Comparison of SVM and DPC for reactive power control of DFIG based wind energy systems

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Abstract

This paper presents the Comparative Analysis of the two different control strategies Space Vector Modulation (SVM) and Direct Power Control (DPC) being applied to a Doubly fed Induction Generator (DFIG) based wind energy generation system. The key approach of the SVM is to obtain the reference voltage of modulator. However this approach requires PI regulators together with coordinated transformation. These will complicate the system and also the steady-state and transient performance are highly sensitive to the PI control parameters and for ensuring the system stability more tuning efforts are required. In DPC approach, the converter switching states are selected directly by the instantaneous active and reactive power based on Hysteresis comparators. The main advantage of the DPC control is that it does not require the use of coordinated transformations and modulation techniques which will reduce the harmonics and also increase the efficiency of the system. In this paper the simulation results are presented for 9 MW DFIG based wind turbine system. The simulation results confirms that the DPC control strategy provides fast, accurate and decoupled power control when compared to SVM.

Keywords: *Direct power control, hysteresis comparator, space vector modulation, doubly fed induction generator*

1. Introduction

The development of renewable energy sources is continuously enhanced because of the depletion of fossil fuels (oil and gas etc.) Wind power generation is one of the Renewable Energy source with distinct advantages such as absence of fuel cost, high dependability and characterized as a pollution free, clean and inexhaustible energy source. The utility-scale wind turbine ranges from 600 KW to 5 MW of rated power. The most common wind turbine for commercial use is in the range of 1.5-3 MW. Doubly fed induction generator (DFIG) based wind turbine has become popular due to the variable speed operation with the converter [16]. However, the stator of DFIG is directly connected to the grid and the power rating of the converter is limited and also the system is quite responsive to grid disturbances. The grid code conditions for wind power integration states that DFIG controllers should be able to overcome temporary voltage disturbances [11].

To control the DFIG under the unbalanced grid conditions several methods has been proposed and the performance of generator during the unbalanced conditions is well known. Most of the control methods proposed are based on symmetrical theory where the unbalanced three phase quantities are decoupled into positive and negative sequence components which may introduce time delay and the overall control system may get affected [8-10]. One of the control methods for DFIG is vector oriented control in which rotor currents are decoupled into stator active power and reactive power and those two currents are controlled in the reference frame [13]. In this method exact value of parameters such as inductances and resistance are required and nonlinear operation of converter is not considered therefore the performance and efficiency of vector oriented control method is seriously affected by varying operating conditions and machine parameters.

In this paper, the two high performance control methods Space Vector Modulation (SVM) and Direct Power Control (DPC) have been investigated and the comparison has been made for DFIG based Wind Energy System. The DFIG is interfaced to the grid through 2-level Voltage Source Converter (VSC). The whole system is simulated using Matlab software. Simulation results for 9MW

DFIG based wind turbine are presented and discussed to verify the effectiveness of the proposed method.

2. System description

The most commonly used model for converting the wind power and to supply the utility grid is doubly fed Induction generator and is shown in Fig. 1. The rotor of the Induction generator is connected to back-back voltage source converter with dc link capacitor and the stator is connected to the grid [12, 14]. The grid side converter controls the flow of power between the dc side and AC side and also maintains the system to be operated in synchronous speed. The rotor side converter controls the active and reactive power by employing the Direct Power Control (DPC) [1]. There are four modes of operation possible in DFIG and it can be operated as motor as well as generator.

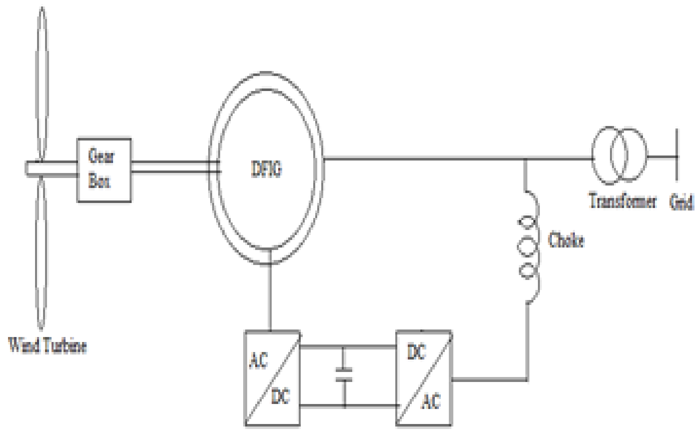


Fig. 1 Schematic Diagram of DFIG based Wind Energy Conversion System

Direct power control. The direct power control is similar to the direct torque control instead of torque and flux control the active and reactive power is controlled in this method [2]. Two hysteresis comparators are used in this method as shown in Fig. 2.The hysteresis comparators are used to track the errors between the actual and estimated values of active and reactive power and then the two digitized signals dp and dq are generated. According to the digitized signals dp and dq the positions of the voltage vectors are selected from the switching table. The active power is controlled by regulating the dc link voltage and to control the reactive power to zero the unity power factor is achieved [7,9]. The estimated line voltage vector control is used in this method and the digitized signal θm is taken from the phase of the line in stationary reference frame and it is divided into six sectors. The relation between the voltage vector position and sector can be expressed in Eq. 1.

$$(m-1)\frac{\pi}{3} \le \theta_m < m\frac{\pi}{3}. \tag{1}$$

Where m=1, 2, 3,...., 6.

The main advantage of this control method the coordinate transformation is not required and also no inner current loops which make the system easy to implement.

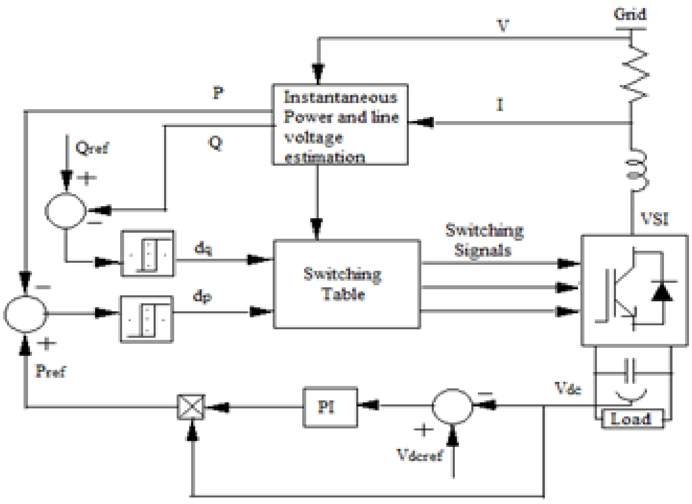


Fig. 2 Block Diagram of Direct Power Control (DPC)

Instantaneous active and reactive power estimation. To estimate the instantaneous active and reactive power different methods are proposed. In this work the active and reactive power is controlled without any sensors [3-4]. The line currents and the line voltages are measured and then used to calculate the estimated powers. For balanced three phase voltage the estimation can be done by Eq. 2, Eq. 3. The instantaneous active power is determined with the help of dc voltage loop with PI controller to maintain the dc-link voltage more stable.

$$P = \left(e_{s\alpha} I_{s\alpha} + e_{s\beta} I_{s\beta}\right). \quad (2)$$

$$Q = \left(e_{s\beta} I_{s\alpha} - e_{s\alpha} I_{s\beta}\right). \quad (3)$$

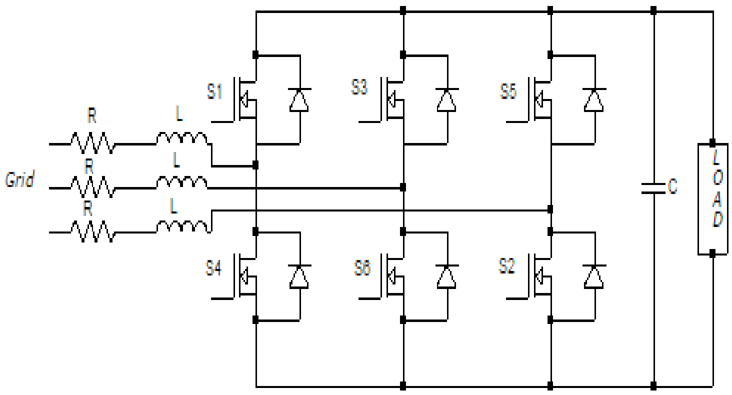


Fig. 3 Circuit Topology of VSI

Switching strategy of DPC for two level converter. To optimize the system performance in DPC method the correct selection of vectors from the Switching table is very important otherwise it may lead to voltage disturbances and the circuit topology for Vsi is shown in Fig. 3. To control the active and reactive power the three level hysteresis comparators are used and the digitized signals are defined as

$$d_p = \begin{cases} +2, \Delta P \in \left(h_p, +\infty\right) \\ +1, \Delta P \in \left(0, h_p\right) \\ -1, \Delta P \in \left(-\infty, 0\right) \end{cases} \tag{4}$$

$$d_q = \begin{cases} +1, \Delta q \in \left(h_q, +\infty\right) \\ -1, \Delta q \in \left(-\infty, -h_q\right) \end{cases} \tag{5}$$

The switching table for the above mentioned control strategy is shown in Table 1.

Table 1. Switching table for DPC

d_p	d_q	S_1	S_2	S_3	S_4	S_5	S_6
1	1	001	101	100	110	010	011
2		000	111	000	111	000	111
-1		010	011	001	101	100	110
1	-1	101	100	110	011	011	001
2		111	000	111	000	111	000
-1		110	010	011	001	101	100

Space vector modulation. To achieve the constant switching frequency Space vector modulation is used to integrate the voltage vectors in fixed period to generate the average vector of the converter. The key approach of this method is to find the reference voltage of the modulator [5, 6].

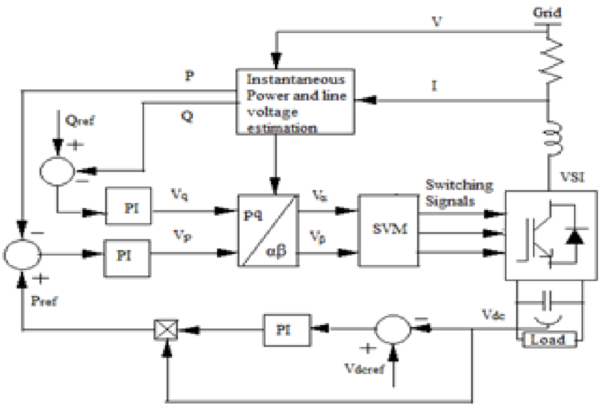


Fig. 4 Block Diagram of Space Vector Modulation (SVM)

To generate the switching signals in SVM instead of switching table and hysteresis controller PI controllers are used to track the errors between active and reactive power and transferred into stationary reference frame as shown in Fig. 4. But one of the major drawbacks in this method is the use of coordinate transformation along with the PI controller this will leads to the large amount of power and system become complex [15].

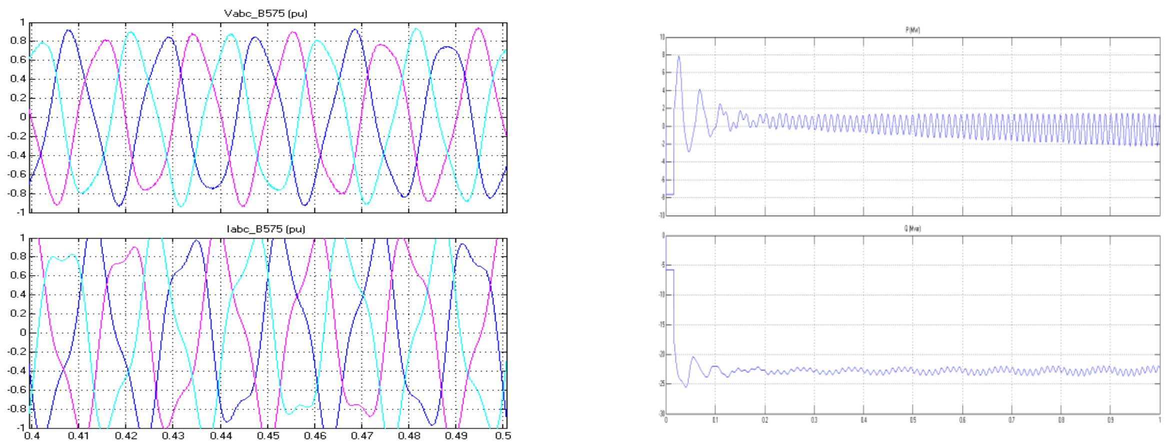
3. Simulation results

The control strategies for the DFIG based wind energy system are simulated in Matlab/ Simulink and the parameters involved are listed in Table 2.

Table 2. Simulation Parameters

Parameter	Value
Stator Resistance (Rs)	1.0713Ω
Rotor Resistance (Rr)	1.29511Ω
Stator Inductance (Ls)	0.028mH
Rotor Inductance (Lr)	0.015mH
Mutual Inductance (Lm)	1.591H
Pole pairs	2
Rated Power	1.5MW
Stator Voltage	690V
DC Link Capacitance	8mF
DC Link Voltage	1150V
Grid side Inductance	0.2mH
Switching Frequency (fs)	20KHz

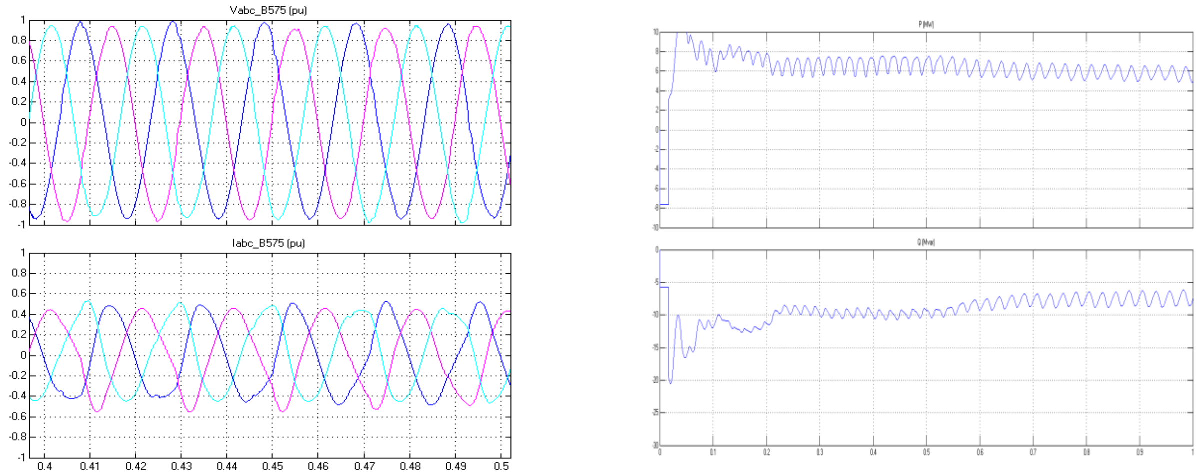
The waveforms of phase voltage, load current, active power and reactive power for the Space vector modulation (SVM) and direct power control (DPC) methods respectively are shown in Fig. 5 and 6. The simulation was done with 6 units of wind turbine (6*1.5=9MW) Wind Farm along with the DC-link voltage of 1150V and to maintain unity power factor Qs=0. Fig. 4 shows the fluctuation in voltage and current waveform which means the demand for the reactive power is more and this will increase the harmonic distortions. The current and voltage waveforms are not in phase this will lead to excessive voltage jumps in phase and line voltages. In Power waveform, the x-axis has the magnitude of "0-1". But for Voltage and Current waveforms the x-axis magnitude has been in the range of "0.4-0.5" in order to show the distortions clearly this magnitude has been chosen.



(a) (b)

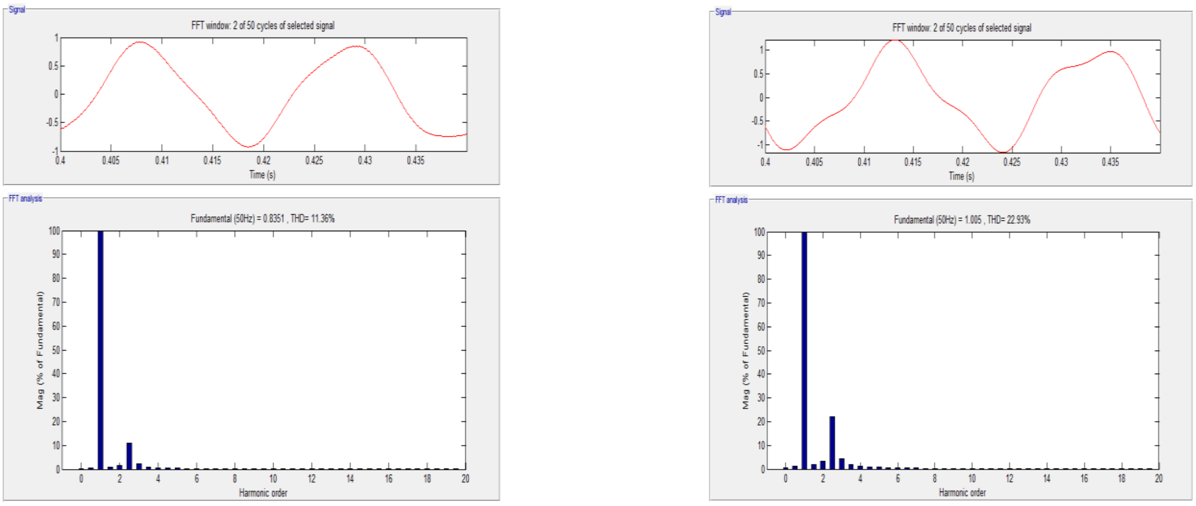
Fig.5 Simulation results of Phase Voltage, Load Current, Active and Reactive Power by using SVM method.

In SVM method, there are some fluctuations in voltage and current waveform this can be eliminated by using DPC method where the fluctuations in the voltage and current waveforms are eliminated as shown in Fig. 6.



(a) (b)

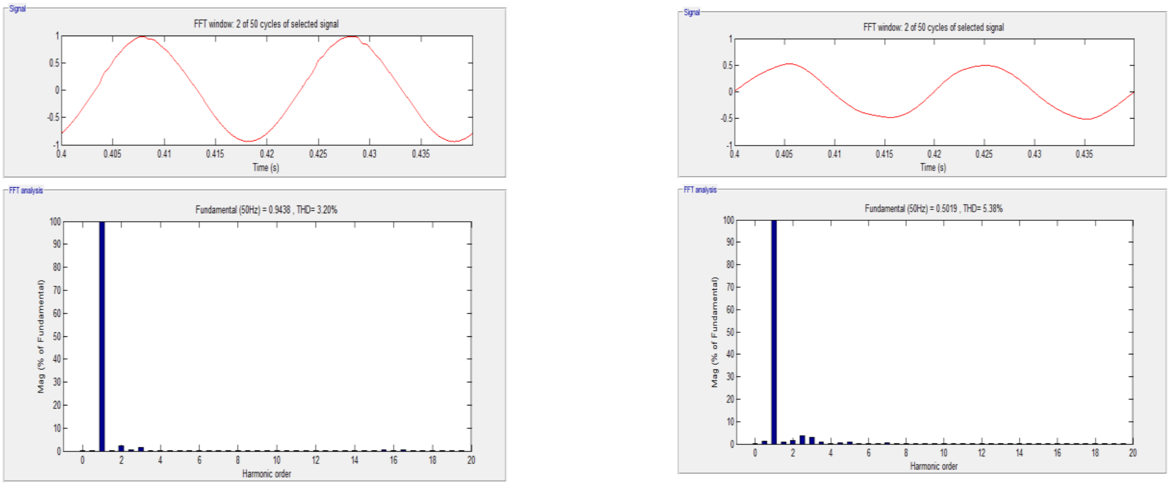
Fig. 6 Simulation results of Phase Voltage, Load Current, Active and Reactive Power by using DPC method.



(a) (b)

Fig. 7 FFT Analysis using SVM method (a) Phase Voltage, (b) Load Current

The FFT Analysis of both the Voltage and the Current using SVM and DPC methods are shown in Fig. 7 & 8. The voltage and current waveforms are in phase and the harmonic distortions are very less in DPC when compared to SVM because of the optimized selection of voltage vectors in the look up table which ensures the instantaneous control of active and reactive power by maintaining unity power factor.



(a) (b)

Fig. 8 FFT Analysis using DPC method (a) Phase Voltage, (b) Load Current

Table 3. Total Harmonic Distortion (THD) of DPC and SVM Methods

Control Strategy	Line Voltage THD	Line Current THD
SVM	11.36%	22.93%
DPC	3.20%	5.98%

The Total Harmonic Distortion (THD) of Line voltage and line current for SVM and DPC Control strategies are summarized in Table 3. The DPC method has very low voltage and current harmonic distortion compared to SVM and this clearly shows that the DPC Method is very effective in decreasing disturbances in Grid. The DPC method has certain merits when compared to SVM they are listed as follows; Sensorless operation, noise immune power approximation algorithm, good start-up terms, simple tuning process of PI active and reactive power regulators, little pairing between active and reactive power and good dynamics.

4. Conclusion

In this paper the comparative analysis of SVM and DPC methods for Doubly fed Induction generator based Wind energy generation system has been presented. The DPC algorithm performs the control of instantaneous active and reactive power in stationary coordinate system. Compared to SVM the simulation results of DPC method have proved the excellent performance of the system and the control of active and reactive power is obtained.

5. Acknowledgements

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