A Suitable 4.5kV HVIGBT for 3-level Neutral-Point-Clamped Converter

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Abstract-This paper will introduce the suitable power module for 3-level neutral-point-clamped converter from the cost-performance and electric performance. As a conclusion, CM1200HC-90R developed by Mitsubishi Electric is selected for a 3MW 3-level NPC converter. And the power loss for this application is also calculated.

I. INTRODUCTION

Generally, the input of MV-converters covers from 1kV to 13.8kV. And the power capability covers from 0.4MW to over 100MW. Now the high power MV-converters are widely used for driving pipeline pumping, exhaust gas fan, water supply pumping, steel main rolling mill and traction motors, etc. With the application of MV-converters, the energy saving and improvement on production efficiency could be realized.

Comparing to the LV-converters, there are many higher requirements for MV-converters, such as low cost, small volume, high efficiency, fault protection and maintenance free, etc. As for the technical requirements, it include: a) low harmonic of input current; b) high input power factor of over 0.9, which is requested by the grid company; c) lower dv/dt; d) low common mode voltage pressure; e) suppression of LC resonance, etc [1].

Now there are several kinds of topologies widely used in MV-converters, including 2-level VSI, 3-level NPC VSI, and Cascaded H-bridge inverter. What’s more, CSI technology is also widely used in MV-converter application.

Moreover, as the key components of MV-converters, the switching power devices are also deciding the application of the topologies in MV-converters.

II. TOPOLOGIES FOR HIGH-POWER MV-CONVERTERS

A. 2-level converter

Fig. 1 shows the circuit of 2-level PWM converter (3-phase full-bridge PWM converter), which is popular for 1140V MV-converters by using 3300V IGBT modules.

The advantages of 2-level PWM converters include: a) simple control algorithm; b) simple control of pre-charge of DC capacitor; and c) 4-quator operation. While there are also some disadvantage for this topology: a) high dv/dt for inverter output; b) high harmonic in output current and voltage; and c) high common voltage.

B. Cascaded H-bridge converter

Fig. 2 shows the topology of nine-level cascaded H-bridge converter [2], which is popular for 6kV and 10kV MV-converters by using 1700V IGBT modules.

The topology of CHB converter is easy to realize: a) modularization structure design for low cost and easy maintenance; b) sinusoidal output; and c) N+1 redundant operation. But this topology will use much more switching power modules. On the other hand, the phase-shift transformer will cause high cost.

C. 3-level NPC converter

Fig. 3 gives the topology of 3-level NPC converter using IGBT modules.

Comparing with 2-level converters, 3-level NPC converters have lower harmonics and could use lower output filter. While 3-level NPC converters could use less switching power...
modules than CHB converters, which will reduce the cost and improve the system reliability.

III. DEVELOPMENT OF HIGH VOLATGE IGBT MODULES

So far, High-Voltage-IGBT modules with the rated voltage up to 6500V are widely used in the market.

Now the new generation Mitsubishi Electric HVIGBT modules, R series HVIGBT, are also launched to the market. R series HVIGBT modules include 3300V series, 4500V series and 6500V series. While the current could be up to 1500A for 3300V IGBT module. As for the isolation voltage of power module, it could be classified as 10.2kV (HG type) and 6.0kV (HC type) [3].

Fig. 4 shows the cross-section of IGBT chips for previous generation (H series) and the new generation (R series). From Fig. 4, it could be found that R series adopts some new technologies in IGBT chips for R series HVIGBT module, such as N-well an N-drift layer, etc. Therefore, R series HVIGBT has good electric performance as: a) very low power loss; b) high robustness and reliability; c) wide operation temperature range of -40°C~150°C; d) maximum junction temperature of 175°C.

IV. SELECTION OF POWER MODULES FOR 3-LEVEL NPC CONVERTER

According to the analysis in section II, it could be found that 3-level NPC converter is the suitable topology for 3300V converters with the consideration on cost-performance. And the design tips on selection of power modules will be explained from consideration on isolation voltage, limitation of Vces and selection of current.

A. Consideration on isolation voltage of HVIGBT

As explained in section III, there are 2 types HVIGBT modules by the isolation voltage of power modules, including 10.2kV (HG) type and 6.0kV (HC) type. According to IEC 1287, the relationship of the isolation voltage of power modules (Viso) and the highest peak repetitive working voltage (Vm) is shown as the following equation.

\[ V_{iso} = 2 \times \frac{V_m}{\sqrt{2}} + 1000 \text{ (V)} \]  

From the equation (1), it could calculate that the Vm is 6500V and 3500V for HG type and HC type respectively.

In the practice application, the heat-sink will be directly connected to the earth, which means the baseplate of power modules are also connected to the earth. Under this condition, HC type could not be used for this application, because the DC bus voltage of 3-level NPC converter is 5000V.

It should be noted that the neutral point of 3-level converter should be regarded as a dangerous live part according to IEC61800-5-1, which shouldn’t be directly connected to the earth. Meanwhile, according to IEC61800-5-1, when connecting a large resistor between the clamped neutral point of converter and the heat-sink (earth), the heat-sink could be regarded as PELV circuit, and the voltage between the heat-sink and power terminals of power modules is only 2500V, which could satisfy the requirements of IEC standard.

So HC type could be selected for 3300V 3-level NPC converters by connecting a large resistor between the clamped neutral-point and the heat-sink.

B. Selection of rated voltage of power modules

Fig. 5 shows the RBSOA of CM1200HC-90R. According to the RBSOA curve, the collector-emitter DC voltage for each module should be lower than 2/3 of blocking voltage of
power module. For example, the collector-emitter DC voltage is less than 3000V for 4500V IGBT modules. Based on this limitation, 4500V HC type HVIGBT modules will be selected for this application.

C. Power loss calculation

Based on the above analysis, CM1200HC-90R is selected for 3MW 3300V 3-level NPC converter, which is for wind power application.

Fig. 6 shows one phase leg of 3-level NPC converter. And the current conduction for 3-level NPC converter is demonstrated in [6].

The power losses of power modules include the conduction losses and the switching losses.

The conduction losses for each switch could be calculated as the following equation [6].

\[
P_{\text{con}} = U_0 \cdot I_{\text{avg}} + r_f \cdot i_{\text{rms}}^2
\]  

(2)

Where \(U_0\) is the forward voltage drop with zero current, \(r_f\) is the forward resistance, \(I_{\text{avg}}\) is the average current and \(i_{\text{rms}}\) is the root-means-square of the current.

And the calculation equations of the average current and RMS current for IGBTs T1 and T4 are also given in [6].

\[
I_{\text{avg}} = \frac{M I}{4\pi} \left[ \sin|\phi| + \left( \frac{\pi}{2} - |\phi| \right) \cos \phi \right]
\]  

(3)

\[
I_{\text{rms}}^2 = \frac{M^2}{4\pi} \left[ 1 + \frac{2}{3} \cos \phi + \frac{1}{3} \cos(2\phi) \right]
\]  

(4)

Where \(I\) is the peak current of the output, \(\phi\) is the phase difference between the output current and voltage, and \(M\) is the modulation index.

The currents for T2 and T3 are shown in [6].

\[
I_{\text{avg}} = \frac{i}{4\pi} \left[ \sin|\phi| - \phi \cos \phi \right]
\]  

(5)

\[
I_{\text{rms}}^2 = \frac{i^2}{4\pi} \left[ 1 - \frac{4}{3} \cos \phi + \frac{1}{3} \cos(2\phi) \right]
\]  

(6)

The currents for diodes D5 and D6 are

\[
I_{\text{avg}} = \frac{i}{4\pi} \left[ \cos \phi + \frac{2}{\pi} \sin \phi - \frac{2}{\pi} \cos \phi \right]
\]  

(7)

\[
I_{\text{rms}}^2 = \frac{i^2}{4\pi} \left[ 1 + \frac{1}{3} \cos(2\phi) \right]
\]  

(8)

While the switching losses could be calculated as

\[
P_{\text{sw}} = \frac{1}{2} \cdot f \cdot \epsilon(\Delta\phi)
\]  

(9)

Where \(f\) is the switching frequency and \(\epsilon\) is the switching energy.

Fig. 7 gives the collector-emitter saturation voltage characteristics of CM1200HC-90R [7]. From it, it could be concluded that \(U_{ce(0)}\) is 1.6V and \(r_f=2\text{m} \Omega\).

The working conditions for 3MW 3300V 3-level NPC converter are defined as: DC bus voltage \(V_{\text{cc}}=5000\text{V}\), switching frequency \(f_{\text{sw}}=500\text{Hz}\), \(R_{\text{g(on)}}=2.7 \Omega\), \(R_{\text{g(off)}}=10 \Omega\), \(I_o=525\text{Arms}\), \(I_{in}=525\text{Arms}\), output frequency \(f_o=50\text{Hz}\). Under these conditions, the critical parts of power losses are showed in Table I.

<table>
<thead>
<tr>
<th>Power losses of IGBT modules</th>
<th>Rectifier unit</th>
<th>Inverter unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P_{\text{con}})</td>
<td>32.6W</td>
<td>78.5W</td>
</tr>
<tr>
<td>(P_{\text{sw}})</td>
<td>941.3W</td>
<td>338.0W</td>
</tr>
<tr>
<td>(P_{\text{total}})</td>
<td>973.9W</td>
<td>416.5W</td>
</tr>
<tr>
<td>(T_{(\text{on})})</td>
<td>9.74 ℃</td>
<td>7.91 ℃</td>
</tr>
<tr>
<td>(T_{(\text{off})})</td>
<td>9.74 ℃</td>
<td>7.91 ℃</td>
</tr>
</tbody>
</table>

From Table I, it could be concluded that the temperature rise is very low, which indicates that CM1200HC-90R could be used for 3MW 3-level NPC converter with high reliability.
V. CONCLUSION

By connection a large resistor between the heat-sink and the clamped neutral point of converter, Mitsubishi Electric R series HC type could be used for 3300V 3-level NPC converter. Moreover, with the consideration on RB SOA of HVIGBT and her application conditions, CM1200HC-90R is selected for 3MW 3300V 3-level NPC converter. And the power loss is also calculated for this application.

REFERENCES