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Resonance Damping of Weak Grid Connected DFIG Generation System

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ABSTRACT

This work presents control of grid connected DFIG system with the HFR damping and harmonics suppressor. In order to improve the performance of the system and reduce harmonic content of the weak grid, the HFR needs to be effectively damped. In this work, the proposed active damping control strategy implemented effectively both in the Rotor Side Converter (RSC) and in the Grid Side Converter (GSC), through the introduction of virtual positive capacitor by reshaping the DFIG system impedance and mitigate the high frequency resonance.

***Keywords**: High frequency Resonance (HFR), Doubly Fed Induction Generator (DFIG), Rotor Side Converter (RSC) and in the Grid Side Converter (GSC).*

1. INTRODUCTION

An alternative source of energy, which is environmental friendly and attracted most of the attention, is wind energy. Wide spread generation has initiatives to increase the share of wind power in electricity generation. Wind power generation system (WPGS) may be fixed speed and variable speed. Variable speed is most widely used since it has high utility and can be more precisely controlled but it requires Power electronics interface. One such most widely used WPGS is Double Fed Induction Generator (DFIG).

DFIG is a wind generation having dual converter connected to the rotor. One is grid side converter (GSC) and another is Rotor side converters (RSC) which are shared by the same DC bus. The DC bus linkage can manipulate the difference between the mechanical speed of the rotor and the electrical speed of the grid can be compensated via injecting a current with a variable frequency into the rotor circuit. The duo converters assist the regulation of voltage and current at PCC both in the normal operation and faulty operating conditions too.

The grid connected operation of DFIG may increase the harmonics at point of interconnection (POI) and may cause instability of the grid, or may convert the grid into a weak grid. Hence DFIG systems face the double problems of stability and power quality (PQ). When DFIG is connected to the harmonic grid, the POI voltage distortion may contain the different orders harmonic components due to the nonlinear loads and interactions between grid-connected power electronics devices [1]-[6].

IEEE standard 519-2014 [7] recommends THD in grid is less than 5%, all odd harmonics less than 50orders are allowed to exist, where 5th, 7th, 11th, 13th orders harmonics have a lager tolerance than other orders. According to the impedance stability theory [8], the occurrence of resonance is the result of phase angle difference between DFIG system and weak grid at amplitude intersection closes to 180°. Whenever the impedance between weak network and DFIG system interact, it creates the condition of resonance. Generally resonance maybe of two categories; firstly when the network is series compensated and secondly when network is parallely compensated. In series compensation condition sub-synchronous resonance (SSR) occurs which can be overcome by using active damp controller like TCSC [9]. In parallel compensation condition High Frequency Resonance (HFR) occurs. This work focuses to mitigate this condition of HFR by active damping control. The proposed active damping control strategy implemented effectively both in the Rotor Side Converter (RSC) and in the Grid Side Converter (GSC), through the introduction of virtual positive capacitor by reshaping the DFIG system impedance and mitigates the high frequency resonance.

2. MODELLING OF DFIG

DFIG is designed using asynchronous induction generator fed from two ends, one end is connected to the grid and another end is to the two back to back GSC and RSC as shown in figure 1. The converters are designed using three phase 2 level universal bridge inverter with three arms. Both the inverters are linked with Dc link capacitor to stop circulation of leakage current and proper matching of inverters. The RSC controls the rotor voltage to deliver the DFIG stator output active and reactive power, the GSC provides a stable dc-link voltage, and the LCL filter is adopted due to its better switching harmonics filtering performance. The DFIG with parallel compensation and harmonic grid is given by equivalent impedance model is presented in figure-2. As per IST, system stability depends on Zdfig/(Zdfig+Zg) [15]-[17]. If phase angle difference between Zdfig and Zg does not have enough phase margin at the amplitude intersection point, the resonance will occur. the voltage and current at PCC Vpcc and Ipcc can be written as;

$$V_{PCC} = V_g + V_h + I_{PCC}Z_g$$

$$I_{PCC} = I_S - \frac{V_{PCC}}{Z_{dfig}} \quad (1)$$

$$I_{PCC} = I_0 + I_h \quad (2)$$

$$I_{PCC} = \left(I_S - \frac{V_g}{Z_{dfig}}\right)\frac{Z_{dfig}}{Z_{dfig}+Z_g} - \frac{V_h}{Z_{dfig}}\frac{Z_{dfig}}{Z_{dfig}+Z_g} \quad (3)$$

where, I_0 is fundamental frequency component, *Is* is converter output current, I_h is the harmonic current caused by harmonic voltage V_h. It can be concluded from (3) that stability of DFIG system connected to harmonic grid still depends on $Z_{dfig}/(Z_{dfig}+Z_g)$. As long as $1/(1+Z_g/Z_{dfig})$ is stable, stability of DFIG system can be guaranteed.

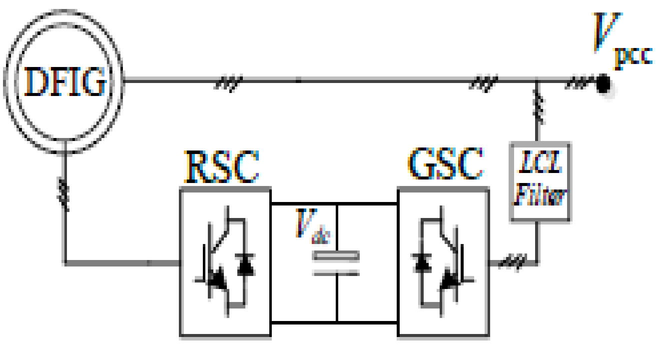

Fig. 1: Principle of a Double Fed Induction Generator connected to a wind turbine

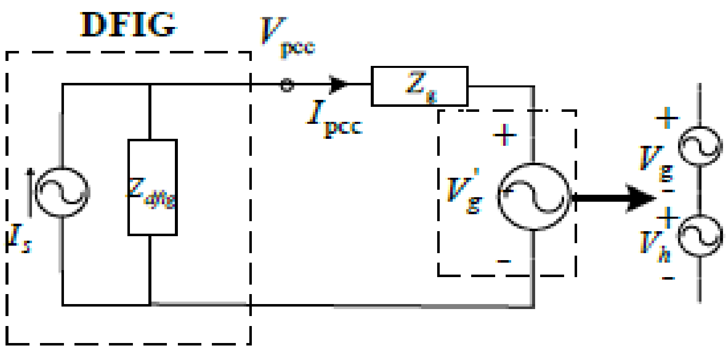

Fig. 2: Equivalent circuit model

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3. PROPOSED WORK

The high penetration of RE may results in various PQ issues and could be a serious threat to the system stability especially in case of DFIG units connected to parallel weak grid. When DFIG is connected to the harmonic grid, the point of common coupling (PCC) voltage distortion may contain the different orders harmonic components due to the nonlinear loads and interactions between grid-connected power electronics devices. According to impedance stability theory [18], resonance will occur when the phase angle difference between DFIG system and weak grid at amplitude intersection closes to 180°. Especially for the parallel compensation grid, a HFR may occur, since DFIG system shows an inductance characteristic in high frequency. HFR if not mitigated in weak grid connected to the parallel DFIG units, may create condition of instability. A proper impedance selection for DFIG units with respect to the grid may prevent the occurrence of HFR phenomenon. Else a virtual impedance insertion at the PCC of grid and DFIG may also mitigate such condition. In this work also a proper damping control strategy is employed by the means of effective impedance control to mitigate the HFR. This can be evaluated by reducing the THD of the system.

This work proposes active HFR damping control strategy implemented effectively both in the RSC and in the GSC, through the introduction of virtual positive capacitor by reshaping the DFIG system impedance and mitigate the high frequency resonance. When HFR frequency is close to harmonic frequency (5th, 7th, 11th, 13th…), HFR damping controller will couple with resonant regulator based harmonic current suppression, which can cause degraded suppression performance on HFR and harmonic current. The proposed control is implemented using impedance stability theory (IST); according to which the complete system is converted into thevenin's equivalent circuit.

Table 1: System parameters

Components	Ratings
DFIG	9 MW
Stator parameters (Rs, Ls)	0.0108, 0.102
Rotor parameters (Rr, Lr)	0.012, 0.11
Fundamental grid Voltage	1pu
Three phase transformer	10.5 MVA
Mutual inductance three phase	0.96mH
System frequency	50Hz
Grounding Transformer	100 MVA
Series L filter	5e-3
Parallel RC filter	0.1Ω and 500µF

3.1 Proportional Resonant (PR) controller

The digital PR controller in Fig. 3 consists of a proportional gain (kp) added to a resonant path. The resonant path consists of the resonant gain (ki) and the resonant filter, which is described by a z-domain transfer function Hr(z) and it is given by equation below;

$$Hr(z)=\frac{b_0+b_1z^{-1}+b_2z^{-2}}{a_0+a_1z^{-1}+a_2z^{-2}}$$

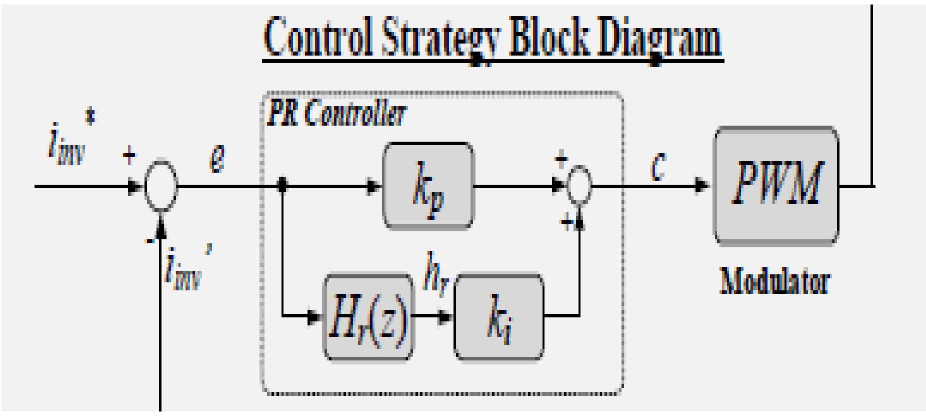


Fig. 3: Control architecture

Table 2: Parameters for PR controller

Parameter	Variable	Value
Proportional Gain	Kp	0.827435088694
Resonant Gain	Ik	234.028059558631
B_0	b_0	3.14159265359 e-4
B_1	b_1	3.14159265359 e-4
B_2	b_2	0
A_0	a_0	1
A_1	a_1	1.999528003287
A_0	a_2	0.999685890077

3.2 Damping Controller

When the parallel compensation grid has the harmonic voltage components, the PCC current can be represented as (2).

In traditional control strategy [9]-[12], the resonant regulator was usually employed to suppress the harmonic current. When HFR frequency is close to harmonic frequency (5th, 7th, 11th, 13th…), HFR damping controller will couple with resonant regulator based harmonic current suppression, which can cause degraded suppression performance on HFR and harmonic current. The transfer function with the proposed damping controller is given below with the parameters;

$$H_s=\frac{s^2}{s^2+ks+\omega_c}$$

With K=85 and ωc is frequency in hz with 600.

4. SIMULATION RESULTS

To eliminate HFR related stability issue a proportional resonant (PR) controller has been designed in matlab-simulink. The parameters for the controller have been presented in table-1 Secondly the impedance reshaping is done by introducing filter element between DFIG and grid. The design of the RSC and GSC include PLL, current PR controller and DC controller. The system has been analyzed under two conditions;

a) Without PR controller + filter
b) With PR controller + filter

The complete simulation model of the proposed system is presented in figure 4. The DFIG system is connected through a transformer for variable wind speed. The rating of transformer is 10.5 MVA with 25k to 575 V. the other end of the system is connected to a three phase programmable voltage source which acts as a replica for grid. At POI grounding transformer is connected to ground the leakage current if occurs. The control for DFIG is given in figure 5. It consist of two converters one is series and another is parallel linked at common DC bus. A filter is connected having RC elements with 50 MVAr reactive power. The simulation model of the proposed PR controller is shown in figure 6. The voltage and current waveforms without proposed controller is shown in figure 7. The bode plot at this condition is presented in figure 8 which shows that the un-damped system may suffer from stability issues and contains high harmonics. The voltage and current waveforms without proposed controller is shown in figure 9. The bode plot at this condition is presented in figure 10. This shows that the potential stability risk existed in the HFR can be mitigated with the damping strategy cooperated with harmonic current suppressor, also the existed HFR damping control has low THD which tabulated in table 3. In order to implement the HFR damping and harmonic current suppression simultaneously, this paper proposes an impedance characteristic reshaping strategy for DFIG system. Furthermore, HFR frequency detection can be avoided in the proposed strategy, then the unstable problem during the changing of parallel compensation degree in the grid can be solved.

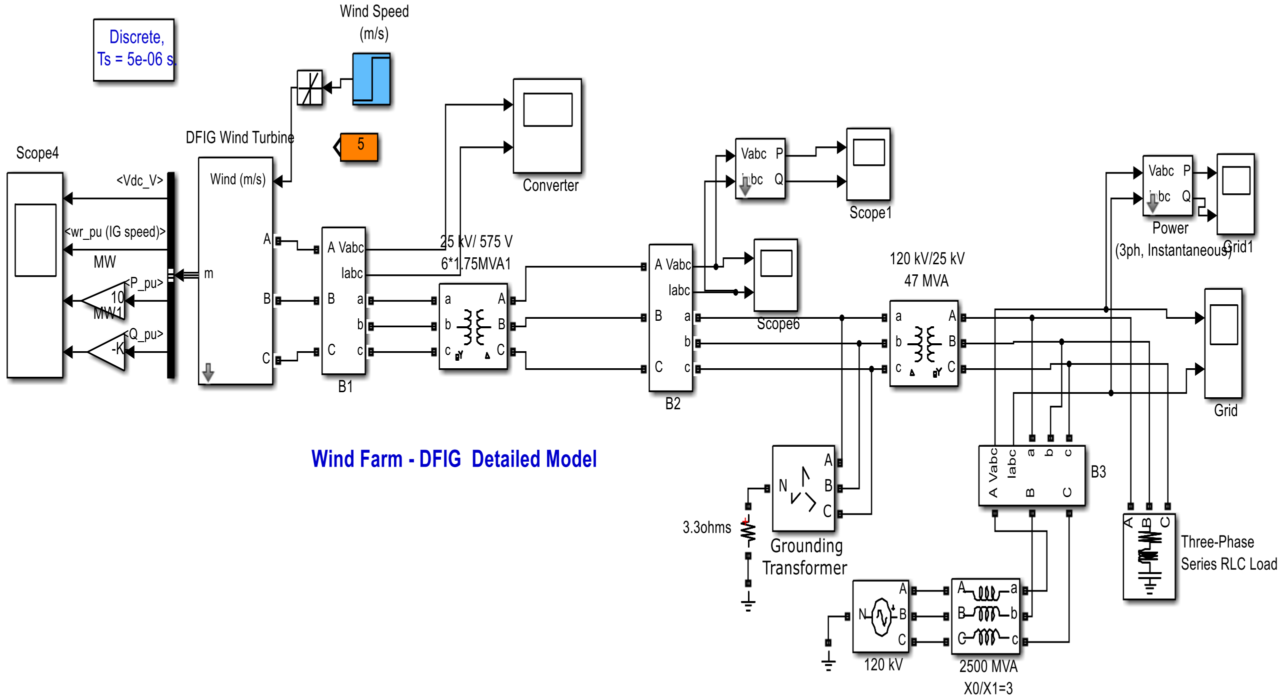


Fig. 4: Simulation model of the proposed system

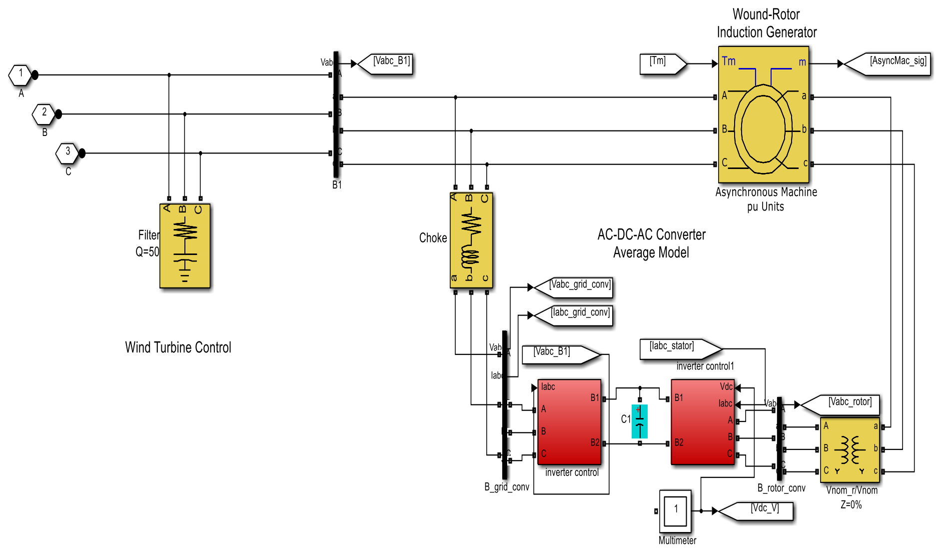


Fig. 5: Simulation model of the proposed DFIG control system

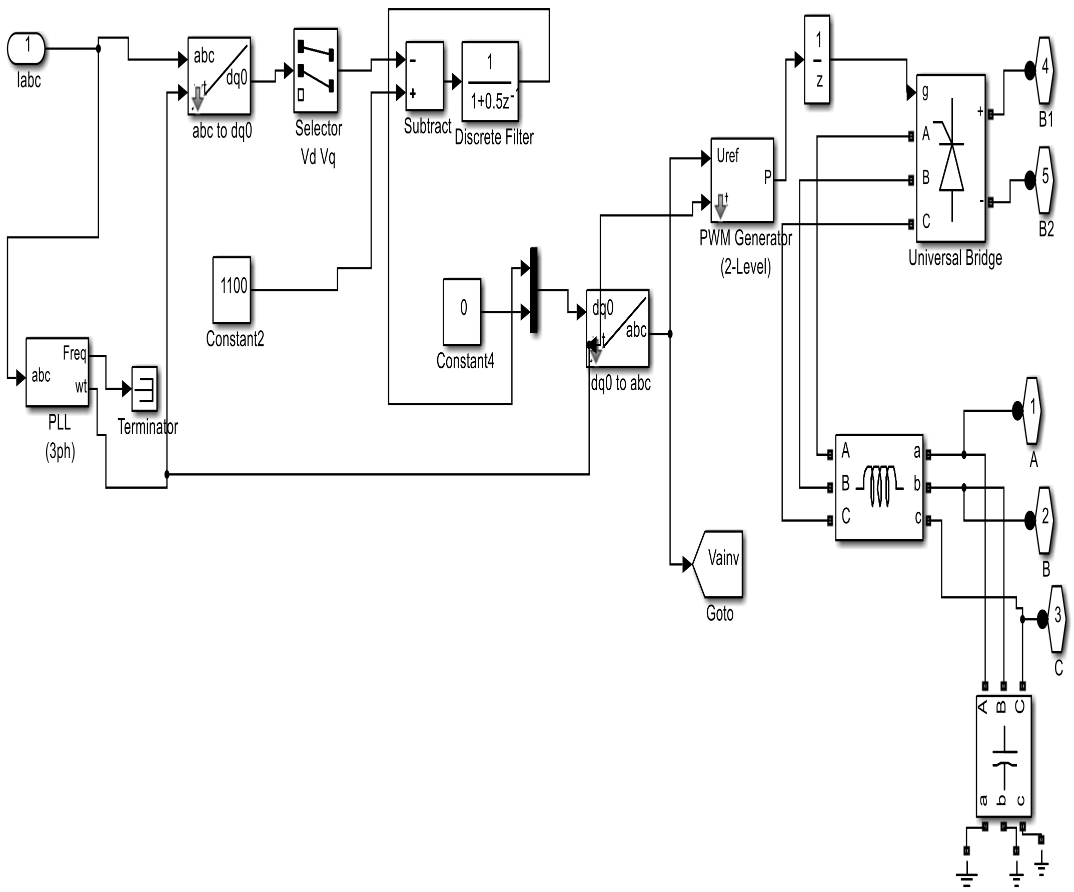


Fig. 6: Simulation model of the proposed PR controller

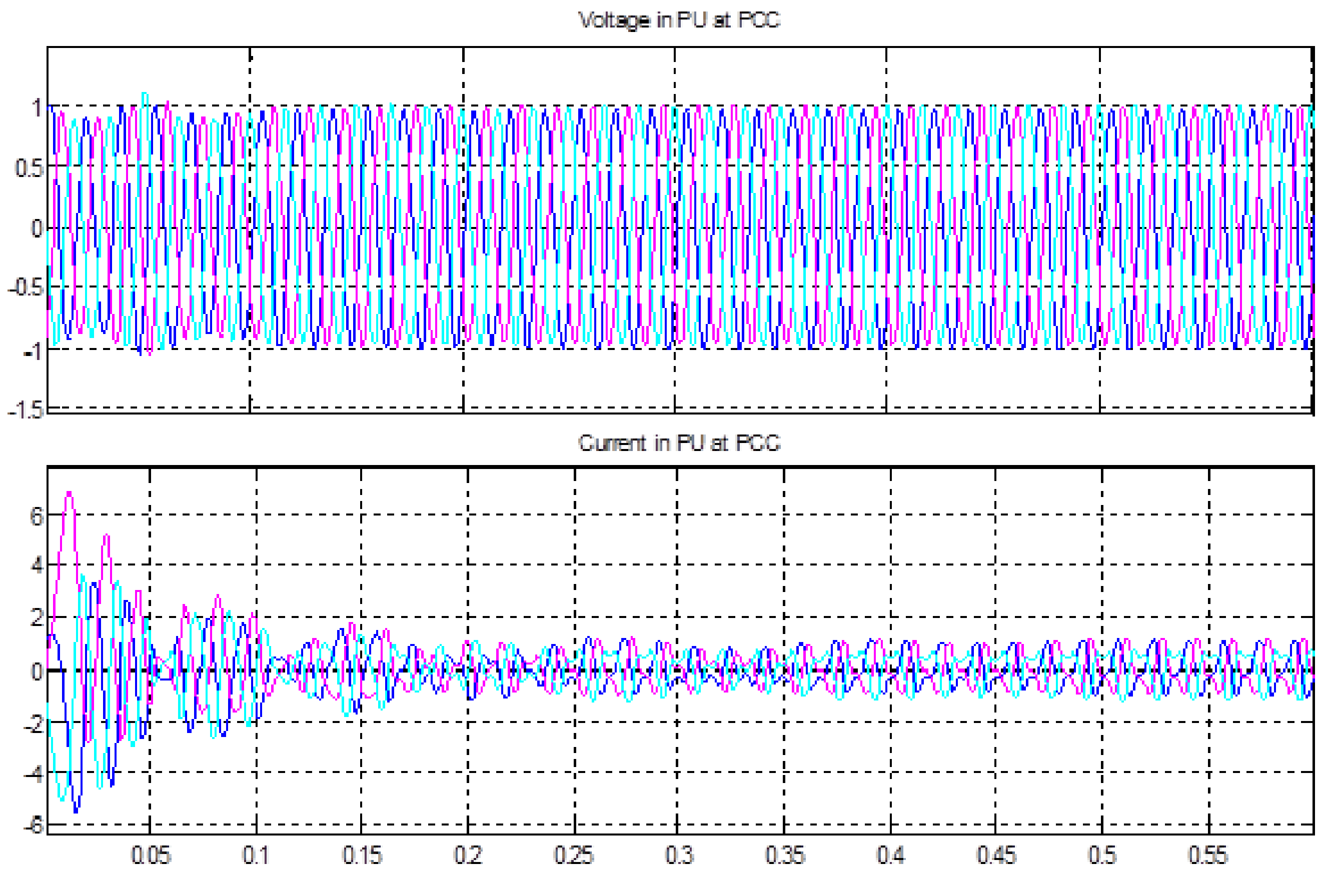


Fig. 7: Output waveform Without PR controller at PCC.

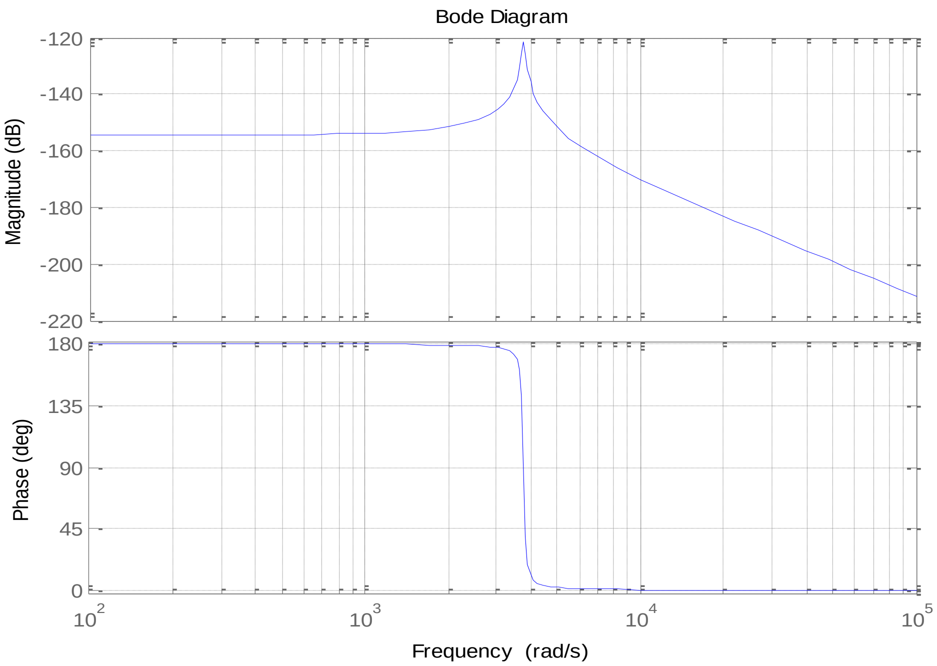


Fig. 8: Bode plot of the proposed system without controller

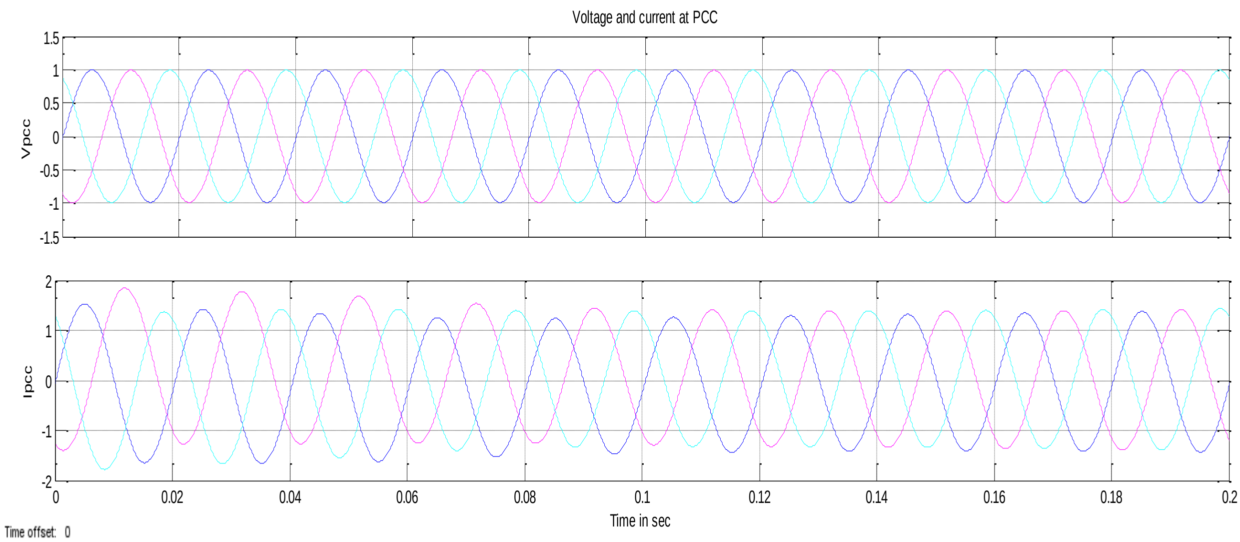
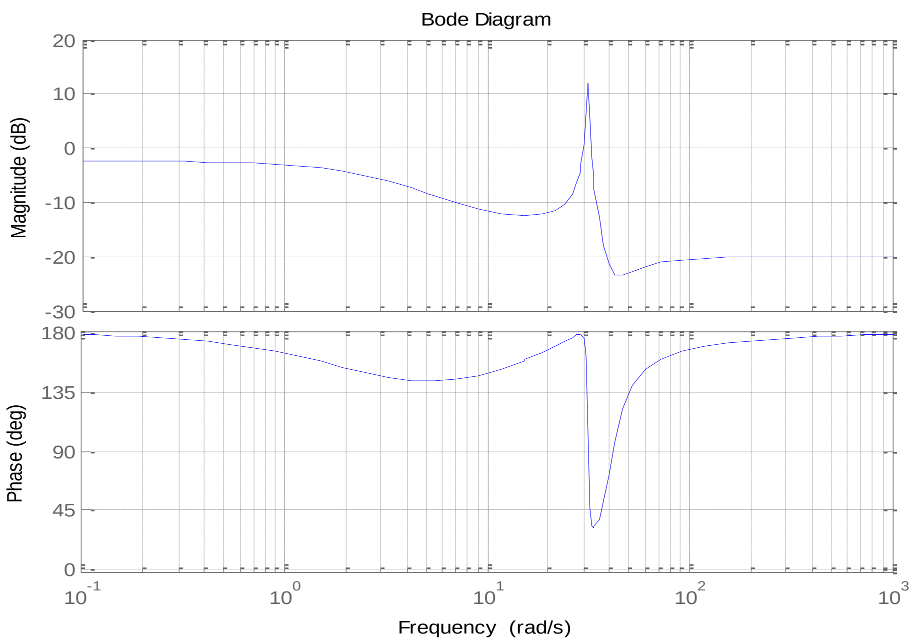


Fig. 7: Output waveform Without PR controller at PCC.



5. RESULT DISCUSSION

System is analysed for variable wind speed with the proposed control. When the parallel compensation capacitor of 500μF is connected across the harmonic grid the THD of the voltage and current at PCC at fundamental frequency is 0.14 and 0.94 % respectively. It can be seen that the proposed control strategy can suppress current harmonics significantly. Also the ripples in P and Q at 0.02 sec is 5.5 and 4.4 % respectively.

Without parallel capacitor compensation the THD at DFIG side output voltage and current is 10% and 15% respectively where as for voltage and current at PCC the THDs are 0.37% and 15.3% respectively as shown in table 3.

Table 3: THD comparison for higher order harmonics

	Fundamental Component	5orders (250Hz)	7orders (350Hz)	11orders (550Hz)	13orders (650Hz)
Vpcc with PR controller	0.14%	0.13%	0.02%	0.03%	0.03%
Ipcc	0.94%	0.09%	0.05%	0.02%	0.01%
Vpcc without PR controller	1.09%	0.15%	0.5%	0.3%	0.04%
Ipcc without PR controller	2.94%	0.69%	0.8%	0.14%	0.13%

6. CONCLUSION

This paper analyzes stability of DFIG system connected to the harmonic grid with the parallel compensation capacitors. The proposed HFR damping strategies effectively suppress the harmonic current, which may deteriorate the system efficiency.

The improved control strategy of DFIG system based on impedance reshaping is proposed in this paper. With the proposed control strategy, DFIG system is able to simultaneously suppress HFR and harmonic distortion, and can avoid the unstable situation during the changing of compensation degree.

The harmonic spectra analysis for 5th.7,11,13 order harmonic is also presented have a lager tolerance than other orders. Thus, DFIG system should be capable to operate on the harmonic grid voltage and the outputted power quality should satisfy the requirement of grid code.

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