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Performance Analysis of DFIG System Connected to Weak Grid

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ABSTRACT: High penetration of DFIG units in a weak harmonic grid may lead to stability issues due to high frequency resonance (HFR). These HFR occurs due to frequency mismatch and phase angle deviation. 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 paper, 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.

I. INTRODUCTION

The 21st century in India has bought up with new policies and roadmap to increase the renewable energy capacity. Various programs like "Greening the grid" and "Green energy corridors" has been initiated by Government of India to increase the green power generation and also installation of new inter-state and intra-state transmission corridors to evacuate theses Renewable Energy (RE) based electricity among the various states.

The high penetration of RE may results in various power quality issues and could be a serious threat to the system stability especially in case of DFIG units. 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 [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.

As per the impedance stability theory (IST) [8] the system under study is converted into a source and a load-subsystem. The source subsystem is modeled by its Thevenin equivalent circuit consisting of an ideal voltage source in series with output impedance, while the load subsystem is modeled by its input impedance. According to the IST the occurrence of resonance is the result of phase angle difference between DFIG system and weak grid at amplitude intersection closes to 180°. Especially for the parallel compensation grid, a high frequency resonance (HFR), since DFIG system shows an inductance characteristic in high frequency [9]-[12]. HFR existed in DFIG system deteriorates the voltage at PCC as well as output current hence the may results in serious damage to the device connected [2], [13]-[15]. For the improvement of performances of the grid tie DFIG units and to eliminate HFR numerous work has been reported in literature. The proportional-resonant (PR) controller [24], proportional-integral-resonant (PIR) controller [25]-[26] and direct resonant controller (DRC) [9]-[12] was proposed to suppress 5th and 7th orders distorted current. In the weak grid or distributed generation, not only 5th, 7th but 11th, 13th, 17th, 19th orders components will exist in harmonic voltage. Thus, the multi-resonance regulator and repetitive controller (RC) was used to suppress 5th, 7th and high orders harmonic current for grid side converter (GSC) and rotor side converter (RSC) in DFIG system [11]-[12]. In the proposed work GSC and RSC control has been designed with series L and parallel RC filter, rather than the traditional LC filter to achieve the active damping in. The virtual RC impedance is introduced to achieve better performance of harmonic resonance damping.

This paper is organized as; in section II modeling of DFIG impedance based is presented. Section III presents the proposed work with active damping control. Simulation results are presented in section IV. At the end conclusion is given in section V.

II. MODELLING OF DOUBLY FED INDUCTION GENERATION (DFIG)

The basic construction principle comprises of rotor mounted on a shafted connected to the generator through the gear box as shown in Figure-1. 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. 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. At both the ends of converter filters are connected whose parameters are mentioned in Table 2.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 $Z_{dfig}/(Z_{dfig}+Z_g)$ [15]-[17]. If phase angle difference between Z_{dfig} and Z_g 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.

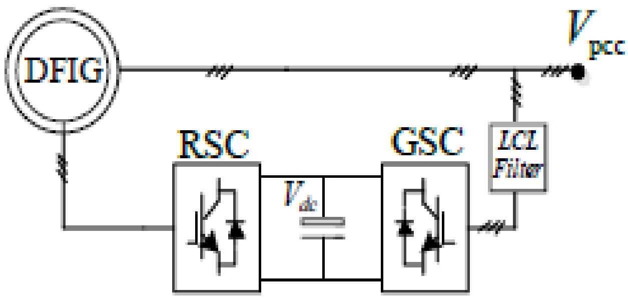

Figure-1. Principle of a Double Fed Induction Generator connected to a wind turbine

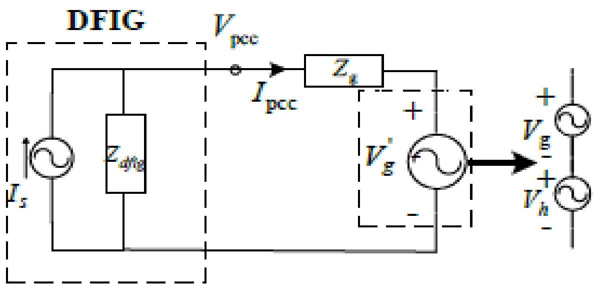

Figure-2. Equivalent circuit model

III. PROPOSED WORK

Firstly, DFIG has been modelled using Synchronous Reference Frame, so that fundamental component of voltage current can be easily extracted. 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 paper, the proposed active 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. In conventional control strategy, 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 proposed work is carried out in two parts; firstly the DFIG system is modeled in SRF two extract the synchronous current signals. Secondly the impedance reshaping is done by introducing filter element between DFIG and grid. The design of the RSC and GSC include PLL, current PI controller and DC controller. The conventional synchronous reference frame PLL (SRF-PLL) is used in this paper to track the phase angle of grid voltage. An ideal PLL should track the fundamental components of the grid voltage only, while the overlarge bandwidth can introduce the disturbance of unbalanced and harmonic grid voltage. The system designed has been analyzed for voltage and current profile at PCC also the harmonic spectrum for higher order of harmonic content is presented.

IV. SIMULATION AND RESULT DISCUSSION

The system has been modeled using MATLAB SIMULINK tool box. The simulation model is given in figure-3.

The rated capacity of the proposed wind turbine is 9 MW. Table-1 shows the component and rating used in the proposed topology. A high pass filter (HPF) is used to for impedance reshaping, which is employed in this paper to increase output impedance of DFIG system within the high frequency range. Also, the HPF should ensure that amplitude difference of DFIG system impedance at fundamental frequency and HFR frequency are large enough, which is helpful to keep fundamental frequency control away from the influence that caused by the proposed HFR suppression controller.

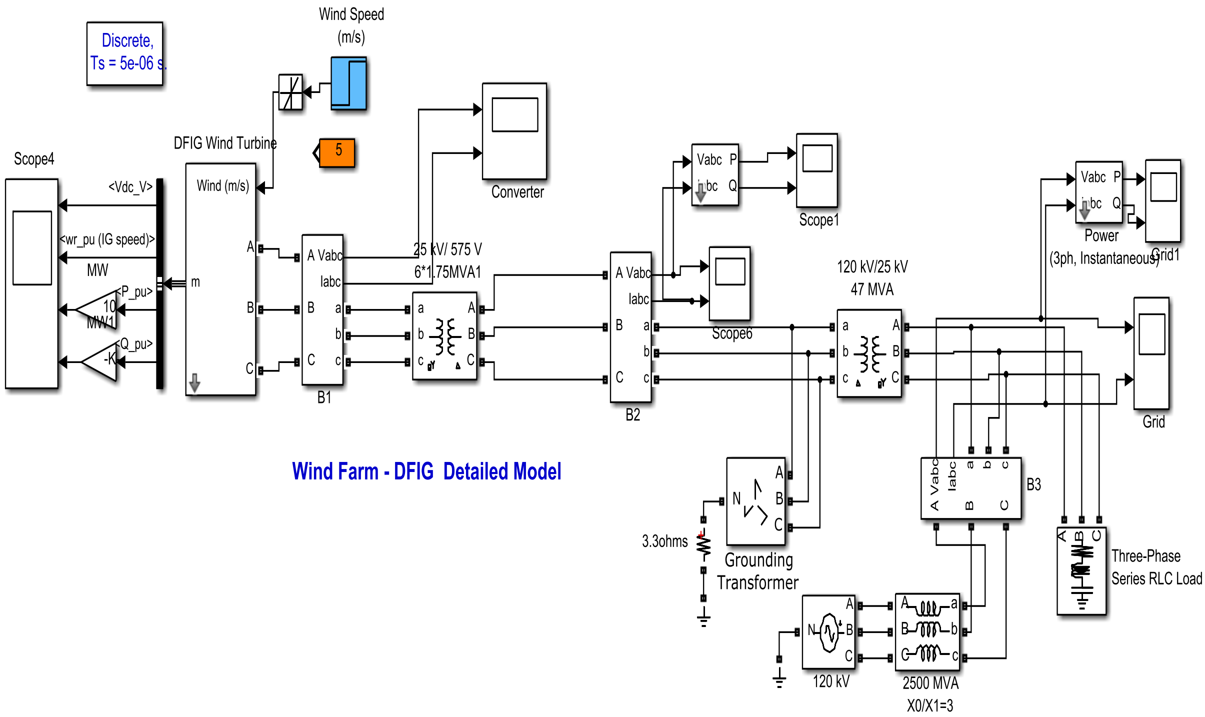

Figure-3 Simulation model of the proposed topology

Table-1 Component and rating used in the proposed topology.

Components	**Ratings**
DFIG	9 MW
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

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. The output voltage and current of DFIG is shown in figure 4 and figure 5 gives the active power P of DFIG. The THD at fundamental frequency for DFIF output voltage and current is 0.74 and 1.4% respectively. The output voltage and current at PCC is shown in figure 6 and figure 7 gives the active power P and reactive power Q at PCC. It can be seen that the proposed control strategy can suppress current harmonics significantly. Also the ripple 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.

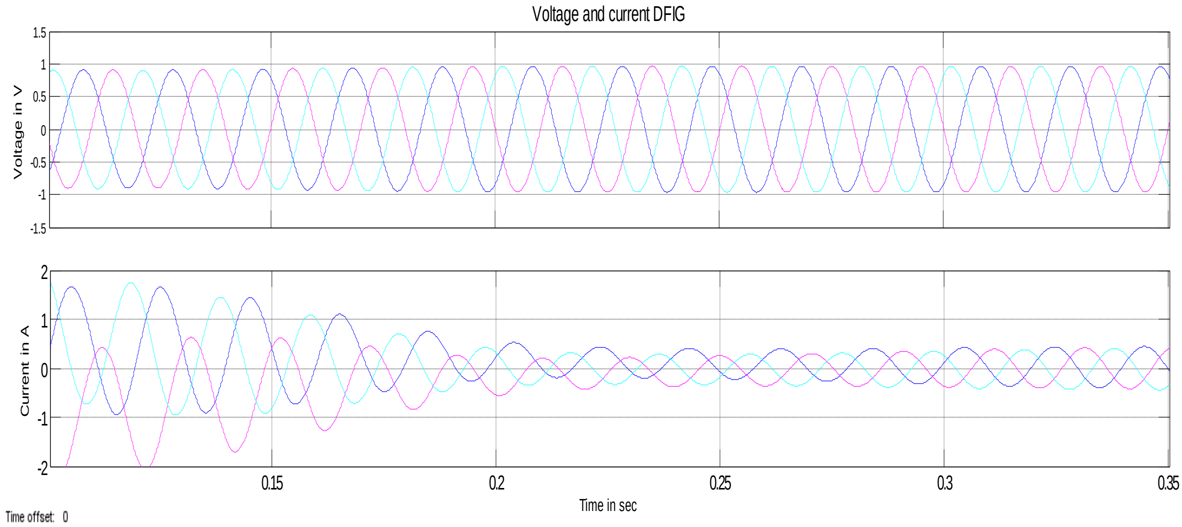

Figure-4 Voltage and current DFIG side

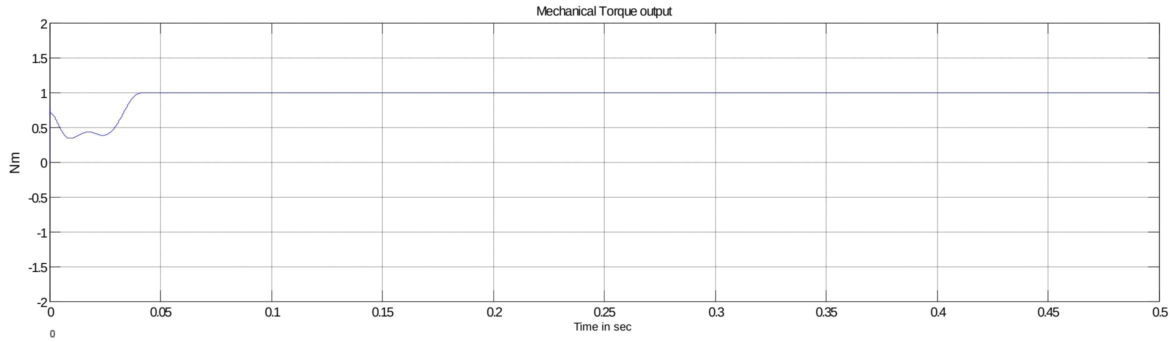

Figure-5 Mechanical torque

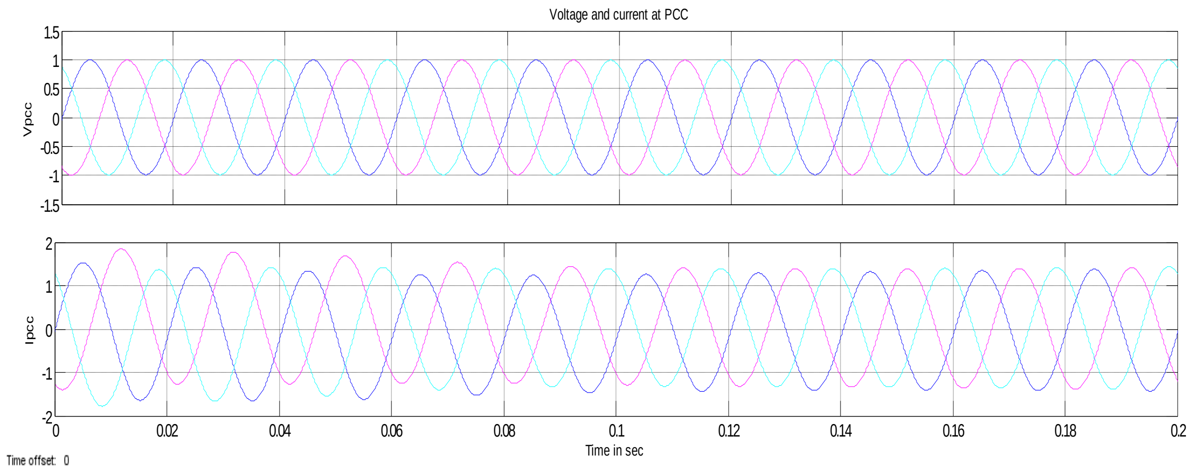

Figure 6 Output waveform at PCC.

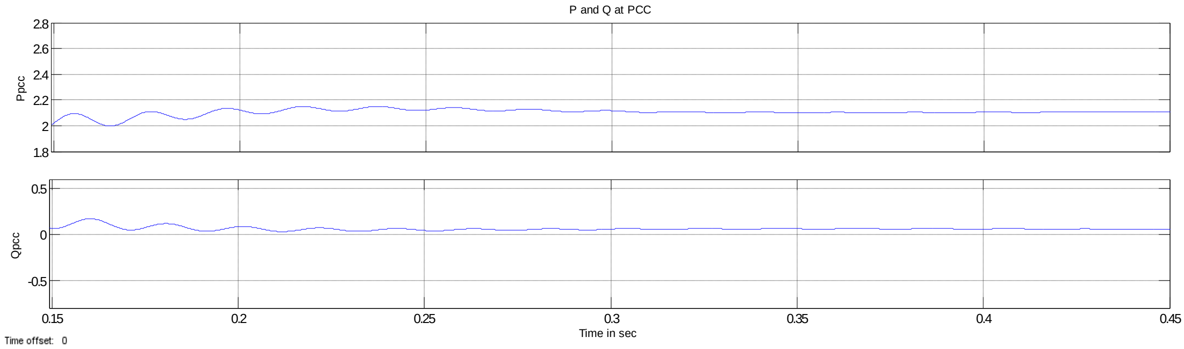

Figure 7. Power output at PCC.

Table-2 Comparison of harmonic

	Fundamental Component	5^{th} order (250Hz)	7^{th} order (350Hz)	11^{th} order (550Hz)	13^{th} order (650Hz)
V_{PCC}	0.14%	0.13%	0.02%	0.03%	0.03%
I_{PCC}	0.94%	0.09%	0.05%	0.02%	0.01%
V_{DFIG}	0.57%	0.1%	0.08%	0.06%	0.04%
I_{DFIG}	1.4%	0.34%	0.24%	0.14%	0.13%

V. CONCLUSION

The performance of DFIG has been studied for the variable speed condition. 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 5^{th},7^{th}, 11^{th}, 13^{th} 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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