Direct Power Control Scheme of Improved Command Tracking Capability for PMSG MV Wind turbines

Gookmin Kwon and Yongsug Suh
Department of Electrical Engineering, Smart Grid Research Center, Chonbuk National University

ABSTRACT

This paper proposes a Direct Power Control (DPC) scheme of improved command tracking capability for Permanent Magnet Synchronous Generator (PMSG) Medium Voltage (MV) Wind Turbines. Benchmarking is performed based on a neutral point clamped three-level back-to-back type voltage source converter. It is introduced to design the DPC modeling and propose DPC scheme of a three-level NPC (3L-NPC) converter. During the fault condition in wind farms, the proposed control scheme directly controls the generated output power to the command value from the hierarchical wind farm controller. The proposed control scheme is compared with conventional control scheme as respect to loss and thermal analysis. The DPC scheme of improved command tracking capability is confirmed through PLECS simulations. Simulation result shows that proposed control scheme achieves a much shorter transient time in a step response of generated output power. The proposed control scheme makes it possible to provide a good dynamic performance for PMSG MV wind turbine to generate a high quality output power under grid fault condition.

1. Introduction

Recently, wind power system is one of the fastest growing renewable energy systems. In the multi-MW wind turbine market, the maximum power rating of a commercial wind turbine has been increased more than 5MW with a view to generate more power from wind power sites [1]. As the penetration of renewable resources into the grid is rapidly increasing, high-performance control of power converters is a must to maintain high power quality and system stability. In particular, large-scaled offshore wind farms have become a subject to various grid codes demanding tougher grid adaptive features such as LVRT, voltage support, frequency stability, ramp rate control, rapid shut down control, and etc. To satisfy these requirements, fast and accurate power regulation is essential [2]. In wind power systems, most of previous studies regarding the peak power points have focused on the Maximum Power Point Tracking (MPPT) controller of the machine-side converter control system irrespective of the type of generator used. Based on the principle of Direct Toque Control (DTC) strategy for ac machines, an alternative control approach, namely DPC was developed for the control of three-phase grid-connected two-level VSCs. This DPC method is designed to effectively obtain the maximum generated power and improve the steady-state and transient performance, and also maintain the simplicity and robustness of the control system. Considering various grid codes and active/reactive power generation requirements imposed on large-scaled offshore wind farms, the efficient utilization of DPC method together with MPPT control strategy for wind turbines has not been explored in detail in previous literatures.

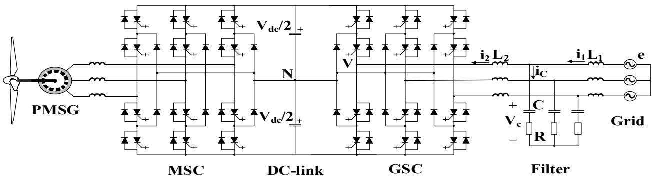


Fig 1 3L-NPC back-to-back configuration for PMSG MV wind turbines

This paper proposes DPC scheme of improved command tracking capability for PMSG MV Wind turbines. DPC strategy is adopted in controlling the grid-side converter (GSC) of a wind turbine. Control of machine-side converter (MSC) employs dc-link voltage regulation scheme. The proposed DPC scheme also includes the MPPT control concept during steady-state operation of wind turbines. Therefore the proposed control method makes it possible to provide the maximum output power from a MV PMSG wind turbine while effectively complying with various grid codes on wind farms. The junction temperature of semiconductor device is analyzed through the loss analysis under the steady-state operating conditions of 5MW PMSG wind turbines.

2. Direct Power Control and Ramping Rate Criterion

A. Modeling of three-level NPC VSC

For a typical wind turbine of PMSG type, the GSC of a three-level rectifier is shown in Fig. 1 [3]. The rectifier model in a stationary $\alpha\beta$-frame can be expressed. e and i_1 are space vector of grid voltage and current. V and i_2 are space vector of rectifier voltage and current. In this case, damping resistor is ignored. The complex power at the grid side can be represented as.

$$S=\frac{3}{2}\left(ei_1^*\right)=\frac{3}{2}\left(\left|e\right|e^{j\omega t}i_1^*\right) \qquad (1)$$

Differentiating complex power is given in (2).

$$\frac{dS}{dt}=1.5\left(\frac{de}{dt}i_1^*+\frac{di_1^*}{dt}e\right)=j\omega S+1.5(\frac{L_2C(\frac{d^2V_c}{dt^2})^*e+\left|e\right|^2-eV^*}{L_1+L_2} \qquad (2)$$

V is represented as $V_n e^{j\theta_n}$ where V_n and θ_n are determined according to the switching state. It means that not related to the time domain. Based on (2), derivative term of complex power can be divided into real and imaginary component as (3) and (4).

$$\frac{dP}{dt}=-\omega Q+1.5(\frac{\left(\frac{L_2+L_1-L_1L_2C\omega^2-L_2^2C\omega^2}{L_2+L_1-L_1L_2C\omega^2}\right)\left|e\right|^2-\left|V_n\right|\left|e\right|cos\left(\omega t-\theta_n\right)}{L_1+L_2}) \qquad (3)$$

$$\frac{dQ}{dt}=\omega P+1.5(\frac{-\left|V_n\right|\left|e\right|sin\left(\omega t-\theta_n\right)}{L_1+L_2}) \qquad (4)$$

According to ramping rate of instantaneous active and reactive power are illustrated in Fig. 2. In case of using large vector.

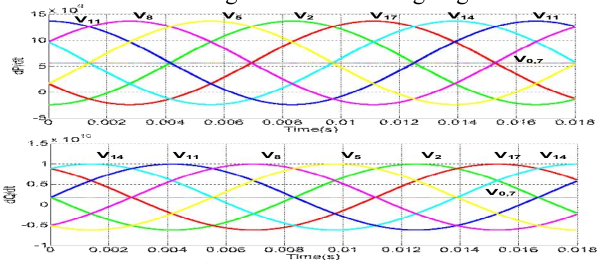


Fig 2 Ramping rate of instantaneous active and reactive power by using large vectors in 12 different sectors (P=5 MW, Q=0 MVAr)

3. Proposed Control Scheme for Entire System

A. Conventional control scheme

Wind energy has an intrinsic intermittent physical properties as wind speed changes throughout the day. The amount of power output from a wind energy conversion system depends upon the accuracy with which the peak power points are tracked by MPPT controller of the MSC control system irrespective of the type of generator. MPPT equation is expressed as

$$P_m=\frac{1}{2}\pi\rho C_p\left(\lambda,\beta\right)R^2v_{wind.}^3 \qquad (5)$$

Considering (5), the conventional control block diagram of MPPT is described in Fig. 3.

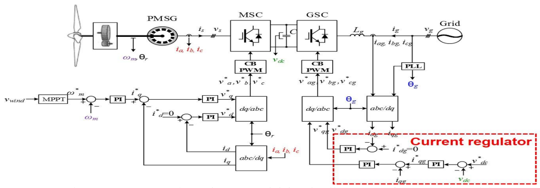


Fig 3 Conventional control block diagram for wind turbines

B. Proposed control scheme

In general, MPPT control does not have a good dynamic performance under varying active power command. There has been a growing demand on large-scaled offshore wind farms with respect to grid adaptive features. These features involve transient and rapid variation of active and reactive power output from wind farms in the comparable level as conventional thermal power plants. The newly proposed grid adaptive control method consists of voltage oriented control and DPC. In general, DPC does not require a separate PWM voltage modulation block, current regulation loop, and rotating transformation. Therefore it has a good dynamic performance and robustness independent of the accuracy of PLL block. In the proposed control strategy of this paper as shown in Fig. 4. DPC method is employed in GSC while MSC adopts dc-link voltage regulation loop. Under the normal steady-state condition, system control is done in MPPT control mode. When LVRT and fault conditions occur, active power command is changed to grid adaptive control by AGC

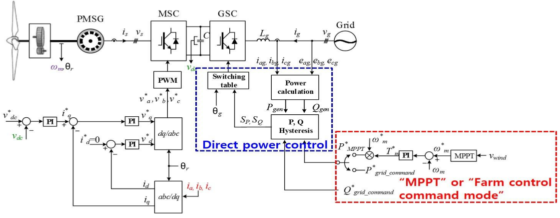


Fig 4 Proposed control block diagram for wind turbines

4. Simulation

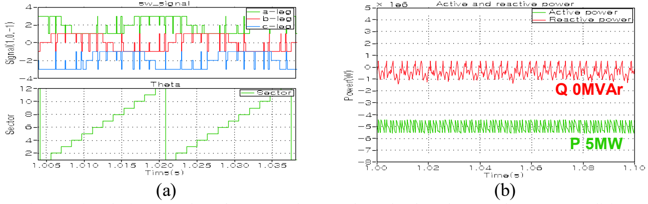
The simulation is performed based on the parameters of PMSG MV back-to-back converter as specified in Table I.

Table I Simulation parameters of 5MW MV 3L-NPC VSC

Parameter	Symbol	Value	Parameter	Symbol	Value
Output power	$P_{rated\text{-}out}$	5 MW	Grid side input current	I_{AC_input}	708 A
Rated wind speed	v_{wind}	11 95 m/s	Sampling frequency	f_{GSC_samp}	60 kHz
Grid frequency	f_{sw}	60 Hz	DC-link voltage	$V_{DC\text{-}link}$	7 kV
Grid side inductance	L_{grid}	1 56 mH	Grid side input voltage	V_{ll}	4 16 kV

A. Simulation results under steady-state condition

The waveforms under the steady-state conditions are described in Fig. 5. Switching signal for DPC in GSC waveform is obtained and shown in Fig. 5 (a). Fig. 5 (b) shows the active and reactive output power waveform.

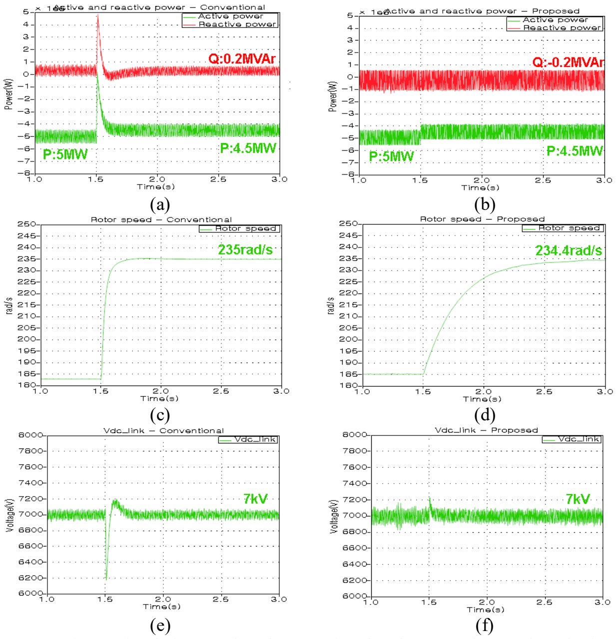


(a) (b)

Fig 5 Simulation results of proposed control method under steady-state condition

B. Comparison of conventional control scheme and proposed control scheme

In a typical grid code for large-scaled offshore wind farms, ramp rate of generated power output from a wind farm is limited below 10% of power/min [4]. Two control methods are compared through simulation. If a grid fault occurs at 1.5s in simulation, the reference of active power is reduced to keep the ramp rate of generated power within the grid code level. In the simulation condition, active power is controlled to be 4.5MW by AGC. In Fig. 6 (a), (b) proposed control method exhibits a much shorter transient time and a good dynamic performance owing to DPC.



(a) (b) (c) (d) (e) (f)

Fig 6 Simulation results of conventional and proposed control method

C. Comparison of losses and junction temperatures

Total power loss of conventional and proposed control method in GSC are summarized in Table II.

Table II Power loss of conventional and proposed control method in GSC

Device	Rating (kV/A)	Part	Manufacturer	Loss / phase (kW)	Number of device / (EA)	Total loss of conventional method	Loss / phase (kW)	Number of device / (EA)	Total loss of Proposed method
Press-pack IGCT	6.5/3800 ABB	Switch(Q)	ABB IGCT	10.49	4	43.17	14.17	4	57.33
		FWD(D)	ABB FRD	0.00	4		2.02	4	
		NPD(ND)		3.90	2		2.91	2	
		Sub Total		14.39	10		19.11	10	

Junction temperature of each device is given in Fig. 7. It is noted from Table II and Fig. 7 that, although the proposed control method has a higher total loss, it generates a relatively even distribution of junction temperatures among devices without suffering from a particular heat spot device.

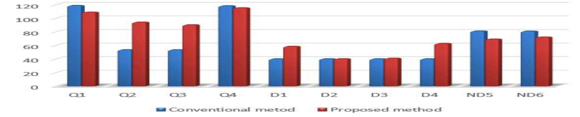


Fig 7 Profile of junction temperatures for the case of conventional and proposed control methods

5. Conclusion

In this paper DPC scheme of improved command tracking capability method is newly proposed to control PMSG MV wind turbines. The proposed control strategy involves dc-link voltage regulation for a MSC and DPC for a GSC. It is shown that the active and reactive power can be directly controlled under various grid fault conditions. In the steady-state normal condition, proposed control method is intended to track the maximum power point. In the transient fault condition, due to DPC characteristic, proposed control method achieves a much shorter transient time in the step response of output power. The proposed control method makes it possible to provide a good dynamic performance for PMSG MV wind turbines to generate a high quality output power under grid fault condition. Also proposed control method achieves a much lower junction temperature profile of semiconductor.

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP)(No 2010-0028509) & (No 2014R1A2A1A11053678)

Reference

[1] BTM Consult ApS: World Market Update 2008, Forecast 2009-2013

[2] Y Zhang, M Lisserre, R Teodorescu, and P Rodriguez, “Low-Complexity Model Predictive Power Control: Double-Vector-Based Approach,” *IEEE Trans. on Industrial Electronics*, vol 61, no 11, pp 5871–5880, Nov 2014

[3] Y Zhang, Z Li, Y Zhang, W Xie, Z Piao, and C Hu “Performance Improvement of Direct Power Control of PWM Rectifier with Simple

[4] E ON Netz GmbH, Grid Code for high and extra high voltage, 1st Apr 2006