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Harmonics Reduction using a Modified Controller for Doubly Fed Induction Generator

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Abstract*: *This paper discusses a control system for the converter of doubly fed induction generator (DFIG) driven by wind energy. The converter of DFIG consists of two main parts; rotor side converter (RSC) and grid side converter (GSC). Two advanced control methods for GSC are presented here in this paper; vector control strategy based on pulse width modulation (PWM) and direct power control (DPC). DPC is based on switching table for voltage vector selection. In addition to grid voltage position, direct and quadrature current components are used here as inputs to the switching table instead of active and reactive powers respectively. This paper proposes a modified switching table for DPC to reduce ripples and total harmonic distortion (THD) of current produced by GSC. A Simulink model for 9 MW wind system based on DFIG is given in this paper. Simulation results are given for PWM, DPC and Proposed system for GSC. In view of THD calculations and simulation results a comparative study and conclusion are given in the end of this paper.

Keywords* : *DFIG, DPC, GSC, THD.

I. INTRODUCTION

The world's attention is directed to new and renewable energy due to the successive increase in population numbers as well as potential concerns about the depletion of traditional energy sources. Wind energy is at the forefront of renewable energy sources as a clean source has a wider availability [1]. In addition, wind energy has minimum maintenance requirements compared with other resources [2].

Nowadays, DFIG is the most common and suitable solution for wind energy conversion systems (WECSs) because of its flexibility and variable speed operation. However, grid connected WECSs based on DFIG have many challenges such as grid stability and power quality issues, maximum power point tracking, control difficulties and sensor-less operation [3, 4].

WECS based on DFIG consists of turbine, wound rotor induction machine and 4-quadrant AC/AC converter. The converter is inserted in the rotor, while the stator is directly connected to grid. Injecting a voltage of slip frequency in the rotor can controls the machine speed [1]. Fig. 1 shows a schematic diagram for DFIG-based WECS.

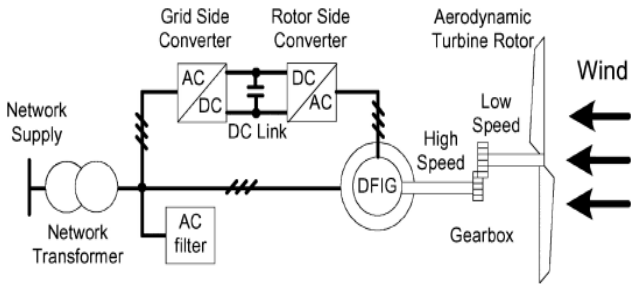

Figure 1 DFIG-based WECS

The 4-quadrant converter enables bidirectional operation, result in sub and super-synchronous operation [5]. This converter is characterized by improved system efficiency due to reduced cost of the converter and the filter because they handle about 25-30 % of the total generated power from the machine [6]. This paper presents two common control methods for GSC in section II. Section III proposes a modified controller for GSC to reduce THD in inverter output current. Simulation and results are given in section IV, while conclusion is given in section V.

II. GSC

Grid side system consists of GSC, filter, grid voltage and GSC controller. GSC controls the DC-bus voltage and the power factor by controlling active and reactive powers or direct and quadrature current components respectively [1]. Two common control methods; vector control and DPC are presented here. These methods provide decoupled control of active and reactive powers of the generator.

A. Vector Control

Vector control is based on pulse width modulation (PWM). High switching frequency PWM enables fast dynamic response and low harmonic distortion [7]. The block diagram for vector control strategy based on grid voltage orientation is shown in Fig. 2. In this technique PI regulators are used to obtain the references of direct and quadrature voltages from the references of direct and quadrature current components, then these voltages are transformed to abc form and finally given to the modulator to produce signals to the inverter switches [3].

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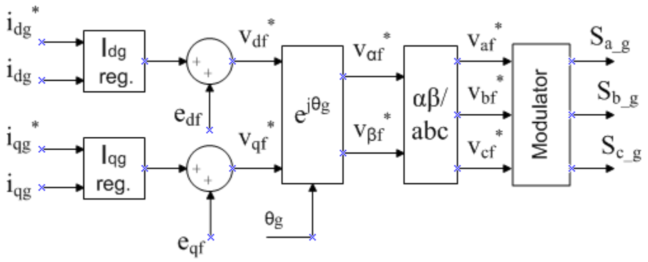

Figure 2 Vector control of GSC

Reference of direct current is given using DC-bus voltage regulator, while reference of quadrature current is kept constant at zero. Fig. 3 shows DC-bus voltage regulator.

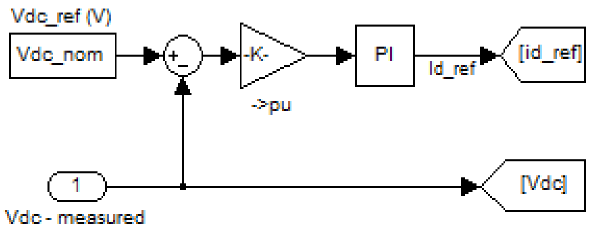

Figure 3 DC-bus voltage regulator

For voltage and current coordinate transformations, the grid voltage angle is determined using a phase locked loop (PLL) [3].

B. DPC

DPC technique was proposed instead of using PWM. Direct control is characterized by fast electromagnetic torque response, lower computational requirements and lower dependence on machine parameters. In addition, modulator is not needed in this method [8, 9]. One of the problems with the direct control method is its performance degradation during starting and low speed regions [10].

DPC consists of switching table, two hysteresis comparators (for direct and quadrature current components) and direct and quadrature current estimators. The switching table selects the appropriate voltage vector to be applied to the inverter. Block diagram for DPC of GSC is given in Fig. 4.

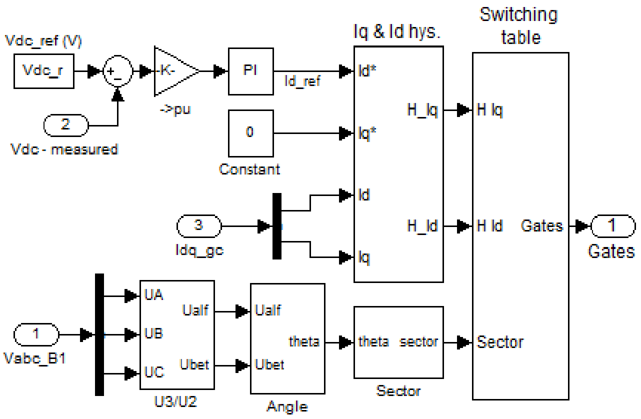

Figure 4 DPC of GSC block diagram

The switching table keeps the errors of the direct and quadrature current components between the limits of the hysteresis comparators by an appropriate selection of the voltage vector applied on the switches of the inverter. Instead of conventional PI controllers used in PWM, using hysteresis controllers leads to good performance [11]. Voltage vector selection using the switching table provides fast response, low harmonic losses and low switching frequency and reduces the complexity of vector control method [12]. Table- I gives the switching table for GSC.

Table- I: Switching table for GSC

H_{iq}	H_{id}	Sector of grid voltage					
		S_1	S_2	S_3	S_4	S_5	S_6
1	1	V_5	V_6	V_1	V_2	V_3	V_4
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_1	V_2	V_3	V_4	V_5	V_6
-1	1	V_4	V_5	V_6	V_1	V_2	V_3
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_2	V_3	V_4	V_5	V_6	V_1

III. PROPOSED SYSTEM

The proposed system is a direct power controller based on a proposed switching table. The proposed table is given in Table- II. The first and forth rows in Table- I are replaced by the second and fifth rows respectively (zero vectors). This modification leads to reduced current ripples and minimum THD compared with other techniques. Applying zero voltage vectors for direct current increase states result in reducing direct current with a more suitable value than it given when applying active vectors given by Table- I for direct current increase states [13].

Table- II: Proposed switching table for GSC

H_{iq}	H_{id}	Sector of grid voltage					
		S_1	S_2	S_3	S_4	S_5	S_6
1	1	V_0	V_7	V_0	V_7	V_0	V_7
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_1	V_2	V_3	V_4	V_5	V_6
-1	1	V_7	V_0	V_7	V_0	V_7	V_0
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_2	V_3	V_4	V_5	V_6	V_1

Synchronization is made by shifting all columns of the switching table gradually until the monitored abc voltages for both stator and inverter output become in phase.

IV. SIMULATION

A. Model

A 9 MW wind farm consists of 6*1.5 MW machines is modelled and simulated here using Matlab. This farm is connected to a 25 kV distribution system and delivers 9 MW through a 25 kV, 30 km 3-phase line to a 120 kV grid. During simulation, wind speed is kept constant at 15 m/s. Machine speed is kept constant at 1.2 pu using a torque controller. The reactive power generated by the wind turbine is kept constant at zero. Simulink model of 9 MW wind farm is shown in Fig. 5. Table- III and Table- IV give parameters of the machine and the converter respectively.

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Table- III: Parameters of DFIG

Stator voltage	Rotor voltage	frequency	Machine power	Pole pairs	Stator resistance	Rotor resistance	Stator inductance	Rotor inductance	Mutual inductance
575	1975	60	1.5	3	0.023	0.016	0.18	0.16	2.9
V	V	Hz	MW	—	P.U.	P.U.	P.U.	P.U.	P.U.

Table- IV: Parameters of the converter and filter

Grid side coupling resistance	Grid side coupling inductance	Nominal DC-bus voltage	DC bus capacitor	Maximum current for GSC	Line filter capacitor	Frequency of rotor side PWM carrier
0.003	0.3	1150	10	0.8	120	1620
P.U.	P.U.	V	mF	P.U.	KVAR	Hz

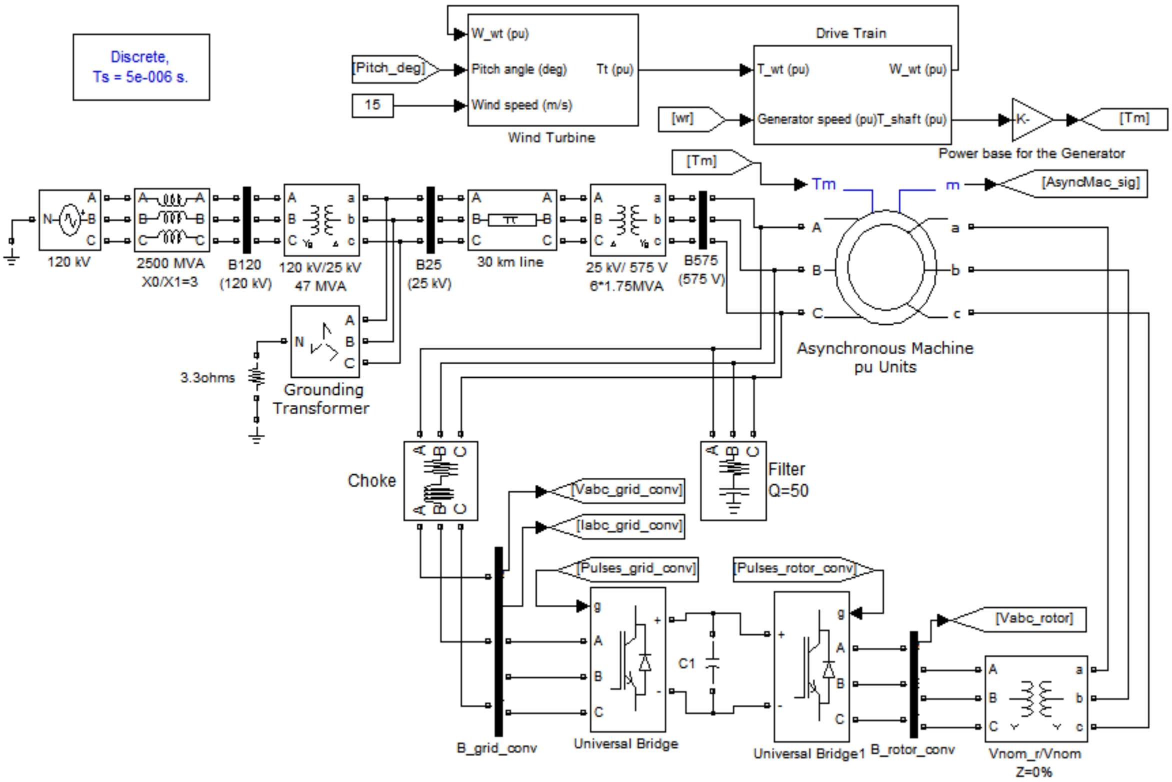

Figure 5 Simulink model of 9 MW wind farm

B. Results

Results for current are given in per unit quantities, while results for power and DC-bus voltage are given in their actual values.

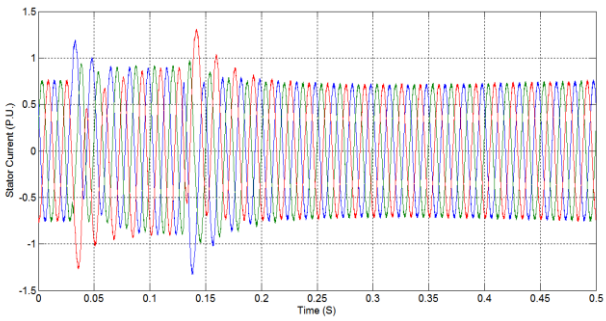

Figure 6 Stator current

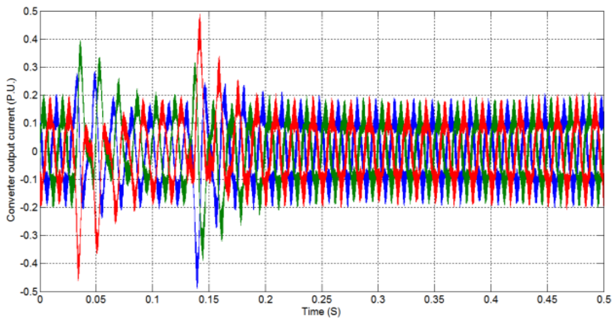

Figure 7 Converter output current using PWM

Fig. 6 and Fig. 7 show stator current and converter current using PWM-based vector control for GSC. These currents reach their steady state values.

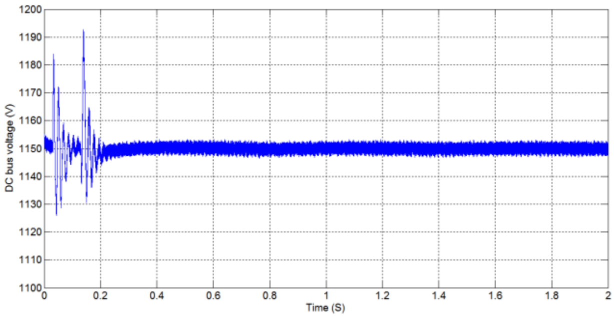

Figure 8 DC link voltage

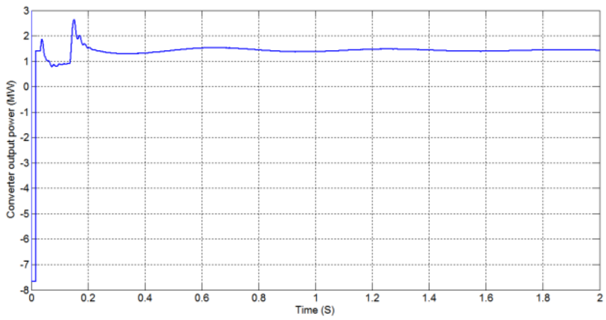

Figure 9 Converter output power

Fig. 8 shows DC link voltage, its value is kept about 1150 V using GSC controller. Converter output power is given in Fig. 9, its value is about 1.3 MW. Steady state has been attained for the shown wave forms

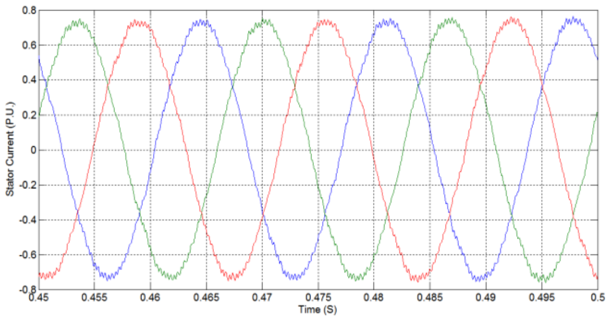

Figure 10 Stator current

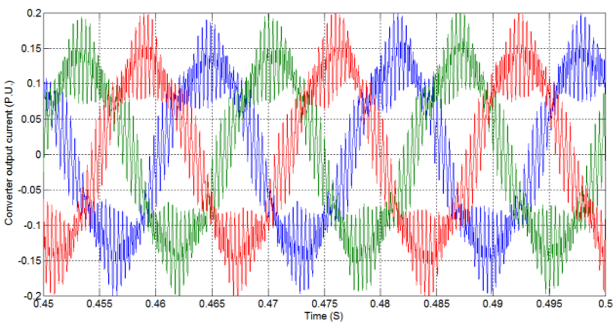

Figure 11 Converter output current using PWM

Fig. 10 and Fig. 11 show a zoomed image of the stator current and converter current using PWM, these currents are in phase.

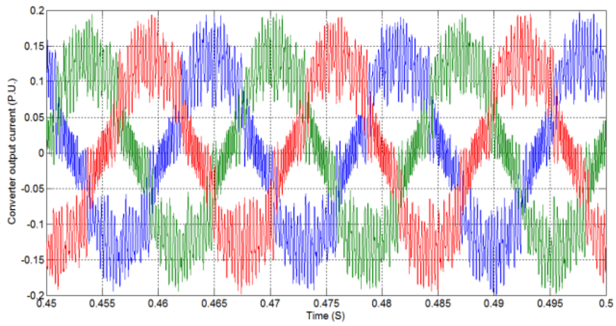

Figure 12 Converter output current using DPC

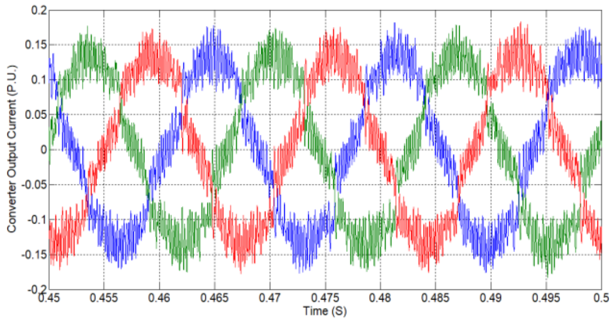

Figure 13 Converter current using modified DPC

Fig. 12 and Fig. 13 show the converter current using DPC and modified DPC based on modified switching table, it is clear that the converter current using modified DPC (proposed system) has minimum ripple.

The following analysis is made using Matlab FFT analysis tool. This tool gives a detailed analysis in view of THD. This analysis is made at time of 1 second for the three control strategies of GSC.

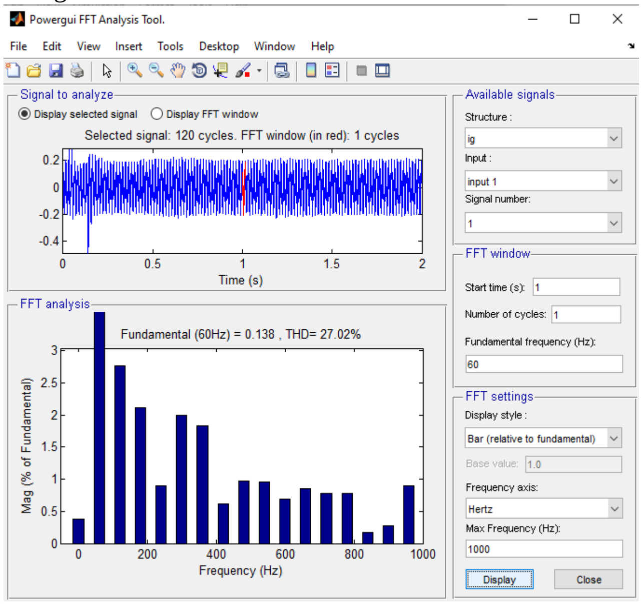

Figure 14 THD for PWM

THD for current given by PWM-based vector controlled inverter is 27.02 %.

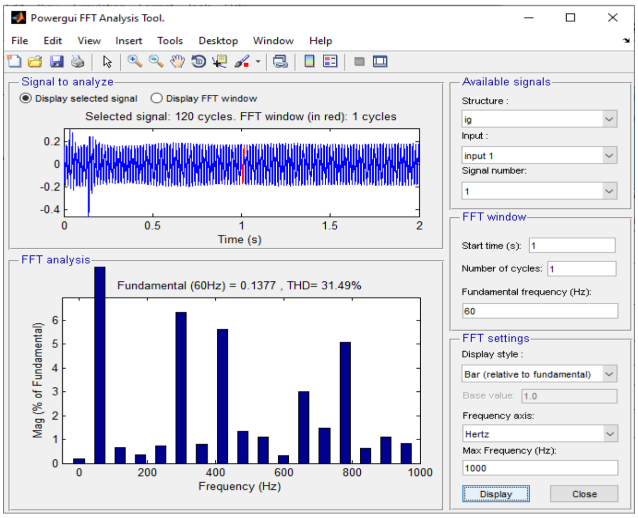

Figure 15 THD for DPC

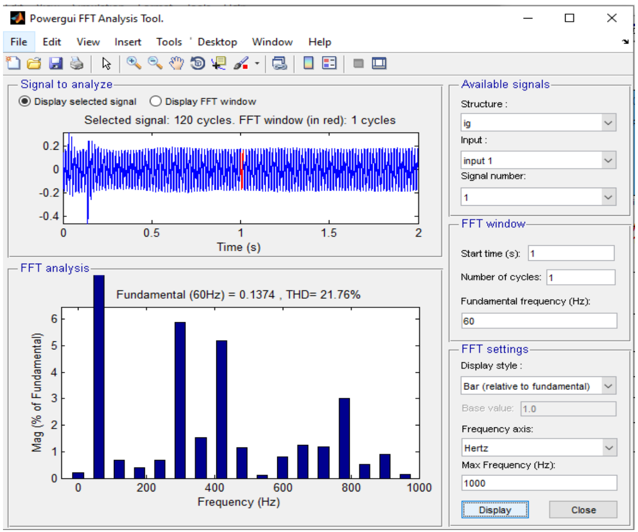

Figure 16 THD for proposed system

Fig. 15 shows that THD for DPC is 31.5 %, while THD for proposed system is given in Fig. 16 and its value is 21.76 %.

V. CONCLUSION

This paper presents two common and advanced control techniques for GSC; vector control and DPC. This paper proposes a modified DPC based on a modified switching table to reduce THD in current produced by the inverter. Simulation of A 9MW grid connected wind farm is made using Matlab. From the simulation results above it is clear that the converter current using the proposed system for GSC has minimum ripple compared with other techniques. The results also shows that THD for proposed system has minimum value. In addition to this, there are many advantages for using DPC instead of PWM such as simplicity, less computational requirements, less dependence on machines parameters and the modulator isn't required.

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