Characteristics of High Power Semiconductor Device Losses in 5MW class PMSG MV Wind Turbines

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ABSTRACT

This paper investigates characteristics of high power semiconductor device losses in 5MW-class Permanent Magnet Synchronous Generator (PMSG) Medium Voltage (MV) wind turbines. High power semiconductor device of press-pack type IGCT of 6.5kV is considered in this paper. Analysis is performed based on neutral point clamped (NPC) 3-level back-to-back type voltage source converter (VSC) supplied from grid voltage of 4160V. This paper describes total loss distribution at worst case under inverter and rectifier operating mode for the power semiconductor switches. The loss analysis is confirmed through PLECS simulations. In addition, the loss factors due to di/dt snubber and ac input filter are presented. The investigation result shows that IGCT type semiconductor devices generate the total efficiency of 97.74% under the rated condition.

1. Introduction

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]. Power electronic converters in medium-voltage level are generally realized as Multi-Level (ML) voltage source converters (VSC) instead of 2L-VSCs in order to improve the performance factors regarding switch power losses, harmonic distortion, and common mode voltage/current [2]. In the family of multilevel inverters, the three-level topology, called Neutral Point Clamped (NPC) inverter, is one of the few topologies that have received a reasonable consensus in the high power community [3]. These NPC inverters have also been implemented successfully in the industrial applications for high power drives and wind turbines [4].

In the multi-MW wind turbine systems, there are many different types of power converter topologies and high-power switching devices in use. In particular, the recent development of high power semiconductor technology has resulted in a wide variety of practical power devices. The benchmarking of these topologies and its optimal power switches is important for industry to select the most feasible solution in product development of wind turbines. In general, comparison of various power switches involves a great deal of engineering work considering many different aspects of device characteristics. Therefore, it is necessary to pick critical performance factors on which the comparison for device is made so that the selection of the most feasible power device can be made with a meaningful engineering work and insight.

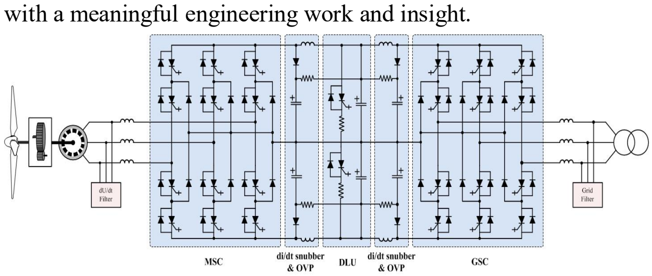


Fig. 1. Three-level neutral-point-clamped (3L-NPC) back-to-back configuration for 5MW PMSG MV wind turbine.

This paper investigates the utilization of press-pack type IGCT for 5MW PMSG wind turbine systems. The power converter topology of 3L-NPC VSC is selected as a main platform. Power loss dissipated in the semiconductor device is one of the most important performance factors in high power drives considering the total system efficiency and the requirement on cooling system. In addition, power loss analysis gives an engineering insight into the cost-effective system design [5]. This paper performs an analysis on press-pack type IGCT with respect to the power loss dissipation. 6.5kV IGCT is considered in the loss calculation of 3L-NPC VSCs. The loss distribution among several switching devices in the converter including the snubber is also explained in this paper.

2. Medium-voltage VSCs for 5MW PMSG Wind Turbines

A. Medium Voltage Press-pack type IGCT

A simplified schematic of the 3L-NPC VSCs for 5MW PMSG MV wind turbines is presented in Fig. 1 [6]-[7]. Major operating characteristics of 6.5kV press-pack type IGCT and Diode are summarized in Table I and used in the loss analysis throughout this paper. MV IGCT press-pack devices are mainly used in high power industrial applications owing to advantageous features such as press-pack housing cases, a higher thermal / power cycling capability, and an explosion-free failure mode [5]. Recently, 10kV IGCT device has been introduced and its switching capability has been confirmed. In this paper, 6.5kV/3800A press-pack IGCT (ABB 5SHY42L6500) is considered for the loss analysis. As for the anti-parallel and neutral-point diode, 6.5kV/1100A FRD (ABB 5SDF10H6004) is employed [8]-[9].

Table I. Characteristic values of IGCT and Diode

Device	6.5kV IGCT	6.5kV Diode
I_{TGQM} / $I_{F(AV)M}$	3800A / -	- / 1100A
Part	GCT-part	Diode-part
V_{TO} (Max)	1 88 V	1 5 V
R_T (Max)	0 56 mΩ	0 6 mΩ
E_{on} (Max)	3 1 J (4kV/3800A)	- (2 9kV/1000A)
E_{off} (Max)	44 J (4kV/3800A)	5 J (2 9kV/1000A)
$T_{vj\_max.}$	125℃	125℃
$R_{th(j-c)}$	8 5 K/kW	12 K/kW
$R_{th(c-h)}$	3 K/kW	3 K/kW
$R_{th(h-a)}$	6 K/kW	6 K/kW

B. Medium-voltage 3L-NPC VSCs

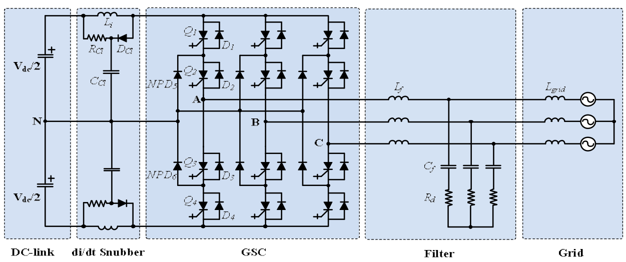


Fig. 2. Three-level neutral-point-clamped VSC under loss analysis.

Figure 2 shows the 3L-NPC VSCs for loss analysis of selected high power semiconductors. Each leg of the VSC consists of two neutral-point clamped diodes, four switches, and four anti-parallel diodes. 2nd-order *LC*-filter system has been employed at the grid side of converter to meet the harmonic constraint of grid code. In addition, di/dt snubber is essential for all IGCT converters to achieve the required di/dt characteristics during switching on.

C. Snubber circuit losses

Converters employing IGCTs need a di/dt limiting inductor to meet the required di/dt characteristics during switching on transients. This di/dt limiting inductor (L_i) usually necessitates an additional OVP snubber or clamping circuitry as shown in Fig. 3. This snubber circuitry dissipates additional power loss and gives a rise to an important loss factor.

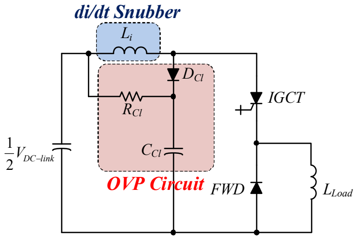


Fig. 3 OVP and di/dt snubber circuit in the upper-half part of 3L-NPC VSC.

Figure 3 presents an equivalent circuit of di/dt limiting inductor, OVP, and one particular IGCT being subject to switching transients in Fig. 2. At the instant of switching off, the stored energy in the inductor is mainly dissipated in the snubber resistor (R_{Cl}) or fed back to charge the dc-link capacitor ($C_{DC\text{-}link}$). In this paper, the total stored energy in the di/dt limiting inductor is considered to be an additional device loss factor since loss analysis is performed to be check the full functionality of power semiconductor switching devices. Therefore, clamp circuit loss P_{cl} can be expressed as;

$$P_{cl} = E_{R_{Cl}} \times f_{sw} = \frac{1}{2} L_i \cdot i(t)^2 \times f_{sw} \qquad (1)$$

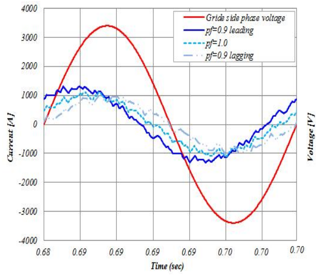
3. Simulation Results of 5MW MV Wind Turbine

The simulation is performed based on the parameters of 5MW MV VSCs as specified in Table II.

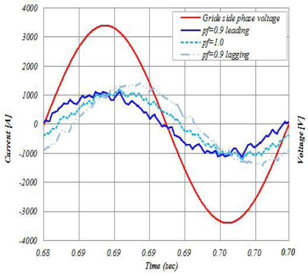
Table II. Simulation parameters of 5MW MV 3L-NPC VSC

Parameter	Symbol	Value	Per unit
Output power	$P_{rated\text{-}out}$	5 MW	1 0
Grid frequency	f_{sw}	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_{GSC_PWM}	1020 Hz	-
DC-link voltage	$V_{DC\text{-}link}$	7 kV	-
AC filter inductance	L_f	1 5 mH	0 16
AC filter capacitance	C_f	0 35 mF	0 45
di/dt limiting inductance	L_i	4 µH	-

In Fig. 4, ac input currents at the converter pole under the three different power factor conditions (0.9 leading, 1.0, and 0.9 lagging condition) are given with a respect to grid phase voltage. It is noted that the amplitude of ac input current for the case of 0.9 leading condition under inverter operating mode is at largest among three conditions. This is due to the fact that the grid side *LC*-filter adds further leading power factor so that the input current at the converter pole has more leading angle to generate 0.9 leading power factor at the ac input, i.e. up stream of grid side *LC*-filter.



(a) Inverter operating mode



(b) Rectifier operating mode

Fig. 4 Waveforms of ac input current at the converter pole and grid phase voltage.

4. Analysis of High Power Semiconductor Device Losses

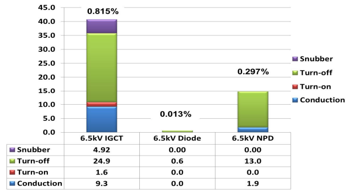
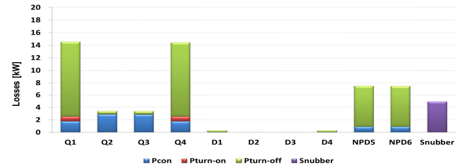
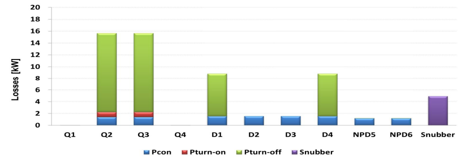


Fig. 5. Total loss distribution in IGCT, Diode, and NPD under inverter operating mode.

The power losses of 6.5kV IGCT and Diode in 5MW PMSG MV wind turbines have been summarized in Fig. 5 under 0.9 leading power factor condition of inverter operating mode. It shows that press-pack IGCT for GSC has the loss value of 56kW (1.13%) including the snubber losses. As a result, 6.5kV press-pack type IGCT platform has the total efficiency of 97.74% under the rated condition in back-to-back 3L-NPC VSCs.



(a) Inverter operating mode



(b) Rectifier operating mode

Fig. 6. Total loss distribution in each switch element of a phase-leg.

Figure 6 describes total loss distribution at worst case under inverter operating mode and rectifier operating mode. Under the inverter operating mode, Q_1, Q_4, NPD_5, and NPD_6 are subject to most of power loss. Under the rectifier operating mode, Q_2, Q_3, D_1, and D_4 are subject to most of power loss. As noted in Fig. 4, the amplitude of ac input current at the converter pole changes as the power factor is varied from 0.9 leading to 0.9 lagging. Higher amplitude of ac input current at the converter pole naturally results in higher power losses in power semiconductor switches.

5. Conclusion

In this paper, loss analysis of 6.5kV/3800A IGCT for 5MW PMSG MV wind turbine employing a back-to-back 3L-NPC voltage source converter is presented. The switching frequency is set to 1020Hz, under the grid side input voltage of 4.16kV. The press-pack type IGCT has been found to have the total efficiency of 97.74% under the rated condition, with the additional snubber loss of IGCT being taken into consideration.

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References

[1] BTM Consult ApS: World Market Update 2008, Forecast 2009-2013
[2] B Wu, High-Power Converters and AC Drives, Piscataway, NJ, IEEE Press, 2006, ISBN 978-0-471-731-9
[3] A Nabae, I Takahashi, and H Akagi, A new neutral point clamped PWM inverter," *IEEE Trans. Ind. Applicat.*, vol IA-17, pp 518-523, Sept /Oct 1981
[4] Information about ACS1000 medium voltage drive product at http://www abb com/motor&drives
[5] Y S Suh, J Steinke, and P Steimer, Efficiency comparison of voltage source and current source drive system for medium voltage applications," IEEE Transactions on Industrial Electronics, vol 54, no 5, pp 2521-2531, October 2007
[6] S Kouro, M Malinowski, K Gopakumar, L G Franquelo, J Pou, J Rodriguez, B Wu, M A Perez and J I Leon, Recent Advances and Industrial Applications of Multilevel Converters," IEEE Trans Ind Electron , vol 57, no 8, Aug 2010
[7] A Zuckerberger, E Suter, C Schaub, A Klett, and P Steimer, Design, simulation and realization of high power NPC converters equipped with IGCTs", Proc of the Thirty-Third IAS Annual Meeting, vol 2, pp 865-872, 1998
[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