PMSG 풍력발전기용 3L NPC와 ANPC 컨버터에서의 10kV IGCT 성능 비교 평가

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Comparative performance evaluation of 10kV IGCTs in 3L NPC and ANPC Converter in PMSG MV Wind Turbines

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ABSTRACT

The three level(3L) neutral point clamped (NPC) voltage source converter (VSC) topology is widely used for grid interface in high power wind energy due to its superior performance as compared to the two level(2L) VS. However, one of the major drawbacks of this topology is the unequal dispersion of loss and therefore the junction temperature among the power devices. The 3L ANPC topology derived from the NPC topology was proposed to resolve this drawback of unequal loss profile of 3L NPC.The 3L ANPC can work under various switching strategies. In this paper a comparative study of the various switching strategies of 3L ANPC using the recently developed 10kV IGCTs which has the capability to raise the current and voltage rating of the wind turbines is carried out. The comparison is performed using ABB make 10kV IGCT 5SHY17L9000 and PLECs simulations.

1. INTRODUCTION

The multilevel converter topologies provide unique solutions to work in high power applications. Amongst all the numerous multilevel converter structures, the 3L NPC is one of the widely accepted topologies because of its superior performance in terms of output voltage quality, reduced switch power losses, harmonic distortion and common mode voltage/current[1].However, this topology suffers from uneven switching stress and loss distribution for each power device. Due to this over and underutilization of switches, switching frequency, maximum achievable power and even the reliability of the converter is restricted. The Active NPC(ANPC) topology which is a derivation from NPC was proposed to resolve this issue[2].

The 3L ANPC in back to back configuration for PMSG wind turbine system is presented in Figure 1. As compared to the NPC topology, the ANPC topology features two additional switches across the clamping diodes.

With the wind turbine pushing its output capability to higher power limits,10kV IGCT will play an important role. Power converter failures is also a major reason for wind power plant downtime. Device failure are often due to device aging caused by thermal stress. It is therefore important to evaluate loss and the loss profile in a converter to ensure to the extent possible the even distribution of thermal stress amongst the individual switches. Very limited research is available on loss distribution of 3L ANPC and no investigations are available for 10kV IGCT in 3L ANPC topology. This paper investigates the performance of 10kV IGCT in 3L ANPC with four different modulation techniques. Comparisons are made with the conventional NPC topology.

This paper is structured in the following manner. Section 2 describes the difference in the operation of 3L NPC and 3L ANPC and brief description of the modulation techniques of both the topologies. The 10kV IGCT[3] under investigation and the simulation parameters with switching waveforms are presented in Section 3. The performance comparisons of the 10kV IGCTs for 3L NPC and 3L ANPC

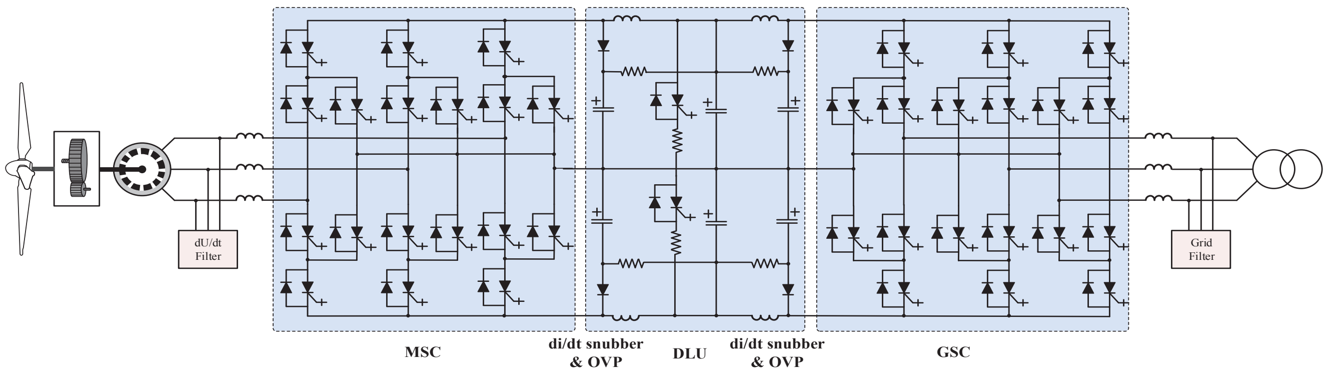

Figure 1:Three-level active neutral point clamped(3L-ANPC) back to back configuration for 5MW PMSG MV wind turbine

are presented in Section 3. And Finally, conclusions are presented in Section 4.

2. THREE LEVEL NPC and ANPC

Single leg of 3L NPC topology is represented by figure 2. In this conventional topology, to achieve the positive state(P), the top switches Q1 and Q2 are on as indicated in figure 2(a) and For the negative state(N), the bottom two switches Q3 and Q4 are turned on as shown in figure 2(b). For the neutral state(0), the current direction determines the path and therefore both switches Q2 and Q3 are turned on in figure 2(c). The current paths C_P,$C_{P'}$,C_N,$C_{N'}$$C_{01}$ and C_{02} defines the inverter or rectifier mode of operation. The NPC topology provides six different current paths and has only one switching strategy for P,0 and N states.

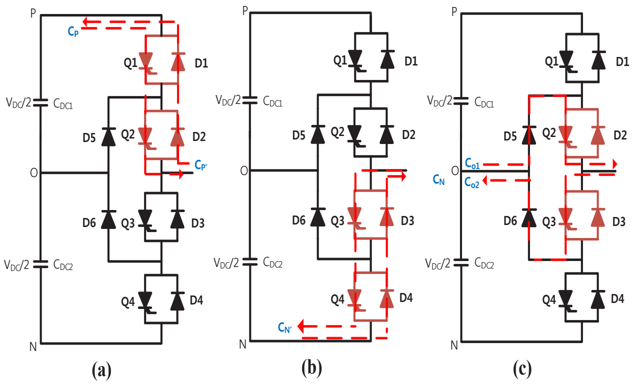

Figure 2 Three Level NPC Topology

Figure 3 shows the single leg of 3L ANPC topology composed of six bidirectional switches. Like 3L NPC topology, for P and N state switches Q1, Q2 and Q3, Q4 are turned on as indicated by figure 3(a) and 3(b). In certain switching strategy of ANPC switches Q6, Q5 may also be kept turned on during the P and N state respectively for equal voltage distribution. As shown in figure 3(c) to 3(e),the zero state in case of ANPC topology can be realized in multiple ways – the upper path(Q2,Q5 turned on) – short switching loop(SSL) of the clamping point or the lower path(Q3,Q6 turned on) – long switching loop(LSL) of the clamping point or both the upper and lower path(Q2,Q3,Q5,Q6 turned on)–Only one zero state(OOZS) or doubled frequency(DF)[4] when SSL and LSL are used alternatively in one switching period, can be used to realise the zero state. Based on the output voltage and current direction, the ANPC topology provides eight different current paths as shown in Fig 3(a)–(d). The multiple option to implement the neutral current paths (Co1, Co2, Co3, Co4) enables more variety in the modulation strategies.

3.10kV IGCT AND SIMULATION PARAMETERS

10 kV IGCT device has been launched recently and its switching capability confirmed. This device can be applied in the voltage class of 6–7.2kV MV 3L VSCs without the conventional series connection technique. When compared with the power component count of series connected 4.5kV or 5.5kV IGCT device, the use of 10kV IGCT device contributes

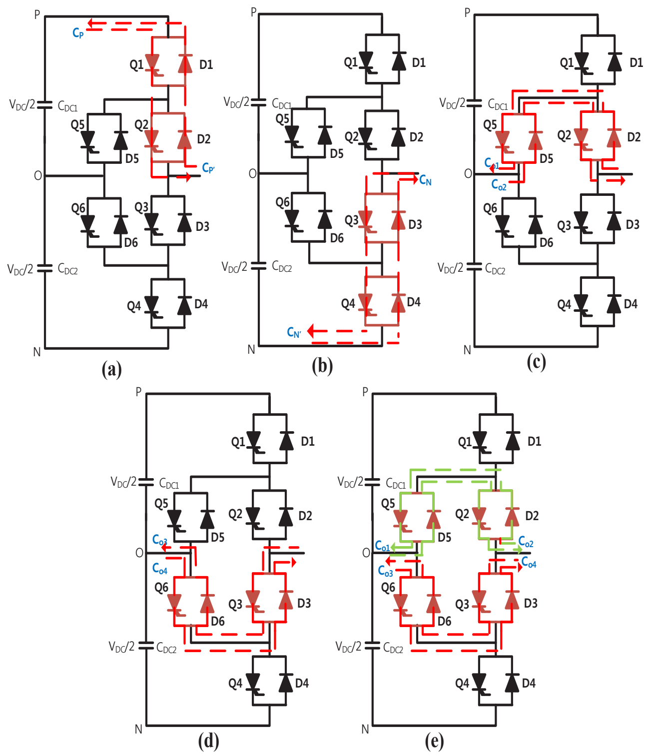

Figure 3 Three Level ANPC Topology

to a total reduction of device count by 41–71%.

The simulation operation parameters based on 5MW grid side and machine side VSCs are given in the Table 1. Grid side switching frequency is dominated by the optimal selection between the switching loss and harmonic content of ac input current. Table 1 also include the characteristic specifications of the device – 10kV IGCT[3],[6].The given data are employed for loss analysis of 5MW MV 3L–ANPC Grid Side VSCs in this paper

Table 1 Simulation Parameters

Parameter	Symbol	Value	Parameter	Symbol	Value
Output Power	$P_{rated\text{-}out}$	5 MW	AC filter inductance	L_f	1.5 mH
Grid Frequency	f_{grid}	60 Hz	AC filter capacitance	C_f	0.35 mF
Grid side inductance	L_{grid}	1.56mH	di/dt limiting inductance	L_i	4 μH
Grid side input voltage	V_{LL}	4.16kV	PMSG Output	$PMSG_{rated\_out}$	5 MW
Grid side input current	I_{AC_input}	708 A	Machine side Frequency	f_{pmsg}	29.1 Hz
Switching Frequency	f_{GSC_PWM}	1020 Hz	Machine side input voltage	$V_{LL(PMSG)}$	3.3 kV
DC-link voltage	$V_{DC\text{-}link}$	7 kV	Rated stator current	I_{stator}	920 A
DC-link Capacitance	$C_{DC\text{-}link}$	2.6 mF	Switching Frequency	f_{MSC_PWM}	1020 Hz
Device	**Parameter**	**Value**	**Device**	**Parameter**	**Value**
IGCT	Blocking Voltage	9kV	Diode	Blocking Voltage	9kV
	$I_{TGQM}/I_{F(AV)}$	1700A		$I_{TGQM}/I_{F(AV)}$	1700A
	V_{TO}	2.2V		V_{TO}	2.2V
	R_T	1.2mΩ		R_T	1.6mΩ
	E_{on}(5kV/1.7kA)	1.5J		E_{on}	-
	E_{off}(5kV/1.7kA)	19.5J		E_{off}(5kV/1.7kA)	22J
	T_{vj_max}	125°C		T_{vj_max}	125°C
	$R_{th(j-c)}+R_{th(c-h)}+R_{th(h-a))}$	(9.5+3+6) K/kW		$R_{th(j-c)}+R_{th(c-h)}+R_{th(h-a))}$	(6+3+6) K/kW

10kV IGCT switching voltage and current waveform per phase during one ac line period of 0.9 leading power factor are given in Figure 4 and 5.By sampling the voltage and current switching instant from the waveform for each IGCT, Diode and using these sampled values, the switching loss is calculated under the condition of maximum ac input current ,line under–

voltage of 90% and power factor of 0.9 leading. The losses are calculated assuming linear loss [5] behavior. The loss is also verified using the look up table loss calculation model in PLECs simulation tool.

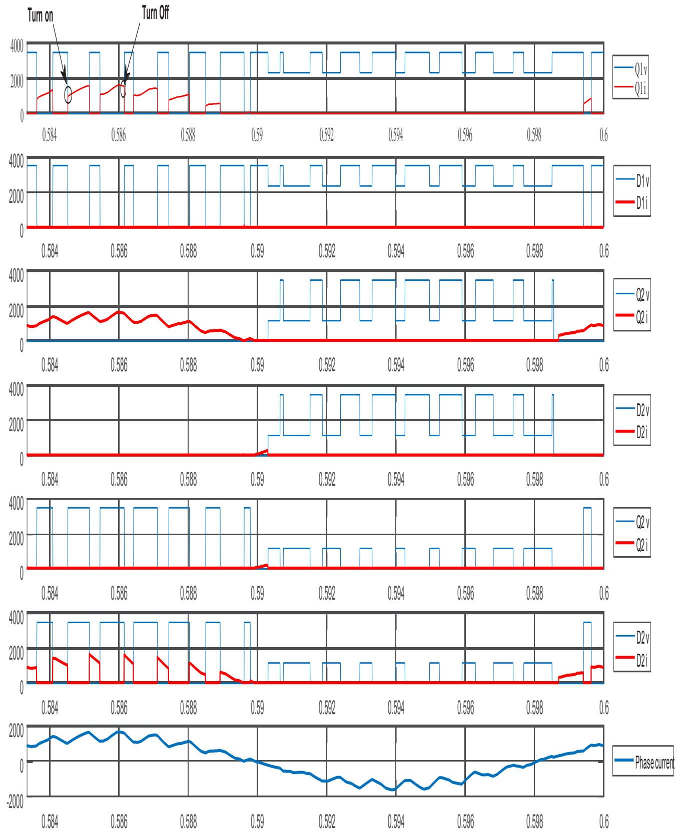

Figure 4 IGCT switching voltage and current waveforms in the upper side of phase leg A

4.LOSS ANALYSIS COMPARISON

The complete loss profile of 10kV IGCT in NPC and ANPC distribution profile as compared to ANPC which has four different loss distribution profile. Clearly ANPC with SSL modulation technique behaves like the conventional NPC. However, in the LSL strategy, the outer switch losses are dispersed to the inner switches. LSL technique also provides better spread of the conduction losses amongst the switches. With the OOZS technique where all the switches(Q2,Q3,Q5,Q6) are turned on, some of the losses from the inner switches are dispersed to the clamping devices. The doubled frequency method uses both the SSL and LSL in one switching period, thereby effectively increasing the output switching frequency by double. As can be seen in this technique the switching losses are distributed well amongst the inner and the outer switches.

5.CONCLUSION

In this paper, performance of 10kV IGCT in 5MW MV wind turbine with both NPC and ANPC topology is conducted. Loss behavior and thereby the thermal loading of a switch define the power limit, cooling system size as well as the reliability and lifetime of the power converter. Amongst all the modulation techniques of 3L ANPC, DF method portray the best loss sharing profile. However, the classical SSL and LSL are much easier to implement. As compared to NPC, the total loss in ANPC does not change however ANPC provide the opportunity to spread thermal stress amongst switches to a certain extent which is not feasible in NPC.

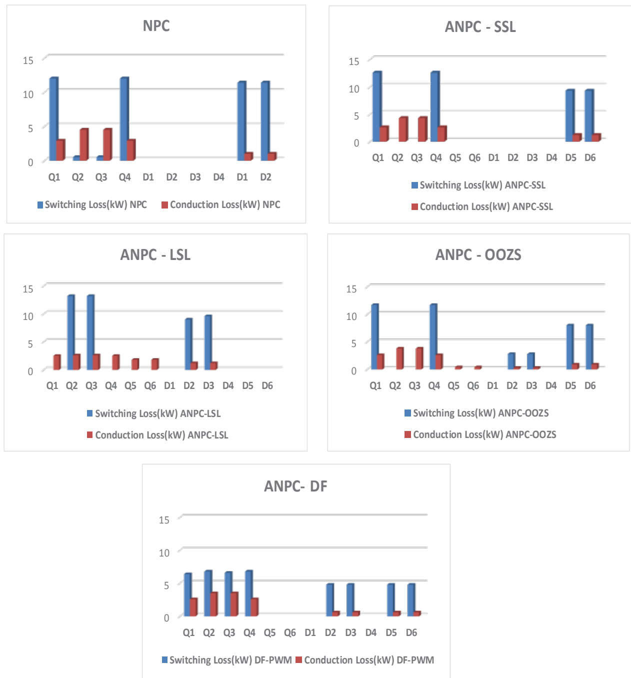

Figure 5 Loss profile of NPC and ANPC with 10kV IGCT

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