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Control Strategy for Total Harmonic Distortion Reduction in Generated Voltage for Grid Connected DFIG under Symmetrical & Unsymmetrical Fault Conditions

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Abstract- Variable-speed DFIG wind energy system is one of the main WECS configurations in today's wind power industry. The variable-speed operation is possible due to the power electronic converters interface allowing a full (or partial) decoupling from the grid. For a DFIG based wind energy system, the rotor-side converter (RSC) controls the torque and active/ reactive power of the generator while the grid-side converter (GSC) controls the DC-link voltage and its AC-side reactive power. The stability of DC link capacitor voltage is very important in ensuring that a nearly sinusoidal voltage is delivered by the grid side converter which is used as inverter. The fluctuations in the dc-link voltage cut down the lifetime and reliability of capacitors in voltage source converters. The present paper explores one of the extremely important issues regarding the WECS i.e. wind energy conversion system and its reactive power management under certain common types of faults which are both symmetrical and unsymmetrical. With continuously increasing penetration of the wind energy in the overall energy market, this issue is gaining significant prominence. The paper compares the capability of the DFIG based wind energy conversion system to maintain the value of its DC-link capacitor constant. The analysis was performed for normal, symmetrical fault and unsymmetrical fault conditions on DFIG integrated with grid using MATLAB/ SIMULINK.

Index terms -wind energy conversion system (WECS), DFIG, PI controller, dc-link voltage, symmetrical and unsymmetrical fault, RSC, GSC

1 INTRODUCTION

With increased penetration of wind power into electrical grids, doubly fed induction generator wind turbines are largely deployed due to their variable speed features and hence influencing system dynamics. The DFIG system is currently used for multi-MW Wind turbines. DFIG is a popular wind turbine system due to advantages like it can operate in generator and motor mode for both sub and super synchronous speed mode, also speed variation of ±30% around synchronous speed can be obtained, and the size of the converter is related to the selected speed range. Variable speed wind turbines are currently the most used wind energy conversion system (WECS). The doubly fed induction generator (DFIG) based WECS (fig. 1), also known as improved variable speed WECS, is presently the most used by the wind turbine industry [1],[3],[4-11].

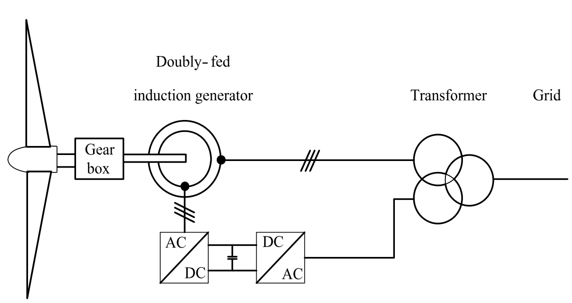

Fig 1.General Structure of an improved variable speed WECS

WECS are highly controllable, allows maximum power extraction over a large range of wind speeds. DFIG is a wound rotor induction generator (WRIG) with the stator windings connected directly through three phase, constant-frequency grid and the rotor windings connected to a back-to-back (AC-AC) voltage source converters (VSC). This system provides variable-speed operation over a large, but restricted range, with the generator behaviour being governed by the power electronics converter and its controllers. The power electronics converter consists of two IGBT converters namely the rotor side converter (RSC) and grid side converter (GSC), connected to a direct current (DC) link [3]. In normal operation, the RSC controls the real and reactive power outputs of the machine. The generator rotor speed increases during a grid voltage dip through control of rotor side converter and the Grid side converter has to transmit the active power from the dc-link to the grid, so that the dc-link voltage is kept within the limits. The Grid side control scheme provides a compensation item, during the faulty conditions to smooth the fluctuations in the grid.

The stator outputs power into the grid at all the time. The rotor, depending on the operation point, is feeding power into the grid when the slip is negative (over synchronous operation) and it absorbs power from the grid when the slip is positive (sub-synchronous operation). In both the cases, the power flow in the rotor is approximately proportional to the slip. The DFIG system therefore operates in both sub and super-synchronous modes with a speed range around the synchronous speed [4],[5],[6],[7],[8],[9],[10],[11].

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2. OPERATING PRINCIPLE OF DFIG

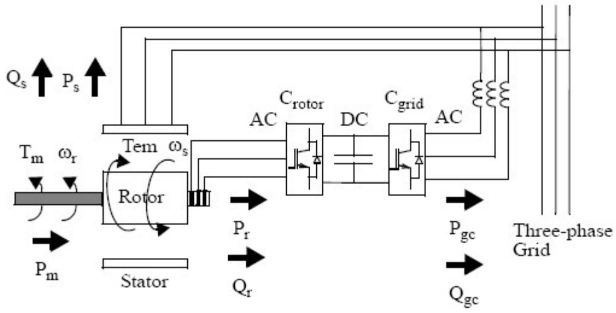

Fig. 2. Power flow diagram of DFIG

The stator is directly connected to the grid while the rotor is fed from the power electronics converter via slip rings to allow DFIG to operate at changing wind speeds. The active and reactive power control is fully decoupled by independently controlling the rotor currents. Finally, DFIG based WECS can either inject or absorb power from the grid, hence actively participating at voltage control. The slip power can flow in both the directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor or stator side converter in both super and sub-synchronous speed ranges.In the fig.2 Crotor and Cgrid have the capability for the reactive power or the voltage at the grid terminals.

3. DC LINK VOLTAGE CONTROL BY PI CONTROLLER

The DC capacitor connecting the stator and rotor side converters facilitates the storage of power from induction generator for further generation. For obtaining total control of grid current, the dc-link voltage must be enlarged to a level higher than the amplitude of grid voltage [1].

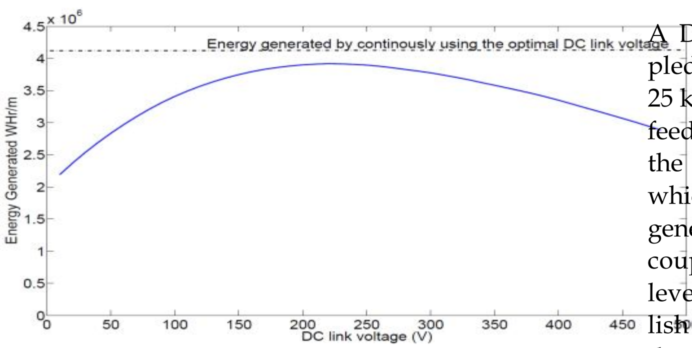

Fig. 3. Energy generated by continuously using the optimal DC link voltage.

3.1 DC-link Voltage Controller

The load fluctuations affect the dc-link voltage directly. The sudden removal of load would result in the dc link voltage above the reference value. While a sudden increase in the load would reduce the dc-link voltage below its reference value. A proportional – integral (PI) controller is used to maintain the dc-link voltage to the reference value. The controller which is used for maintaining the dc-link voltage is shown in fig 4. To maintain the dc link voltage the dc-link capacitor needs a certain amount of real power, which is proportional to the difference between the actual and reference voltages.

$$P_{dc} = K_p(V_{dc\,ref} - v_{dc}) + K_i \int (V_{dc\,ref} - v_{dc})dt. \quad (8)$$

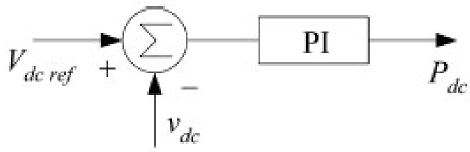

Fig. 4. Schematic diagram of conventional dc-link voltage controller

The response subjected to transient is dependent on the values of K_P and K_i when Pdc is comparable to P_{1avg}.

4. MATLAB SIMULINK MODEL OF DFIG BASED WIND TURBINE SYSTEM

Fig. 5 shows the simulation of grid connected doubly fed induction generator. The DFIG turbine block contains induction generator and the control schemes; these are supply side control and rotor side control.

A DFIG-based wind turbine of 1.5 MW is coupled to a 25 kV bus via 575V/25 kV transformer. 25 kV bus is integrated with 120 kV grid via 5 km feeder and 25kV/120kV transformer. In the Fig. 5 the doubly-fed induction generator (DFIG) which is essentially of a wound rotor induction generator is integrated with grid, there is a direct coupling of stator with grid and IGBT based 2 level PWM converters in the rotor circuit establish the connection between rotor and grid. Both the PWM converters are coupled by dc-link capacitor of 10pF.

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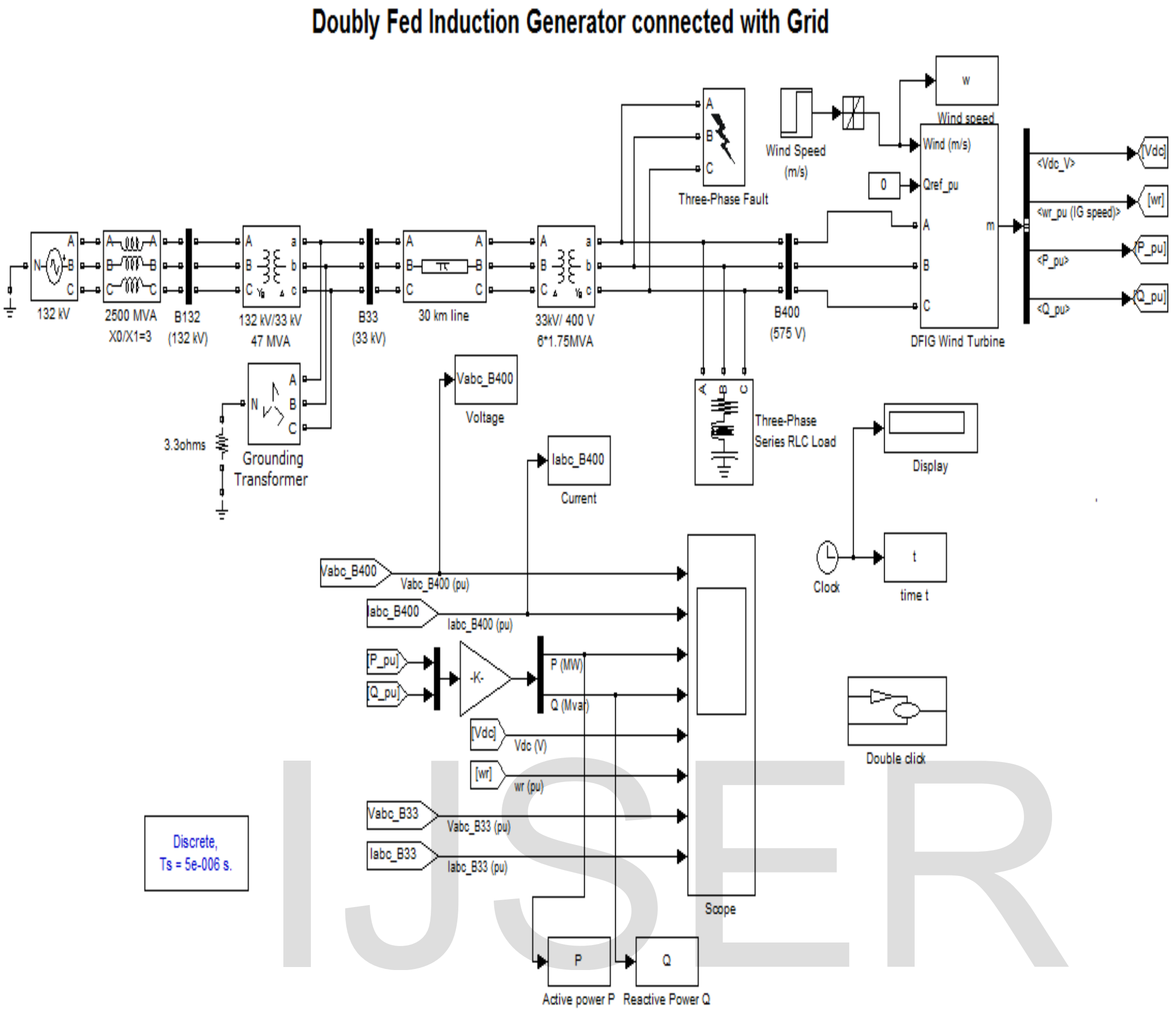

Fig. 5. Matlab Simulink model of DFIG based wind turbine system

5. DFIG WITH PI CONTROLLER UNDER VARIOUS TYPES OF FAULT AND LOAD CONDITIONS:

5.1 Case 1: DFIG with load and no fault:

5.1(a) Voltage at B400:

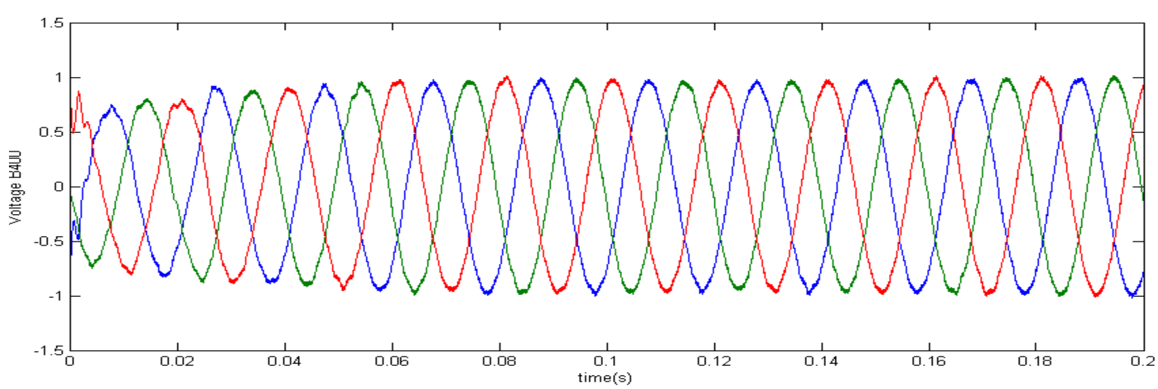

Fig:6 Variation of Voltage at 400V bus with time under load and without fault with PI Controller

5.1(b)DC Voltage:

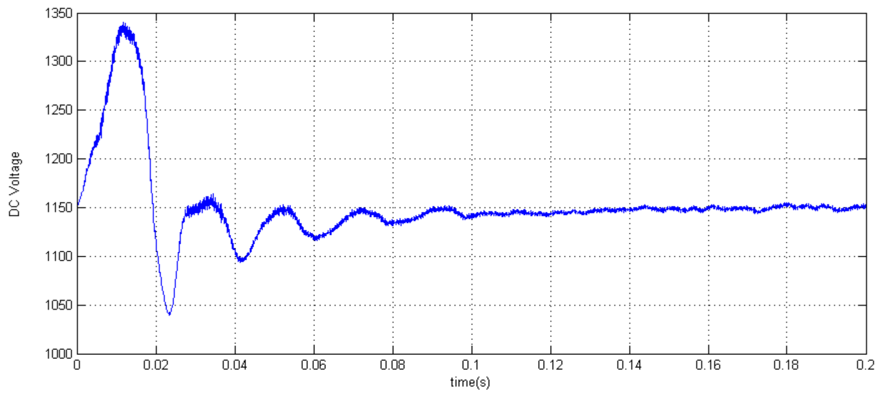

Fig . 7 Variation of Vdc with time under no load and without fault with PI Controller

***5.1(c)THD With PI Controller [no fault]*:159.42%**

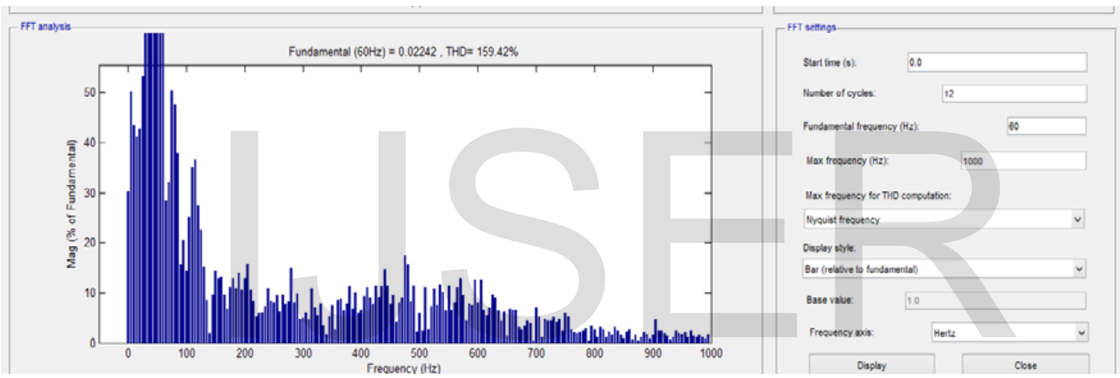

Fig:8 Total harmonic distortion in voltage under load and without fault with PI Controller

5.2 Case 2: DFIG with Load and With 3 Phase Fault:

5.2 (a)Voltage at B400:

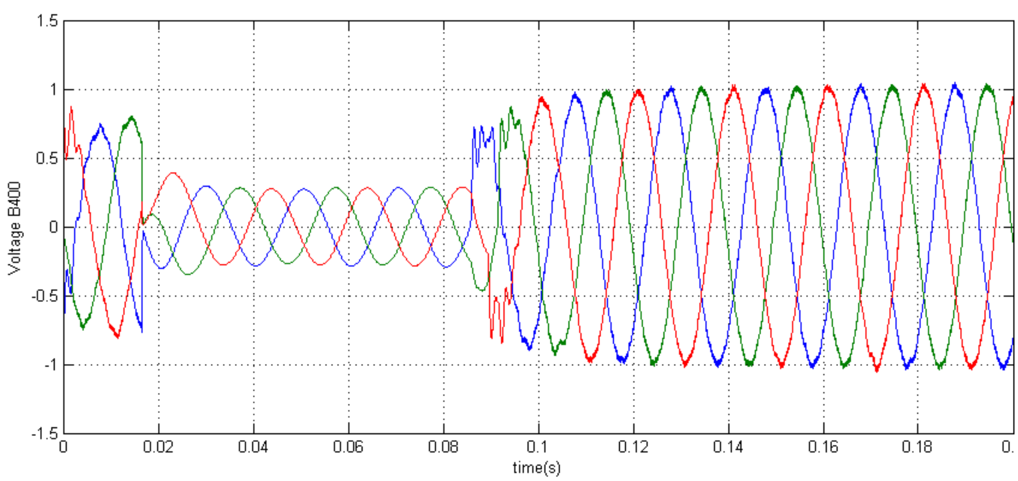

Fig.9 Variation of Voltage at 400V bus with time under load and withthree phase fault with PI Controller

5.2 (b) DC Voltage:

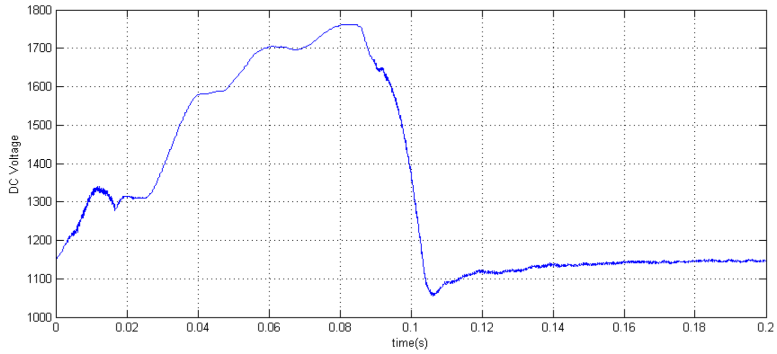

Fig:10 Variation of DC link Voltage with time under load and with three phase fault with PI Controller

***5.2 (c)THD with PI [with 3PH fault]*:75.26%:**

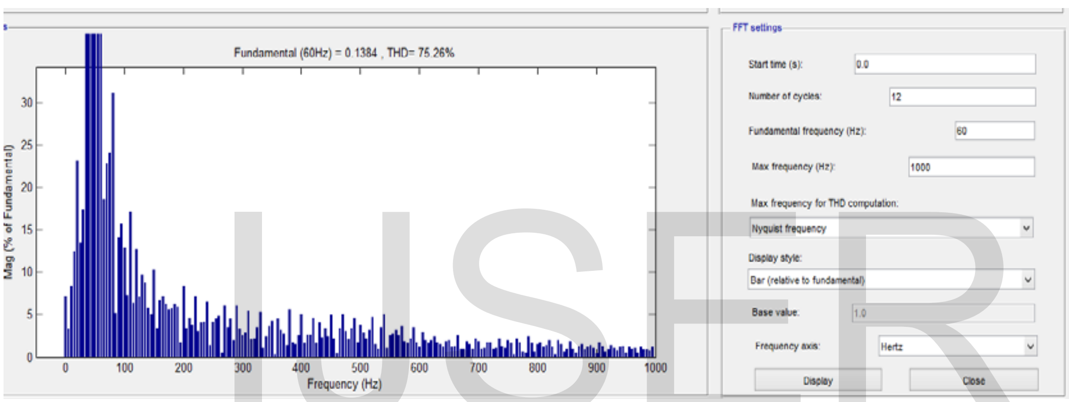

Fig:11 Total harmonic distortionin voltage under load and without fault with PI Controller

5.3 Case 3: DFIG with Load and With Phase A Fault:

5.3(a) Voltage at B400:

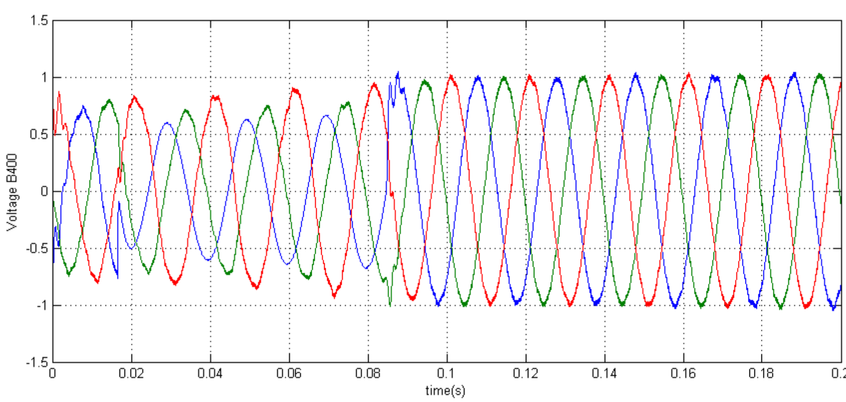

Fig:12 Variation of Voltage at 400V bus with time under load and withfault on phase A with PI Controller

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5.3 (b)DC Voltage:

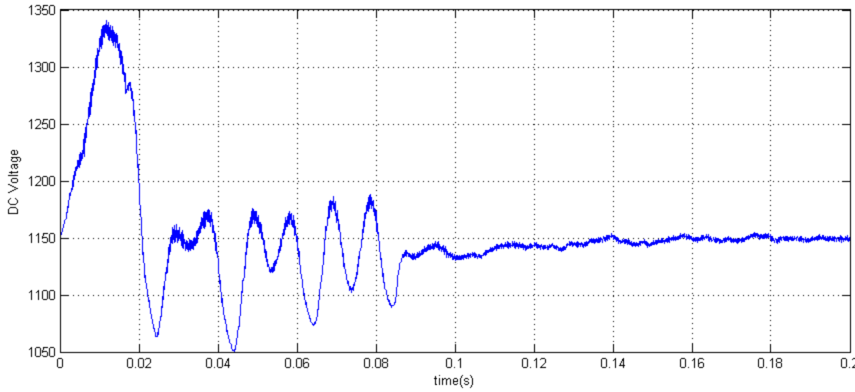

Fig:13 Variation of DC link Voltage with time under load and with fault on phase A with PI Controller

5.3 (c) THD with PI [with PH A fault]96.17%:

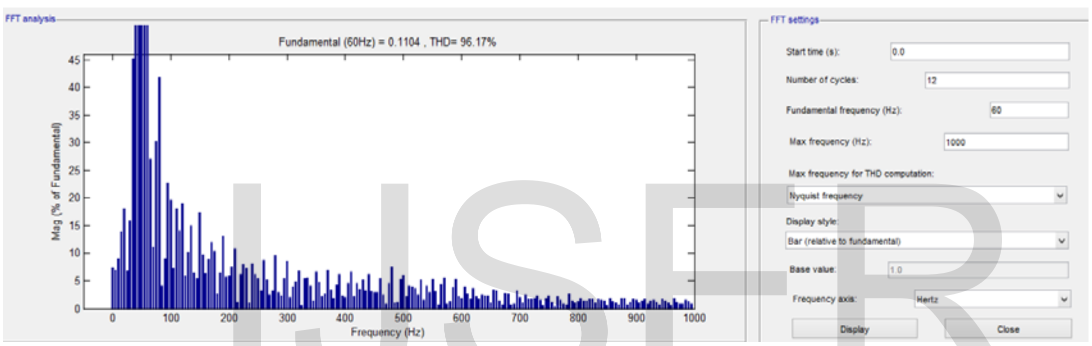

Fig:14 Total harmonic distortionin voltage under load and without fault with PI Controller

6. DFIG WITHOUT PI CONTROLLER UNDER VARIOUS TYPES OF GRID FAULTS AND LOAD CONDITIIONS.

6.1 Case 1: DFIG with Load and No Fault:

6.1 (a)Voltage at B400:

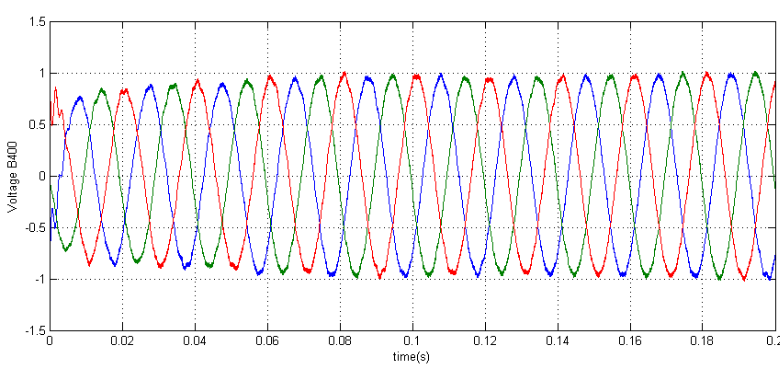

Fig:15 Variation of Voltage at 400V bus with time under load and without fault without PI Controller

6.1 (b)DC Voltage:

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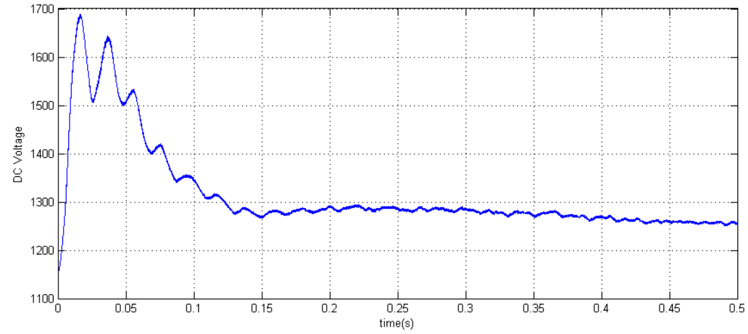

Fig:16 Variation of DC link Voltage with time under load and no fault without PI Controller

6.1 (c) THD without PI [no fault] 186.82%

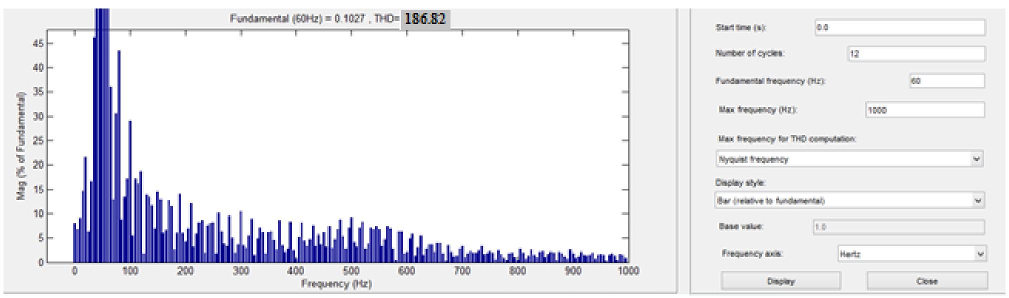

Fig:17 Total harmonic distortion in voltage under load and without fault with PI Controller

6.2 Case 2: DFIG with Load and with 3 Phase Fault

6.2 (a)***Voltage at B400:***

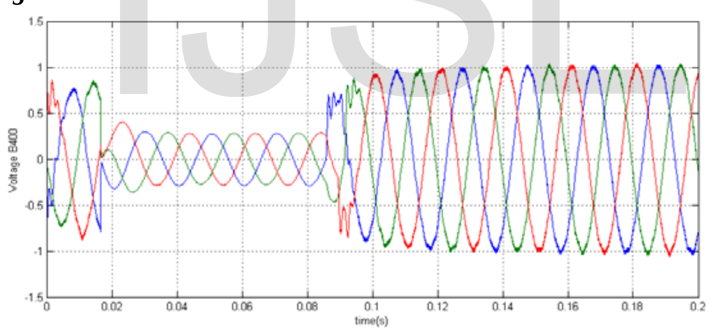

Fig.18 Variation of Voltage at 400V bus with time under load and with three phase fault without PI Controller

6.2 (b)DC Voltage:

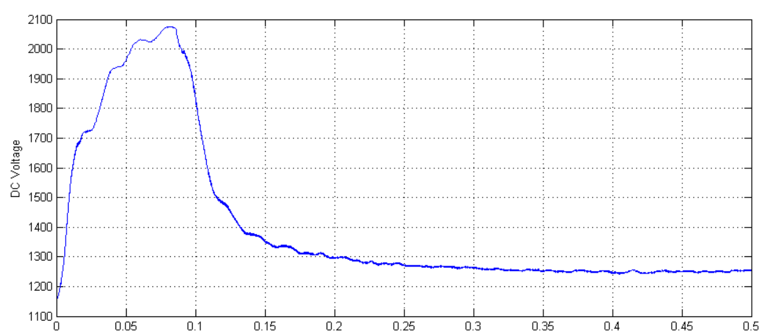

Fig.19Variation of DC link Voltage with time under load and with three phase fault without PI Controller

6.2 (c) THD without PI [with 3PH fault]: 81.71%

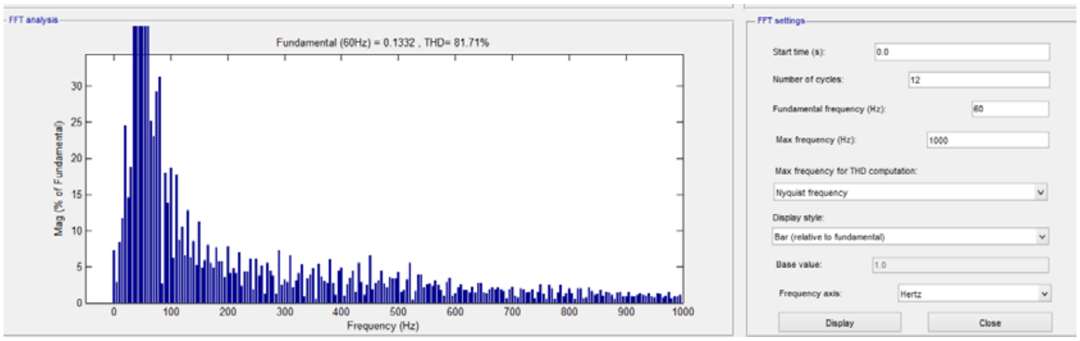

Fig:20 Total harmonic distortionin voltage under load and without fault without PI Controller

6.3 Case 3: DFIG with Load &Phase A Fault:

6.3 (a) Voltage at B400:

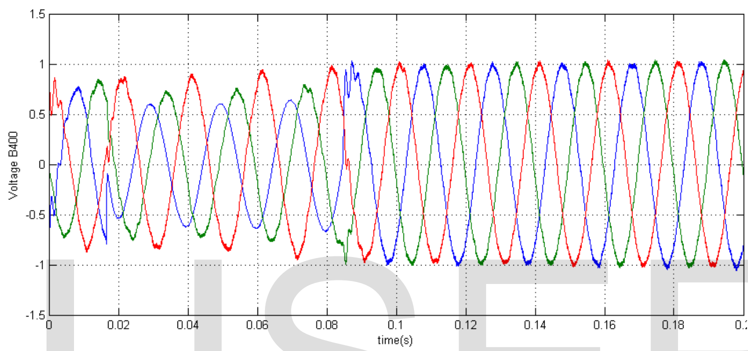

Fig:21 Variation of Voltage at 400V bus with time under load and withfault on phase A without PI Controller

6.4(b)DC Voltage:

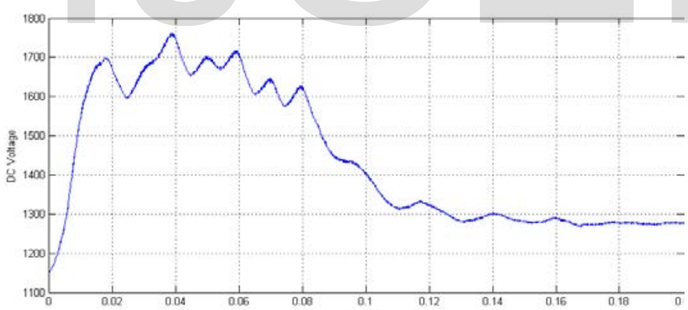

Fig:22 Variation of DC link Voltage with time under load and with fault on phase A without PI Controller

6.4(c)THD without PI [with PH A fault]:104.38%

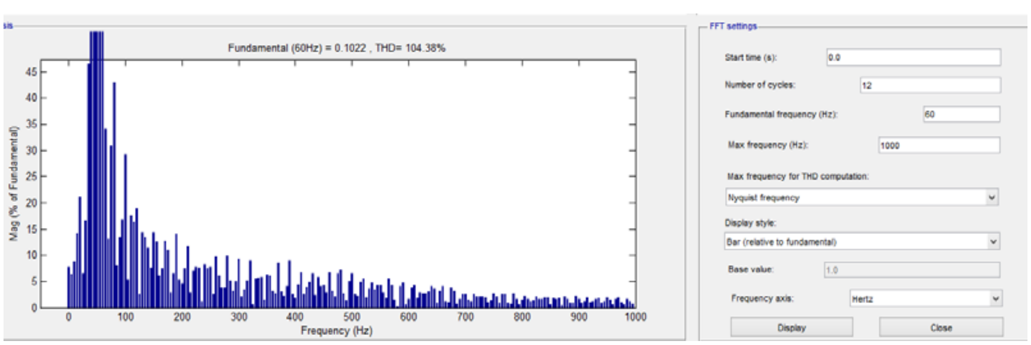

Fig:23 Total harmonic distortionin voltage under load and with faulton phase A without PI Controller

TABLE:1 :COMPARISON OF TOTAL HARMONIC DISTORTION UNDER VARIOUS OPERATING CONDITION

Status of load	**Status of Fault**	**Total Harmonic Distortion**	
On Load		Without PI Controller	With PI Controller
	No Fault	**186.82%**	**159.42%**
	line to ground fault at phase A	**104.38%**	**96.17%**
	3 Phase fault	**81.71%**	**75.26%**

7. CONCLUSION:

The fluctuations in the DC-link voltage cut down the lifetime and reliability of capacitors in voltage source converters [1]. The present paper explores one of the extremely important issues regarding the WECS i.e. wind energy conversion system and its reactive power management under certain common types of faults which are both symmetrical and unsymmetrical. With continuously increasing penetration of the wind energy in the overall energy market, this issue is gaining significant prominence. The paper compares the capability of WECS using a DFIG to maintain its DC Voltage value as close as possible to the value of 1150 V. By comparing the results we found that PI Controller is useful in reducing the THD i.e. Total harmonic distortions and in also reducing the DC Voltage fluctuations and maintains its value as close as possible to value of 1150V. The simulation was performed for normal, symmetric fault, unsymmetrical fault and load conditions on DFIG integrated with grid under MATLAB/ SIMULINK.

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