TOSHIBA

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UNINTERRUPTIBLE POWER SUPPLY SYSTEMS

G8000MM UPS CONVERTER CONFIGURATION TECHNICAL PAPER

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1. Introduction

The following paper describes the Toshiba G8000MM UPS Module Converter configuration and direct digital control. Details of the TOSHIBA G8000MM UPS Module design philosophy and the converter configuration and simplified block diagram is at first addressed, followed by the advantages of such configuration and control specific to this type of UPS module and its application.

2. G8000MM UPS Module Design Concept

Before we look at the specific details of the G8000MM UPS Module converter section, it is important to understand the original design concept regarding the G8000MM UPS Module product. The G8000MM UPS is not only designed to meet the expected TOSHIBA high quality and reliability standards, but also offer a highly efficient, competitively priced, high performance, large capacity UPS system (available in capacity ranges from 100kVA through 750kVA per UPS Module and also for Multi Module System applications - Parallel Systems offering large system kVA capabilities). It is also important to emphasize here that for large MMS applications, high UPS efficiency characteristics can have significant operating (running) cost advantages, and so the overall efficiency for the G8000MM UPS Module was a key design principle.

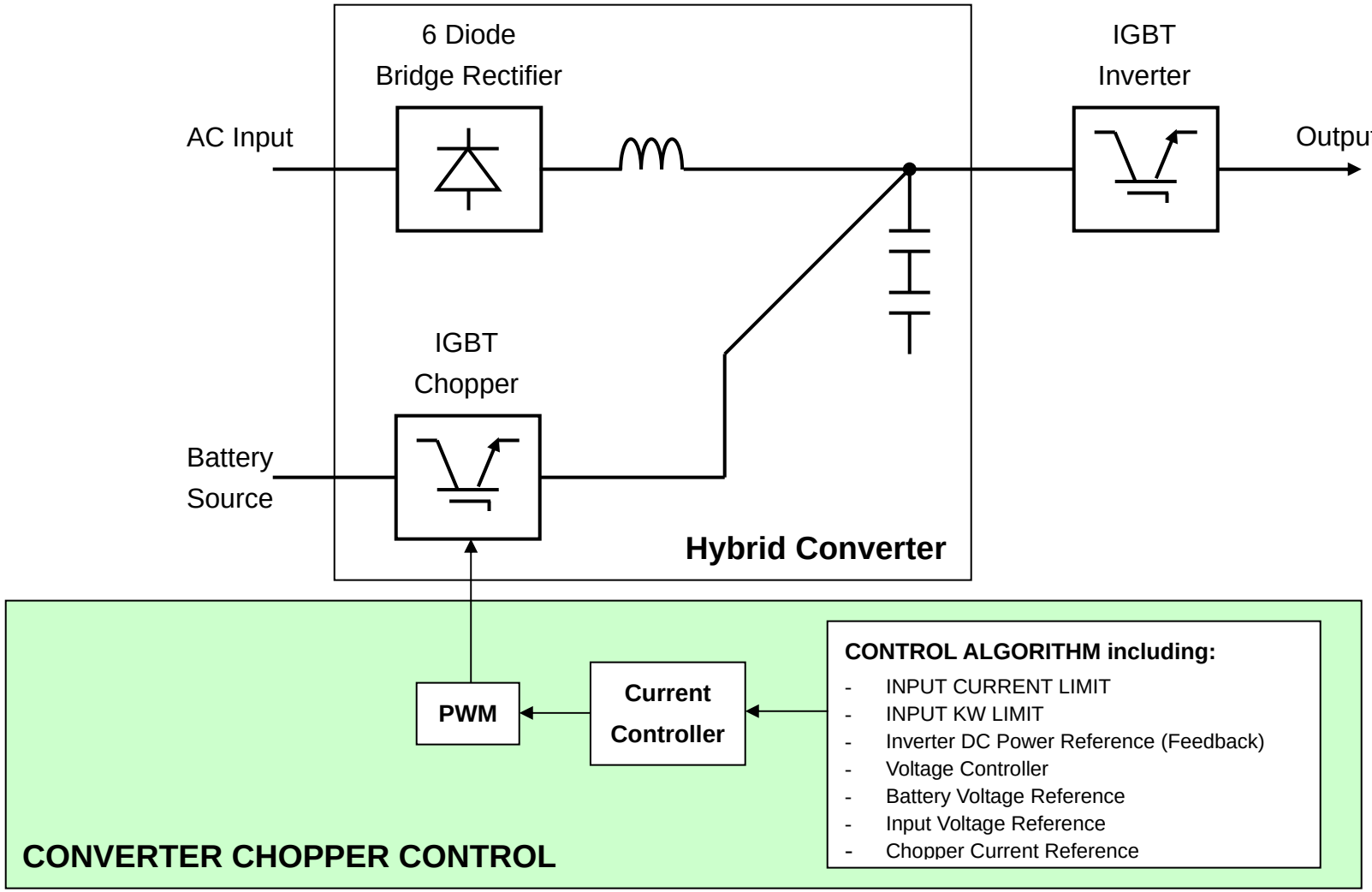
It is well known that the TOSHIBA series of UPS products utilize the latest power device and power conversion technology available to meet today's market needs. Technological advancement of power device technology shows the emergence of the Insulated Gate Bipolar Transistor (IGBT) as the key power device to offer superior UPS performance and reliability for both the UPS inverter and converter sections. All TOSHIBA series of UPS products utilize a full application of IGBT power devices within their converter and inverter sections with the exception of the G8000MM (and G8000) products. In order to satisfy the previously mentioned design constraints, the G8000MM UPS Module converter section utilizes an innovative combination of diode bridge rectification and IGBT chopper with direct digital control. With this innovative combination, a high performance and highly efficient converter section is realized. First we shall take a look at the G8000MM UPS Module converter configuration in detail, followed by the advantages associated with such a design and configuration.

3. G8000MM UPS Module Converter Configuration

The G8000MM UPS Module converter consists of a Six Diode Bridge Rectifier circuit and a direct digital controlled Insulated Gate Bipolar Transistor (IGBT) Chopper circuit. TOSHIBA refers to this configuration as a Hybrid Converter because the rectifier and chopper circuit combination create a high performance AC to DC converter section. The principal of a three-phase converter with diode bridge rectification and digital IGBT chopper control is shown in Figure 1. - The TOSHIBA G8000MM UPS Module Converter Block Diagram:

Note: [It is important to understand that this converter configuration is not simply a diode bridge design. The digitally controlled IGBT chopper circuit plays an important role in the performance and operation of the converter section. The advantages of such a converter configuration for the G8000MM UPS module are shown in this paper.]

Figure 1. - TOSHIBA G8000MM UPS Module Converter Block Diagram



[Full DDC DSP, ASIC, FPGA Adoption]

The combination of the high power diode bridge rectifier and the IGBT chopper circuit converts the utility AC input power into regulated DC power that serves as the inverter input. This combination is also used for the DC charge power to the system batteries. The chopper circuit can be divided into charger and booster circuits which utilize solid state Pulse Width Modulation (PWM) controlled IGBTs. The charger switching frequency is 12kHz, and the booster switching frequency is 2kHz.

The UPS converter chopper control adopts high- speed microprocessor DSP (Digital Signal Processor), Application Specific Integrated Circuit (ASIC) and Field Programmable Gate Array (FPGA) Control that achieves the following advantages:

- Advanced controllability and simplified circuitry
- High reliability and functionality of Converter
- Reduction of number of parts - Improved reliability (decreased failure rate)
- High ampacity and efficiency Converter performance

The IGBT Chopper circuit and associated control can be considered as the main intelligence and function control of the converter section. The IGBT Chopper charge and booster circuit controls all associated functions related to battery operation including: Charge and discharge control, charge current limiting, equalize charge, and battery test functions. The IGBT Chopper circuit and associated control also performs input current limiting (converter protection), rapid power demand capability, power walk in functions, and boosts the dc voltage when required.

It can be seen that this combination of diode rectifier and IGBT chopper realizes a high performance and highly functional digitally controlled converter section. This converter configuration design philosophy can now be analyzed and compared to the conventional TOSHIBA full IGBT converter design, and to the converter design utilizing thyristor (SCR) technology typical used by other UPS manufacturers. Taking into consideration and applying the previously mentioned original G8000MM UPS Module design concept and constraints.

The Toshiba standard of a high quality and reliable UPS Module satisfying the following features was required in the product design concept of the G8000MM UPS:

1. High Efficiency double conversion UPS Module (AC to AC).
2. Cost Competitive in the Global market.
3. High Performance, reliability, and capability to meet application specifications.
4. Large Capacity UPS System Applications up to and greater than feasible capacities.

4. UPS Module Converter Configuration and Design Comparison

The following tables shows such comparison and explanation related to different design and configurations of the converter section, and gives the advantages and disadvantages of each in relation to the specific design points above.

	Diode Bridge Rectifier and IGBT Chopper Converter	Full IGBT Converter	Thyristor (SCR) Converter
1. Efficiency	**Improves UPS Module AC-DC and Overall AC-AC Efficiency** G8000MM UPS Module has Excellent AC-AC Efficiency up to 94.5% (100% Load) ■ Low switching and conduction Loss for Diode device (Natural commutation) ■ IGBT chopper switching and conduction loss is negligible due to small quantity of IGBT devices ■ No control circuitry associated with Diode Bridge ■ Additional input current harmonic filters are not required so losses associated with this equipment are eliminated. Refer to Performance comparison. ■ Lower Operating (Running) Costs	**Reduces UPS Module AC-DC and Overall AC-AC Efficiency** Typical UPS Module with IGBT converter and inverter has AC-AC Efficiency of approx 94-96% (100% Load) ■ IGBT switching and conduction loss ■ Simple IGBT drive control circuit ■ Low IGBT control power consumption ■ Additional input current harmonic filters are not required so losses associated with this equipment are eliminated. Refer to Performance comparison. ■ Higher Operating (Running) Costs	**Reduces UPS Module AC-DC and Overall AC-AC Efficiency** Typical UPS Module with SCR converter and IGBT inverter has AC-AC Efficiency of approx 91- 92% (100% Load – with no additional harmonic filters) ■ SCR switching and conduction loss (SCR firing angle and partial conduction per half cycle) ■ Simple On (Gate) Circuit ■ Self Commutating (Natural off control) ■ Additional input current harmonic filtering usually required that reduces efficiency further Refer to Performance comparison. ■ Higher Operating (Running) Costs
2. Cost Competitiveness	**Cost Competitive UPS Module** ■ Diode devices with large current capabilities have been available for many years and are therefore reasonably priced. ■ No control circuitry associated with Diode Bridge ■ IGBT chopper utilizes small quantity of IGBT devices ■ Simple IGBT drive control circuit ■ Additional input current harmonic filters are not required so cost associated with this equipment is eliminated. Refer to Performance comparison. [Note: Additional system costs external to the UPS Modules, for example generator cost can also be effected by the UPS Module converter performance. (Refer to Performance comparison]	**Not Cost Competitive UPS Module** ■ Cost is important when applying IGBT power devices. The G8000MM product is designed for large power UPS Modules (up to 750kVA). The cost consideration for using IGBT with large current capabilities in the converter section (as well as the inverter section) is very technically difficult and not cost effective to meet the US market pricing at this time.	**Cost Competitive UPS Module** ■ SCR devices with large current capabilities have been available for many years and are therefore reasonably priced. ■ Simple On (Gate) Circuit ■ Self Commutating (Natural off control) ■ The negative side of utilizing SCR in the converter section is the inherent input harmonic distortion generation. If additional filters are used, additional cost will be incurred. Refer to Performance comparison [Note: Additional system costs external to the UPS Modules, for example generator cost can also be effected by the UPS Module converter performance. Refer to Performance comparison]

	Diode Bridge Rectifier and IGBT Chopper Converter	Full IGBT Converter	Thyristor (SCR) Converter
3. High Performance	**High Converter Performance** ■Fast IGBT Chopper/Converter Response Time - IGBT Chopper On/Off Control - Fast Switching Speed - New Improved PWM control, High converter performance and specification ■Low input current THD - Typically 6% Max. at 100% Load, 9% Max at 50% Load. - No need for additional harmonic filters - No effect to utility - No Generator Compatibility problems **Note:** [Typically a 6 Diode Bridge rectifier would give input current THD at approx 10% for 100% Load. The G8000MM incorporates a small input filter that brings this THD down to typically 6% input THD on full load without offering any generator incompatibility problems.] ■High Power Factor - Typical 0.9 to 0.95 (naturally generated due to in phase nature of input current and voltage due to diode conduction) ■1:1.1 Generator Rating - No Over-sizing of Generator rating requirement due to high power factor (lower KVA requirement) and low input current THD. ■ No Battery Cycle during 100% Step Loads – Battery Longevity (Also related to Inverter Control) ■Low Audible Noise ■Small size (inverter footprint reduced)	**Excellent Converter Performance** ■Fast IGBT Converter Response Time - IGBT On/Off Control - Fast Switching Speed - New Improved PWM control, High converter performance and specification ■Low input current THD - Typically 3% Max. at 100% Load, 5% Max at 50% Load. - No need for additional harmonic filters - No effect to utility - No Generator Compatibility problems ■Power Factor Control - Near unity (1.0) power factor can be achieved ■1:1.1 Generator Rating - No Over-sizing of Generator rating requirement due to controlled unity power factor (low KVA requirement) and low input current THD. ■No Battery Cycle during 100% Step Loads – Battery Longevity (Also related to inverter control) ■Low Audible Noise ■Small size (inverter footprint reduced)	**Poor Converter Performance** ■Slow Thyristor Converter Response Time - Slow Switching - Poor control, converter Performance and input specification ■High input current THD: - 6 Pulse Typically 33% THD (Lowest cost rect. cct) - 12 Pulse Typically 12% THD (More expensive cct - addition of transformer and extra 6 diode bridge) [These THD values are without additional input filters] - High THD feedback to utility - Need for additional Input harmonic filters to reduce input current THD - Additional space and cost. - Generator compatibility problems on low loads - Reduction in overall efficiency - Higher operating (running) cost ■Low Power Factor - Typically 0.7 to 0.8. - Larger input kVA requirement ■Generator rating requirement Over-sizing - Required due to high input THD and larger kVA requirement - Additional cost for larger generator ■Battery cycled during 100% Step Load - Reduced Battery life ■High Audible Noise
4. Large Capacity	**High converter power capabilities** ■Diode and IGBT power devices available in high current capacities	**High converter power capabilities** ■IGBT power devices available in high current capacities	**High converter power capabilities** ■ SCR power devices available in high current capacities

5. Conclusion

The G8000MM UPS Module concept was designed not only to maintain the high quality and reliability associated with the TOSHIBA UPS product, but also to offer a highly efficient, competitively priced, high performance and large capacity UPS system.

It was shown that a full IGBT concept within a UPS converter sections offers superior converter performance in exceeding efficiency specifications; however there is a trade off of cost competitiveness with only minor improvements in efficiencies when compared to the high power diode bridge rectifier and the IGBT chopper circuit used in the G8000MM design.

The G8000MM UPS Module converter solution utilizing a diode bridge rectifier in conjunction with an IGBT Chopper with full digital control and improved PWM circuitry, offers increased efficiency and cost competitiveness while continuing to meet high input specifications and converter performance a-kin to the full IGBT converter. It was shown the G8000MM converter solution produces low input current distortion and maintains a high input power factor. It was also shown that this solution has far superior performance and benefits compared to thyristor converter applications.

The hybrid converter design and configuration of the G8000MM UPS Module is therefore an innovative and ideal concept to meet the large capacity UPS application specifications. The G8000MM UPS Module design criteria achieves a highly efficient power stage with all the required control functions for the UPS operation. With the combination of this converter configuration and control, and the TOSHIBA UPS Module IGBT Inverter with unique inverter control scheme, it can be seen that the G8000MM UPS Module is specifically designed to offer a highly reliable, high performance, cost competitive, and highly efficient On Line Double Conversion UPS System solution.