Comparison of Efficiency for Voltage Source and Current Source Based Converter in 5MW PMSG Wind Turbine Systems

Tahyun Kang and Yongsug Suh
Department of Electrical Engineering, Smart Grid Research Center, Chonbuk National University

ABSTRACT

This paper provides a comparison of power converter loss and thermal description for voltage source and current source type 5MW-class medium voltage topologies of wind turbines. Neutral-point clamped three-level converter is adopted for voltage source type topology while two-level converter is employed for current source type topology considering the popularity in the industry. In order to match the required voltage level of 4160V with the same switching device of IGCT as in voltage source converter, two active switches are connected in series for the case of current source converter. The loss analysis is confirmed through PLECS simulations. In addition, the loss factors due to di/dt and dv/dt snubber and ac input filter are presented. The comparison result shows that VSC-based wind turbine system has a higher efficiency than that of CSC under the rated operating conditions.

1. Introduction

The demand of sustainable and renewable energy has been increased remarkably due to the energy crisis and the environmental concern. Among the renewable energy sources, especially, the wind energy capacity has been increased rapidly over the last decade. According to the recent trends, power capability of wind turbines is moving from kW class to MW class to reduce the cost of energy. As the power capacity of wind turbine systems increases, in order to reduce current level, the Medium Voltage (MV) system has been adopted for power converter and generators of wind turbine [1]-[3]. MV converter becomes more preferable due to less component count, high efficiency and simple power stage design in power converters of wind turbines [4].

Among various topologies of MV converter, back-to-back type three-level neutral-point clamped Voltage Source Converter (VSC) is one of popular choices in wind power systems. This converter topology has become a quite reliable industrial solution in wind turbines of MV class owing to many existing high power semiconductor switch components and modules in the market. Current source type converter has been regarded as one of many interesting circuit topologies in motor drives of MV class due to its inherent short circuit protection capability and low dv/dt characteristic of ac line voltage in a long-range cable connection. Previous literatures regarding Current Source Converter (CSC) have focused on the design and loss analysis of current source converters [5]. In addition, most of previous work has dealt with high-power motor drive applications of current source converters [6]-[7]. However, in contrast to voltage source type converters, current source type converters, particularly those with turn-off power semiconductor switching devices, have received less attention in the field of wind turbines in spite of its many powerful advantages in MV applications.

This paper investigates the application of current source converter topology in wind power systems. This paper also includes both the quantitative and qualitative investigation on the performance comparison of current source converter and voltage source converter in a wind turbine of MV class. The wind turbine of 5MW/4160V PMSG type is chosen as a common platform for the comparison work. Back-to-back type three-level neutral-point clamped voltage source converter, which is regarded as the most popular topology choice in this power range of 5MW, and back-to-back two-level current source converter topologies are analyzed. Due to the industrial practices of simpler implementation, instead of three-level current source topology, two-level current source converter equipped with a series connection of power semiconductor switches is proposed to be the target circuit topology of current source converter in this paper. The performance of two different types of converter system is studied with respect to the loss factors.

The main objective of this paper is to provide a comparison result of system efficiency for high-power VSC and CSC of the wind turbine system.

2. VSC AND CSC BASED WIND TURBINE SYSTEMS

A. Current Source Converter

Figure 1 shows the schematic of two-level CSC with series connection of two IGCTs, i.e. ns=2. Each leg of the CSC consists of four switches (S_{m_x}, S_{g_x}), and four reverse blocking diodes (D_{m_x}, D_{g_x}).

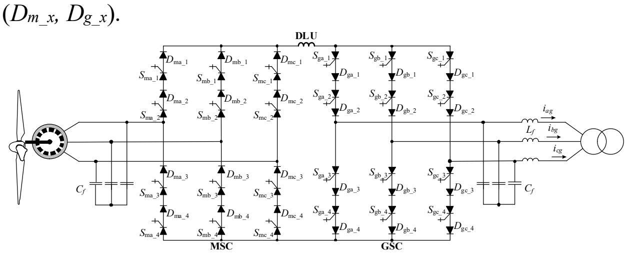

Fig. 1. Back-to-back type CSCs for 5MW PMSG MV wind turbines.

B. Voltage Source Converter

Figure 2 shows the schematic of 3L-NPC VSC. Each leg of the VSC consists of two neutral-point clamped diodes (ND_{m_x}, ND_{g_x}), four switches (S_{m_x}, S_{g_x}), and four anti-parallel diodes (D_{m_x}, D_{g_x}). The DC-link voltage is split into three-levels by two series connected capacitors.

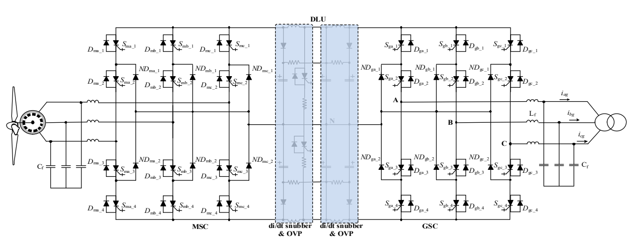

Fig. 2. Back-to-back type 3L-NPC VSCs for 5MW PMSG MV wind turbines.

C. Power Semiconductor Device(*Press-pact IGCT, Press-pace Diode*)

In this paper, VSCs and CSCs employ the same switching devices of press-pack IGCT (ABB 5SHY42L6500) and FRD (ABB 5SDF10H6004) devices for the sake of consistent and fair comparison of two topologies. The same type of FRD is utilized as anti-parallel diodes, neutral-point diodes, and reverse blocking diodes [8]-[9].

D. System Specification

The simulation is performed based on the parameters of 5MW MV VSC and CSC as specified in Table I and II,

TABLE I
SIMULATION PARAMETERS OF 5MW VSC

Parameter	Symbol	Value	Per unit
Output power	$P_{rated\text{-}out}$	5 MW	1.0
Grid frequency	f_{grid}	60 Hz	1.0
Grid side inductance	L_{grid}	1.56 mH	0.17
Grid side input voltage	V_{LL}	4.16 kV	1.0
Grid side input current	I_{AC_input}	708 A	1.0
Switching frequency	f_{VSC}	1020 Hz	-
DC-link voltage	V_{DC}	7 kV	-
DC-link capacitance	C_{DC}	2.6 mF	-
AC filter inductance	L_f	1.5 mH	0.16
AC filter capacitance	C_f	0.35 mF	0.45

TABLE II
SIMULATION PARAMETERS OF 5MW CSC

Parameter	Symbol	Value	Per unit
Output power	$P_{rated\text{-}out}$	5 MW	1.0
Grid frequency	f_{grid}	60 Hz	1.0
Grid side inductance	L_{grid}	1.56 mH	0.17
Grid side input voltage	V_{LL}	4.16 kV	1.0
Grid side input current	I_{AC}	708 A	1.0
Switching frequency	f_{CSC}	1020 Hz	-
DC-link current	I_{DC}	997 A	-
DC-link inductance	L_{DC}	8.3 mH	-
AC filter inductance	L_f	0.98 mH	0.11
AC filter capacitance	C_f	0.26 mF	0.34

E. Model of Semiconductors for Calculating the Losses

The total semiconductor device loss P_t consists of the conduction loss P_{cond} and switching loss $P_{switching}$;

$$P_t = P_{cond} + P_{switching} = P_{cond} + P_{on} + P_{off} \qquad (1)$$

F. Snubber Circuit Losses

In general, The IGCTs need a di/dt snubber in voltage-source inverters (VSI). Reverse blocking IGCTs are specified with an R-C snubber, which additionally limits the dv/dt at turn-off. This is a typical snubber for current source inverters (CSI).

Snubber loss for VSI and CSI is calculated from the following formula, respectively:

$$P_{cl} = \frac{1}{2} L_i \cdot i(t)^2 \times f_{sw} \quad (2) \qquad P_{cl} = \frac{1}{2} C_s \cdot v(t)^2 \times f_{sw} \quad (3)$$

3. COMPARISON OF VSC AND CSC BASED WIND TURBINE SYSTEMS

The device losses of two different 5MW WTS have been summarized in Fig. 3 and 4 under the 0.9 leading condition. The total loss and efficiency of VSC and CSC are under the three different power factor conditions (0.9 leading, 1.0, 0.9 lagging) in Figure 5.

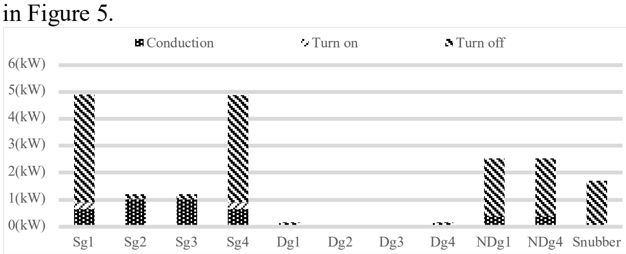

Fig. 3. Loss distribution of each phase in four switches (S_{g_1} - S_{g_4}) and six diodes (D_{g_1} - D_{g_4}, ND_{g_1}, ND_{g_2}) of VSC (*pf*=0.9 leading)

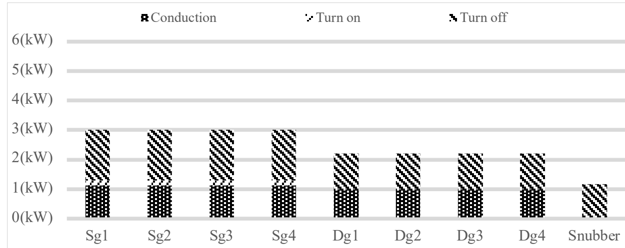

Fig. 4. Loss distribution of each phase in four switches (S_{g_1} - S_{g_4}) and four diodes (D_{g_1} - D_{g_4}) of CSC (*pf*=0.9 leading)

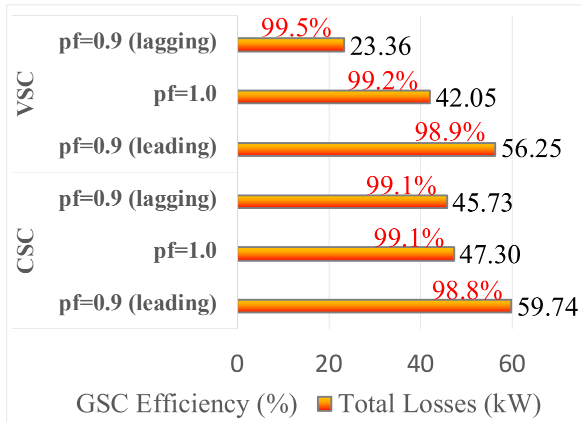

Fig. 5. Total losses of grid-side converter for VSC and CSC-based wind turbine systems

4. CONCLUSION

This paper investigates the performance of VSC and CSC in PMSG type wind turbine of 5MW/4160V. In order to effectively compare the performance of two converter topologies, this paper calculates and compares the efficiency of two different types of WTS. Along with efficiency, the detailed loss distribution of each functional block of the entire WTS is presented. The loss analysis is confirmed through PLECS simulations in both of VSC and CSC. The loss calculation method proposed in this paper can determine relatively accurate switching losses in semiconductor devices on the basis of simulated switching waveforms.

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

References

[1] H.J. Lee and S.K. Sul, "Wind power collection and transmission with series connected current source converters," in *Proc. 14th EPE*, Aug. 30-Sep. 1, pp. 1 –10, 2011.

[2] J. Sayago, T. Bruckner, and S. Bernet, "How to select the system voltage of MV drives: A comparison of semiconductor expenses," *IEEE Trans. Ind. Electron.,* vol. 55, no. 9, pp. 3381–3390, Sep. 2008.

[3] K. Lee, K. Jung, Y. Suh, C. Kim, H. Yoo, and S. Park, "Comparison of high power semiconductor devices losses in 5MW PMSG MV wind turbines," *IEEE Applied Power Electronics Conference and Exposition (APEC),* pp. 2511-2518, Mar. 2014.

[4] O.S. Senturk, L. Helle, S. Munk-Nielsen, and P. Rodriguez, "Power Capability Investigation Based on Electro-thermal Models of Press-Pack IGBT Three-Level NPC and ANPC VSCs for Multimegawatt Wind Turbines," *IEEE Trans. Power Electron*., vol. 27, no. 7, pp 3196-3206, Jul. 2012.

[5] F. Filsecker, R. Alvarez, and S. Bernet, "Design and losses of PWM current source converters," in *Proc. IEEE Int. Conf. Ind. Technol.,* pp. 737–744, 2010.

[6] E. P. Wiechmann, P. Aqueveque, R. Burgos, and J. Rodriguez, "On the efficiency of voltage source and current source inverters for high-power drives," *IEEE Trans. Ind. Electron.*, vol. 55, no. 4, pp. 1771–1782, Apr. 2008.

[7] Y. Suh, J. K. Steinke, and P. K. Steimer, "Efficiency comparison of voltage-source and current-source drive systems for medium-voltage applications," *IEEE Trans. Ind. Electron.*, vol. 54, no. 5, pp. 2521–2531, Oct. 2007.

[8] "Asymmetric Intergrated Gate-Commutated Thyristor 5SHY 42L6500", Datasheet, Doc. No. 5SYA1245-03 Dec. 12, ABB Switzerland Ltd., Online: www.abb.com.

[9] "Fast Recovery Diode 5SDF 10H6004", Datasheet, Doc. No. 5SYA1109-03 Jan. 10, ABB Switzerland Ltd., Online: www.abb.com.