Consideration on Protecting IGBT Modules in 3-level Neutral-Point-Clamped Converter

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Abstract

This paper will introduce short-circuit function for IGBTs, including arm-shoot and load short-circuit. The influence on short-circuit by the stray inductance will also be explained in this paper. And the experiment will be shown to explain this influence. And the suggestions on designing busbar with low stray inductance for 3-level NPC converter will also be given in this paper.

1. Introduction

Energy conservation and emission reduction is one of the most important countermeasures to protect the environment. And the utilization of the renewable energy, like wind power and solar power, could be helpful to realize this target.

In recent years, the utilization of wind power is increased more and more in China. So far, the 690V wind turbine up to 3MW takes most of the shares in the market, which is mainly for the on-land wind turbine. As for the off-shore wind turbine, there are several advantages: a) More abundant wind source; b) Stable wind speed; c) Less negative effect to the environment; etc. To utilize the off-shore wind power, it needs to develop wind turbine larger than 5MW which satisfies the requirement of easy installation and maintenance free.

So far, the power capacity of converters used for wind turbine is up to 7.5MW, which was developed by Enercon. It is E126-7.5MW wind turbines with 3kV output. And 10MW wind turbine is expected to research from this year. As for the high capacity full-power wind turbine, the free-maintenance is the most important requirement for wind turbine. And the wind power converters should play the important role in these requirements.

![3-level NPC topology](image)

Fig. 1. 3-level NPC topology
In the beginning stage, some MV-inverters were using GTO and IGCT as the power switching devices. Recently IGBT is becoming more and more popular in the market. In this paper, 4500V IGBT application for 3300V MV-inverter using 3-level topology will be discussed in details, which is popular in 3300V wind power converters shown in Fig.1.

2. Development of 4500V IGBT modules

2.1 IGBT chip technology

Now both Mitsubishi H series HVIGBT and R series HVIGBT are widely used in the market. Fig. 2 shows the cross section of H series and R series HVIGBT chips, which are developed by Mitsubishi Electric. Compared with H series IGBT, the new developed R series HVIGBT has been improved on 3 points: a) Enhanced planar gate cell by additional carrier enhanced N layer; b) Optimized N- drift layer; c) LPT structure [3].

2.2 Safety-Operating Area (SOA) of R series 4500V HVIGBT

Fig. 3. SOA of CM1200HC-90R
Fig. 3 gives RBSOA (Reverse Biased Safety Operating Area), SCSOA (Short Circuit Safety Operating Area) of CM1200HC-90R respectively. RBSOA stands for the ability of turning off the current under the rated voltage. SCSOA stands for the ability of turning off the current under short-circuit, which is also related with the positive drive power supply closely. In the actual application, IGBT should be guaranteed to run in SOA.

Fig. 4. Actual test waveform of CM1200HG-90R

Fig.4 gives the actual test results of turn-off waveform of CM1200HG-90R, which shows that there is much margin for turn-off ability [3].

3. Influence of stray inductance of DC busbar during SC

3.1 Functions of short-circuit

There are two different types of short-circuit for an IGBT: a) short-circuit I, the IGBT is turned on when a load or bridge short circuit already exists; b) short-circuit II, the IGBT is already turned on before the short circuit occurs.

3.2 Short circuit test and the influence of the stray inductance of busbar

Fig. 5. Test circuit of short circuit
In this paper, short-circuit I will be taken as the example. And the test circuit was shown as Fig.5.

3.2.1 Short circuit test under large stray inductance busbar

Fig. 6. Example layout of busbar and test result of short-circuit

Fig.6(a) gives the example layout of bus bar for short circuit test, in which positive busbar and negative busbas are connected independently. It is easy to understand that there is large stray inductance of DC busbar in this layout. And Fig.6(b) gives the test results of short circuit based on DC busbar layout in Fig.6(a). The test module is CM900HC-90H and DC bus voltage is 1000V. From it, it could found that the current could be over 11000A, while Vce(peak) is 3000V. By comparing the test results with the SCSOA, it could be found that the test result is over SCSOA as shown in Fig.7, which cannot satisfy the actual application.

Fig. 7. SCSOA of CM900HC-90H
3.2.2 Short circuit test based on laminated busbar

Fig. 8. Laminated busbar and test results

Fig. 8 gives the laminated busbar for short circuit test and the related test results. The test results showed that the current is 6100A and the Vce(peak) is 3700V. The DC bus voltage is set up as 2500V, which is similar with the actual application conditions in 3-level NPC converter. Comparing with SCOSA in Fig.8, it could found the test results are within SCOSA.

From the test results in Fig.6 and Fig.8, it could be concluded that the stray inductance of DC busbar has a very large influence on keeping IGBT running in SCOSA. This is caused by: a) larger stray inductance will cause higher Vce(peak); b) larger stray inductance (load inductance) will cause lower current increasing, which will introduce longer time on protecting turn-off of IGBT modules.

4. Consideration on reducing the stray inductance of DC bus bar

Fig. 9. Current shifting loop during IGBT turn-off
Fig. 9 gives the current shifting loop [1]. In Fig. 9(a), the peak voltages for T1 and T3 during turn-off are respectively as the following.

When T1 turn off and T3 turn on, the peak voltage on T1 is

$$V_{T1(\text{peak})} = \frac{V_{cc}}{2} + L_1 \frac{di}{dt} + L_{\text{Module}} \frac{di}{dt} + L_{\text{Diode}} \frac{di}{dt} + L_2 \frac{di}{dt} + L_3 \frac{di}{dt}$$  \hspace{1cm} (1)

When T3 turn off and T1 turn on, the peak voltage on T3 is

$$V_{T3(\text{peak})} = \frac{V_{cc}}{2} + L_1 \frac{di}{dt} + L_{\text{Module}} \frac{di}{dt} + L_{\text{Diode}} \frac{di}{dt} + L_3 \frac{di}{dt}$$  \hspace{1cm} (2)

Where, $V_{cc}$ is the DC bus voltage, $L_i (i=1, 2, 3)$ is the stray inductance of busbar, $L_{\text{Module}}$ is the stray inductance of IGBT, $L_{\text{Diode}}$ is the stray inductance of Diode.

From (1) and (2), it could be found that T1 would bear the higher voltage than T3, which is similar as the actual test results. Based on this, it is recommended to try to reduce the stray inductance in LOOP A.

On the other hand, it is important to reduce the stray inductance in short-circuit loop (busbar 1, 4, 6, 7, 8), which is to keep IGBT running in SCOSOA when short-circuit occurs.

5. Conclusion

With the development of wind power market, 3300V output voltage wind power converters will be more and more popular. And the 3-level topology and 4500V IGBT modules, including both H series and R series, could satisfy this development. In this paper, the actual test results of CM900HC-90H (900A/4500V) were given, which show that the stray inductance of busbar will have a big influence on running of IGBT module. In order to make IGBT run in SOA, the design of busbar with low stray inductance should be concerned. And the stray inductance could be reduced with the analysis of current shifting loop.

6. References

