous dq reference frame are given in equation 2. The expressions of flux, voltages and currents are as in [6].

$$V_{ds} = R_s i_{ds} + \frac{d\lambda_{ds}}{dt} - w_e\lambda_{qs}$$
$$V_{qs} = R_s i_{qs} + \frac{d\lambda_{qs}}{dt} + w_e\lambda_{qs}$$
$$V_{dr} = R_r i_{dr} + \frac{d\lambda_{dr}}{dt} - (w_e - w_r)\lambda_{qr}$$
$$V_{qr} = R_r i_{qr} + \frac{d\lambda_{qr}}{dt} + (w_e - w_r)\lambda_{dr} \quad (2)$$

In Equation 2 V_{ds} ,V_{qs} are stator voltages and V_{dr},Vqr are dq rotor voltages. i_{ds} , i_{qs} are dq stator currents and i_{dr} , i_{qr} are dq rotor currents. w_e is the supply angular frequency and w_r is the rotor angular frequency. λ_{ds} , λ_{qs} are the dq stator flux linkages and λ_{dr}, λ_{qr} is the dq rotor flux linkages. R_s and R_r are the stator and rotor resistance respectively.

The L_s and L_r are the stator and rotor inductance respectively as given in Equation 3 and the flux linkages are given in Equation 4.

$$L_s = L_{is} + L_m$$
$$L_r = L_{ir} + L_m \quad (3)$$

Here, L_{is} and L_{ir} are the stator and rotor leakage inductance respectively. L_m is the magnetizing inductance.

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr}$$
$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr}$$
$$\lambda_{dr} = L_m i_{ds} + L_r i_{dr}$$
$$\lambda_{qr} = L_m i_{qs} + L_r i_{qr} \quad (4)$$

The threshold values of rotor current and DC-link voltage are essential to ensure efficient system capability. The DC-link voltage rating is 1200 V.

III.PROPOSED METHOD

Power quality is one of the major challenges of a power system. By increasing use of power electronic converters as harmonic distortions have been increasing rapidly. Active power filters (APFs) being dynamic & fast. These are preferred over passive filters to compensate power quality issues. UPQC is a combination of series & shunt APFs with common DC link. The series APF mainly adapt for voltage related power quality difficulties such as voltage sag, voltage swell & harmonics. The shunt APF mainly adapt for current related power quality issues such as poor power factor, unbalance & harmonics. The benefits of both series & shunt APFs compensate for most of the power quality issues [7][8].

In this paper, we used a solution of UPQC in DFIG to diminish power quality difficulties like voltage sag, voltage swell & harmonics. The below fig.3 represents configuration of a UPQC.

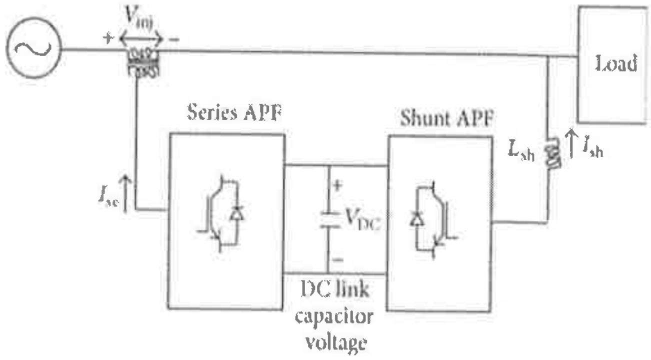

Fig.3 Configuration of UPQC

The method of UPQC is based upon three-phase three wire supply system, which is most common in the distribution system. This configuration has two major Power Electronic Converters are shunt APF and series APF. Both series and shunt APFs are IGBT based three phase three leg bridge and six pulse inverters sharing a common DC link. Single phase series injection transformers are used in each phase to inject voltage. It is produced by series APF. Interfacing inductors are used at the output of both series and shunt APFs. Low pass RC filters are used at the output of series and shunt APFs to filter out low frequency components in voltage or current, generated by PWM switching of these APFs [9][10].

IV. CONTROL METHOD OF GSC

Shunt APF used at GSC of DFIG. The shunt APF to injects compensating currents for mitigating grid current based power quality issues and handles current required for maintaining DC link voltage (Fig. 3). The synchronous reference frame (SRF) theory-based extraction method is used for generating reference signals corresponding to compensating currents. In SRF based extraction, three phase stator currents are transformed from abc frame to dq0 frame using Park's transform and wt signal required for this transformation is generated using a three phase PLL on source voltages. Equation 5 shows park's transform of current.

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(wt) & -\sin(wt) & \frac{1}{2} \\ \cos(wt - \frac{2\pi}{3}) & -\sin(wt - \frac{2\pi}{3}) & \frac{1}{2} \\ \cos(wt + \frac{2\pi}{3}) & -\sin(wt + \frac{2\pi}{3}) & \frac{1}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (5)$$

The Park's transform converts fundamental components of AC quantities into DC quantities which are easily extracted using low pass filters. Current need for maintaining DC link voltage is estimated using a PI controller and added to d-axis load current. The resultant current is the d-axis reference source current I_d*, which is transformed into three phase balanced sinusoidal reference source currents using inverse Park's transform. Reference and measured source currents are passed through a hysteresis current controller. The below Fig.4 shows the Simulink model of shunt APF in DFIG and Fig.5 shows the Simulink model of hysteresis current controller. The hysteresis current controller to generated switching pulses for shunt APF and compensating current.

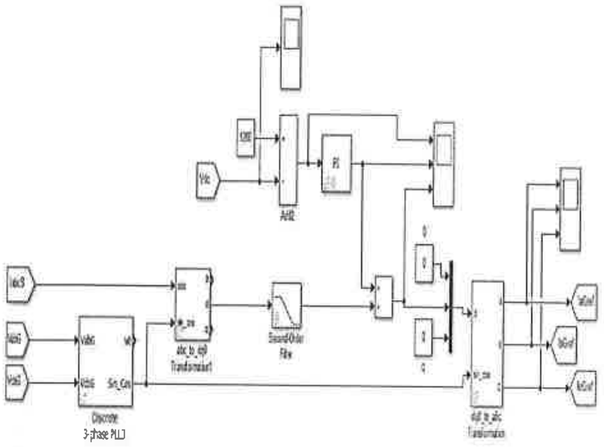

Fig.4 The Simulink model of shunt APF

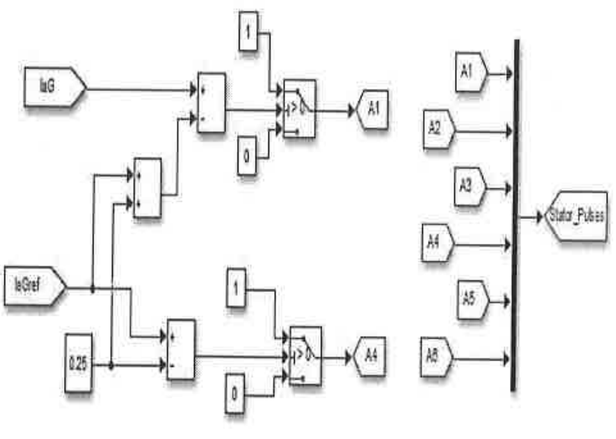

Fig.5 The Simulink model of hysteresis current controller

V. CONTROL METHOD OF RSC

Series APF used at RSC of DFIG. The series APF injects suitable series voltage to compensate for power quality issues in supply voltage and to supply a part of load reactive power. The SRF theory-based extraction method is used for general reference signals corresponding to compensating voltage. In SRF based extraction, three phase reference voltages are transformed from abc to dq0 frame using the park's transform and wt signal required for this transformation is generated using a three phase PLL on source voltages. Equation 6 shows park's transform of voltage.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(wt) & \sin(wt - \frac{2\pi}{3}) & \sin(wt + \frac{2\pi}{3}) \\ \cos(wt) & \cos(wt - \frac{2\pi}{3}) & \cos(wt + \frac{2\pi}{3}) \\ \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (6)$$

Park's transform converts fundamental components of AC quantities to DC quantities which are easily extracted using low pass filters. Reference and measured source voltages are passed through a pulse width modulation (PWM) controller. Fig.6 shows Simulink model of series APF and Fig.7 shows Simulink model of PWM controller. The PWM controller to generated switching pulses for series APF. The power transfer in RSC is only 30%. The voltage power quality issues diminished up to some percentage.

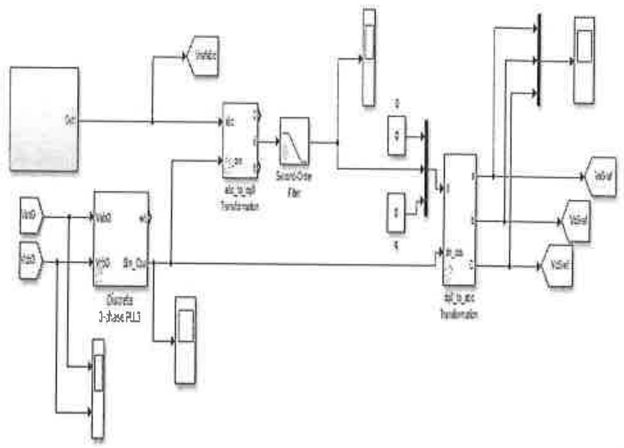

Fig.6 The Simulink model of series APF

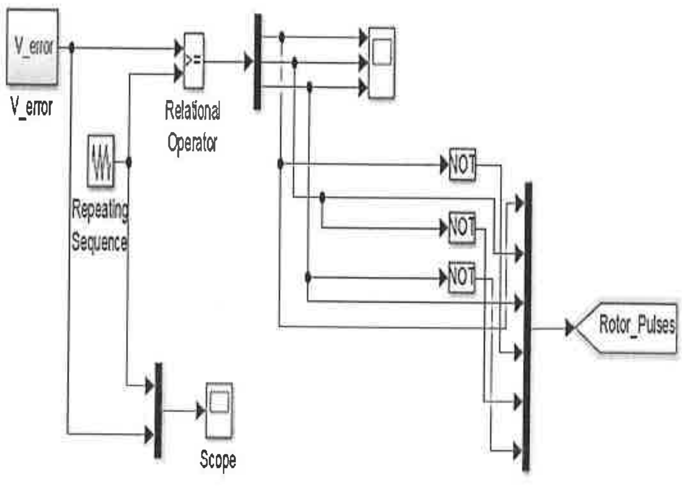

Fig.7 The Simulink model of PWM controller

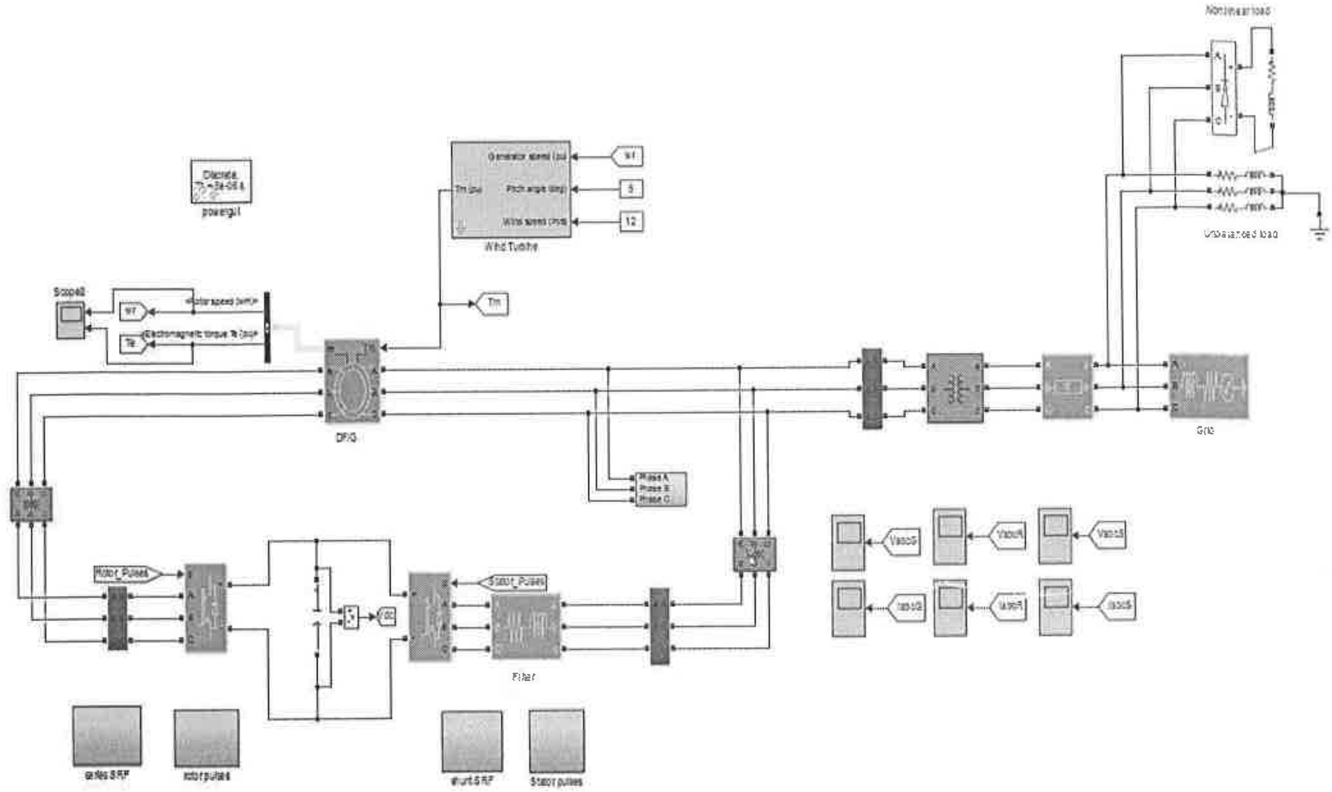

Fig.8 Simulink model total system

VI. RESULTS AND DISCUSSION

The above Fig.8 shows the Simulink model of total system. Here the DFIG of the stator is directly connected to the grid via a transformer and the rotor is connected via sliprings to a back to back converter. The rotor currents to achieve a variable speed necessary for maximum energy capture in variable winds. The Series APF is used in RSC and shunt APF are used in GSC. Fig.9 results show voltage and current waveforms of disconnected nonlinear and unbalanced loads of DFIG system at the grid.

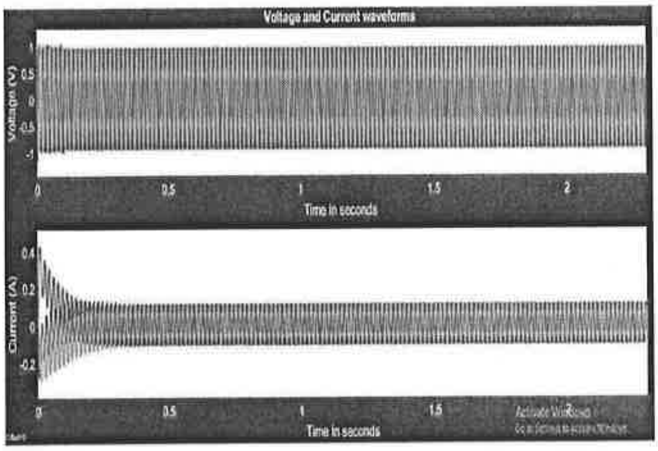

Fig.9 Steady state voltage & current waveforms

The implementation of the UPQC controller with different control strategy for partial alleviating voltage sag, voltage swell and load current harmonics is implemented in a DFIG based grid connected wind power system. The success of system is proven by comparing without and with proposed PI controller. The value of P & I are chosen by trial and error method appropriate for compensation. The below figures show comparison between without and with controller of voltage and current waveforms of RSC, GSC and integrating grid of the stator.

The Fig.10 & Fig.13 shows without and with controller of voltage and current waveforms of RSC respectively. By using controller to controlled inrush currents in RSC. Similarly, the Fig.11 & Fig.14 shows without and with controller of voltage and current waveforms of GSC respectively. Here the rotor inrush voltage and current passed into the GSC. By using controller to controlled inrush voltage in GSC and the Fig.12 & Fig.15 shows without and with controller of voltage and current waveforms of the stator in DFIG system.

The performance comparison results in Fig.16 & Fig.17 of a source current total harmonic distortion (THD) without controller is 45.78% and UPQC with PI controller of source current harmonics achieved is 1.69%. Thus, the performance of UPQC is improved by partial mitigating voltage sag, voltage swell and the THD of a load current is drastically diminished.

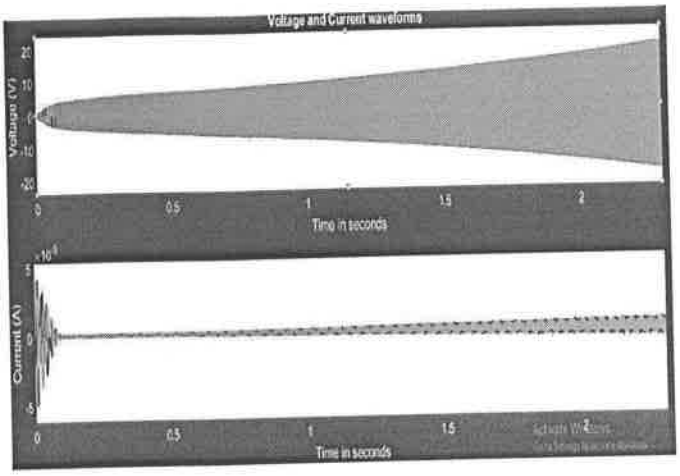

Fig.10 Without controller of voltage and current waveforms of RSC

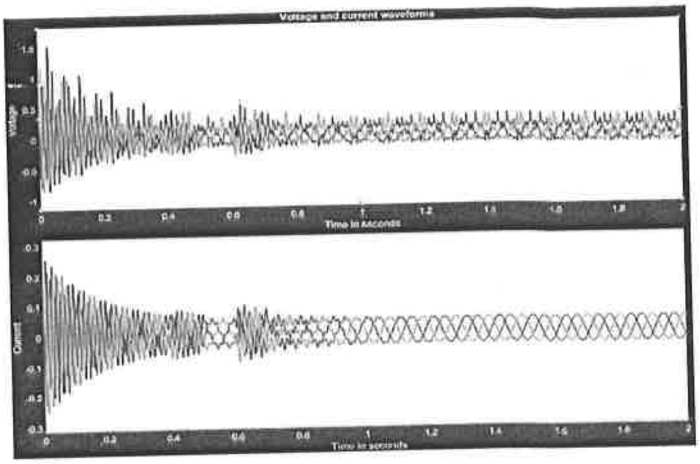

Fig.13 With controller of voltage and current waveforms of RSC

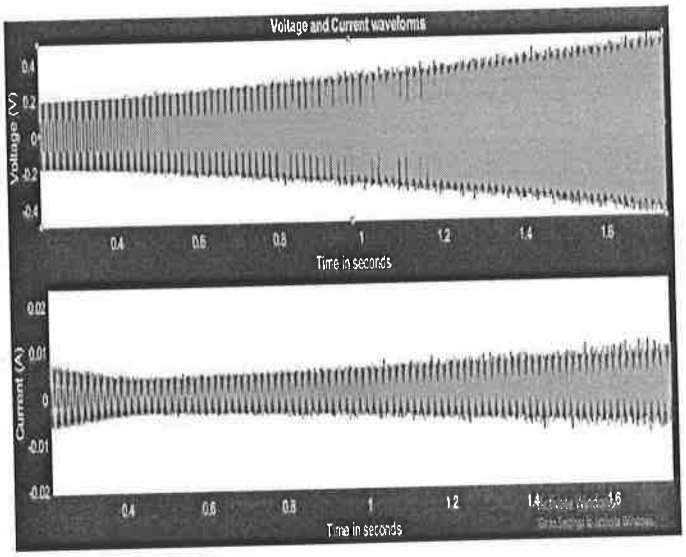

Fig.11 Without controller of voltage and current waveforms of GSC

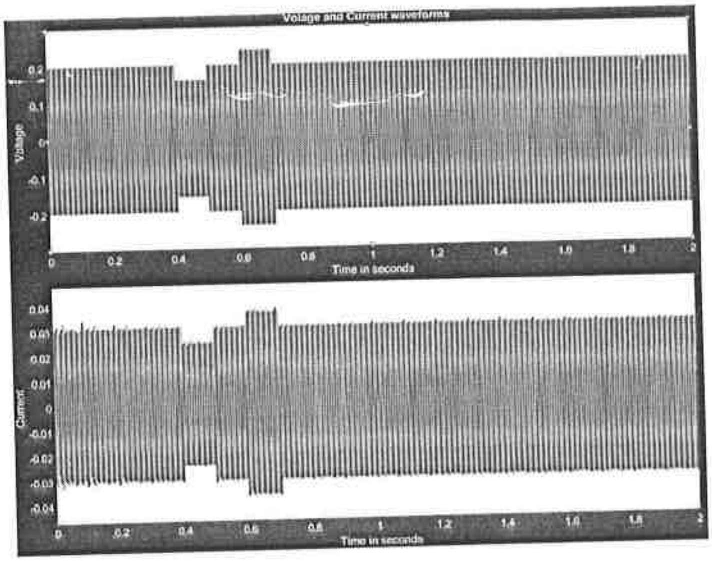

Fig.14 With controller of voltage and current waveforms of GSC

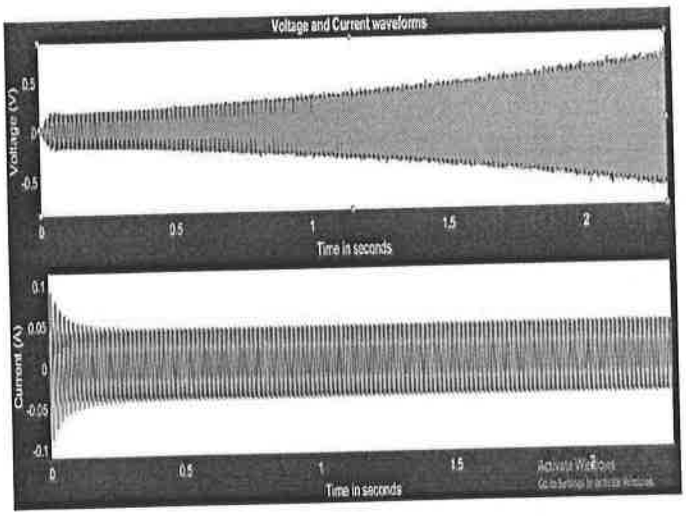

Fig.12 Without controller of voltage and current waveforms of stator

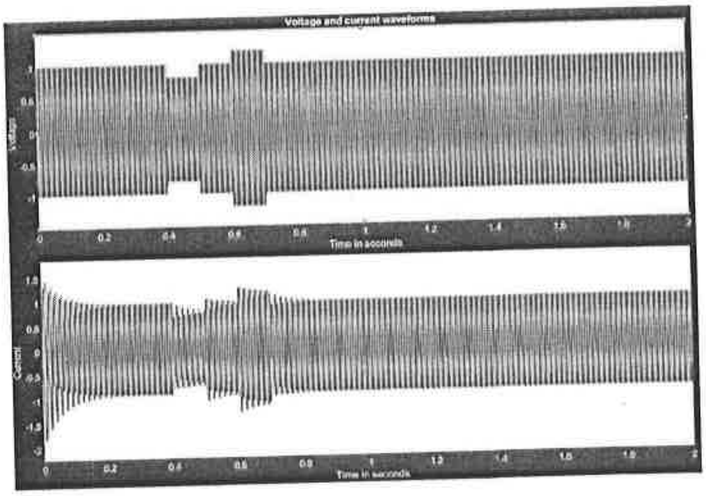

Fig.13 With controller of voltage and current waveforms of stator

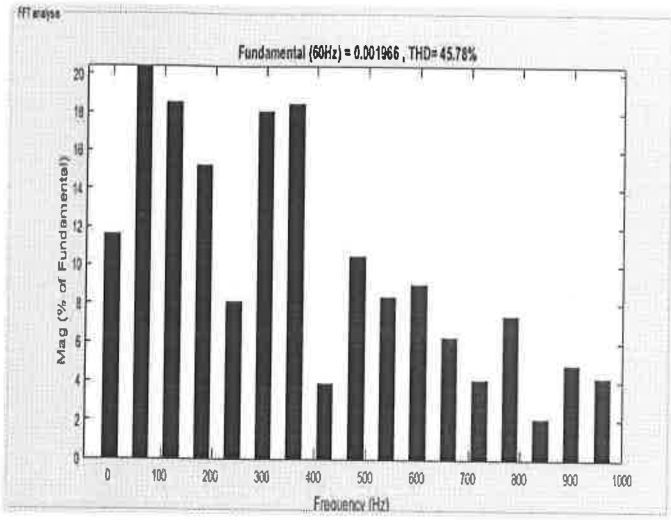

Fig.15 THD of source current without controller

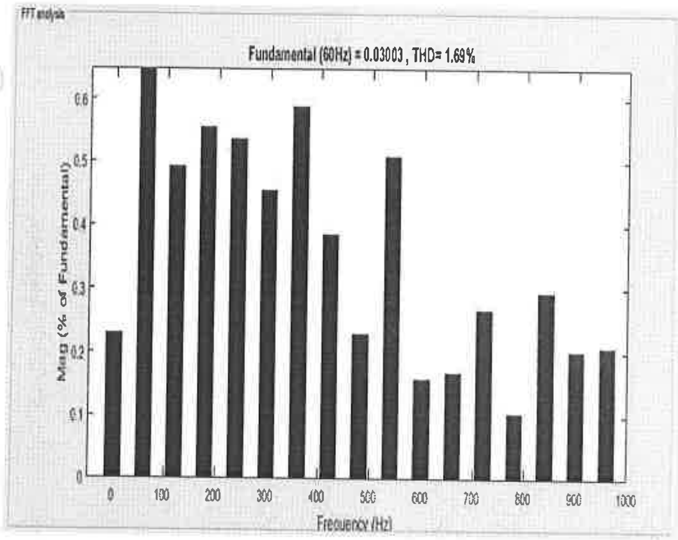

Fig.16 THD of source current with PI controller

TABLE-I
DFIG SYSTEM PARAMETERS

Mechanical output power	2.5MW
Voltage (line-line)	690V
Rated frequency	60HZ
Pole pairs	4
Synchronous speed	1200 rpm
Stator resistance R_s	0.00488
Stator leakage inductance L_{ls}	0.09231
Rotor resistance R_r	0.00549
Rotor leakage inductance L_{lr}	0.09955
Mutual inductance L_m	3.9579
Inertia constant	3.25
Friction factor	0.05479

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