Compact 2kV IGBT Modules for Cascaded Static Var Generator

Bo Hu, Jian Sun, Gaosheng Song

Mitsubishi Electric & Electronics (Shanghai) Co., Ltd, China

Corresponding author: Bo Hu, HuBo@mesh.china.meap.com

Abstract

With the continuous development of industrialization and increasing of power load, the power system is facing grid voltage fluctuation, which brings great risks to the stability and security of the power grid [1][5]. Therefore, how to improve the stability of power system has become one of the core contents in power system engineering. To cope with the above problems, it is necessary to enhance the voltage control ability of the power grid and increase its dynamic reactive power reservation. Static Var Generator (SVG) is a new type of reactive power compensation system based on modern power electronics technology, which can quickly track and compensate the reactive power of the power grid [2][3].

In the future, the requirements for power electronic converters will continue to increase, such as higher power density, higher converter efficiency, higher reliability, etc. As key components of power electronic converters, IGBT modules play a more and more important role. Mitsubishi Electric developed LV100-package T-series Insulated Gate Bipolar Transistor (IGBT) Module for industrial use. The new power-semiconductor product is expected to downsize and reduce the power consumption of power conversion equipment.

1 Introduction

1.1 Background

Efficient power conversion through the deployment of increasing operation voltages is needed, especially for power grids with renewable-energy power sources, which had led to the power converters rated at DC1500V. To simply the design of DC1500V power conversion system and reduce the power consumption, Mitsubishi Electric developed LV100-package IGBT module CM1200DW-40T. The main spec is as Table. 1.

Table. 1. Main specification

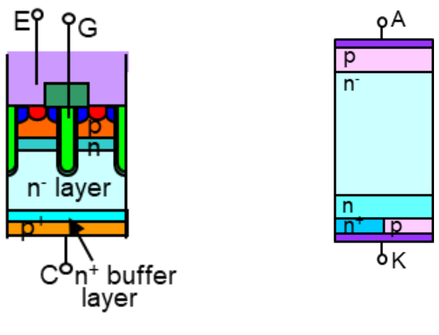
Product	CM1200DW-40T
Rated voltage	2kV
Rated current	1200A
Isolation voltage	$4kV_{rms}$
Internal connection	2in1
Size	100mm×140mm×40mm

Fig. 1. LV100-type T-series 2.0kV IGBT Module

The outline is as Fig.1, the upper-side AC main terminals and bottom-side DC terminals are aligned in opposite side, and auxiliary terminals are placed in the middle. This optimal terminal layout is suitable for IGBT paralleling connection to achieve flexible converter capacities.

1.2 Chipsets

CM1200DW-40T adopts 7th generation IGBT technology with CSTBT™3 structure, which can be seen as Fig.2(a), compared to last generation, thinner N^- drifter layer was used to realize lower power loss. Meanwhile, the dv/dt controllability in switching becomes easier when changing R_G value, which can benefit the system EMC design.



(a) (b)

Fig. 2. chipsets

RFC (Relaxed Filed of Cathode) diode technology was applied for CM1200DW-40T, as in Fig.2(b), P layer is partially added on the cathode side, so holes are in-

ISBN 978-3-8007-6414-3

jected at the timing of reverse recovery, which can suppress the rise of steep recovery voltage and avoid snappy recovery.

1.3 Package

Industrial LV100-type package adopts a novel structure with IMB (Insulated Metal Baseplate), as shown in Fig.3, the insulation layer and baseplate are integrated, eliminate the conventional solder layer under substrate, so there's no solder delamination issue caused by thermal strain. As a result, thermal cycling capability is much improved. The lifespan which is caused by system stop and start is prolonged.

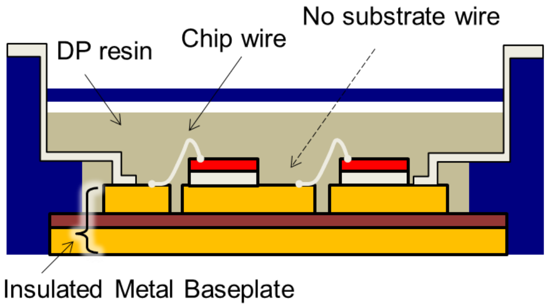


Fig. 3. Internal structure

2 Cascaded SVG

2.1 Working principle

If we ignore the losses in series inductors and IGBT losses in converters, the single-phase equivalent circuit of SVG system is as Fig.4. Here $\dot{U}_S$ is grid voltage, $\dot{U}_C$ is SVG output voltage, $\dot{U}_L$ is the inductor voltage, $\dot{U}_L = j\omega L\dot{I}$. Meanwhile, $\dot{U}_L = \dot{U}_S - \dot{U}_C$. SVG system can be equivalent to an AC voltage source, by adjusting its amplitude and phase, reactive power exchange between SVG and the power grid could be controlled.

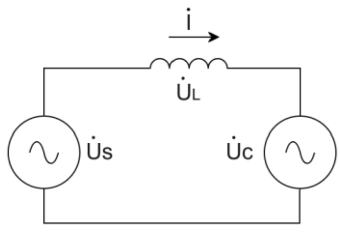
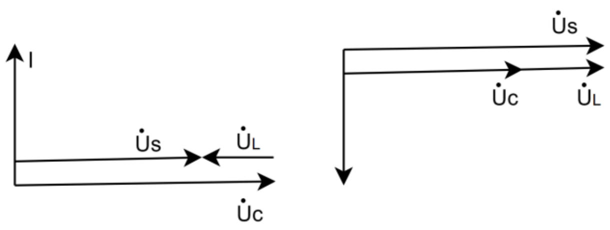


Fig. 4. Single-phase equivalent circuit



(a) (b)

Fig. 5. The phasor diagrams

As shown in Fig.5(a), if the amplitude of $\dot{U}_C$ is greater than $\dot{U}_S$, the phase of current $\dot{I}$ leads the voltage $\dot{U}_S$ by 90°, SVG obtains capacitive reactive power from the grid. In contract, in Fig.5(b), the amplitude of $\dot{U}_S$ is greater than $\dot{U}_C$, the phase of voltage $\dot{U}_S$ leads the current $\dot{I}$ by 90°, SVG obtains inductive reactive power from the grid [3].

2.2 Typical topology

The continuous expansion of the power capacity and the increasing of reactive power load make the demand for large-capacity SVG increasing. A typical topology of cascaded large-capacity SVG is as Fig.6, three phases connect in Y-style, and each phase connects the grid with a reactor. Each phase is composed of multiple power units, which adopt H-bridge, each power unit can output 3 levels, if N sets of power units connects in series, the output voltages are superimposed to form 2N+1 level. It can effectively improve the quality of phase output voltage.

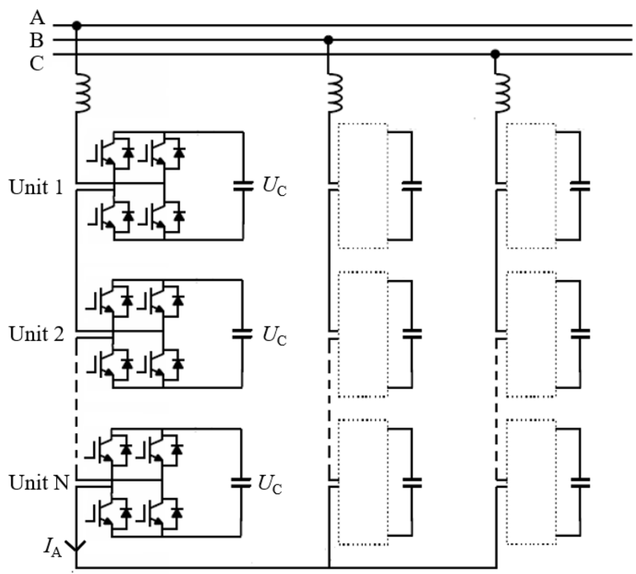


Fig. 6. Y-connection cascaded SVG

2.3 IGBT choosing

Currently, for the CHB (Cascaded H-Bridge) topology of SVG, 1.7kV IGBT modules is usually selected. Based on the power ratings, 75A, 100A…600A IGBT modules are chosen accordingly. In some larger capacity SVG, the required output current exceeds the IGBT specification, so IGBT paralleling is required.

Here we take Mitsubishi Electric 1.7kV/600A IGBT module CM600DX-34T as the conventional IGBT solutions, it utilizes NX-package, as shown in left figure of Table. 2. Meanwhile, we take 2kV/1200A IGBT module CM1200DW-40T as the new IGBT solution. We'll compare the two solutions in the following chapters.

Table. 2. Different IGBT solutions

	Conventional IGBT solution	New IGBT solution
IGBT outline		
IGBT package	NX	LV100
Size	62mm×152mm	100mm×144mm
Voltage	1.7kV	2kV
Current	600A	1200A

3 Comparison on different IGBT solutions

3.1 Power unit volume

Here we take 35kV/50MVar SVG for example, the rated current I_O=825A, the topology is as above Fig.6. In this case, 1.7V/600A IGBT 2-paralleling is required.

One layout example of SVG power unit adopting NX-package IGBT modules is as Fig.7. Each unit is consisted of 4pcs 1.7kV/600A IGBT modules.

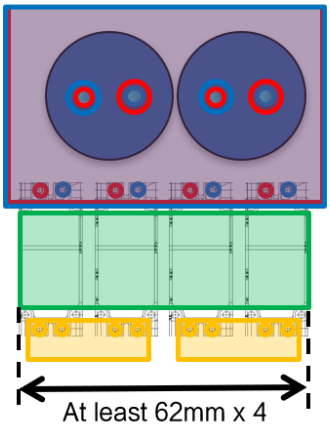


Fig. 7. Power unit with NX-package IGBT module

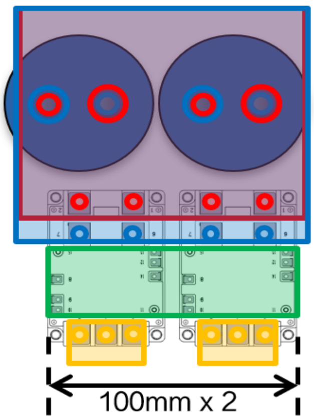


Fig. 8. Power unit with LV100-package IGBT module

Another IGBT solution is 1pcs LV100-package 2.0kV/1200A IGBT module CM1200DW-40T. The power unit adopting LV100-package IGBT modules is as Fig.8. Each unit is consisted of 2pcs 2kV/1200A IGBT modules.

From Fig.7 and Fig.8, we can see the power unit with LV100-package IGBT module has a narrower width, which could bring the merits of less bus-bar area and smaller heatsink volume. As a result, power unit volume could be smaller for 2kV LV100-package IGBT solution.

3.2 Cascaded power units' quantity

The grid voltage of SVG system V_S=35kV, the maximum phase voltage of SVG can be calculated as equation (1), here k is voltage fluctuation coefficient, we set k=1.1; L is SVG series inductance with the grid, and we set L=10mH.

$$V_A = k\frac{V_S}{\sqrt{3}} + \omega L I_O \qquad (1)$$

From above equation (1), we get phase voltage V_A= 24.8kV.

The cascaded quality of power units in each phase can be calculated by equation (2), here V_{DC} is bus voltage of power unit, for 1.7kV NX-package IGBT module, we set V_{DC}=1kV, while for 2kV LV100-package IGBT module, we set V_{DC}=1.5kV.

$$N = \frac{\sqrt{2}V_A}{V_{DC}} \qquad (2)$$

Based on equation (2), we can get the comparison for 1.7kV NX IGBT solution and 2kV LV100 IGBT solution as Table.3.

Table. 3. Comparison of different IGBT solutions

35kV SVG	Use 1.7kV NX IGBT	Use 2kV LV100 IGBT
DC voltage of power unit	1kV	1.5kV
Cascaded power unit quantity for one phase	36	24

From above Table.3, we can see, due to 2kV LV100 IGBT has a higher operation voltage, the cascaded quantity of power units for one phase reduces from 36 sets to 24 sets, which decrease 1/3.

If we consider the whole SVG system, as in Fig.9, the total power units decrease from 108 sets to 72 sets, and the total IGBT quantity reduces from 432pcs to 144pcs, which decrease 2/3. Both power units and IGBT modules can be decrease a lot, which is in favor of cost and dimension of SVG.

ISBN 978-3-8007-6414-3

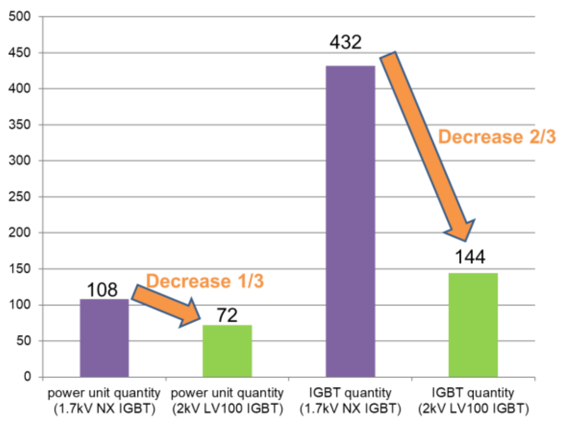


Fig. 9. Comparison of different IGBT solutions

3.3 SVG power loss

For proposed 35kV/50MVar SVG, the IGBT working conditions are as Table.4, besides the DC voltage and output current, the other conditions keep the same.

Table. 4. IGBT working conditions

Parameters	1.7kV/600A NX IGBT	2kV/1200A LV100 IGBT
DC voltage	1kV	1.5kV
Output current	412.5A	825A
Switching frequency	500Hz	←
Power factor	0	←
Modulation ratio	1	←
Heatsink temperature	90℃	←
$R_{G(on)}$/ $R_{G(off)}$	1Ω/1Ω	←

We calculate the IGBT power loss as Table.5.

Table. 5. IGBT power loss

Power loss	1.7kV/600A NX IGBT	2kV/1200A LV100 IGBT
IGBT DC loss	195.8W	417.85W
IGBT switching loss	51.47W	231.19W
Diode DC loss	220.62W	414.55W
Diode switching loss	14.22W	62.01W
Total loss (1 module)	964.22W	2251.24W

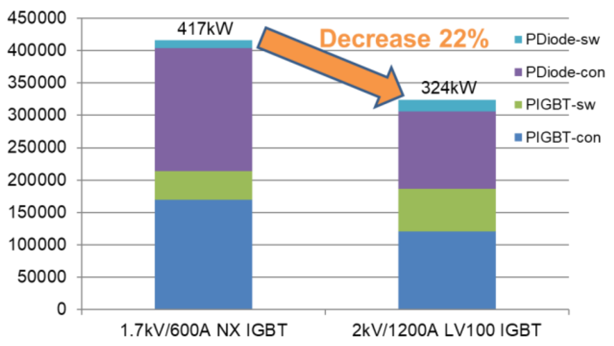


Fig. 10. IGBT power loss comparison

From above Fig.9, we know the quantity of CM1200DW-40T is only 1/3 of CM600DX-34T, so considering the total IGBT losses in the whole SVG system, the power loss comparison can be seen in Fig.10. The IGBT power loss decreased 22% for 2kV LV100-package IGBT solution.

4 Experimental results

To verify the switching characteristics of CM1200DW-40T, we take the Double Pulse Test (DPT). According to the conditions in Table.4, the maximum current $I_{max}=\sqrt{2}\times825A=1167A$, here we approximately set I_C $=1200A$ as DPT testing current and V_{CC} $=1500V$ as DPT testing voltage, $V_{GE}=15V/-10V$, $R_{G\ (on)}=0.47\Omega$, $R_{G\ (off)}=10\Omega$, no snubber capacitor, $T_j=25℃$.The turn on waveform is as Fig.11. The turn off waveform is as Fig.12. The peak voltage at turn off is 1787V, which leaves more than 200V margin to the breakdown voltage 2kV. Meanwhile, we can see the stable operation at V_{CC} =1500V and no oscillation occurrence.

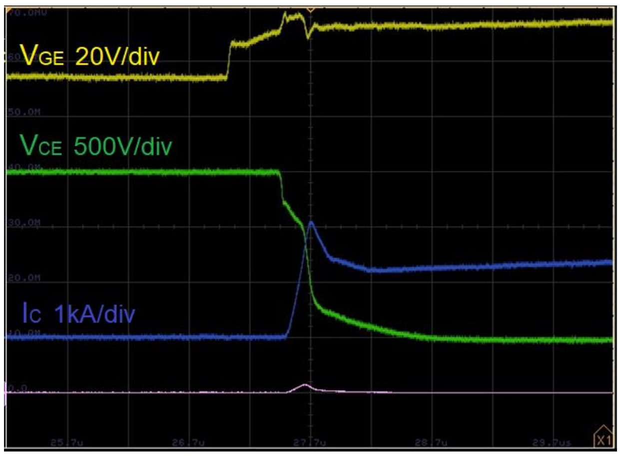


Fig. 11. CM1200DW-40T turn on waveform

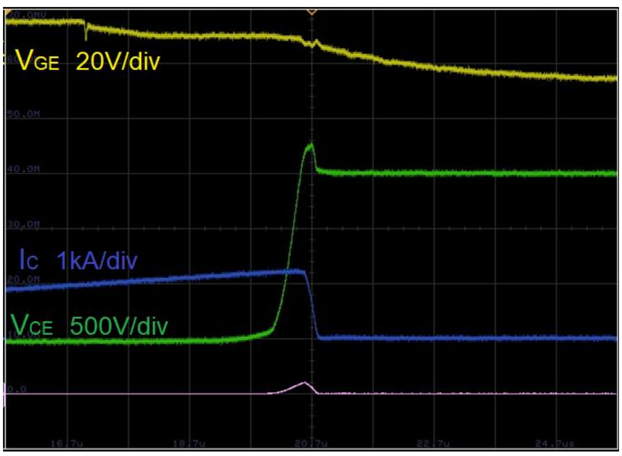


Fig. 12. CM1200DW-40T turn off waveform

5 Conclusion

The paper introduced Mitsubishi Electric 2kV LV100-type IGBT module CM1200DW-40T. Two different

IGBT solutions for Cascaded SVG were compared in detail. Compared to conventional 1.7kV NX-package IGBT module, 2kV LV100-package IGBT module can shrink the power unit volume by around 20%, reduce the quantity of cascaded power units by 1/3, and decrease the total IGBT power loss could by 22%, which could bring downsizing, high current density, and high efficiency for Cascaded SVG system. At last, based on the proposed SVG working conditions, double pulse test was done to verify the switching characteristics.

6 References

[1] Z. Gao, Y. Li: Modulation method model and optimization for cascaded H-bridge converters, Electric Power Automation Equipment，2010，30(10):12-16.

[2] D. He, R. Wei: Research on H-bridge cascaded static var generator, Proceedings of the CSU-EPSA，2006，18(4)：97-100.

[3] J. Guo, J. Niu, J. Yao: Research and analysis on static var generator (SVG), Industrial Instrumentation & Automation, 2014(2):6.

[4] Y. Luo, H. Rao, S. Xu, X. Li: Efficient modelling for cascading multilevel converter, Proceedings of the CSEE，2014，34(15)：2346-2352.

[5] R. Luo, Y. He, Y. Liu: Analysis on the Unbalanced Compensation of Star Connection Cascaded H-bridge Multilevel Static Var Generator, Proceedings of the CSEE. 2018, 38(3): 861-869.

[6] S. Miyahara, K. Masuda, M. Miyazawa, K. Suzuki, and H. Fujii: 2000V Class IGBT Concept for Renewable Energy Converter, PCIM Europe 2020.

[7] Mitsubishi Electric: Mitsubishi Electric to Ship Samples of LV100-type T-series 2.0kV IGBT Module for Industrial Use, https://www.mitsubishielectric.com/news/2022/0421.html.

[8] Mitsubishi Electric: 7th Generation T-Series Industrial LV100-type Application Note, www.mitsubishielectric.com/semiconductors/powerdevices/design_support/note/.

ISBN 978-3-8007-6414-3