Research on the Selection of 35kV STATCOM Power Device

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Abstract

With increased smart upgrading and reconstruction of power grid in China, typical representative of the third generation dynamic reactive power compensation technology, i.e. STATCOM(SVG), has been used widely in power transmission and distribution network all over China with good economic and social benefits. Yet restricted by the power device, existing STATCOM generally requires a large number of IGBTs for operation at load center substation (above 330kV). Due to high construction cost and many hidden troubles, people begin to seek new power device. This paper firstly lists those power devices used for STATCOM in recent years, conducts contrast analysis on their advantages and disadvantages at 35kV voltage level from the viewpoints of economic level and loss level, and provides reference for designers.

Keywords: STATCOM, GTO, IGBT, IGCT, IEGT

1. Introduction

In accordance with the Regulations of the State Grid Corporation of China for Voltage Quality and Reactive Power Management in the Power System, in fault operation mode of the bus on MV side of 500 (330) kV substation, voltage tolerance is -5% to +10% of rated system voltage; in fault operation mode of 35 to 110 kV bus at 220 kV substation, the voltage tolerance is ±10% of rated system voltage. It can be seen that, stable voltage is a very important. Since some power grid faults occur in a very short time, traditional reactive compensation equipment can not suppress substation voltage fluctuation effectively, which can cause major accidents.

At present, some domestic substations attempt to install STATCOM to stabilize the voltage, for example, Shanghai 220kV Western Suburb Substation STATCOM(±50MVar) in 2006, Liaoning Power Grid 66 kV Daoerdeng Substation STATCOM(±5MVar) in 2011, and Southern Power Grid 500kV Dongguan Substation STATCOM(±200mVar) in 2012. The voltage class and capacity of STATCOM have been increased continuously, and the power device for it also experienced the process from initial GTO to IGBT then to IGCT, IEGT. This paper firstly analyzes the features of these power devices one by one.

2. Introduction to typical power electronic power devices

GTO(Gate Turn-off Thyristor). As a full-controlled device, GTO is a thyristor with self-turnoff capability, allowing turn-off via negative gate signals. Through decades of development, commercial GTO thyristors can withstand voltage up to 6kV and current up to 6kA, playing an important role in high power inversion, chopped wave and other fields.

Fig.1. GTO physical diagram

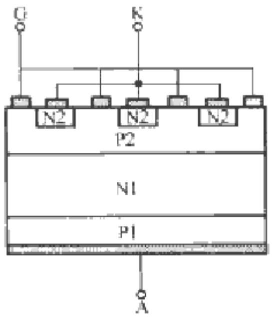

Fig.2. Basic unit structure of GTO

IGBT(Insulated-gate Bipolar Transistor-IGBT or IGT). IGBT takes the best of both MOSFET and GTR, and is a three-terminal component with grid G, collector C and emitter E. It can withstand relatively high voltage in cut-off state, high current with very low voltage drop in conducting state and very high di/dt and du/dt at fast switching speed in case of switching.

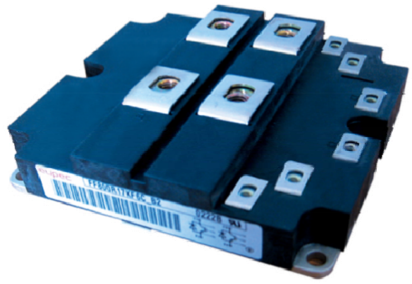

Fig.3. IGBT physical diagram

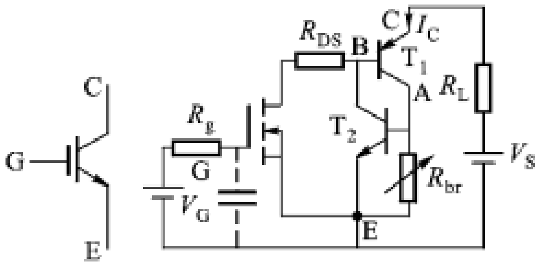

Fig.4. Equivalent circuit of IGBT

IGCT(Integrated Gate Commutated Thyristor). IGCT is the general name of Integrated Gate Drive Circuit and Gate-Commutated Thyristor (GCT), a derivative device of GTO. Its basic structure adopts a series of improvement measures on the basis of GTO, such as special annular gate, gate drive circuit integrated with the tube core etc., which enables IGCTs to have equivalent capacity as GTOs, featuring superior ON/OFF capacity.

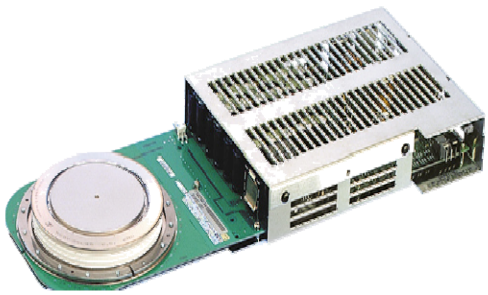

Fig.5. IGCT physical diagram

IEGT(Injection Enhanced Gate Transistor). IEGT is a high capacity power electronic device that utilizes voltage driven MOS grid to control high current. IEGTs and IGBTs have very similar structure with the difference in large gate width Lg of IEGT. IEGTs adopt injection enhanced structure to realize low pass state voltage, enabling high capacity power electronic device to be developed by leaps and bounds. IEGTs feature low loss, high speed operation, high withstand voltage and intelligent active grid drive, slot structure and parallel chips, featuring self current-balancing characteristic.

Fig.6.   IEGT physical diagram

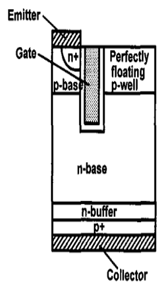

Fig.7. schematic structure of IEGT

The above-mentioned power devices have their own features. Generally, when voltage is low, IGBT will be selected; when voltage is high, IGCT/IEGT will be selected, while for extra high voltage, GTO still occupies an important position.

3. Economical comparison among IGBT, IGCT and IEGT

Since GTO has not been used as power device of STATCOM in recent two years, the comparison of economical efficiency focuses on IGBTs, IGCTs and IEGTs. 35kVSTATCOM converter chain adopts “Y” and “Δ” connection modes, connections. Relevant parameters of these three devices in both connection modes are listed in Table 1.

Table 1 Economical Comparison of Different Power Devices in Y/Δ Connections

No.	Category	IGBT	IGCT	IEGT
1	Quantity of serial valve block	22/37	16/26	16/26

	unit per phase			
2	Total quantity of valve block unit	132/222	96/156	96/156
3	Whether the device is connected in parallel	Two in parallel	No	No
4	Total quantity of the device	1056/1776	384/624	384/624
5	Cost,%	100/160	130/140	130/140

It can be seen that, at 35kV voltage class, if only overall cost of the power devices is considered, overall cost of IGBTs is relatively cheap. In addition, if IGCTs/IEGTs devices are used, the cost of valve block in "Δ" connection is about 10% higher than that in "Y" connection.

4. Loss comparison among IGBT, IGCT and IEGT

Through the above-mentioned analysis, at 35kV voltage class, no matter in "Y" or "Δ" connection, quantity of IGBT is the largest, and almost 2.75 times of the other two devices. So, to analyze the loss, only IGCTs/IEGTs are compared. Take an example of a 35 kV/±200 MVar chain STATCOM, the complete equipment consists of 6 sets of valve blocks, each valve block contains 26-stage H bridge cascade, and switching frequency of the power device is 250 Hz.

Stability loss formula of single IEGT:

$$
\begin{aligned}
P_{\mathrm{ss}} &= I_{\mathrm{cp}} U_{\mathrm{ce(sat)}} \frac{1}{2\pi} \int_0^{\pi} \sin^2 x \frac{1+\sin(x-\theta)}{2} \mathrm{d}x \\
&= I_{\mathrm{cp}} U_{\mathrm{ce(sat)}} \left(\frac{1}{8} + \frac{D}{3\pi}\right) \cos\theta \\
&= 0.14 I_{\mathrm{cp}} U_{\mathrm{ce(sat)}} \qquad (1)
\end{aligned}
$$

Where,

$U_{ce(sat)}$ refers to saturation voltage drop;

I_{cp} refers to the peak of sinusoidal output current;

D refers to PWM signal duty ratio, takes D=0.5;

Θ refers to the phase angle between output voltage and current, takes cosθ=0.8.

Switching loss is:

$$
\begin{aligned}
P_{\mathrm{sw}} &= (E_{\mathrm{sw(on)}} + E_{\mathrm{sw(off)}}) \frac{1}{2\pi} \int_0^{\pi} \sin x \mathrm{d}x \\
&= (E_{\mathrm{sw(on)}} + E_{\mathrm{sw(off)}}) F_{\mathrm{sw}} \frac{1}{\pi} \\
&= 79.58 (E_{\mathrm{sw(on)}} + E_{\mathrm{sw(off)}}) \qquad (2)
\end{aligned}
$$

Where,

$E_{sw(on)}$ refers to IEGT turn-on energy corresponding to each pulse;

Esw(off) refers to IEGT turn-off energy corresponding to each pulse; Fsw refers to PWM switching frequency.

Total power consumption is:

$$P_c = P_{ss} + P_{sw} \tag{3}$$

Main inverter unit adopts Model ST1500GXH24 IEGT as converter component, turn-on, turn-off loss is 8 J and 6.8 J respectively, conducting voltage drop is 3 V, operating current 1.5 kA, 624 devices. Maximum conduction loss of main circuit is:

$$P_{\text{o-loss}} = 624 P_{ss} = 399.86\text{kW} \tag{4}$$

Switching loss of main circuit is:

$$P_{\text{s-loss}} = 624 P_{sw} = 734.75\text{kW} \tag{5}$$

If this equipment adopts Model 5SHY 35L4510 IGCT, turn-on, turn-off loss is 1.5 J and 22 J respectively, conducting voltage drop is 2.4 V, operating current 1.5 kA, 624 devices, then Po-loss and Ps-loss are as follows:

$$P_{\text{o-loss}} = 624 P_{ss} = 319.89\text{kW} \tag{6}$$

$$P_{\text{s-loss}} = 624 P_{sw} = 1166.96\text{kW} \tag{7}$$

It can be seen that, when IEGT is used, total loss is 1134.61 kW, when IGCT is used, total loss is 1486.85 kW. Therefore, if IEGT is used, annual energy saving is 3085.62MWh.

5. Conclusion

In high voltage high capacity STATCOM field, GTO is lagged behind in various properties, and thus is firstly excluded. In order to meet 35kV voltage class, a large number of IGBTs should be connected in series, although cost of the device itself is not high, plus auxiliary devices, total cost is high, the structure is complicated, system loss is high, and there are many hidden troubles. IGCTs and IEGTs belong to up-to-date power devices, so the quantity used is reduced greatly, control becomes relatively simple, and overall cost is also acceptable. With respect to the analysis of system loss, due to the reason of IGBT quantity, loss is relatively high; compared with IGCT, IEGT loss is smaller, which is more suitable to meet the national energy-saving requirements.

In fact, the space of many substations is very limited, STATCOM volume is often considered with emphasis. Use of IGCTs and IEGTs can reduce the quantity of serial valve block units, and avoid direct parallel connection of the switching devices, which allows more reasonable power modular structure to be designed and more compact of the whole device.

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