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WIND & SOLAR POWER

New Design Proposals for High-Power Renewable Energy Applications

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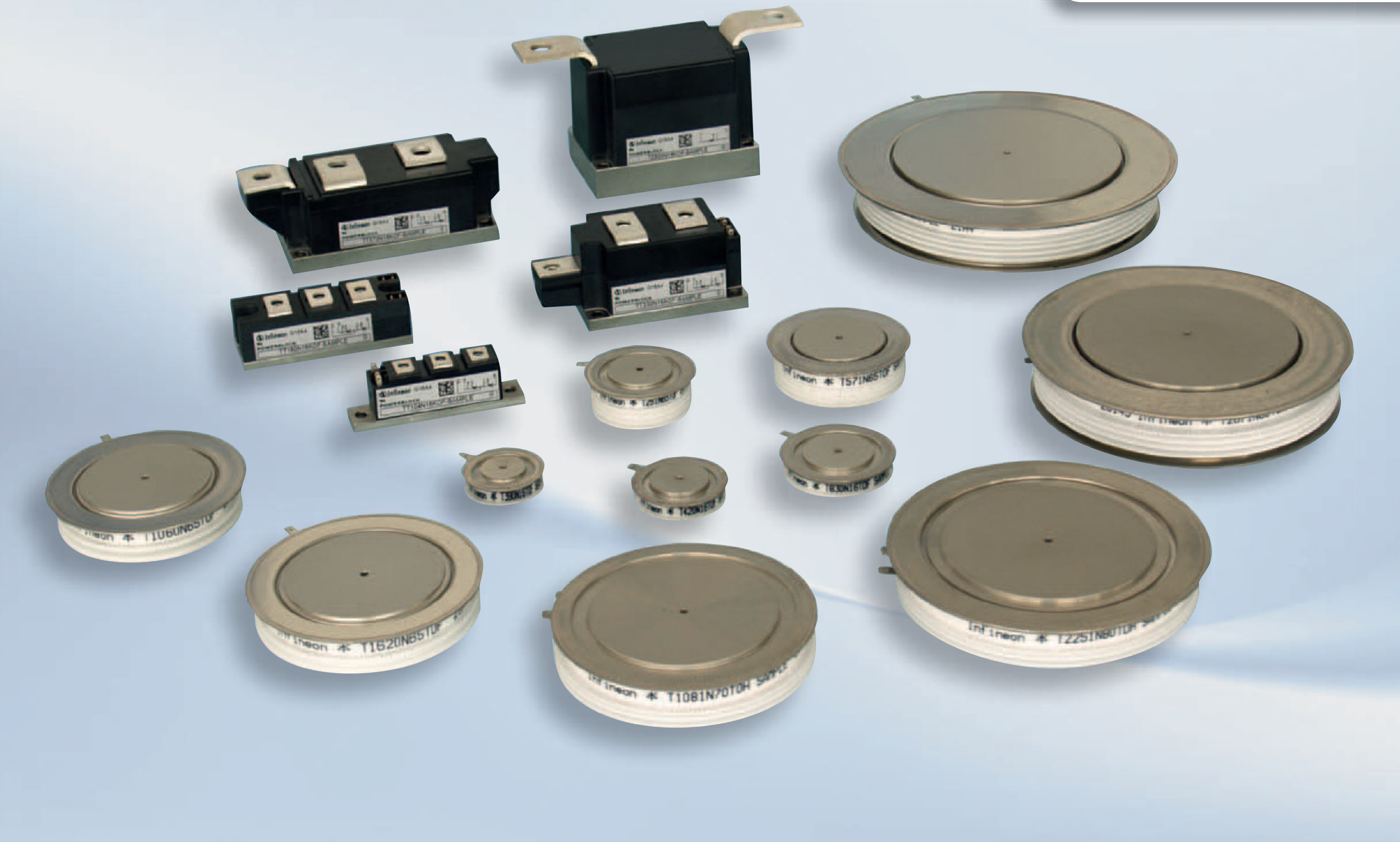
COVER STORY

New Design Proposals for High-Power Renewable Energy Applications

Renewable energy applications are a great challenge for Power Electronics, with efficiency and reliability being the prevailing requirements. Today, 1700V low-voltage Silicon is vastly superior. For input/output powers of several MW, dozens of modules with dozens of chips need to be connected in parallel. The best solution is paralleling inverters / power blocks, but such solutions require additional low-voltage transmission from the source to the medium-voltage (MV) transformer. An alternative solution is a MV source and transmission connected to MV grid-side inverter based on low-voltage Silicon - power blocks - connected in series. In addition, interleaved PWM reduces the size of the sinusoidal filter and the switching frequency, as well as the total losses. Full story on page 24.

Cover supplied by SEMIKRON, Nuremberg, Germany

Infineon Technologies Bipolar GmbH & Co. KG



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Good Times for Power Semiconductor Suppliers

The last time the global semiconductor industry achieved annual revenue growth greater than 30% was when the Dot-Com boom was hot. Now, 10 years after the chip business's whopping 37% expansion of 2000, according to market researcher iSuppli the industry is expected to finally break the 30% barrier once again in 2010, with revenue set to rise to $300 billion, up 30.6% from $230 billion in 2009. Unlike the Internet-crazed spike in 2000, growth in chip sales this year will be driven by real fundamental supply/factors that slowly have been gaining momentum during the past 12 months. 2010 is bringing a return to normal semiconductor market conditions after the aberrant industry performance in 2009, when chip sales plunged due to external economic conditions. Compared to 2008, the semiconductor industry in 2010 will achieve more moderate revenue growth of 15.4%.

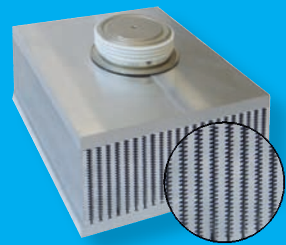
The power semiconductor market (discretes and power modules) was worth $10.1 billion in 2009, declining by 24% from 2008 (power modules dropped 26%, and discretes 24%). The market has not dropped by such a large extent since 2001, when it fell 22% because of the "Dot-Com" collapse. By end of 2010 a recovery up to $12 billion is expected by IMS Research. EMEA's power semiconductor market fared little better in 2009, as the European industrial markets finally plunged into the downturn at the end of Q1 09; some countries are still fighting their way out. This could explain why the American power semiconductor market outperformed those of Japan and EMEA, as the USA was one of the first countries to enter the global downturn and was one of the first countries out. The SiC Schottky diode market was worth an estimated $29 million in 2009. It fell in line with the total power semiconductor market during the global downturn; but enjoyed strong demand in 2H 2009. Overall the SiC Schottky diode revenues were estimated to be 25% higher in 2009 than in 2008. The SiC Schottky diode market will increase by over 50% in 2010. PFC power supplies for server and telecom applications currently account for the most SiC Schottky diodes sold. The huge developments in the Chinese telecom and cellular infrastructure, and high system-efficiency standards generally, are driving their adoption. However, PV inverters could become the largest market for SiC Schottky diodes within the next 3-4 years. Currently, SiC Schottky diodes are the only SiC power devices sold in large volumes. SiC JFETs are also available on the commercial market but have not yet succeeded to the same extent. IMS forecasts the SiC power semiconductor discrete and module market will be worth $110 million by 2012. Interestingly, the GaN power device market is projected to be worth $20 million in 2012. Although these GaN revenues are much lower than predicted by some other industry observers, they are much higher than SiC Schottky diodes achieved in their first three years on the market.

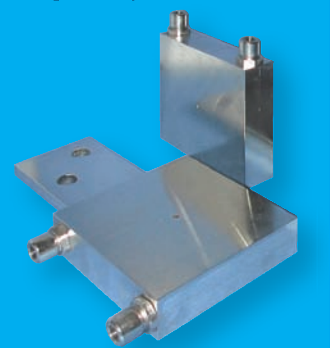
At PCIM 2010 all power semiconductor suppliers felt enthusiastic about full manufacturing capacity loading, but on the other hand this situation leads to long lead times of more than 28 weeks for smaller and around 12 weeks for larger orders i. e. for power MOSFETs, according to market observers. Even longer lead times up to 40 weeks are announced for IGBTs. Thus power electronics system suppliers with their typical smaller orders are facing shortages in components supply and in consequence market opportunities. Chinese power semiconductor manufacturers and their distributors such as Advanced Power Electronics Corp. (www.a-powerusa.com) or Alpha Europe (www.alpha-europe.de) offer compatible products at competitive pricing and lower lead times in the range of 4 - 6 weeks.

Another way to cope with long lead times is ramping-up production capabilities, as Texas Instruments is demonstrating with the recent purchase of more than 100 tools from former memory maker Qimonda North America and Qimonda Dresden, Germany. This is the first step in launching the Phase II expansion of RFAB, the industry's first 300mm analog/power wafer fab, located in Richardson, Texas. TI additionally invested $172.5 million to purchase this semiconductor manufacturing equipment at an opportune price. Phase II of RFAB will double the analog manufacturing capacity in the North Texas facility, bringing its revenue capability to about $2 billion. First products qualified by end of 2010 are based on the company's LBC7 linear BiCMOS technology which is capable of integrating a variety of components, including power transistors (up to 40V), CMOS logic, bipolar transistors and passives. Key benefits of LBC7 are low on-resistance, high current carrying capabilities, high integration capability and extremely low leakage. With shipments beginning by the end of the year, this phase II expansion will give TI a head start in providing customers access to significant analog capacity to fuel their growth, according to TI.

More on that and on PCIM at the following pages.

Achim Scharf
PEE Editor





Semikron Invests in Hybrid and Electric Vehicles

By taking over the majority of Compact Dynamics GmbH, a designer for innovative electrical drives and control systems, Semikron can now offer development competence from power electronics to electrical motors. Recently a new line of

By taking over the majority of Compact Dynamics Semikron's CEO Dirk Heidenreich takes another step towards electro-mobility

converters for special (H)EVs was introduced.

The company's aim is to develop high efficiency, light-weight and compact systems in order to meet the ever increasing demand for highly compact drives combining state-of-the-art power electronics and control systems. The drive systems are optimized for use in hybrid and electric vehicles such as cars, busses and utility vehicles, as well as construction, forest, agricultural systems and forklift trucks. "We complement each other perfectly, both our companies have long ranging experience in power electronic systems", said Semikron's CEO Dirk Heidenreich. "Together, we integrate the technology of electrical motors, control electronics and power electronics to offer highly efficient, compact and light-weight drive systems to vehicle manufacturers", added Maximilian Eck, General Manager of Compact Dynamics. Compact Dynamics specializes in the development and prototyping of electric drive systems with a particular focus on automotive applications including high-power electric drives for motor sport applications. Following the joint venture with Magna in June 2009 and the launch of the new Semikron SKAI2 IGBTs and MOSFET systems for hybrid and electric vehicles in May 2010, this investment is another step into the market for electro-mobility.

SKAI systems are developed in line with the latest automotive standards and are supplied as standard modules with low-voltage MOSFETs, high-voltage IGBTs or with the topology of single, dual and multiple inverters. SKAI systems are also developed to meet individual customer specifications. All SKAI 2 modules are fully qualified using analysis such as highly-accelerated life testing (HALT) and end of component-life testing, with full failure-mode effect analysis studies conducted at all critical points of the design cycle, to ensure that they are in line with relevant automotive standards.

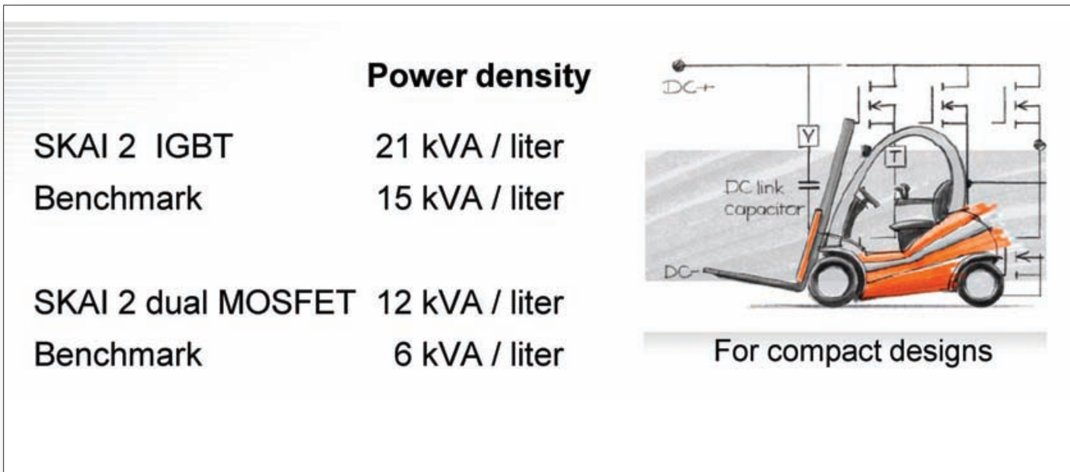
The high-voltage SKAI 2 is a water-cooled 600/1200V IGBT inverter system, and has been optimised for use in applications such as full-electric cars, plug-in hybrid cars and electric buses. This system is based on the sintered, solder-free SKiM93 IGBT modules and a polypropylene film DC-link capacitor, driver electronics, a latest-generation DSP controller, EMC filters, and current, voltage and temperature sensors, and comes in an IP67 module case. Communication with the vehicle master controller is via a CAN bus. These systems are designed for outputs of up to 250kVA. The low-voltage SKAI 2 is an air-cooled or water-cooled 50/100/150/200V MOSFET single and dual inverter system that is used mainly in fork-lift trucks and other materials-handling applications suitable for motor output of up to 55 kVA. They incorporate many of the same features as the IGBT-based systems. The third type of SKAI 2 platform is a multi-converter box also housed in water-cooled, IP67-protected case. The signal interface features analog and digital I/Os to allow for the connection of a wide

"With SKAI we offer complete converters exclusive software which can be used for all wheel-equipped vehicles", commented Semikron's Manager Concepts & Application Peter Beckedahl

variety of sensors, such as temperature sensors and resolver inputs. A typical multi-converter system would include a three-phase 40kVA active front-end converter, a three-phase 20kVA drive inverter, a three-phase 10kVA drive inverter, and a 14V/300A or 28V/165A DC/DC converter.

"Our SKAI products are complete converters exclusive software and can be used for all wheel-equipped vehicles", commented Peter Beckedahl, Semikron's Manager Concepts & Application. "The low-voltage SKAI2 is equipped with SJ MOSFETs from Infineon and Vishay, for the high-voltage version we use IGBTs from ABB, Fuji and Infineon. We do not address the mass market, typical units are in the range of 1000".

www.semikron.com



SKAI2 parameters and applications

300 Millimeter Fab for Analog and Power

Texas Instruments is expanding its analog/power manufacturing capacity with the recent purchase of more than 100 tools from former memory maker Qimonda North America and Qimonda Dresden, Germany. This is the first step in launching the Phase II expansion of RFAB, the industry's first 300mm analog wafer fab, located in Richardson, Texas, near TI's headquarters.

Texas Instruments' latest US-based manufacturing facility (RFAB) was completed in 2006. Since that time, the company has weathered the economic downturn and focused its business on analog and embedded processing, while watching market demand to determine when to equip and open the facility. This production strategy has enabled the company to ramp up production when conditions call for increased production.

The RFAB project began with ambitious goals regarding cost, energy and the environment, and required rethinking every aspect of the design. TI engineers spent time with experts from the Rocky Mountain Institute to create an extremely efficient complex unlike any other semiconductor facility. Its energy-saving features will enable 35% more efficiency than code requirements, which will help reduce related emissions by 50%. Water conversation efforts, including re-use and recycling, will reduce water consumption by 40%. In total, TI spent about $1.5 million of its $320 million construction costs on sustainable design. In return, the company expects to see a million dollars of savings in the first year of production, ramping up to more than $4 million a year once the factory is fully operational.

TI additionally invested $172.5 million to purchase semiconductor manufacturing equipment at an opportune price from bankrupt Qimonda. Phase II of RFAB will double the analog manufacturing capacity in the North Texas facility, bringing its revenue capability to about $2 billion. The fab will produce analog ICs based on TI's proprietary processes. First products qualified by end of 2010 are based on the company's LBC7 linear BiCMOS technology which is capable of integrating a variety of components, including power transistors (up to 40V), CMOS logic, bipolar transistors and passives. Key benefits of LBC7 are low on-resistance, high current carrying capabilities, high integration capability and extremely low leakage. "Our 300mm fab is a unique cornerstone of our analog business. With phase I progressing well and on track to begin shipments by the end of the year, this phase II expansion will give us a head start in providing our customers access to significant analog capacity to fuel their growth," said TI's SVP Gregg Lowe.

www.ti.com

TI's new RFAB in Richardson/Texas incorporating 300mm wafer manufacturing equipment for analog and power semiconductors

Higher Power Density for DC/DC Converters

Picor, a subsidiary of Vicor Corporation specialising in the design and development of high performance power management solutions, announces surface-mount isolated DC/DC converters delivering 3-4 times more power density than existing solutions.

Vicor's revenues for the first fiscal quarter ended March 31, 2010, increased to $51,709,000, compared to $50,448,000 for the corresponding period a year ago, and increased from $49,138,000 for the fourth quarter of 2009. "Each of our three primary business units experienced improved bookings and revenue. Consolidated revenue increased 5.2% sequentially, while the consolidated book-to-bill ratio for the first quarter was 1.39:1, as compared to 1.16:1 for the fourth quarter of 2009. Total backlog at the end of the first quarter of 2010 was $78,407,000, as compared to $58,489,000 at the end of 2009", said CEO Patrizio Vinciarelli. "Our brick components business grew sequentially, with particular strength in its configurable product lines. V-I Chip revenue for the first quarter grew 99% sequentially, while bookings grew at a faster pace as a large customer placed initial production orders for new programs. V-I Chip also received initial orders from other early adopters of Factorized Power. With increased volume, we expect to achieve improvement in product-level profitability, although we do not expect to reach our efficiency and margin targets in 2010. Picor also grew sequentially and experienced strong bookings. Picor is collaborating closely with V-I Chip in providing power management solutions and, in particular, is sharing in V-I Chip's success with important early adopters."

Picor as a relatively new subsidary is focusing on Silicon solutions contributing with single digit share for Vicor's power modules business. "Besides Silicon we are looking for the features of the upcoming GaN power devices", said Carl Smith, Director Strategic Marketing & Business Development. "Next generation ASICs, DSPs, FPGAs and high-speed microprocessors are constantly evolving to enable enhanced system performance. But it's not all about the processor! Improvements are required in component technology and packaging concepts in all areas of the system to keep pace with system-level goals. Next generation processors demand higher power requirements, more voltage rails, while leaving less aggregate real estate for the power conversion solutions. Even though maybe not obvious to the end-system designer, the choice of power conversion solution & power architecture is a technology enabling decision. Thus our Cool-Power high-density isolated DC-DC converter technology was developed for end-systems such as advanced telecom and wireless infrastructure, networking & communications, Power-over-Ethernet applications and high speed server platforms. The PI3101 is the first in a new family of high-density power conversion products that leverages the company's core strength in power management, silicon integration and system-level packaging."

The Cool-Power family is built on a proprietary ZVS topology with planar magnetics enabling switching frequencies in excess of 1MHz with up to 87% efficiency. Delivering a regulated 3.3V output at up to 18A output current, from a wide input voltage range of 36V to 75VDC, the PI3101 achieves 25W/cm^3 (400W/in^3), representing 3-4 times the power density of existing solutions, and optimises board area by providing 16.5W/cm^2 (105W/in^2). The PI3101 combines isolation, voltage transformation and output regulation into a high density, surface-mount Power-System-in-Package (PSiP) platform with a tiny footprint 3.6cm^2 (0.57in^2) and very low profile 6.7mm (0.27in). "This equals to half of the size of a sixteenth brick" Smith stated.

www.picorpower.com

Picor's Carl Smith showing an evaluation board for the company's new Cool-Power device

Highest Annual Growth in 10 Years for Semiconductors

The last time the global semiconductor industry achieved annual revenue growth greater than 30% was when the Dot-Com boom was hot. Now, 10 years after the chip business's whopping 37% expansion of 2000, the industry is expected to finally break the 30% barrier once again in 2010, with revenue set to rise to $300 billion, up 30.6% from $230 billion in 2009.

However, unlike the Internet-crazed spike in 2000, growth in chip sales this year will be driven by real fundamental supply/factors that slowly have been gaining momentum during the past 12 months. "Building on the continuing expansion in sales that followed the downturn in late 2008 and early 2009, the semiconductor industry is set to achieve remarkable revenue growth and record size in 2010," said iSuppli's analyst Dale Ford. "Chip sales growth this year will be fueled by a number of key factors, including continued strong consumer demand for hot electronic products, diligent inventory and capacity management efforts among chip makers and the arrival of innovative technologies at both the component and end-system levels."

This year will mark an all-time annual high for global semiconductor revenue, eclipsing the previous record of $274 billion set in 2007 by about 9%. Ford noted that 2010 is bringing a return to normal semiconductor market conditions after the aberrant industry performance in 2009, when chip sales plunged due to external economic conditions. "While the growth in 2010 is impressive, it still needs to be viewed in context of the dismal results in 2009. Compared to 2008, the semiconductor industry in 2010 will achieve more moderate revenue growth of 15.4%."

The stage for strong annual growth in 2010 was set by unusually robust conditions in the first quarter. "Semiconductor sales most commonly decline in the seasonally slow first quarter compared to the peak holiday period in the fourth quarter. However, in 2010, first-quarter chip sales expanded by 1.1% compared to the fourth quarter of 2009. This is the first time the industry has achieved sequential growth in the first quarter since 2004, and it represents the strongest growth during the period since 2002, when revenue grew by 5.4%", Ford observed.

A major factor driving demand in the first quarter and beyond is consumer demand for electronic products, which continues to surpass expectations. Strong sales growth is predicted for 2010 in PCs, mobile handsets, LCD-TVs and other semiconductor-rich electronic systems. This will propel global factory revenue for electronic systems to a record high of $1.55 trillion in 2010, up 10.4% from $1.4 trillion in 2008. The previous high for electronic OEM revenue was $1.53 trillion in 2008.

Overall electronic equipment demand is being boosted by the health of the overall economy. "The economy represents the biggest wild card in our 2010 forecast," Ford warned. "While many indicators have shown sustained improvement, there are, however, a number of financial and economic trouble spots that could endanger the continued growth in the market before the end of 2010."

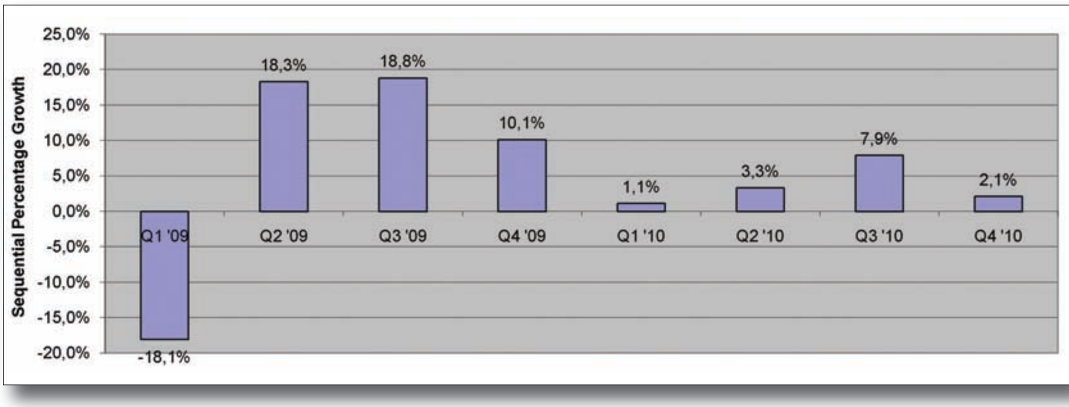
Beyond strong demand, semiconductor suppliers also are benefitting from careful management of chip inventories and tight controls on manufacturing capacity.

"By keeping a tight reign on stockpiles and production, semiconductor companies have been able to hold supplies at levels less than demand. As a result, many semiconductor product segments are experiencing strong upward price pressure", Ford said.

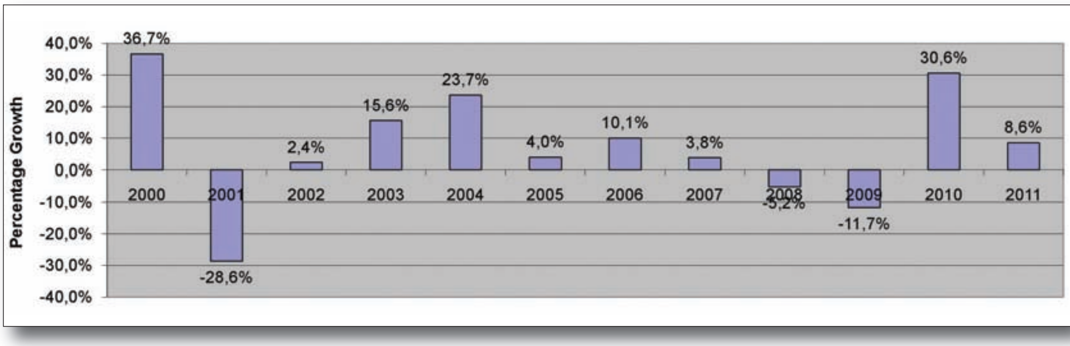
Dramatic growth in DRAM revenues will be a major driver of growth in the overall semiconductor market. DRAM revenue growth in 2010 is projected to reach nearly 77%.

Other major growth drivers in 2010 will be NAND flash memory, analog ICs, discretes, LEDs and Programmable Logic Devices (PLDs). All of these major market segments are forecasted to attain growth of more than 30% during the year. Most of the significant product segments are expected to expand by more than 20%.

According to market researcher Gartner total worldwide semiconductor revenue reached $228.4 billion in 2009, down $26.8 billion, or 10.5%, from 2008. Intel held the No. 1 position ($33.253 billion) for the 18th consecutive year. It increased its market share to 14.6% in 2009 from 13.6% despite its revenue declining $1.6 billion. This performance was primarily due to the relative strength of the PC market, mobiles in particular, which sold well despite the recession. With a huge gap (7.7% market share) Samsung was second, followed by Toshiba (4.2%).



Forecast of quarterly global semiconductor revenue growth **Source: iSuppli**



Forecast of annual global semiconductor revenue growth **Source: iSuppli**

www.isuppli.com
www.gartner.com

Power Semiconductor Market Rebound in 2010

2009 Rank	Supplier	2009 Share
1	Infineon	11,7%
2	Toshiba	7,8%
3	Fairchild	6,9%
4	STMicroelectronics	6,6%
5	Vishay	6,4%
6	Mitsubishi (inc. Powerex)	4,9%
7	Fuji Electric	3,9%
8	International Rectifier	3,5%
9	Semikron	3,3%
10	Renesas	3,2%
	Others	41,8%
	Total Market Size:	$10,1 bn

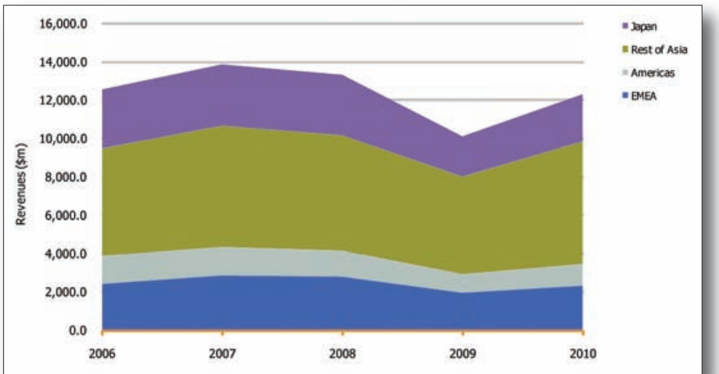
World power semiconductor supplier market share estimates **Source: IMS Research**

The power semiconductor market was worth $10.1 billion in 2009, declining by 24% from 2008 (power modules dropped 26%, and discretes 24%). The market has not dropped by such a large extent since 2001, when it fell 22% because of the "Dot-Com" collapse. By end of 2010 a recovery up to $12 billion is expected by IMS Research. The Japanese power semiconductor market was the worst hit in 2009, falling from $3.2 billion to $2.1 billion. However, the Japanese Yen dropped 10% against the US $, which accounts for some of the fall. Indeed, some Japanese power module suppliers reported customer orders dropping by 50-60% in 2009, in the induction heating and welding and commercial HVAC sectors.

EMEA's power semiconductor market fared little better in 2009, as the European industrial markets finally plunged into the downturn at the end of Q1 09; some countries are still fighting their way out. This could explain why the American power semiconductor market outperformed those of Japan and EMEA, as the USA was one of the first countries to enter the global downturn and was one of the first countries out.

Infineon Technologies was estimated to have increased its power semiconductor market share to 11.7% in 2009 and remained the largest supplier to the market for the seventh consecutive year. Toshiba leapfrogged Fairchild, STMicroelectronics and Vishay, which followed in that order. These leading five suppliers were estimated to account for almost 40% of the total 2009 market.

The discrete power semiconductor market was worth $8.1 billion in 2009. Power MOSFETs and power rectifiers together accounted for 74% of the total revenues; revenues of each declined by over 25%. MOSFETs saw the largest decline, falling by nearly 40%, though this is not surprising as over 95% of their market is the automotive sector. The supplier rankings for the discrete power semiconductor market saw an important change in 2009: Toshiba moved from 5th place in 2008 to 1st in 2009. "Toshiba performed incredibly in 2009 considering the economic situation at the beginning of the year. One of the many reasons for Toshiba's strong performance was its large customer base in rest of Asia. The discrete power semiconductor market in the rest of Asia fell by only 5% to 15% depending on the device category", commented Josh Flood, market analyst at IMS Research.



World market for power semiconductor discretes and modules 2006 - 2010

Source: IMS Research

As for power modules, the thyristor/diode module market dropped by 30% in 2009, because of the induction welding and heating markets being severely hit during the economic downturn. Sales of standard IGBT modules remained the most robust of the other power module types. This can be attributed to their use in the renewable energy markets, such as wind and PV generation, which were less ruthlessly hit. Many industry observers believe the market for high power industrial motor drives coped better than that for low power drives, though opinions still differ. The top four power module suppliers - Mitsubishi Electric, Infineon, Semikron, and Fuji Electric in that order - remained unchanged in 2009.

Silicon Carbide comes good

The SiC Schottky diode market was worth an estimated $29 million in 2009. It fell in line with the total power semiconductor market during the global downturn; but enjoyed strong demand in 2H 2009. Overall the SiC Schottky diode revenues were estimated to be 25% higher in 2009 than in 2008. The SiC Schottky diode market will increase by over 50% in 2010. PFC power supplies for server and telecom applications currently account for the most SiC Schottky diodes sold. The huge developments in the Chinese telecom and cellular infrastructure, and high system-efficiency standards generally, are driving their adoption. However, many industry experts believe PV inverters could become the largest market for SiC Schottky diodes within the next 3-4 years, depending on the growth of the PV inverter market.

"Currently, SiC Schottky diodes are the only SiC power devices sold in large volumes. SiC JFETs are also available on the commercial market but have not yet succeeded to the same extent. However, Cree are set to introduce the SiC MOSFET this year, Transic will be releasing its SiC BJTs in 2H 2010, and Infineon will releases its SiC JFET in 2011; thus SiC power devices look very promising for the future", Flood predicts. IMS forecasts the SiC power semiconductor discrete and module market will be worth $110 million by 2012. Interestingly, the GaN power device market is projected to be worth $20 million in 2012. Although these GaN revenues are much lower than predicted by some other industry observers, they are much higher than SiC Schottky diodes achieved in their first three years on the market.

The PV inverter market raced out of 2009, with record shipments of more than 8 GW, 30% more than 2008. "Q4'09 saw huge demand for all PV products as investors rushed to complete systems before feed in tariffs were reduced in many key European markets. 2.3 GW of installations were completed in Germany alone," commented IMS analyst Sam Wilkinson. "This incredible demand resulted in 3.5 GW of inverters being shipped worldwide in the final quarter. Demand has remained high into 2010 and we now see a complete contrast to the first half of last year with a shortage of components limiting the market, rather than weak demand". SMA Solar Technology (Germany) remained the largest supplier of PV inverters in 2009 and increased its share of shipments to an estimated 42%. Fronius International remained the second largest supplier worldwide and Kaco New Energy maintained its position as third largest. The competitive landscape changed somewhat more below these suppliers with Power-One and Sputnik Engineering emerging as winners, surpassing several suppliers to become the fourth and fifth largest in 2009.

www.imsresearch.com

Back to Growth

PCIM Europe 2010 was held from May 4 - 6 in Nuremberg and confirmed with an increase of 3% in visitors (6300), 619 conference delegates and last but not least 255 exhibitors its leading position.

The majority of international exhibitors came from the USA, followed by Italy, Great Britain and France. The number of Asian companies was on the rise. As well as the major players, many aspiring young companies were present. The PCIM Conference encouraged an intensive dialogue between science and industry. 170 previously unpublished papers have been orally presented over the three days. In 22 presentations and 2 poster sessions, the latest developments have been discussed with the conference delegates.

Awards for outstanding papers

The conference focused on solar power, in particular the awarded papers and PEE's Special Session.

Again this year three Young Engineer Awards (€1000.00 each) were presented to exceptional contributions from young professionals (under 35 years old). The papers were selected by the Conference Directors from more than 100 papers and sponsored by ECPE, Infineon Technologies and International Rectifier.

Dayana El Hage, EPFL, Switzerland, was awarded for the paper "A high current pulse-power supply for flash lamps in PV-panel measurement-facilities".

A high current pulse power supply for the feeding of a flash lamp has been developed, on the base of a multilevel converter with cascaded cells. The pulsed high power is provided by capacitive energy storage, directly connected to the cells of the converter. A low current ripple is reached by interleaved switching technique. The original topology, its design regarding the sizing of the storage cells, and the associated control were presented.

Christoph Klarenbach, UAS Cologne, Germany, was the second awardee with the paper "Fast and high precision motor control for high performance servo drives".

He presented a new architecture of a fast current controller with two feedback signals for high performance motion control. Due to parallel processing inside the Field Programmable Gate Array (FPGA), the control algorithm computing time is significantly less than 1µs. Together with advanced control technologies in combination with a new current observer the bandwidth of fast switching IGBT or MOSFET power stages is not limited by the delay time of high precision (integrating) current measurement any longer. Using that technology high control bandwidth in conjunction with high precision current control is now possible at no trade off. The control strategy relies on a simplified machine model without incurring performance degradations. The presented results have been produced with a high speed Computerized Numerical Controlled (CNC) machine (high speed lathe).

Andreas Munding, Liebherr-Elektronik GmbH, Germany, won the price for "Compact PCB-packaging and water cooling of a 25-kW inverter".

This work featured simulation results of a sandwich PCB assembly with an electronic board and a high current board attached to either side of an aluminum heat sink. This heat sink is thermally attached to the metal housing and to a liquid cooling channel which was optimized for low pressure drop. In addition, the effect of the low pressure drop cooler structure on the IGBTs of a directly cooled pin-fin based power module was simulated and characterized. It was found that a geometry with lateral coolant impingement exhibit lowest pressure drop and allows for a large flow rate operation range in automotive applications.

The determining criteria for the Best Paper Award (a PEE-sponsored paid trip to PCIM China 2011 in Shanghai) were originality, topicality and quality. Christian Nöding from University of Kassel, Germany, won this price for the paper "Evaluation of a Three-Phase Two-HF-Switch PV Inverter with Thyristor-Interface and Active Power Factor Control". The certificate was handed over by PCIM Organizer Udo Weller and PEE Editor Achim Scharf on the PCIM 2010 opening ceremony A short version of this paper is published in our feature section.

For the third time time Power Electronics Europe has organised a Special Session with this year's focus on Renewable Energy Applications featuring papers from Björn Backlund, ABB Switzerland Ltd; Dejan Schreiber, SEMIKRON Elektronik (Germany); Alberto Guerra, International Rectifier (USA) and Shang Ming, Mitsubishi Electric Corporation (Japan). These papers can also be found in the feature section of this issue.

Best paper awardee Christian Nöding (middle), PEE Editor Achim Scharf (left) and PCIM Organizer Udo Weller (right) at the PCIM 2010 opening ceremony

New products and services

ABB Switzerland Ltd, Semiconductors starts mass production of 4.5kV SPT+ IGBT modules after successful qualification and proven ramp-up phase in the traction market.

"Our 4.5kV HV-HiPak2 IGBT modules employ the well established SPT+ IGBT and diode technologies. These modules have significantly lower conduction and switching losses while exhibiting higher SOA capability when compared to the previous generation", commented Sven Klaka, ABB's VP Technology & Product Management.

The SPT+ platform exploits an

ABB's new 4.5kV SPT+ IGBT modules

enhanced carrier profile through planar cell optimization, which is compatible with ABB's cell design. The on-state losses of the new 4.5kV IGBT exhibit approximately a 30%

"These 4.5 kV modules have significantly lower losses while exhibiting higher SOA capability when compared to the previous generation", commented ABB's Sven Klaka

reduction as compared to the standard SPT device while keeping the same E_{off} value. For the 1200A rated Hipak2 module the typical on-state voltage drop at nominal current and T_j=125°C is 3.55V. For the same module the typical turn-off switching energy (E_{off}) at 2800 V_{cc} and T_j=125°C is 6J. The new 4.5kV HV-HiPak2 modules will provide high voltage system designers with enhanced current ratings and simplified cooling while further enhancing the recently acquired robustness of the SPT IGBTs. ABB's 4.5kV modules are available in current ratings ranging from 650A - 1200A in single IGBT as well as diode configurations.
www.abb.com/semiconductors

Avago introduced three Miniature Precision Isolation Amplifiers with increased accuracy, bandwidth and high insulation made possible by proprietary optical isolation. Widely used for motor phase and rail current sensing, servo motor drive, switching power supply feedback isolation, DC link voltage monitoring, inverter current sensing and switching power supply feedback isolation, the ACPL-C97x targets industrial automation and instrumentation, renewable energy, and HVAC markets. In a typical motor drive application, currents through a small value current sense resistor cause a voltage drop that is sensed by the ACPL-C79x isolation amplifier and a differential output voltage, proportional to the current, is created on the output side of the isolation barrier. Based on sigma-delta analog-to-digital converters and chopper stabilized amplifiers, the new isolation amplifiers feature high gain accuracy, low temperature drift, 3.3 V/5 V output supply operation and a wide -40 to +105°C operating temperature range. These features are delivered in a stretched SO-8 package that has a footprint 30% smaller than the standard DIP-8 package. "When mounted on a PCB, it occupies a space that is a fraction of that for a traditional Hall Effect or transformer based isolation amplifier. The high common-mode transient immunity of 15kV/µs provides the precision and stability needed to accurately monitor current in high noise motor control environments. This ensures smoother control with less torque ripple in many motor control applications", commented Erik Halvordsson, Avago's European Business Development Manager.
www.avagotech.com/optocoupler

Cree announced the first commercially available 1700V SiC Junction Barrier Schottky (JBS) diodes targeted at high-voltage applications in motor drive, wind energy and traction.

Initial products in the 1700V series include 10A and 25A JBS diodes in die form, ready for integration into 1700V power modules ranging from 50 to 600A. "The 1700V diodes extend our offering in energy-efficient power systems for datacenter and solar power to new markets such as wind energy, train, tram and electric vehicle power converters," said Cengiz Balkas, General Manager Power and RF. "The advantages of Silicon Carbide are clear, and for high-voltage, high-frequency systems, you can't afford not to use SiC."
www.cree.com/power

Dongbu HiTek from Seoul/Korea offered its foundry services at PCIM. "Our BCDMOS processes are compatible with those of National Semiconductor or Texas Instruments and tailored for power management ICs. June 2008 we launched the world's first BCDMOS process at the 0.18 micron level node. This year we plan to introduce mid-voltage chips for cell-phones as well as a high-voltage, more than 200V, BCDMOS process for industrial applications, which is certainly of interest for the European customers", said Lou N. Hutter, GM of the Analog Foundry Business Division. The company operates two fabs currently process

"This year we plan to introduce a high-voltage BCDMOS process for industrial applications within our foundry services", said Dongbu HiTek's Lou N. Hutter

200mm wafers at nodes ranging from 350 to 90 nanometers, supported by design support (IP and design libraries), prototype development/verification, and packaging/module development. Recent references are a Low Frequency (LF) receiver IC for Micro Analog Systems Oy (MAS), a fabless analog semiconductor company based in Espoo/Finland, or high-voltage LED Driver ICs for 60V operation developed in collaboration with ADDtek, a Taiwanese fabless company. Market researcher IC Insights recently ranked Dongbu HiTek as one of the world's top specialized foundries. Among the other foundries that IC Insights ranked in the specialized sector were Vanguard in Taiwan, TowerJazz in Israel and X-FAB in Germany.

According to market researcher Gartner Dongbu held in 2009 with revenues of $370 million position 8 in the worldwide foundry ranking, followed by TowerJazz ($298 million). Market leader was TSMC with roughly $9 billion in revenues.
www.dongbuhitek.com

Infineon Technologies presented new developments in MOSFETs, IGBTs, SiC diodes and packaging. The latter is called .XT technology which optimizes all interconnections within an IGBT module in regard of lifetime. Lifetime of a power module can be defined as the operating time under specific load conditions. The joining technologies such as soldering or bonding define the lifetime, basically once a failure mechanism occurs. Firstly, a copper front-side metallization of the Silicon dies and a copper bond process was implemented. Secondly, the chip-substrate connection is done via diffusion soldering consisting of high-melting intermetallic phases with joint thickness of 10µm (compared to soldering a reduction by a factor up to 8). These efforts lead to a module lifetime simulation of ten times longer compared to a standard module. Alternatively the output power can be increased by 25%. The new .XT technology covers all critical areas on power cycling capability within an IGBT module: bond wiring on the chip front side, soldering on the chip back side (die to DCB) and the DCB (Direct Copper Bond) to base plate soldering. The new set of interconnection technology has been developed to

Infineon's Martin Hierholzer (left) and Arunjai Mittal presented the specifications of the first .XT power module

fit into most of the existing packages as well as into new module packages. All three new joining technologies are adaptable to the standard processes and suitable for junction temperatures up to 200°C and for high volume production. "By introducing the new .XT technology Infineon is setting a new benchmark in power cycling capability and as a key enabler for higher junction temperature operation", said Martin Hierholzer, General Manager Industrial Power. The first .XT product is the PrimePACK 2 module FF900R12IP4LD based on IGBT4 chips (150°C operation) with dual configuration providing 900Arms.

Also Infineon Technologies and Mitsubishi Electric Corporation will both serve the industrial motion controls and drives market worldwide as sources for the advanced IGBT module packages SmartPACKs and SmartPIMs. This package concept, recently developed by Infineon, will be available with the latest generation of power chip technologies from the two companies. Under this agreement, Mitsubishi Electric will market its latest generation power chips of various ratings (15A up to 150A, 600V and 1200V) in the Smart-1,-2 and -3 housings.

Additionally SiC Schottky diodes in the TO-220 FullPAK package have been introduced. The new TO220 FullPak portfolio combines the high electrical performance standards of the 2nd generation SiC Schottky diodes with the advantages of a fully isolated package, including easier and more reliable mounting without having to use isolating bushing and foil. The new TO220 FullPAK devices show a similar junction-to-heatsink thermal resistance as the standard non-isolated TO-220 devices. This is accomplished by using patented diffusion soldering technique, which reduces the chip-to-leadframe thermal resistance. The 600V FullPAK portfolio is offered in current ratings from 2A to 6A. According to Arunjai Mittal, President of the Division Industrial & Multimarket, Infineon is also evaluating the upcoming GaN power technology and will increase wafer size for SiC production from 4 to 6 inch shortly. "And, by the way, I am very pleased to see Infineon again as the leading supplier of power semiconductors in the IMS statistics."

In Power MOSFETs Infineon announced a packaging partnership with Fairchild Semiconductor for their power MOSFETs in the Infineon PowerStage 3x3 or Fairchild MLP 3x3 (Power33™) packages. The compatibility agreement is in response to the need for supply security while balancing the drive towards best-in-class efficiency and thermal performance in DC/DC conversion. It takes advantage of the expertise both companies offer for asymmetric, dual and single MOSFETs for DC/DC applications from 3A to 20A.

"Standardizing power packages benefits our customers as we minimize the amount of 'unique' packages available in the market place, while offering solutions that enhance performance levels in smaller form factors than the previous generations," commented Richard Kuncic, Infineon's product line manager low voltage MOSFETs.
www.infineon.com

Besides its automotive activities Semikron introduced the first vacuum-sealed packaging for power modules called SEMISEAL. The packaging provides proven mechanical and environmental protection from harmful influences such as humidity, corrosive elements and dust, but also from shock and vibration. "The power modules are vacuum-sealed between a plastic film and adhesive coated paperboard. After production, the module is immediately sealed using a close-fitting transparent foil on one side and coated paperboard on the other side. The packaging stays intact during stock handling and transport. In comparison to standard packaging, SEMISEAL provides a seal of integrity for the customer. The quality of the module is ensured until the packaging is opened by the customer", explained Semikron's Technical Director Stefan Starovecky.

The transparency of the state-of-the-art packaging allows for a visual quality check, inspection by customs and data matrix reading for module identification. SEMISEAL packaging allows for different quantities of one module type to be included in a single package that is perforated to

Semikron's Technical Director Stefan Starovecky introduced the first vacuum-sealed packaging for power modules

allow for easy separation of the modules in given quantities as needed. Fast unpacking is simply done by first lifting and taking away the cardboard and then removing the film by pressing down the cardboard template. The paperboard and plastic film used for SEMISEAL are environment-friendly and recyclable. The vacuum-sealed packaging units for SEMIPACK 2 and SEMITRANS 2 weight is approximately 50% less than standard packaging units.
www.semikron.com

Vincotech announced a new family of products called flowPHASE 2 S. Designed for fast-switching power applications beyond 100 kW, these new power modules (600/1200V, up to 400A) provide an ultra-low inductive path for transient current. Parasitic inductances are a major problem in power modules, particularly in fast-switching

Vincotech's Peter Sontheimer showing a model of the new low-inductance power module design

applications. To solve this problem, an ultra-low inductive path for transient current to today's standard power module design has been added. "This reduces parasitic inductance to 7nH and allows for switching frequencies up to 20kHz", commented VP R&D Peter Sontheimer. According to Vincotech's GM Joachim Fietz solar power is one of the booming markets the company is adressing and average lead time is 24 weeks.
www.vincotech.com

PCIM Europe 2011 will be held from May 17 - 19.

AS

Three-Phase Two-HF-Switch PV Inverter with Thyristor Interface

To feed-in an alternating current into the medium voltage AC grid several requirements have to be kept. Next to rugged and interference-insusceptible electronics, attention has to be given to the new grid connection guidelines in Germany since 2008. Such new rules significantly affect the cost of inverters nowadays, especially when usual semiconductor devices like IGBTs are employed. This paper, awarded as best paper at PCIM 2010, deals with an inverter-topology which combines the rugged properties of well known thyristor-circuits with the features of modern inverters. **Christian Nöding, Benjamin Sahan, Peter Zacharias, Center of Competence for Distributed Power Technology (KDEE), University of Kassel, Germany**

Photovoltaic inverter technology rapidly improved during last decades, achieving more than 98% conversion efficiency. In terms of efficiency this leaves little space for major improvements. However, inverter cost are still relatively high, corresponding to approximately 250€/kW. In order to compete with conventional energy sources cost must be drastically cut down without significant prejudice on the efficiency, functionality and power quality. An approach to this is to minimize the amount of HF-switches and to combine high performance IGBTs or SiC switches with rugged low-cost switches like thyristors.

The thyristor is a proven technology since its development in the late 1950s. Because of its high current switching capability and its robustness this device is still popular in high power applications. Inverter topologies consisting of this technology are well known but only able to produce a rectangular output current and therefore require large magnetic components which cause higher weight and size of the devices.

Inverter function principle

An inverter with six thyristors and two buck converters in the front-stage (Figure 1) is capable of modulating sinusoidal output currents. Each buck converter creates a 180° phase shifted DC current which is superimposed by a multiple of the 3rd harmonic. This kind of DC current is then distributed by the thyristor-bridge to all phases of a standard 3-phase transformer in star-delta configuration (Figures 2, 3 and 4). Such a transformer is inherent to large-scale PV generation units (>200kW) which are connected to the medium voltage grid. The star-delta configuration eliminates the 3rd harmonic component, resulting in a

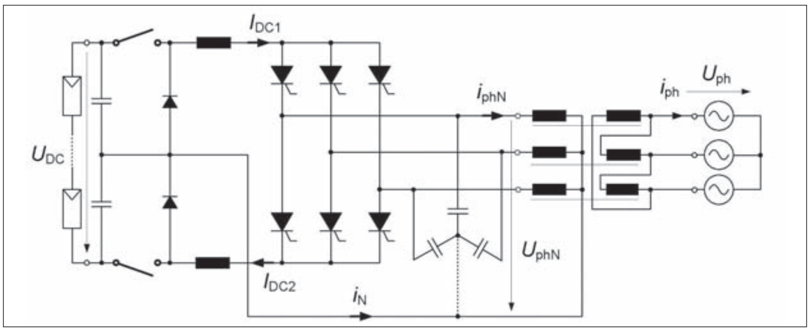


Figure 1: Inverter topology (Minnesota Inverter) with six thyristors and two HF-switches (IGBT or SiC MOSFET)

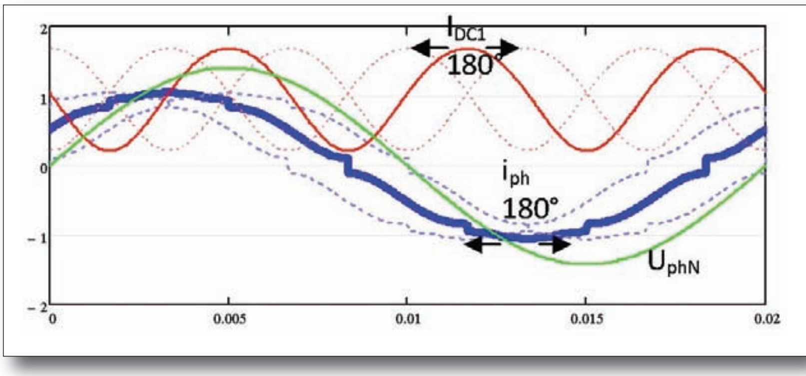


Figure 2: Phase shifted DC-link currents, input voltage and shifted input currents of transformer

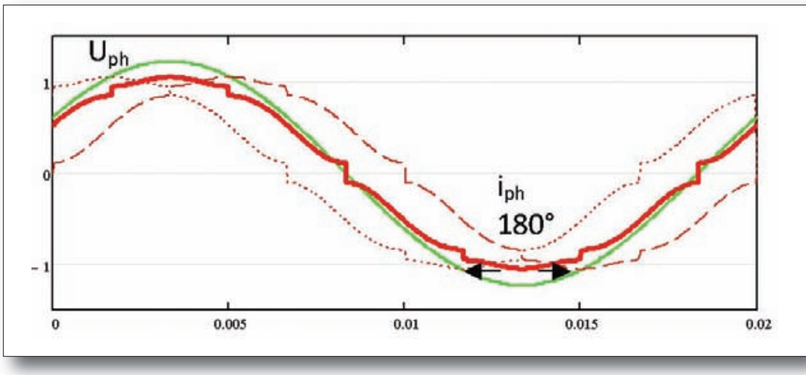


Figure 3: Output voltage and phase shifted output currents of transformer

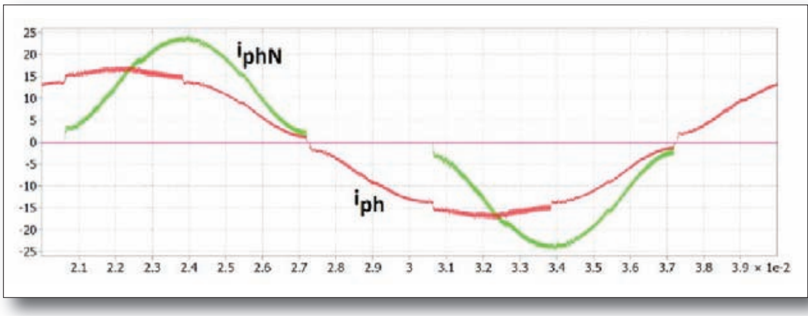
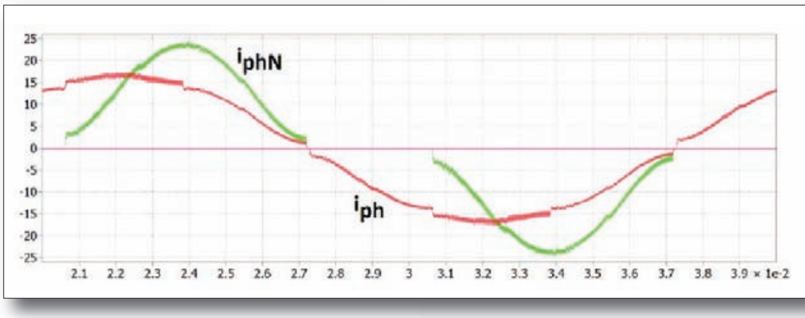


Figure 4: Simulated phase current of transformer

Figure 5: Simulated current of buck converters, neutral point of transformer and AC output



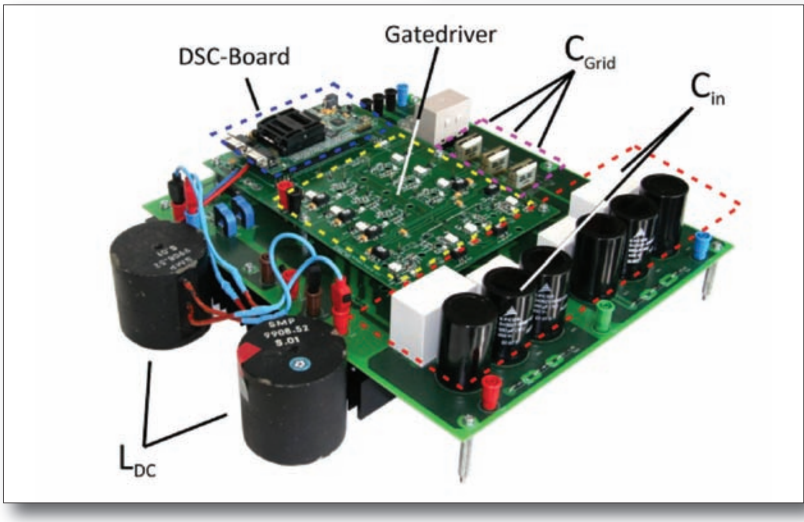


Figure 6: Prototype having a nominal power of 5kW and 800VDC input voltage

nearly sinusoidal output current.

A common problem of thyristor inverters is the loss of stability at firing angles above α=180°. This topoloγy mitigates the problem because the DC-link current can be actively set to zero by the two buck converters (Figure 5). After this turn-off the commutation process in the next phase can be performed as usual. While keeping the DC-link voltage of the buck converters positive at any time this allows an adjustment of the firing angle _ between -30° and +30° around the pure active power point at α=180° (Figure 2 and 3). The circuit is therefore capable of shifting the output current between inductive (α=150°) and capacitive (α=210°) reactive power continuously without any steps, complying with the requirements of the new medium voltage grid code to stabilise the grid voltage with reactive power. This operation mode is new to thyristor based inverters and was so far reserved for self-commutated IGBT topologies.

To classify the performance of the presented system a comparison with three well known standard topologies was done. Important values of each circuit will be normalized to achieve comparably factors. In methods for comparing different topologies are described in detail. These comparison-factors include number of HF-switches, total rms- and mean-current of

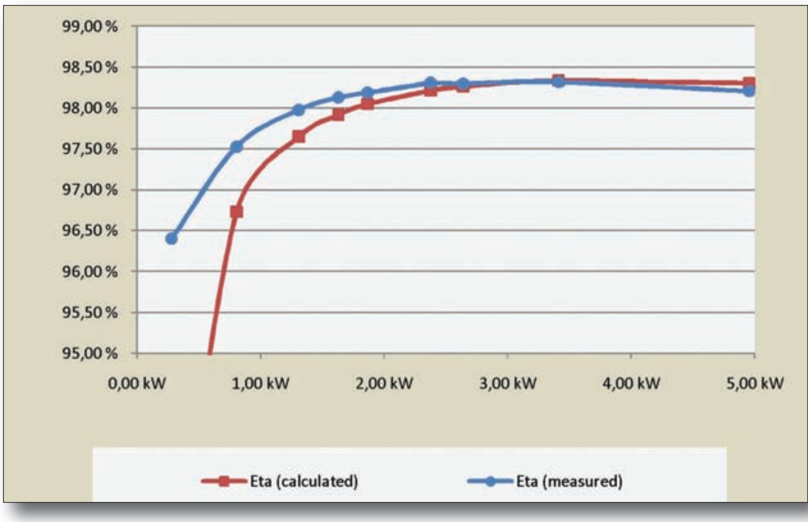


Figure 7: Calculated and measured efficiency of the prototype at U_{DC}=800V

Table 1: Simulation results (Simulink/PLECS) for four topologies normalized to the 2-level inverter

	2-Level	NPC	BS-NPC	MI
HF-Switches	6	12	12	2
LF-Switches	0	0	0	6
Maximum blocking voltage of HF switches	1,00	0,50	1,00	0,50
Inductor volume factor	1,00	0,50	0,50	0,48
Total mean current factor	1,00	2,00	1,21	1,74
Total RMS current factor	1,00	2,01	1,15	2,32
Total switch. loss factor 1	1,00	0,44	0,39	0,46
Total switch. loss factor 2	1,00	0,11	0,20	0,11

the semiconductors, total switching-loss values and number and volume of required inductors. All factors are normalized to the values of the well known 2-level inverter.

To estimate the pros and cons of each circuit, factors for four topologies were calculated with simulation results (Simulink/PLECS) and listed in Table 1. All factors are normalized values in reference to the 2-level inverter topology at a modulation index of 1 and $\cos\varphi=1$.

Experimental results

A laboratory prototype (Figure 6) has been built having a nominal power of 5kW, 800VDC input voltage and switching frequency of 16kHz to verify the feasibility of the approach.

To estimate the potential of this topology the calculated efficiency was compared to the measured one feeding an ohmic load (Figure 7). A peak efficiency of 98.4% could be achieved. Due to a pessimistic switching loss assumption the calculated efficiency within low power region is below the measured one.

Conclusions

An inverter topology for photovoltaic systems connected to the medium voltage grid using inexpensive thyristors and high performance IGBTs or SiC switches has been presented. A three-phase sinusoidal current can be generated while complying with the reactive power specifications of the new medium voltage grid code. Reactive power is an important part of modern inverters for grid stability and compensation features. The major advantages of the circuit are the high performance/cost ratio and the robustness of the semiconductors. Using factors for comparing different types of topologies a comparison between common inverters was made to show the benefits of the presented system. The feasibility of this topology was proved by experimental results presented in this paper, showing its correct operation even with firing angles above $\alpha=180°$. With only two IGBT switches a peak efficiency of 98.4% could be reached with this laboratory setup. Further research of this concept will be focused on behavior of the circuit on single- and multi-phase errors defined in the new grid code.

Literature

Christian Nöding: "Evaluation of a Three-Phase Two-HF-Switch PV Inverter with Thyristor-Interface and Active Power Factor Control", PEE Sponsored Best Paper Award in Session "Inverters for Renewable Energy and UPS", PCIM Europe 2010, May 6, Room London

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Power Semiconductor Technologies for Renewable Energy Sources

High power semiconductors are key components for controlling the generation and connection to the network of renewable energy sources such as wind-turbines and photovoltaic cells. For a highest efficiency of the energy source, it is therefore essential to select the right device for the given conditions. This article looks at the performance features for the available high power semiconductors of choice and also takes a look at future device technologies and their expected impact on efficiency. **Björn Backlund and Munaf Rahimo, ABB Switzerland Ltd, Semiconductors, Lenzburg, Switzerland**

Renewable energy sources as wind-turbines and photovoltaic cells have reached power levels of several MWs which have resulted in the need for high power semiconductor devices for optimized generation and network connection. The state-of-the-art devices of choice for these power levels are the IGBTs and IGCTs. Due to the power quality requirements, the earlier used solutions with thyristors in the wind turbines are rarely seen today. During the last 15 years, high power semiconductors have gone through a remarkable development. Several new generations of IGBT-dies have lead to a reduction in V_{CEsat} of almost 40 % since the early 1990s, and still a potential for further improvement is available. The Bipolar devices have also seen large improvements where the introduction of the IGCT have had a large impact on the MV-Drive design and higher ratings for them have recently been introduced or are in development. The thyristors have also not been standing still but have moved from 6500 V, 2600 A to 8500 V, 4000 A devices based on 150mm silicon now in production.

The power semiconductors are used for two main tasks in the chain of renewable energy sources such as conversion of the power in the plant, as in wind-turbines, and transmission of the power to the grid. The best solution to determine what semiconductors to use for these tasks is to move top-down by following the path system requirements defining equipment requirements which in turn are defining the power semiconductor requirements. Through this chain the requirements on the devices are determined regarding items as required voltage and current ratings, needed degree of controllability, and operating frequency.

Power semiconductors for inverters

The possibilities to achieve the above requirements will be looked at with focus at power ratings above 0.5 MW. For inverter applications, the IGBTs and IGCTs represent the two main candidates due to the main features listed in Table 1.

As can be seen, both devices have a distinct set of features making the question which one is the best technology obsolete. What it comes down to is to select the device based on application requirements and own capability to utilize the device to its best. Certain comparisons are though helpful to see what is possible to achieve with the two technologies. One example is the possible out-put power for a 2-level inverter as function of the switching frequency at a given set of conditions as seen in Figures 1 and 2. Other comparisons can though have been selected to promote a certain technology over another and should not be used to find out which solution is the best for the given task.

In practice the choice of components will be governed by considerations as standardization by the use of basic building blocks for various applications and requests from customers to use a certain

IGCT features	IGBT features
- Available as asymmetric and reverse conducting (with integrated diode). - Voltage ratings 4500 up to 6500 V with current ratings of 210 up to 5500 A of peak turn-off current. - Integrated gate unit is included; critical to device performance. - Low on-state losses. - Press-pack design for double sided cooling with device assembled between heat sinks on potential, enabling very high power density. - Press-pack design without soldering and bonding for high load cycling capability.	- Devices available in various configurations, as single switch, dual switch and dual diode, - - Voltage ratings 1700 - 6500 V and current ratings 400 – 2400 A. - Module package with insulated base plate enables simple bus bar assembly and mounting on a grounded heat sink. - Voltage control enables simple, low power gate drive. - High controllability through the gate for optimized switching behavior also enabling control at short circuit conditions.

Table 1: **Features for IGCT and IGBT**

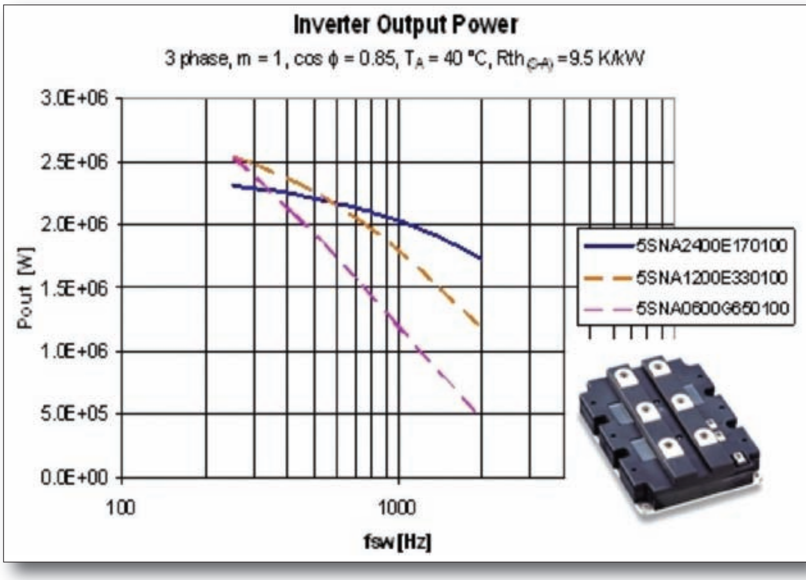


Figure 1: Comparison in current rating for a standard package equipped with SPT dies

solution. The fast development of the devices makes it though necessary to look critically at the used solution from time to time to see if it still is the best possibility to fulfill the requirements or if new designs with new devices can improve the equipment performance.

Since the operating conditions determine the preferred semiconductor technology it is also not possible to give general rules about which component has the highest efficiency. This has to be determined case by case also considering that the different features of the device technologies can have an impact on the complete efficiency for the system. It can though be projected that the efficiency is not static but will improve with time as new improved power semiconductors are continuously being introduced on the market.

Wide band-gap materials

Another interesting item is the development of new wide band-gap semiconductor materials in addition to the dominating silicon starting material. The salient features of Silicon compared with the most developed candidates for new semiconductor materials are listed in Table 2. One important aspect of the high power semiconductor development is its impact on efficiency and energy saving, or in other words how "green" it is. Renewable energy sources are today almost exclusively equipped with power electronics and therefore it makes a difference what power semiconductor are used also due to the large impact of secondary effects as cooling capacity.

One major issue for efficiency comparisons is that SiC and GaN are limited in voltage, current and component types which means that useful comparisons for many systems in renewable energy are not really possible since there are for instance no comparative GaN and SiC components to the Silicon-based IGCTs used in 5MW wind turbines with full power conversion. This often leads to comparisons for special components in special applications where a 1 to 1 comparison is possible thus too often underestimating the potential of energy savings made possible by Silicon or

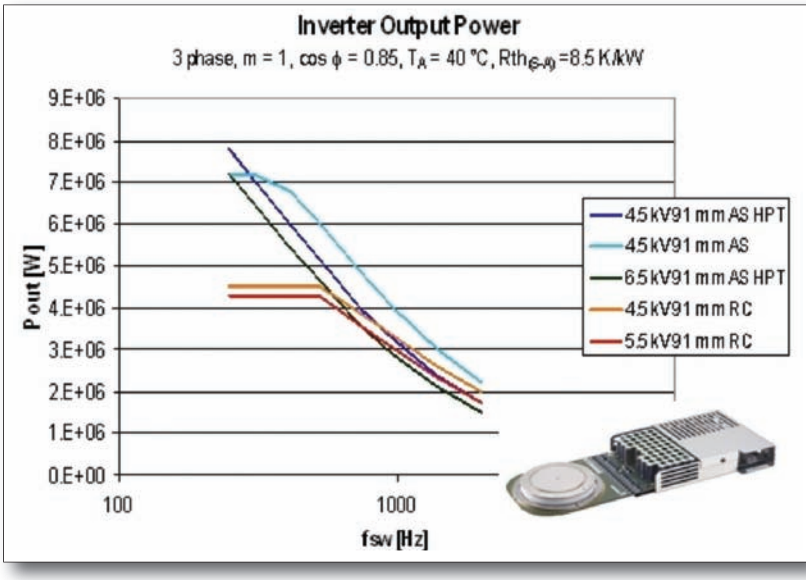


Figure 2: Comparison in current rating for standard IGCTs

Silicon based devices	Wide band-gap (SiC, GaN) based devices
- Well established technology with proven reliability. - Devices up to 8.5 kV available and higher voltages in development [4]. - Single devices available with 5500 A turn-off capability. - Mass production of devices as Diodes, Thyristors, IGCT and IGBT in many different packages and configurations.	- Potential for low statics and switching losses for high switching applications - High junction temperatures capabilities. - Gaining market share in recent years for special applications such as PFC with uni-polar diodes rated up to 1200V. - Current ratings still below 100A in productions.

Table 2: Features for Silicon, Silicon Carbide and Gallium Nitride based devices

showing a decrease in inverter size at equal performance where it is questionable if the small size is of importance. Aspects as EMI and insulation fatigue due to very short switching times also need to be included in the comparisons. This since what may look most promising on equipment level may be a solution that is sub-optimal on system level.

Due to cost, reliability and availability only Silicon is an option for bulk power applications. Other materials are currently only for niche markets where the possible efficiency increase is important enough to compensate for costs, reliability risk, etc.

Although a comparison is very difficult to make at higher power levels we have made an attempt and in Figure 3 a comparison on module level shows the current capability of a standard module size using SPT+ IGBT dies with either a SPT+-diode, extrapolated data for a SiC diode or the new BIGT with IGBT and diode integrated on one die. Based on comparisons like this one, it is also possible to calculate losses and efficiency for the different solutions at one set of conditions in the same way as discussed in the comparison between IGBT and IGCT.

Due to the fast changing landscape of wide band-gap materials and devices, also not forgetting that Silicon-based devices are continuously being improved, it is expected that especially applications below about 0.5MW will see substantial changes during the coming years. As a result of this, and also the development on Silicon-based devices for higher power levels, we will see a gradual improvement in efficiency thus reducing the power lost between generation and consumption having a positive effect both in economical as well an environmental terms.

Bringing the renewable power into the grid

Renewable energy sources are quite often remotely located without a sufficient infrastructure to feed the electrical energy into the grid. For a complete study of power electronics for renewable energy sources we must therefore also look at the possibilities to transmit the energy in an efficient way.

For hydro power stations as the three Gorges dam in China and Rio Madeira in Brazil, HVDC solutions have been chosen to transmit the power. At these systems with transmission lengths of above 2000km the total losses, including the losses in the converter stations, can be reduced with 50% compared to a standard AC-transmission. This corresponds to savings per project of up to several TWh yearly. This is done simply by using large area high voltage mm thyristors where current systems are equipped with 100 - 125mm thyristors with 150mm devices recently being introduced for use in UHVDC-systems with voltage levels up to 800kV.

Also for other transmission systems the

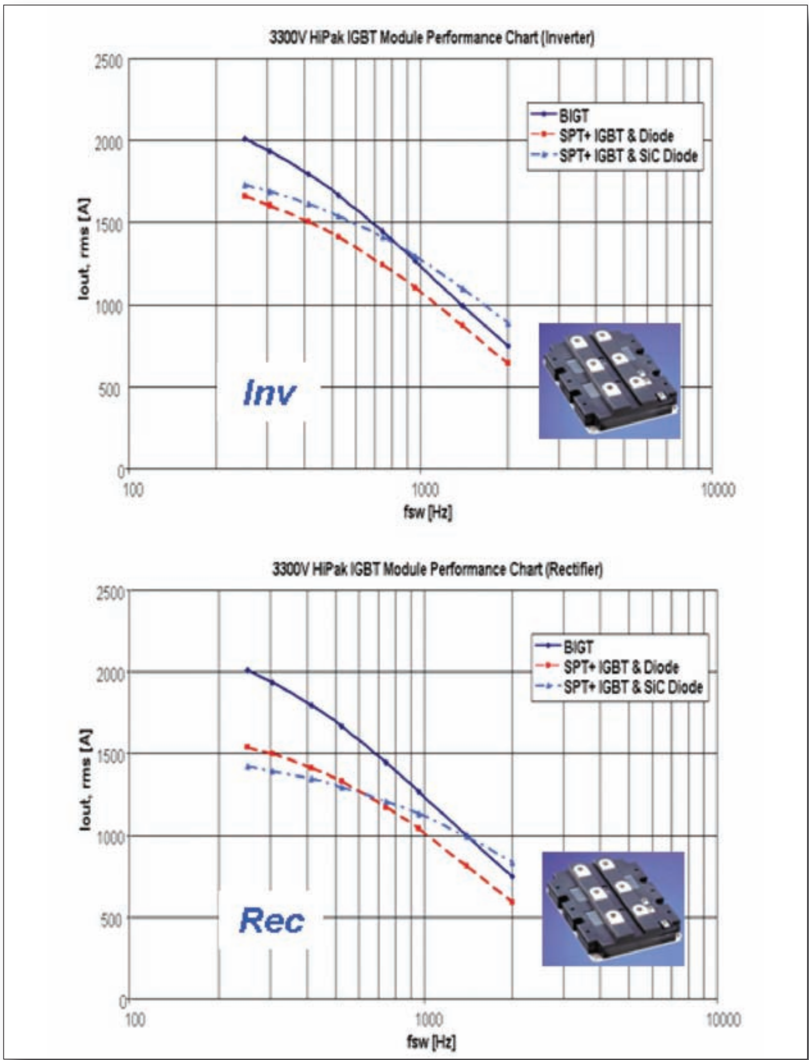


Figure 3: Comparison in current rating for a standard package equipped with BIGT and SPT+ dies vs. SiC carbide diode contribution to an IGBT module (top: inverter mode, bottom: rectifier mode)

Figure 4: **Sea cable for an HVDC Light™ system is laid out for connection of an off-shore wind park to the main land grid**

losses and costs can be largely reduced by the use of HVDC transmission techniques, which is especially apparent for off-shore wind parks where power in the range of 300 - 500MW will be transmitted through the sea to sub-stations on land. The HVDC Light™ system (Figure 4) is based on IGBT technology with a special design that ensures that the module remains shorted in case of a failure enabling a continuation of operation if redundancy is built into the system. Starting at the tender power level of 3MW back in 1997 these systems has gradually grown larger and it is a mere question of time until voltage source converter based HVDC-systems with the use of the latest power semiconductor technologies will brake the GW-barrier.

Small scale renewable energy with a large number of units spread over a large area also create issues for the grid stability which can be solved with different measures normally referred to as smart grids. Although power electronics will play an important part in these systems, we leave them out of the discussion here since they are not directly connected to efficiency of renewable energy sources.

Conclusions

Renewable energy sources as wind turbines and photo-voltaic cells have grown rapidly in size and power in recent years. The requirements on them for network compatibility have also increased since their impact on the grid is far from negligible. Due to a steady development on the high power semiconductor side, devices are available to meet the requirements on controllability and efficiency and new devices and device materials are on the way enabling further improvements. To utilize the possibilities to their optimum the device choice should only be made when the requirements and operating conditions for the high power semiconductors are known. To use a device just because it is popular among other users may not mean that it is the best choice for every case since the best device is determined by the particular circumstances for the actual project.

Literature

Björn Backlund: "Comparison of High Power Semiconductor Technologies for Renewable Energy Sources", PEE Special Session "Power Electronics for Efficient Inverters in Renewable Energy Applications", PCIM Europe 2010, May 4, Room Paris

New Design Proposals for High-Power Renewable Energy Applications

Renewable energy applications are a great challenge for Power Electronics, with efficiency and reliability being the prevailing requirements. Today, 1700V low-voltage Silicon is vastly superior. For input/output powers of several MW, dozens of modules with dozens of chips need to be connected in parallel. The best solution is paralleling inverters / power blocks, but such solutions require additional low-voltage transmission from the source to the medium-voltage (MV) transformer. An alternative solution is a MV source and transmission connected to MV grid-side inverter based on low-voltage Silicon - power blocks - connected in series. In addition, interleaved PWM reduces the size of the sinusoidal filter and the switching frequency, as well as the total losses. **Dejan Schreiber, Senior Application Manager, Semikron, Nuremberg, Germany**

Existing new high-power renewable energy sources are wind turbines (WT) and photovoltaic (PV) applications. The average power of new WTs is over 2MW, but up to 5MW are also in use. As for PV, over the last few years, the trend has been to use individual units of up to 0.5MW, with an increasing tendency towards 1MW+ per unit. Large PV systems of 10MW are the most common and up to 60MW are in operation. Both are connected to the grid through line-side inverters, and both supply the grid with low THD (total harmonic distortion) sinusoidal currents via sinusoidal filters.

WTs have generator-side converters with boost features, rectifying the variable generator voltage to constant DC voltage required for optimal operation of the grid-side converter. Similarly, PV panels supply converters with voltage proportional to sunlight intensity, ambient temperature, load current, and power. The result is a variable input voltage in the range of more than 1:2. Typically high-power PV grid-side inverters do not use additional front-end converters.

Power converting efficiency is the No.1 priority. Today, power electronics (PE) uses industrial Silicon-based components of 1200V and 1700V for WTs and 1200V for PV applications (600V for low-power single-phase supply). The system efficiency can be improved with reduced converter losses by using the right Silicon and new better semiconductors technologies. This article shall not, however, dwell on this for the simple reason that IGBT's will remain the work horse of power electronics for the next 5 to 10 years, with no notable changes to speak of.

WT designs based on a doubly fed induction generator (DFIG) are going out of fashion. In fact, WT companies that employ DFIG technology are now basing their new developments on the full-size principle, the traditional 4-quadrant drive. WT converter efficiency today, for a full-size construction with two serial power electronics converters placed in one casing, and measured from the generator output through generator dv/dt filter, generator-side converter, DC link, grid-side inverter and output sinusoidal filter, is in the range of 96-97%. Power converter sizing is driven by price and high reliability requirements.

Reliability is a very important factor. A wind turbine must not stop working, must not stop turning! First-rate components are therefore an absolute must. What is also important, however, is to have a turbine design which enables continued operation should an individual component fail. The large inverter powers in the range of several MVA require considerable quantities of semiconductor chips in parallel, and this is accomplished by paralleling modules.

Solutions for parallel operation of IGBT modules

1) One inverter phase unit is used for the entire power with one driver for many

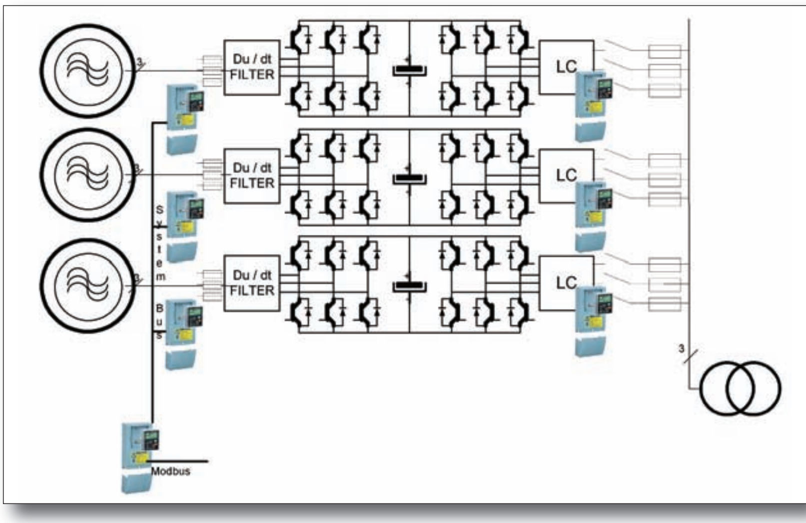


Figure 1: Turbine construction with three generator windings and independent drive trains

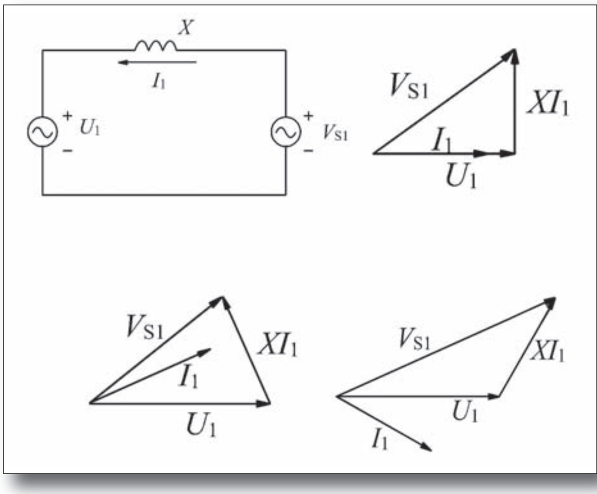


Figure 2: **Per phase equivalent circuit of the line-side inverter and phasor diagrams for unity, leading, and lagging power factor operation**

IGBT modules in parallel. Each IGBT module has its own gate resistors and symmetrical DC & AC connections. One successful example is SEMIKUBE IGBT power STACK, for use in PV applications.

2) Paralleling of several inverter-phase units, each with own driver operating in parallel. Due to different driver delay times, small AC output chokes are also required (paralleling of SKiiP IPM power stack).
3) Paralleling of three-phase units with a DC link and several modules in parallel, driven by its own drivers. For higher power, several three-phase inverters are connected in parallel. Due to different driver delay times, AC output chokes are still needed. One PWM signal and one DC link are in use.
4) Parallel operation of three-phase inverters with one PWM controller and additional control of load current sharing of parallelized inverters (sophisticated PWM control).
5) Master-slave drivers with short delay times, driving the several modules connected in parallel. There is no need for any additional inductances, and in the event of damage to a semiconductor chip, only one module will be damaged.
6) Parallel inverter operation with galvanic isolation on input or output side - is the operation in parallel of standard, independent basic units with different PWM and separate controllers.

In some WT designs, the generator and the entire drive train, as well as the MV transformer, are placed in the nacelle. In these cases, the total weight of the nacelle is very high, but it's the only way to make the transmission losses between the LV generator and the MV grid bearable. In other designs, the WT drive train is located at the bottom, at the base of the tower. Power transmission over that distance of about 100m is low-voltage, with high power losses and cost.

Standard industrial Silicon-based IGBT modules of 1700V have to be used in parallel for one three-phase inverter of 1MW; the maximum available power of a single three-phase inverter today is 1.5MW. Therefore, solutions with several generator windings facilitate parallelization of independent drive trains. At the same time, the reliability of this design is higher than that of designs with one high-power converter with the same number of modules connected in parallel (see Figure 1).

WT generators

Generator requirements such as minimum size, ripple torque, and short circuit torque, especially for low-speed, direct-drive generators, result in generator solutions with a number of phases, such as 2 or 3 x three-phase windings, or 6 x three-phase windings. Generators with poly-phase systems of 5 or 7 or more phases are not used, because of standard industrial three-phase inverters and controllers. For generator sizes in the range of several MW, the traditional method is a medium-voltage output. MV inputs & outputs, however, require the use of MV PE components. State-of-the-art MV converters used on the grid side, with switching frequencies of several kHz, have a much lower efficiency and are far more expensive per kW.

Additional requirements for renewable energy sources are: active power control, reactive power control, low-voltage ride-through capability, as well as a requirement mentioned less often, namely operation under unsymmetrical grid voltages. Reactive power control for renewable energy sources, initially used in WTs, and more recently for PV applications, calls for higher DC link voltage input to the line-side inverter.

Power flow in the PWM converter is controlled by adjusting the phase shift angle δ between the source voltage U1 and the respective converter reflected input voltage Vs1.

When U1 leads Vs1 the real power flows from the AC source into the converter. Conversely, if U1 lags, Vs1 power flows from the converter's DC side into the AC source. The real power transferred is given by equation 1:

$$P = \frac{U_1 V_{s1}}{X_1}\sin(\delta)$$

The AC power factor is adjusted by controlling the amplitude of Vs1. The per phase equivalent circuit and phase diagrams of the leading, lagging and unity power factor operation is shown in Fig.2. The phasor diagram shows that to achieve a unity power factor, Vs1 has to be according to equation 2

$$V_{s1} = \sqrt{U_1^{\,2} + (X_1 I_1)^2}$$

Proposal for series connection of high power WT inverter cells

WT designs with full size converters based on separate generator windings have many advantages, but also one large drawback. Many cables are required between the generator and the converter - 3 x three-phase winding set. All of these converters are therefore situated near the generator, in the nacelle. For high powers at low voltages, the generator currents are >> 1500A. An attractive solution is the MV synchronous generator and only a diode rectifier. However, in this case, the DC

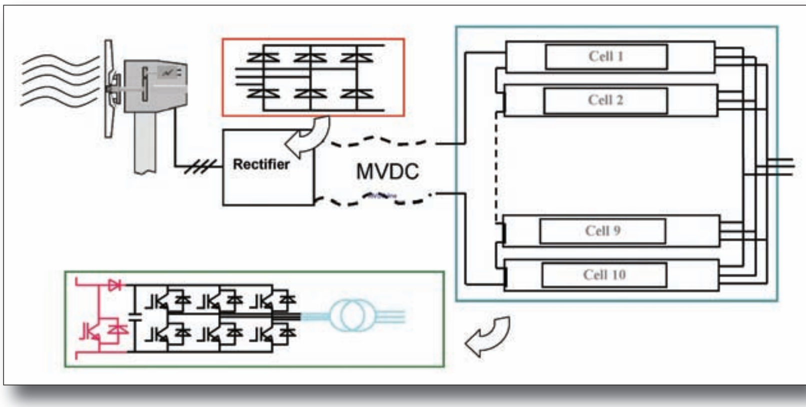


Figure 3: **MV generator with MV grid-side inverter with several cells connected in series**

voltage variations are large (1:2) and require MV Silicon devices. As the WT is supposed to produce power even at minimal rotation speed and a minimal DC voltage, for instance for 1000VDC, the output voltage at the MV transformer is relatively low, i.e. 660V. At the same time, DC voltage may reach more than 2kV.

A logical solution to the MV grid-side inverter is a string of series connected inverters, which can divide the variable rectified generator voltage. These grid-side inverter cells are connected to the primary windings of the MV line transformer, and independently maintain their DC link voltages. For lower generator voltages, some of the cells must be bypassed, so that the equivalent total voltage of the cells is lower and corresponds to the generator voltage. The WT torque requirement is the same as the generator current requirement; it is therefore compared with the real, actual value of the DC current. If the torque demand is higher than the actual current DC value, the sum of bypass times should be larger, more cells are bypassed and the equivalent counter-EMF will be lower, thus increasing DC current.

Each of the grid-side inverters used controls and maintains constant input DC voltage, for instance 1000V, and is connected to the primary winding of the transformer. If the DC voltage is higher than a set value, the discharge currents will be larger. The grid-side inverters can be single- or three-phase units. Single-phase units have only one transformer winding. The rectified generator MV, for instance a dozen kV, supplies this string of inverter cells. Some cells have input bypass switches which allow for DC link control, and some cells can have no input bypass. They are always connected in series and the sum of their voltages corresponds to the minimum generator voltage.

Described below is a power conversion scheme for MW-class wind turbines consisting of a medium-voltage synchronous generator, a diode rectifier in the nacelle, and an MV DC-efficient power transmission down to the MV line-side inverter and the high-voltage grid transformer (see Figure 3). Several cells that share the variable output generator voltage are also used. Each cell has a grid-side inverter, three-phase or single-phase, separate transformer windings and DC link capacitors. The input power - the current from the MV generator - charges the DC link, and the converter discharges it. This is why the DC link voltage remains constant, because the grid-tie inverter controls the DC discharge current to the grid. The cell input features one half-bridge configuration, for instance a conventional booster; this operates, however, as a bypass switch only.

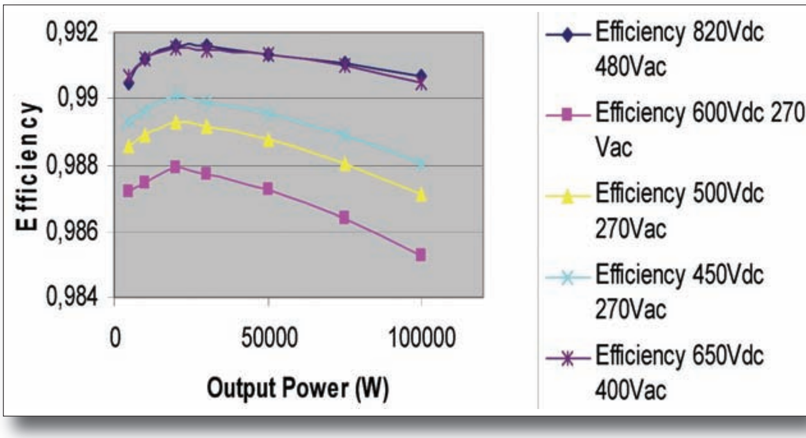


Figure 4: GTI (grid-tied inverter) efficiency at various power; switching frequency 5kHz

If the generator voltage is lower than the sum of the series connected cells, the current from the generator will decline. More cells therefore have to be bypassed, reducing the number of series cells and increasing the generator current.

PV applications

PV applications usually have only one PE line-side grid-tie inverter (GTI). GTI AC output voltage is proportional to the minimum DC input voltage - the start-up PV voltage proportional to the minimum sunlight. If the chosen AC output voltage is lower, the currents for the rated power will be higher; at the same time, however, the start-up voltage will be lower. The AC output voltage is therefore a compromise: some products use 3 x 270V, while others use 3 x 328 V.

The higher AC output voltage design neglects the minimum energy that could be used if the PV voltage / output AC voltage is lower. In a PV application, GTI operate at approximately 1/2 of the rated output voltage only; 1200V silicon is developed for input/output voltage of up to 480VAC, and PV applications today use just 270V...330V. The efficiency of such operation is lower, because it is strongly related to the modulation factor m, VAC/VDC ratio. For 400VAC/650VDC or 480VAC/800VDC, the efficiency is very similar and higher than the ratio used in PV applications of 270VAC (500...900VDC) (see Figure 4).

Described below is a power conversion scheme (Figure 5) for MW-class PV consisting of solar panels, an active front-end with symmetrical voltage boosters next to the solar panels, a DC transmission line to the inverter station, industrial grid-side converter, sinusoidal filter, and standard line voltage / MV transformer.

Inverter input voltage is optimized to the AC transformer input voltage, and the modulation factor m is close to 1 according to equation 3:

$$m = 2\cdot\frac{\sqrt{3}}{3}\cdot\sqrt{2}\cdot\frac{Uac}{Vdc}$$

Sample application from the USA: Circuit from Figure 5 PV voltage is in the range of 200V-600V; booster output voltage / transmission voltage is 800VDC; output: 3x480V, a standard transformer is in use. 600V Silicon is used for the front end, and 1200V for the inverter. For a PV voltage of 400V, for example, the DC transmission losses are four times lower, while the transmission voltage is 800V. The requirement is to have a relatively low ripple current from PV panels, and this can be achieved with higher inductance between the PV panels and the front-end unit, but also with increased switching frequency. The inductance of the

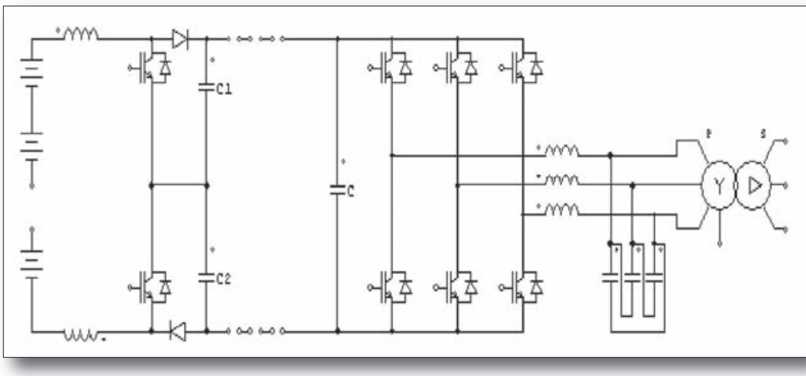


Figure 5: Voltage booster and GTI

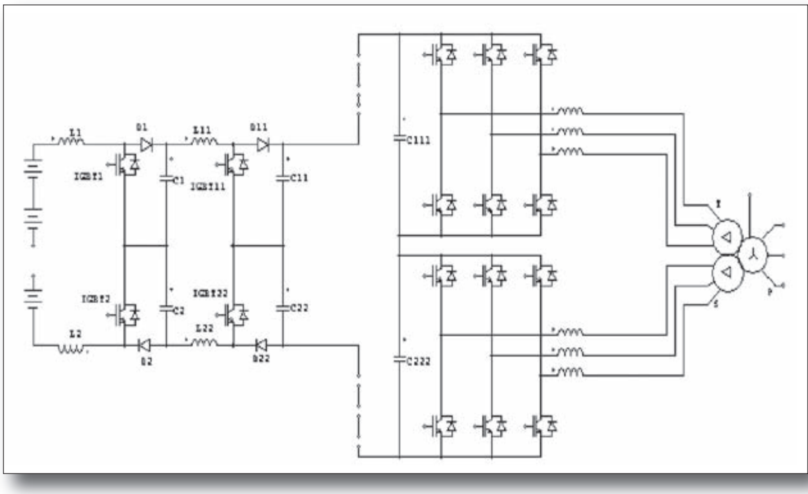


Figure 6: Voltage duplicator, second bypass or booster, two GTI with interleaved PWM

connection cables have a positive influence on the reduction of the current ripple. A 100m long cable has an inductance of more than 0.1mH.

Sample application from the EU: For a PV in the 400-900V range, the front booster will produce 650V for 3 x 400V, or 800V for 3 x 480V. If the PV voltage is higher than 650V or 800V, the booster function is turned off and the PV voltage goes to the GTI unaltered.

The front-end booster alternately supplies the upper and lower half of the output voltage, and when the top IGBT1 and the bottom IGBT2 are turned-on for half of the switching period, i.e. 180° electrics, it operates as a voltage duplicator. This method of operation has great advantages because the output current of the PV panel is constant and does not use additional high inductance L1 and L2. A connection cable length of 50-100m is sufficient. The scheme presented in Figure 6 is used because of this advantage.

The PV voltage is always doubled, i.e. it is in the range of 800V...1800V. As 1800V is too high for the low-voltage silicon used in the GTI, we can use the same idea as for MV wind turbines with two cells in series. The cell bypass circuit can be mounted near to the voltage duplicator and it can adjust the necessary DC voltage for two inverters in series. That way, the transmission voltage will be up to 4 times higher than the PV output voltage.

Example 1: PV voltage 400V...900V; duplicator voltage 800...1800V; second booster output voltage/transmission voltage/inverter voltage: 1600V...1800V, without boosting effect after 1600V, for the transformer 2 x 3 x 480V. All switches in use are for 1200V.

Example 2: PV voltage: 400...900V, duplicator voltage 800...1800V; second booster output voltage/transmission voltage/inverter voltage: 2200V=2x1100V, for the transformer 2 x 3x690V. Voltage duplicating silicon is for 1200V, and the remaining IGBTs & diodes are for 1700V. The inverter efficiency with 1700V silicon is higher than that for 1200V, if the carrier switching frequency is lower than 4kHz.

For a 2200V transmission voltage, the transmission losses are 16 times lower than the losses of a classic, direct connection and a PV voltage of 550V (using the same connection cables).

The grid-side inverters, top and bottom side, have the same power and phase current values, and are connected to windings with galvanic insulation. Interleaving PWM can therefore be easily applied. For two inverters operating in parallel, the interleaved phase shifting is half of the switching period (i.e 180° el). In this way, the size of the sinusoidal filter, with only one inductance L, is significantly reduced. The simulation example in Figure 7 shows inverter 1 and 2 currents, with a carrier switching frequency of 1kHz only and THD=19%, as well as the sum of these currents - the grid current, with very low THD=3.8%.

The advantage of interleaving is clear. Only a low-pass filter with a single inductance, plus stray transformer inductance, corresponding to the short circuit transformer voltage u_k=4%. L_total=12% is used. For a current THD below 4%, one grid-tie inverter with 12% inductance of the sinusoidal output filter needs a carrier switching frequency of more then 6 kHz.

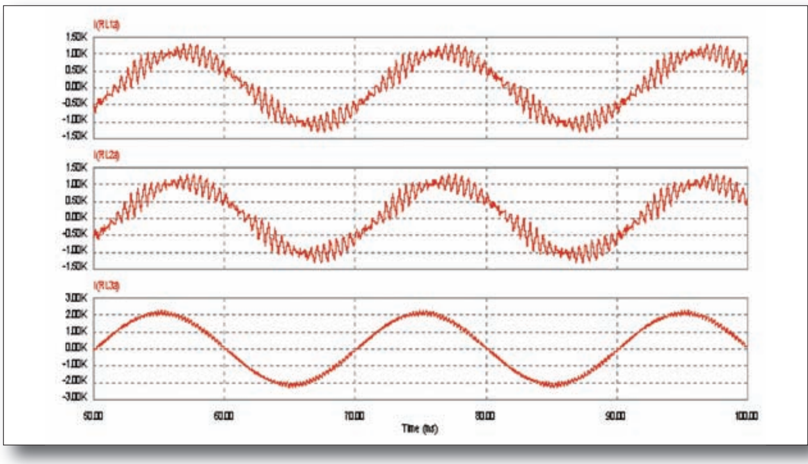


Figure 7: Top-side inverter phase current; bottom-side inverter phase current, both with THD=19% and the grid current, with THD=3.8%; Filter inductance L_total=12%; F_{sw}=1kHz

Conclusions

WT power electronics are based exclusively on 1700V silicon IGBT & diodes. DFIG-WTs are becoming less popular, with current trends moving towards full-size configurations featuring two inverters connected back-to-back. WTs in development have powers in the range of 3-5 MW. The principle with 2, 3 and even 6 three-phase generator windings, using the same number of independent drive trains, with independent control, provides high modular power, as well as a redundant operation in case of a failure. The new design proposal for the WT is a MV generator with MV line-side inverter featuring a string of cells with bypass circuits and LV GTIs connected to independent MV transformer windings.

PV applications are based on GTIs of up to 1MW of power, connected directly to the PV panels. For PV applications, the proposal aims for higher system efficiency, i.e. consists of a voltage duplicator and two cells in series, with 4 times higher transmission voltage and inverter operation with modulation factor 1, using interleaving in PWM control, to significantly reduce the output filter.

Literature

Dejan Schreiber: "High-Power Renewable Energy Applications - State-of-the-Art & New Design Proposals", PEE Special Session "Power Electronics for Efficient Inverters in Renewable Energy Applications", PCIM Europe 2010, May 4, Room Paris

GaN Power Devices for Micro Inverters

GaN power products are set to have a direct impact on future efficient PV solar inverter/converters. By reducing losses in each stage of the power conversion, GaN based devices will help in increasing total energy harvesting. The integration with driver ICs and other components will drive the size reduction and high volume commerzialisation. **Alberto Guerra and Jason Zhang, International Rectifier, El Segundo, USA**

The PV industry has shown various trends for increasing overall conversion efficiency as well as maximizing the harvesting of solar energy. The specific trend toward an intelligent PV panel requires high efficiency, high reliability and low cost. "In-situ" conversion and "in-situ" pre-regulation with micro-inverters/converters require highly efficient DC/DC stage.

All topologies based on Silicon MOSFETs have intrinsically limited improvement capabilities. Based on state-of-the-art active components and passive components, constrained integration opportunities pose a limit to the technology evolution. Gallium Nitride (GaN) based switches, have a better figure of merit (FOM) than other power components based on Si (Silicon) or SiC (Silicon Carbide) material (Figure 1).

The potential improvement exploitable from the GaN technology is large, based on the material limits. The primary conversion stage of micro-inverters and micro-converters can be designed around well known topologies (Fly-Back, Full Bridge or Buck-Boost). To improve overall conversion efficiency, all these topologies require the power MOSFETs with the lowest possible specific R_{ON} x Q_G FOM. GaN based MOSFETs show great potential in FOM improvement over the coming years (Figure 2).

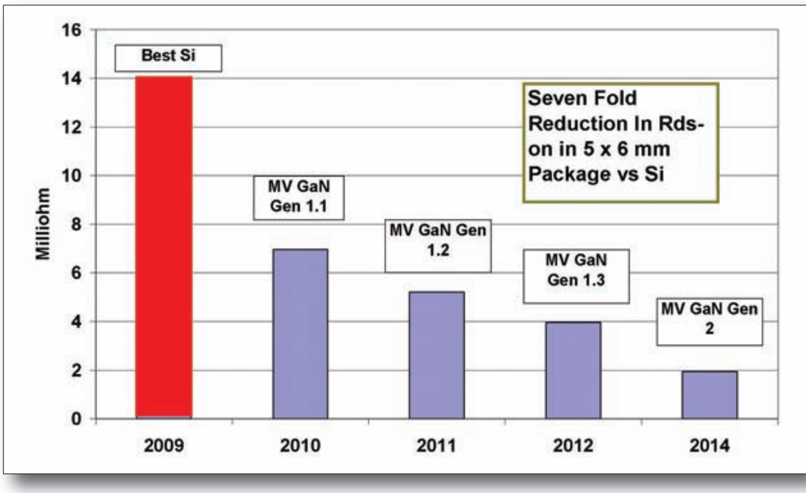


Figure 2: Possible 150V GaN FOM projection vs. Si MOSFET

Practical impact of GaN technology in PV applications

GaN technology is characterized by an intrinsic lateral structure, which simplifies packaging by virtually eliminating parasitic elements of wire-bonding stray inductance and parasitic resistance. Moreover, it enables possible integration of multiple switches and driver IC function with protection and monitoring elements within common packaging or monolithic solutions. The integration capabilities of GaN technology can simplify and reduce the cost of design and construction of power circuits for solar inverter applications.

The expansion of small and mid-size solar installation is opening new alternative venues diverging from the traditional central inverter architecture. Adopting a distributed inverter architecture, micro-inverters or dc-dc solutions, certain advantages over the traditional centralized architecture, are made possible and, among them, the ability to implement maximum power point tracking (MPPT) at the panel level. In addition, these distributed solutions are required to process only the power generated by a single PV panel, typically in the range of 200W; this specific characteristic is opening the possibility for higher degree of power semiconductor integration that in

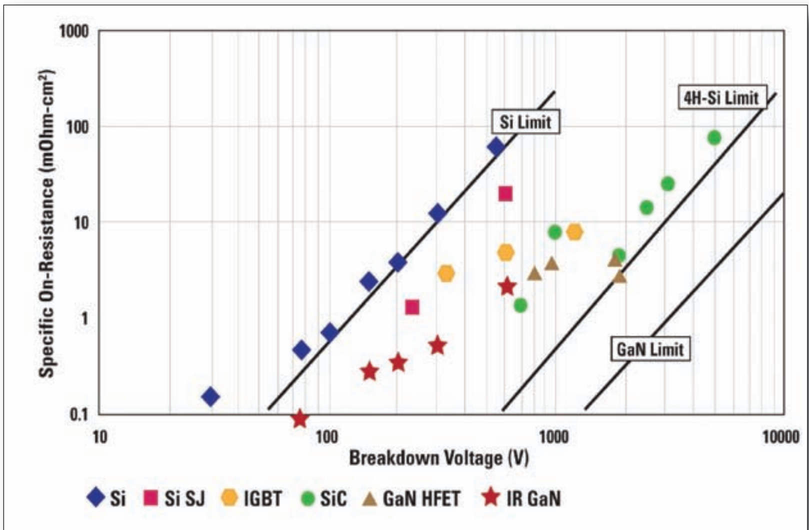


Figure 1: Comparison of Specific R_{ON} for Si, SiC and GaN.

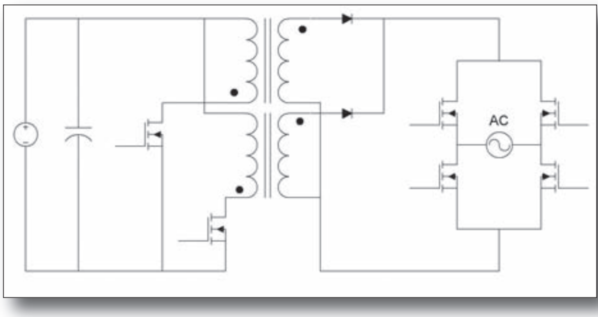


Figure 3: Micro-Inverter simplified schematic

optimal than tracking done at the level of a centralized inverter allowing it to better follow changes in sun irradiance due to environmental factors or weather factors.

Further examples are presented to illustrate the future improvement achievable by applying the GaN technology, in this case high-voltage applications, in centralized inverters with transformer-less advanced topologies.

return is going to drive the unit cost down.

A similar trend in power semiconductor integration occurred in the appliance industry a few years ago. More environmentally friendly government energy saving regulation has driven manufacturers of motor drivers and power semiconductors alike, to develop and adopt advanced system integration solutions that have radically reduced the number of components, increased reliability and dramatically reduced costs delivering on the energy savings targets.

In this article we analyze the practical impact of IR GaN technology, when applied to the primary stage of a 200W micro-inverter module and when used in the buck-boost circuit of a power-optimizer DC/DC module, replacing traditional power MOSFET switches. The 200W micro-inverter (DC/AC) used for the comparison and GaN switch evaluation is manufactured by Enphase Energy, while the DC/DC Power Optimizer utilized for the buck-boost topology evaluation, is manufactured by SolarEdge. Both systems, intended for "in-situ" single PV panel connection, have the MPPT (maximum power point tracking) function performed for each panel. Module-level MPPT is generally considered to be faster and more

150V GaN in Flyback converter

Enphase is the leading micro-inverter supplier. Its inverter module is mounted on the back of each solar panel, and its AC output can be directly connected to the AC wiring at any household. This eliminates the high voltage DC wiring, and enables a safe and simple installation.

The simplified circuit diagram of the micro-inverter is shown in Figure 3. An interleaved two-phase Flyback converter is

	Rdson	Qoss	Qgd	Qg	Qrr	BV
IRFS4321	12mΩ	36nC	16nC	71nC	150nC	150V
GaN MV05	5mΩ	55nC	8nC	22nC	5nC	150V
GaN Gen1.1	5mΩ	35nC	5nC	15nC	3nC	150V

Table 1: Si Power MOSFET and GaN switch comparison

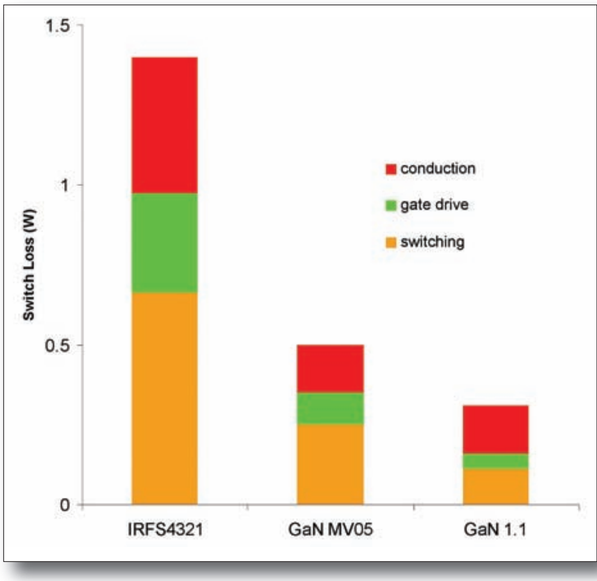


Figure 4: Primary switch power loss breakdown at 170W

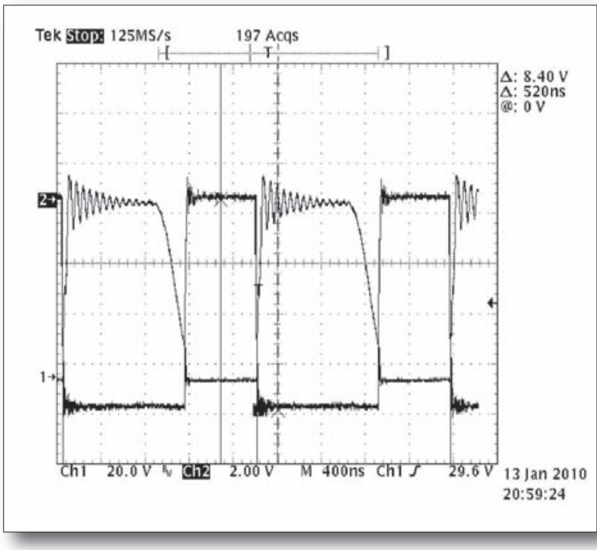


Figure 5: GaN switching waveforms (V_{ds} and V_{gs})

followed by an inverter bridge. The performance is compared by replacing the primary switches with GaN devices. Table 1 compares the parameteric differences between Silicon and GaN switches. GaN MV05 is the sample that is used in this study. GaN Gen1.1 represents GaN device that would be made available later this year. It is obvious that GaN has a significant FOM advantage over Silicon at 150V, which translates into major $R_{ds(on)}$ and Q_g reduction with smaller die size.

The IRF4321 is a D2Pak power MOSFET while the GaN switches are smaller enough to be housed in a much smaller PQFN package (5mm x 6mm). PCB layout was not fully optimized to take advantage of the smaller footprint but simply for a fast drop-in replacement.

A power loss modeling is performed to understand the loss breakdown and explain the performance. Shown in Figure 4, significant power loss reduction of the switch has been predicted from the simulation due to fast switching, low $R_{ds(on)}$ and reduced package parasitic. As illustrated in Figures 5 and 6, much cleaner switching waveforms have been observed in the circuit, even when GaN switches faster. This is contributed by the lateral nature of GaN power device and how it is packaged. Also thermal pictures were taken. At 160W, GaN is slightly warmer (64°C vs. 57°C) even with reduced power loss. This is due to much smaller package size of PQFN comparing to D_Pak.

The measured efficiency (with constant DC voltage of 300V feeding the second stage H-Bridge), is shown in Figure 7. Due to other losses in the circuit, the power loss reduction due to the primary switch is translated into 0.6% efficiency improvement at the system level. With the optimized Gen1.1, power loss will be reduced by another 20% for the switch, which will reduce the temperature rise of 5mm x 6mm PQFN package.

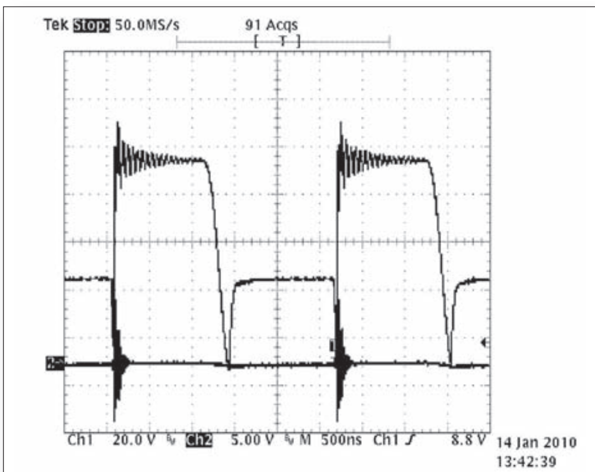


Figure 6: D²Pak MOSFET waveforms (V_{ds} and V_{gs})

150V GaN power optimizer DC/DC stage

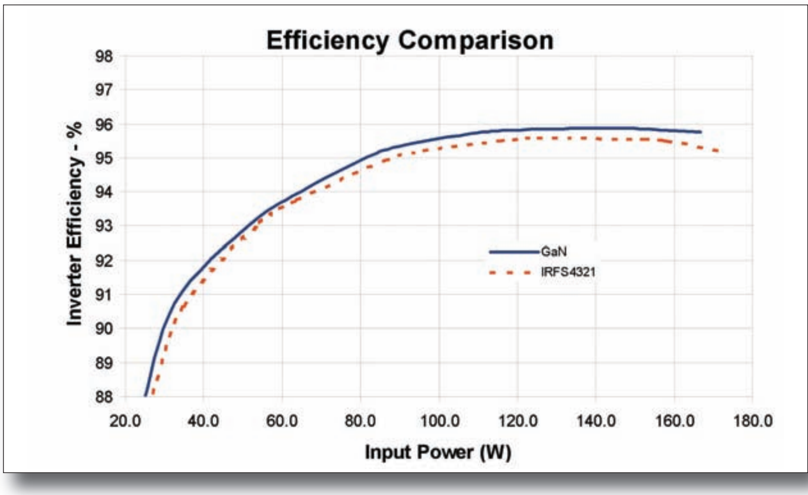
SolarEdge, another leader with innovative solutions for PV solar power management, offers a different architecture. Its DC/DC Optimizer module is mounted on each solar panel with local MPPT, and the output of multiple panels will be connected in series. The resulting high-voltage DC bus is distributed to a central inverter (without MPPT internal stage), which feeds AC power into the grid. This implementation also simplifies installation and provides excellent overall efficiency and performance. The Power Optimizer is designed to work with a standard Silicon based PV panel as well as a Thin Films PV panel. The example analyzed in this case is for Si-based PV panels with average output voltage of 40V.

Buck-boost topology (Figure 8) is used in each DC/DC converter module, which has the ability to regulate its output voltage above or below the panel voltage. The comparison study was done through simulation. All four switches are replaced with mid voltage GaN devices.

Table 2 compares the parametric differences between a Silicon MOSFET and a GaN switch. GaN MV05 is the sample that is used in this study. Even with 50V voltage rating difference, GaN still offers significant $R_{ds(on)}$ reduction with smaller die size. GaN Gen1.1 represents a 100V GaN device that would be released later this year.

The overall efficiency of the power stage of the power optimizer module, based on

Figure 7: Single phase efficiency comparison at constant DC bus voltage of 300V



the sun irradiation model has been simulated and shown in Figure 9. With the improved switches, the power loss is reduced almost by half, and DC/DC converter efficiency is approaching 99% due to significantly reduced gate charge and $R_{ds(on)}$ and the lack of body diode reverse recovery loss.

The centralized inverter (without MPPT functionality) adds 1.5 to 2% efficiency loss in the final conversion process of feeding the electric power into the AC grid, with an estimated total conversion efficiency ≥ 97.5%. GaN HV MOSFETs, can provide further efficiency improvement to the system string inverter as well as to the micro-inverter H-bridge.

GaN switch in transformer-less topologies

Recent studies have demonstrated the possibility to achieve ~99% peak efficiency in transformer-less PV inverter designs when specific topologies like Heric, H5 or 3-level half bridge and SiC JFETs are employed. When traditional Silicon IGBTs and/or Super Junction HV FET are used, the peak efficiency can reach ~98%.

Prototypes of HV GaN MOSFET (75mΩ/650V) in a TO-220 package (Cascode configurations) were tested in switching mode to compare turn-on and turn-off performance vs. traditional Trench IGBT and Super Junction HV FET. The reverse recovery time of the GaN MOSFET body diode is less than 19ns and the turn-off energy 24µJ (E_{off} SJ = 38µJ, Trench IGBT = 830µJ).

Compared to the Super Junction and IGBT technology, the recovery time was 270ns and 140ns (with recovery current of 38A and 13A). In PV inverters efficiency is no longer the problem to solve; however the cost to achieve it is the problem. Because the GaN Epi is grown on Si substrates, large diameters (6 to 12") are readily available in large quantities at low cost ~ $ 0.50/cm². SiC JFETs, used to demonstrate >98% efficiency in traditional string inverters, are available only in smaller 4" substrates (projected at 6" in 2013), which has a cost of ~20$/cm².

	Rdson	Qoss	Qgd	Qg	Qrr	BV
IRF6644	10.3mΩ	34nC	11.5nC	35nC	69nC	100V
GaN MV05	5mΩ	55nC	8nC	22nC	5nC	150V
GaN Gen1.1	5mΩ	25nC	4nC	10nC	2nC	100V

Table 2: Parametric differences between a Silicon MOSFET and a GaN switch

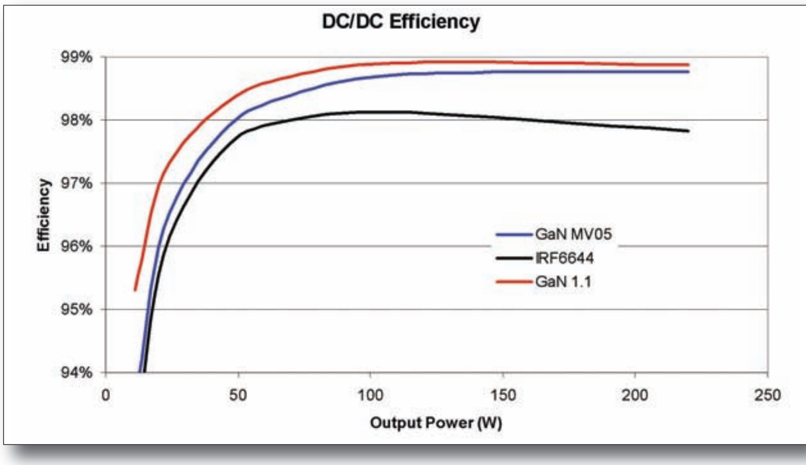


Figure 9: Buck-boost efficiency at 40Vin

GaN on Si substrate is compatible with established high volume manufacturing facilities and equipment and has the potential to deliver the proper performance/cost benefit.

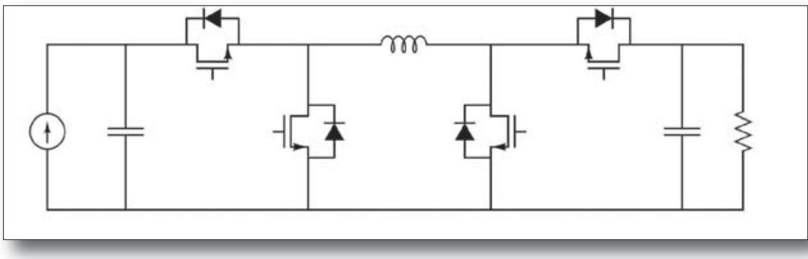
Conclusions

Improvements in total efficiency in innovative PV solar power DC/AC inverter and DC/DC converters have been demonstrated. Performance comparison of high voltage normally-off GaN FETs versus Silicon based devices has been presented. Further work is planned to evaluate final GaN product in optimized application layout as well as in the HV output stage of micro-inverter and string inverter. The possibility to operate GaN switches and diodes at higher frequency, offer the possibility to replace the large and expensive inductors used today, with smaller and hence cheaper ones. The new IR GaN technology when coupled with advanced MCM packaging technology and HV driver IC will enable designers of micro-inverters or power converters or centralized PV inverters, to design, make and market better, cheaper and more efficient products.

Literature

Alberto Guerra: "(GaN)-based power device technology and its impact on future Efficient Solar grid connected micro-inverters, power optimizers and string inverters", PEE Special Session "Power Electronics for Efficient Inverters in Renewable Energy Applications", PCIM Europe 2010, May 4, Room Paris

Figure 8: Buck-boost schematic



Transfer Mold IPM for Photovoltaic Application

A new low loss large Dual In-line Package Intelligent Power Module with rating of 50A/600V is designed for photovoltaic generation. It features a high heat dissipating insulation sheet, 5th generation CSTBT IGBTs and high output current driver IC leading to higher switching frequencies. **Ming Shang, Hirofumi Oki, Kazuhiro Kuriaki, Toru Iwagami, Toshiya Nakano, Power Device Works, Mitsubishi Electric Corporation, Fukuoka-City, Japan**

Mitsubishi Electric manufactured the Dual In-line Package Intelligent Power Module (DIPIPM™) with transfer mold structure from 1997, and since that it has been adopted as the inverter driver of appliances or industrial motors. Low loss photovoltaic large DIPIPM is (PV DIPIPM) developed in respond of the current, fast growing photovoltaic generation market (Figure 1) providing a good trade-off between efficiency and cost. Figure 2 shows a typical block diagram of a photovoltaic inverter. Here the DIPIPM is used as a DC/AC converter to convert the DC electricity to AC electricity.

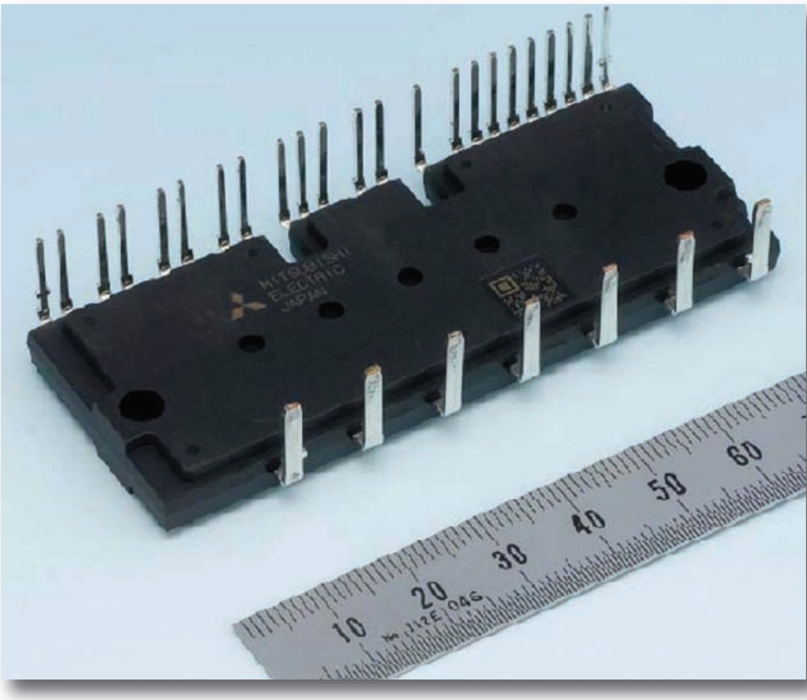


Figure 1: **Photovoltaic 50A/600V DIPIPM with package size of 79mm x 31mm**

Improved IGBT structure

PV DIPIPM adopts the Carrier Stored Trench-Gate Bipolar Transistor (CSTBT™) chip with full gate structure, in order to improve the trade-off relationship of on-state voltage and turn-off loss achieving a loss reduction of about 10% compared with conventional CSTBT (plugged cell merged CSTBT). Figure 3 shows the structure of full gate CSTBT, Figure 4 the structure of plugged cell merged CSTBT.

In a normal IGBT, the resistance of the n-drift layer has to be kept high in order to withstand the blocking voltage at off-state. As the hole injection from collector to n-drift layer at on-state, the resistance of the n-drift layer is reduced, and power loss is reduced. However, the resistance of the n-drift layer near emitter side is difficult to deduce because the hole density here becomes low due to the far away distance to the collector. Hence, it is difficult to achieve a very low on-state voltage.

CSTBT reaches a much lower on-state voltage by the virtue of optimization of the hole density in the whole n- drift layer. A special n barrier called n barred layer is designed under the P base layer to hinder the holes injected from the collector from penetrating to the emitter. This makes the further reduction of the on-state voltage possible because hole density is increased in the n-drift layer even near the emitter side. However, the major hurdle prevent full gate CSTBT from being used in our past design of DIPIPM are it's large gate input capacitance and weak short-circuit withstand ability which need a new driver IC wafer process.

In order to reduce the input capacitance, conventional CSTBT was developed to be with high current carrying capability, sometimes it is designed in a structure called

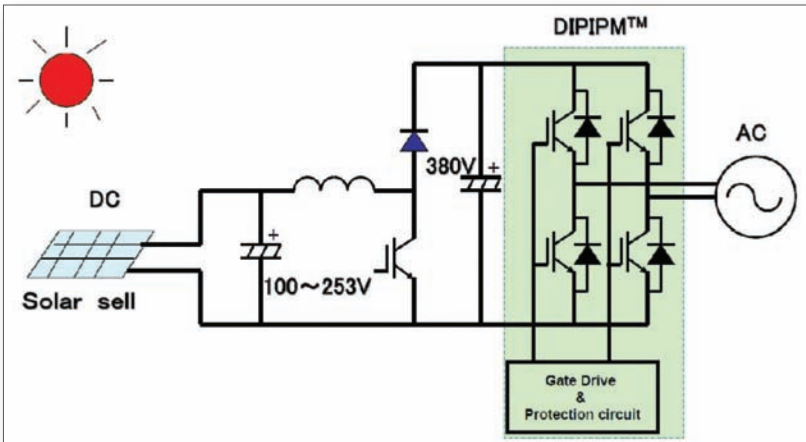


Figure 2: **Typical block diagram of photovoltaic generation system**

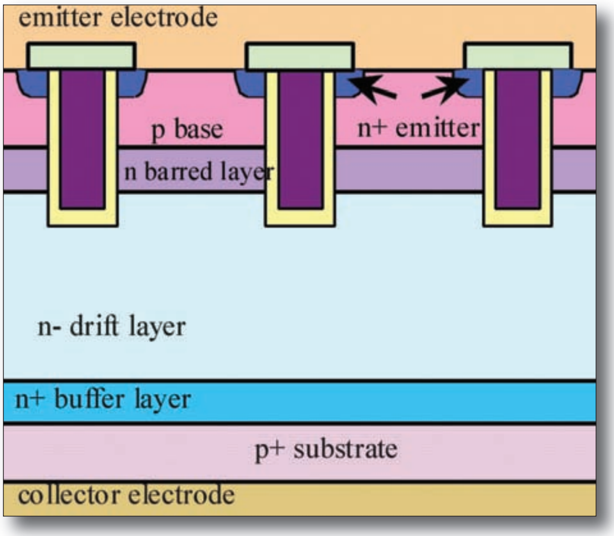


Figure 3: Structure of full gate CSTBT

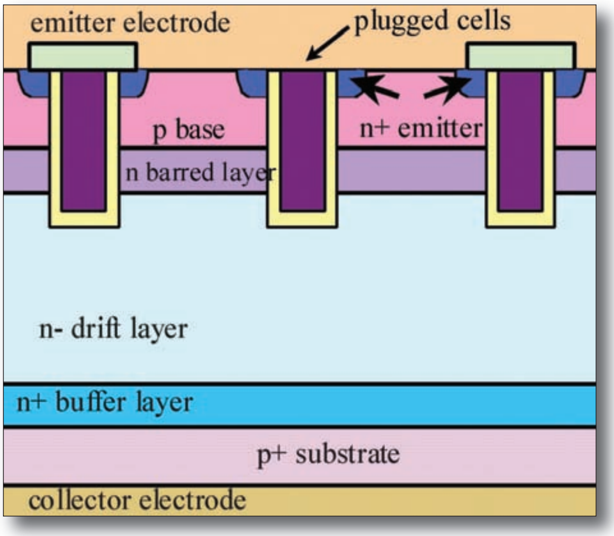


Figure 4: Structure of plugged cell merged CSTBT

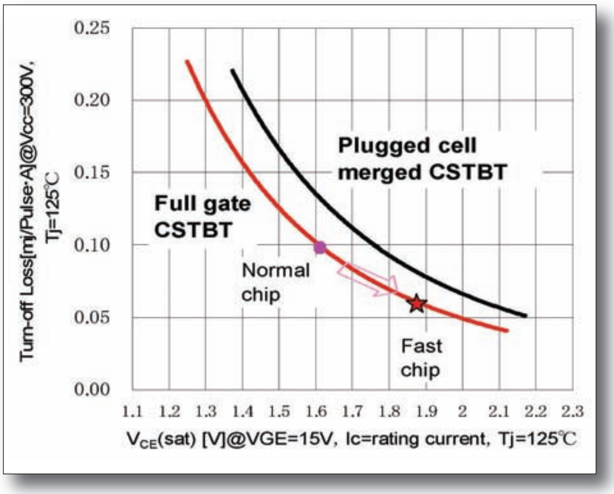


Figure 5: Trade-off characteristic of CSTBT

plugged cell merged CSTBT so as to ensure a certain withstanding capability against short circuit failure (Figure 4). With this structure the cell pitch is adjusted by "plugging" some portion of the cells in a conventional high cell density device. The polysilicon in the "plugging" cell is connected to the emitter electrode. Therefore, the CSTBT was not able to use 100% of performance in this structure.

Because the converter used for photovoltaic generation system applies fast switching, reducing the switching power loss could be a very effective way to enhance the whole system efficiency. In order to achieve an optimized trade-off relation between on-state voltage and turn-off loss, our PV DIPIPM adopted the fast full gate CSTBT chip combined with the advanced driver IC that is capable to handle higher short circuit current. Figure 5 shows the improvement of the trade-off between on-state voltage

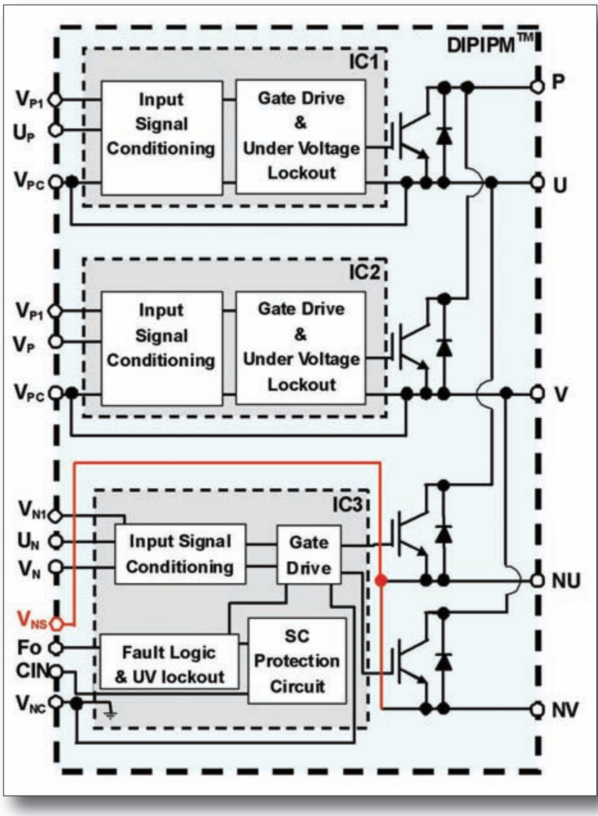


Figure 6: **Internal block diagram of Photovoltaic DIPIPM**

($V_{CE(sat)}$) and turn-off loss.

The internal IC provides optimized drive for the full gate CSTBT and realizes high function by means of the 0.5μm shrink process technology. The traditional offset structured transistor has been finely processed in the lateral direction by combining shallow junction technology which increases the output capability without enlarging the chip size. Although the full gate CSTBT needs larger drive capability than a plugging cell, the fine process technology can realize an IC with high drive capability without sacrificing chip size.

Circuit configuration and components

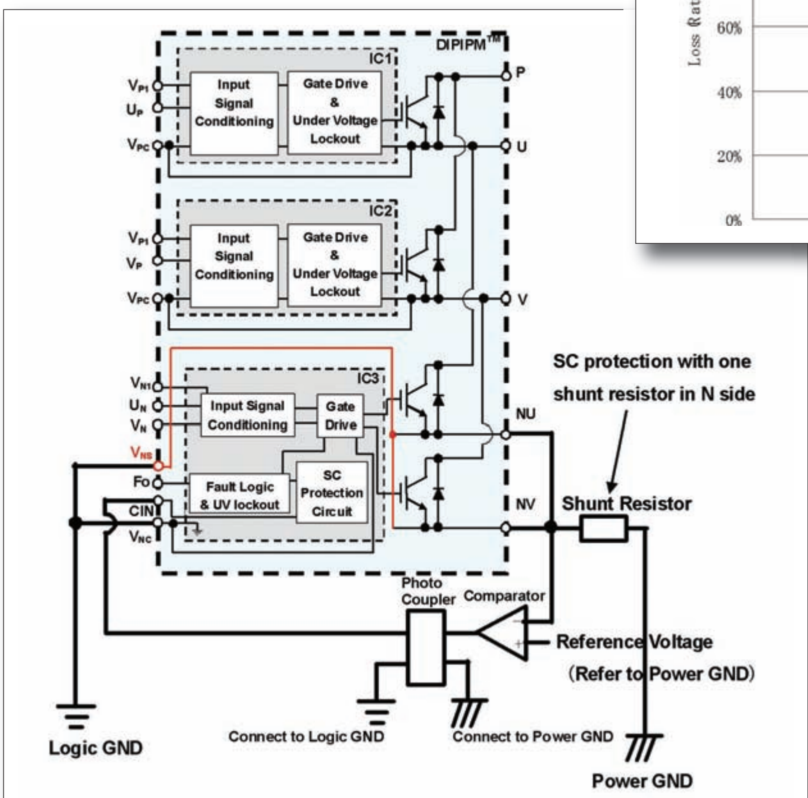
The internal circuitry of PV DIPIPM is composed of IGBTs and FWDs (Free Wheel Diode) in a two-phase inverter structure together with control ICs, which make it different from normal large DIPIPM Ver. 4. Figure 6 shows the internal block diagram of the PV DIPIPM.

Control ICs realize functions such as IGBT drive, under-voltage (UV) lockout, short circuit (SC) protection and fault signal output (FO). The output current of control IC gate driver circuit is up to 5A ensuring high speed IGBT switching.

When DIPIPM is used in fast switching mode, a balanced operation of upper and lower arm power chips is difficult to be achieved. This is because the N-side IGBT's VGE could be significantly lower than the power supply V_{N1}, due to the effect of ΔV1 (ΔV1=I_o×R), generated by the shunt resistor (R) and ΔV2 (ΔV2=di/dt*L), generated by the parasitic inductance (L) of the external circuit.

In order to minimize the side-effect of ΔV1 and ΔV2, an extra control terminal pin V_{NS} is internally connected to the emitter of N-side IGBT (as is shown in Figure 6). Meanwhile, an external opto-coupler is needed to maintain the isolation between power GND and control GND, since the short-circuit protection signal can not be taken directly by shunt resistor voltage sampling. External short-circuit protection circuit is shown in Figure 7. Experimental result has proved that switching power loss of IGBT chip was reduced 13% when compared with non-V_{NS} pin PV modules.

Figure 7: **Short circuit protection circuit of Photovoltaic DIPIPM**



Loss simulation

Figure 8 shows inverter loss simulation result imitated two phases modulation sinusoidal waveform. This fast CSTBT reduced switching power loss compared with a conventional CSTBT leads to a 20% increase in efficiency.

Conclusions

A new low loss Photovoltaic DIPIPM in a large package has been developed by applying fast full gate CSTBT and its optimized drive IC, together with the high-efficient heat dissipating insulation sheet.

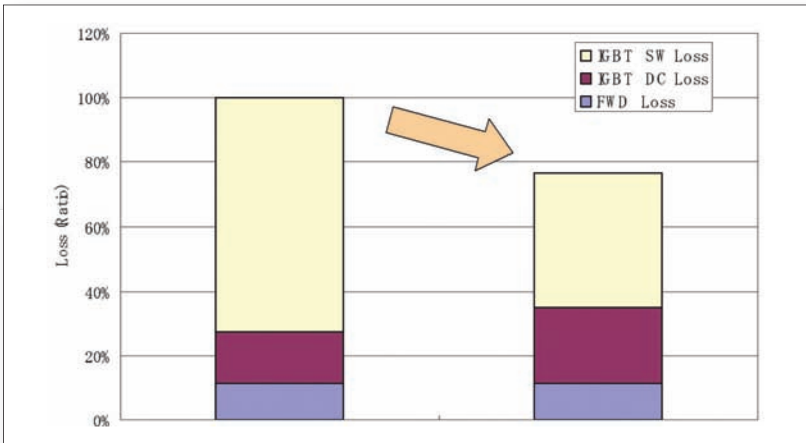


Figure 8: **Power loss comparison (Conditions: T_j=125_, V_{cc}=380V, V_D=15V, I_o=15Arms, PF=0.95, f_{sw}=15.5kHz)**

By adopting the high-speed full gate CSTBT, 10% of IGBT power loss was reduced. By changing the drive circuit of N-side IGBT, since 13% of IGBT switching loss reduction was realizable, 20% of module total loss reduction was realized.

Literature

Shang Ming: "New Low loss Transfer Mold IPM for Photovoltaic Generation", PEE Special Session "Power Electronics for Efficient Inverters in Renewable Energy Applications", PCIM Europe 2010, May 4, Room Paris

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		1200A	●	●	
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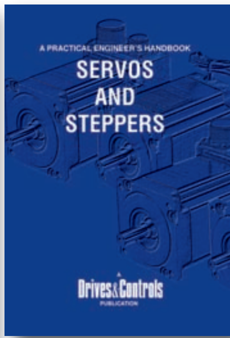

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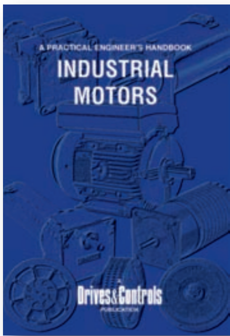

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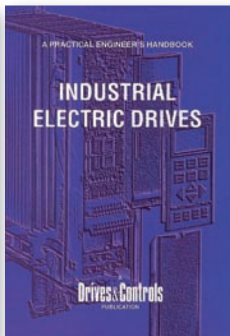

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900A Current Transducer

LEM has introduced its new ITL 900 current transducer based on a double fluxgate closed loop technology for precise measurement of DC, AC and pulsed currents up to ±900A. It provides linearity error of 3ppm over an operating temperature range of 10°C to 50°C, offset stability over four hours of less than 0.5ppm, and offset current temperature coefficient of less than 0.3ppm/K. With a wide measurement bandwidth of more than 200kHz (-3dB) fast current transients can be accurately measured. Other advantages include negligible self-magnetisation, a current overload capability, and galvanic isolation between the high-power primary circuit and the electronic secondary circuit. The ITL 900 works on an internal clock that can also be synchronised to an external clock signal, increasing immunity to periodic noise.

www.lem.com

Power Switch for Industrial Applications

STMicroelectronics has introduced an intelligent power switch (IPS) for use in industrial controls, which provides improved accuracy to minimize energy losses and prevent system errors when faults occur. This new two-channel IC in 6mm x 5mm footprint integrates all the necessary logic, driver circuitry, power stage, protection, and diagnostic functions. The chip's inputs are 3.3V TTL/CMOS compatible; its outputs are connected in the high-side configuration; and two independent resistive, inductive or capacitive loads can be driven.

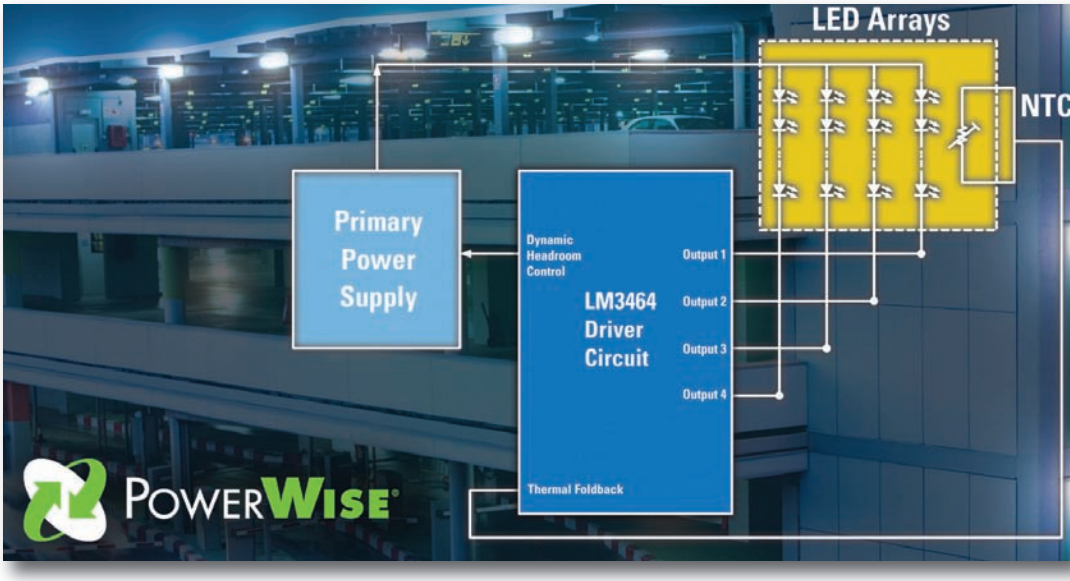
The chip's built-in shorted-load protection with independent active current limitation for each channel prevents load faults from pulling down the system power supply. If either channel becomes overloaded that channel is turned off independently while the other continues operating normally, and it is restarted automatically when the junction temperature has returned to normal. If both channels are overloaded, they are restarted non-simultaneously to avoid drawing high peak currents from the power supply. Other features helping designers to deliver rugged, highly featured solutions include protection against loss of ground, as well as diagnostics such as open-load detection in the off state. The device operates at 9V to 36V supply voltage and nominal current of 0.5A per channel.

www.st.com

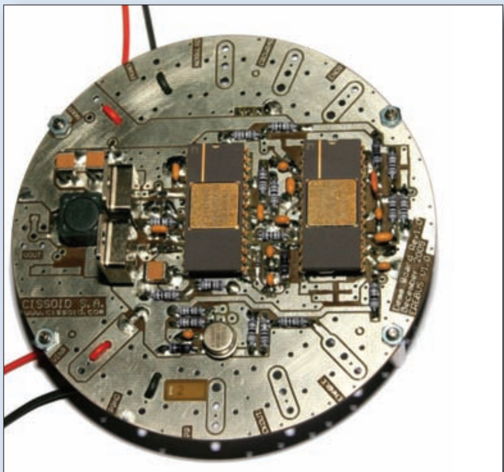
LED Driver with Dynamic Headroom Control

National Semiconductor announced a LED driver with dynamic headroom control and multiple outputs for high-power applications that drives up to four strings of LEDs. The LM3464 is a high-voltage current controller with four individual current regulator channels. It works in conjunction with external N-channel MOSFETs and sense resistors to accurately drive current to each LED string. The LM3464 features a wide input voltage range up to 80V to drive multiple LEDs per string. A thermal foldback feature protects the LEDs from unsafe temperatures that can significantly degrade the light output or lifetime of the LEDs. During an over-temperature condition, the thermal foldback reduces the current through the LEDs until the LED junction temperature of the LEDs returns back to a safe operating temperature. This user-programmable feature allows for a more robust and reliable thermal design, helping to ensure the lifetime and light output of the LEDs over time and through temperature variances due to environmental conditions of the fixture. The dynamic headroom control feature monitors the forward voltages of the LED strings and dynamically adjusts the LED supply voltage through the power supply feedback to the lowest level required. By directly controlling the output of the offline regulator, the LM3464 can eliminate the second stage switching regulator commonly required for offline LED power supplies. The device features both pulse-width modulation (PWM) and analog dimming interfaces to allow the user to select between various dimming types for different applications. The LM3464 is priced at $4.50 in 1,000-unit quantities.

www.national.com/pf/LM/LM3464.html



High Temperature DC/DC Converter Platform



CISSOID released their new EREBUS(tm) buck DC/DC converters operating from -55°C to +225°C. EREBUS can step input voltages from 12V to 50V down to an output voltage adjustable from 10% to 90% of the input. These converters demonstrate efficiencies in excess of 85% above 200°C. When configured as synchronous DC/DC converter, it operates in Continuous Current Mode (CCM) at a constant frequency, making ripple filtering easier for demanding sensor applications and uses the soft-start capability of a PWM controller to enable a smooth start-up. The input voltage feed forward compensation makes it very robust to input voltage transient variations and provides a DC line regulation better than ±1.5mV/V. The demonstration board, adjusted to a 5V output, is available in two versions, for a maximum input voltage of 40V or 50V. It can deliver up to 70W at 225°C. The boards are rated to 175°C but can sustain short excursion to 225°C. EREBUS technology can be used to build DC/DC buck converters with output voltages up to 45V and delivering up to 180W (280W for V_{in} <40V). The reference design and its active bill-of-material can be mapped onto high temperature substrates and assembled in high reliability modules.

www.cissoid.com

Higher Operating Temperatures for Bipolar Modules

IXYS announced a new package generation called Simbus A for its phase-leg rectifier module range featuring spring contacts for solder-free connection of the control board and a maximum junction temperature of 140°C. The first products are a set of three 1600V phase-leg rectifier topologies. The dual thyristor module "MCMA200P1600SA" features two thyristors of 200A rating in phase leg topology and will be followed by the dual diode version "MDMA200P1600SA" and the thyristor/diode combination "MCMA200PD1600SA" for a more flexible circuit requirement. The Simbus A also includes IXYS` Direct Copper Bonded (DCB) substrates that allow the user 4800V isolation voltage from terminals to heatsink.A common application for the Simbus A is the input bridge rectification for AC or DC motor control with 230V AC mains supply.

www.ixys.com

Ultracapacitors up to 3000 Farads

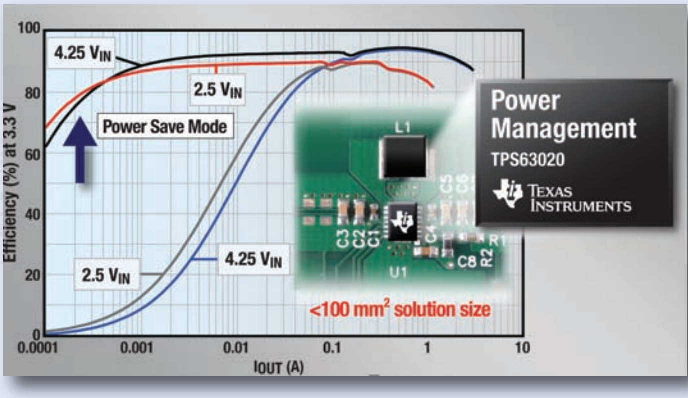
About the size of a can of soda, K2 Series BOOSTCAP® cell operates at 2.7V. Primary applications for Maxwell's products (cells range from 650 to 3,000F) include automotive subsystems, hybrid and electric vehicle drive trains, renewable energy systems, back-up power, grid stabilization, electric rail system power and many other transportation and industrial applications that require burst power and heavy cycling (which cannot be efficiently provided by a battery or power supply alone). These new ultracapacitors also work in parallel with batteries for applications that require both a constant low power discharge capability (for continual function) and a pulse power capability (for peak loads). In these applications, the ultracapacitors relieve the batteries during peak load periods. This in turn results in an extension of battery life (longer use before replacement), reduced battery maintenance requirements, and a reduction of overall battery size and cost. Individual K2 cells (in production volumes) are now available as well as multi-cell modules from Richardson Electronics with working voltage ranging from 16V to 125V.

www.rell.com/RFPD

4A Buck-Boost Converter

Texas Instruments' new TPS63020 power management IC features up to 96% efficiency.

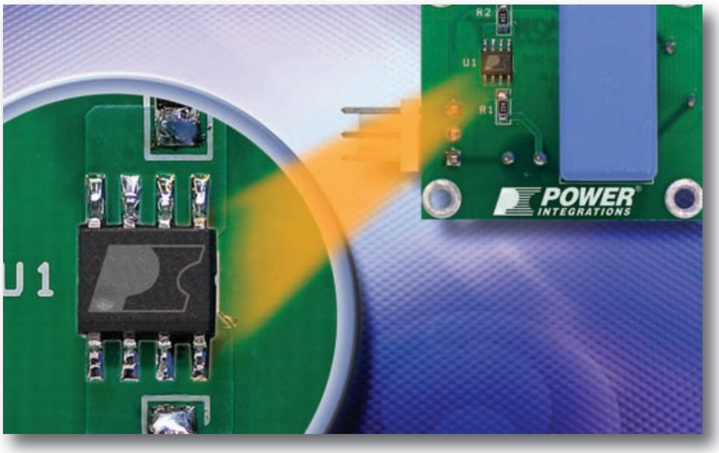
The buck-boost device operates with a wide input voltage range of 1.8V to 5.5V and can discharge lithium batteries down to 2.5V or lower, while maintaining light load efficiency. The single-inductor, 2.4MHz converter comes in a 3mm x 4mm x 1mm package, and can achieve a complete DC/DC converter solution of 100 mm_. Key features of the device include high output current capability allows a battery-powered device to generate the most current with the greatest amount of efficiency; for example, 3A at 3.3V in step-down mode and more than 2.0A at 3.3V in boost mode at typical conditions; dynamic input current limit effectively protects the circuit and system; power save mode maintains high efficiency at light load, and it supports one-cell lithium-based or 2- or 3-cell Alkaline, NiCd or NiMH batteries. The TPS63020 and a 3.3V fixed output voltage version, the TPS63021, are available in volume with a suggested resale price of $2.50 in



1,000-unit quantities. Samples, evaluation modules and application notes are available.

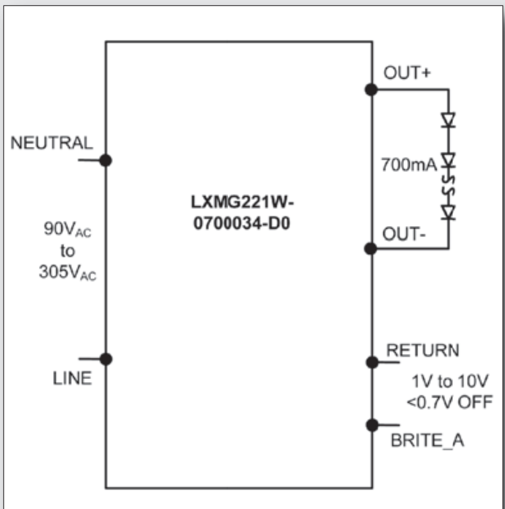
www.ti.com/tps63020-preu

CAPZero ICs Safely Discharge X Capacitors



Power Integrations' new CAPZero is a two-terminal, automatic X capacitor discharge IC that eliminate power losses while allowing power supplies to comply with safety standards. X capacitors are typically positioned across a power supply's input terminals to filter differential EMI noise. Alone, these components could present a safety hazard because they can store unsafe levels of high-voltage energy for long periods of time after the AC is disconnected. To meet safety standards, resistors are commonly used in parallel with the X capacitor and across the AC line to provide a discharge path. However, these discharge resistors produce a constant power loss while the AC is connected and are a significant contributor to no-load and standby input power consumption. CAPZero acts as a smart high-voltage switch when placed in series with discharge resistors. When AC voltage is applied, CAPZero blocks current flow in the X capacitor safety discharge resistors, reducing the power wasted in these components to zero at 230 VAC. When the AC voltage is disconnected, CAPZero automatically and safely discharges the X capacitor by closing the circuit through the bleed resistors and directing the energy away from the exposed AC plug. CAPZero is suitable for all AC/DC converters with X capacitors that require very low standby power, and is offered with 825V or 1000V MOSFETs to support a variety of power supply design needs for a wide range of applications, including appliances requiring EuP Lot 6 compliance and adapters requiring ultra-low no-load consumption. CAPZero devices are available in an SO-8 package at $0.40 each for 10,000-piece quantities.

www.powerint.com/lp/capzero



LXMG221W-0700034-D0 Application Schematic

Driver Module for LED Light Fixtures

Microsemi announced the first product in a planned family of solutions designed to provide optimized power conversion and light management for solid state lighting fixtures, enabling the energy and lifetime cost savings promise of LED-based illumination. Novel features that can be optimally offered by LED lighting include perfectly tuned and personalized light via light intensity and light color controls, as well as reliable integration into smart power and lighting networks starting to appear in the residential, office and commercial space. All of these will only be possible with smart and optimized LED drivers. Designated the LXMG221W-0700034-D0, the power supply module supports 5 to 16 LEDs and will be joined by a portfolio of solid state lighting products in the coming months. Its universal input voltage range of 90 to 305V AC enables operation in 100, 120, 220-240 and 277V AC, 50Hz and 60Hz systems. The module provides 90% power conversion peak efficiency while delivering non-flickering dimming down to 10%. The module can be easily integrated into dimming and non-dimming fixtures and meets requirements for both commercial and residential applications, including its pending CE and UL1310 certification. Its compact, IP66-rated plastic package protects the power supply from dust and temporary water exposure and offers a thru-hole for more secure mounting. The LXMG221W-0700034-D0 is in pre-production. Samples are available with pricing for individual samples at $60.

www.microsemi.com

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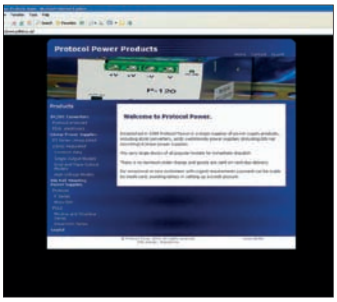

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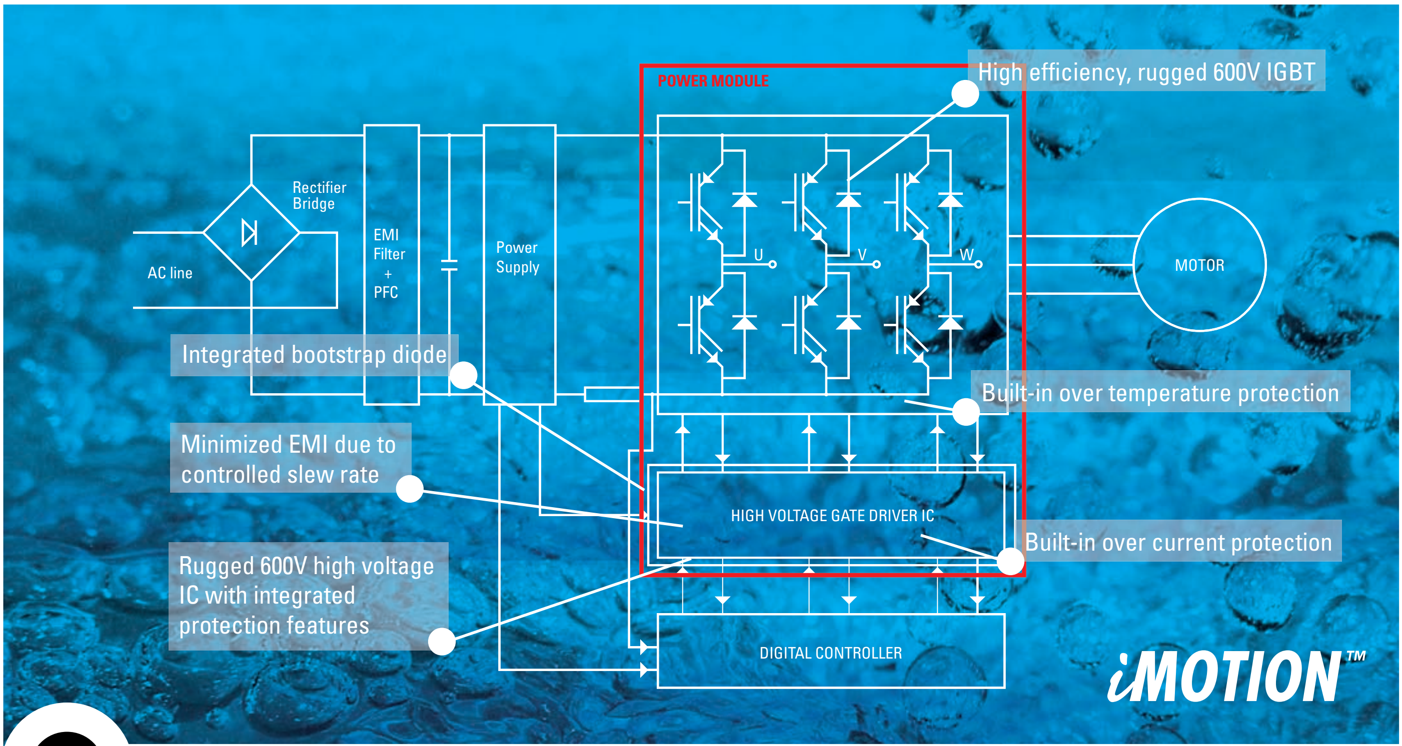

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With IR's IRAM integrated power modules

Part Number	Voltage & Shunt	Typical Load (W)	Io @ TC = 100°C (A RMS)	Package	Configuration
IRAM136-0461G	600V, Integr. Shunt	300W	2	SIP-1	3-phase, 600V + Input bridge
IRAMS06UP60A	600V Open Emitter	400W	3		
IRAMS06UP60B	600V Integr. Shunt				
IRAM136-0760A	600V Open Emitter	400W	3.5	SIP-05	
IRAM136-1060A	600V Open Emitter	750W	5		
IRAM136-1060B	600V Int. Shunt	750W	5		3-phase, 600V
IRAM136-1061A	600V Open Emitter	750W	5	SIP-1A	
IRAMS10UP60A	600V Open Emitter	750W	5	SIP-1	
IRAMS10UP60B	600V Integr. Shunt				
IRAMX16UP60A	600V Open Emitter	1500W	8	SIP-2	
IRAMX16UP60B	600V Integr. Shunt				
IRAMX20UP60A	600V Open Emitter	2500W	10		
IRAMY20UP60B	600V Integr. Shunt			SIP-3	
IRAM136-3063B	600V Integr. Shunt	3000W	15		
IRAM136-3023B	150V Integr. Shunt	750W	15		3-phase, 150V
IRAM336-025SB	500V Integr. Shunt	200W	1	SIP-S	3-phase, 500V
IRAM109-015SD	500V No Shunt	200W	1		H-Bridge

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- Insulated metal substrate technology for reduced EMI
- Optimized for power up to 3kW
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