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December 2009

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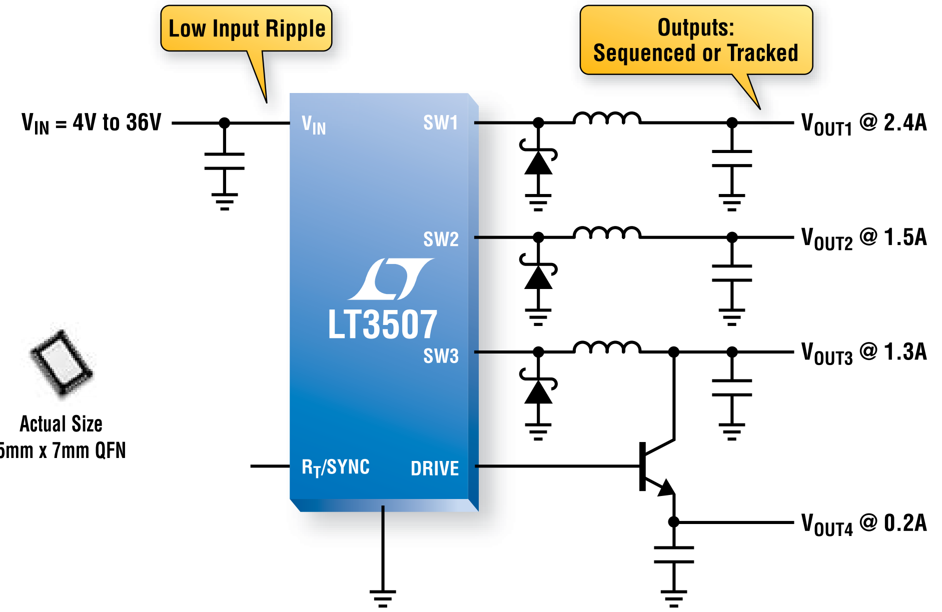
Special Report – Renewable Energy

ISSN: 1613-6365

36V$_{IN}$ Multichannel Bucks



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▼ Multichannel Buck Converters

Part Number	Topology	V_{IN} Range	I_{OUT} (A)	I_{SD} (µA)	Automotive Temp Range: Max Junc Temp (°C)	Package (mm)
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LT3508	Dual Step-Down Regulator	3.7V to 36V	1.40, 1.40	1	150	4x4 QFN-24, TSSOP-16E
LT3506/A	Dual Step-Down Regulator	3.6V to 25V	1.60, 1.60	30	125	4x5 DFN-16, TSSOP-16E
LT1939	Step-Down Regulator + LDO Controller	3.6V to 25V	2.0	12	125	3x3 DFN-12
LT3500	Step-Down Regulator + LDO Controller	3.6V to 36V	2.0	12	150	3x3 DFN-12, MSOP-10E
LT3510	Dual Step-Down Regulator	3.3V to 25V	2.0, 2.0	10	125	TSSOP-20E
LT3501	Dual Step-Down Regulator	3.3V to 25V	3.0, 3.0	10	125	TSSOP-20E
LT3507	Triple Step-Down Regulator + LDO Controller	4V to 36V	2.4, 1.5, 1.5	1	150	5x7 QFN-38

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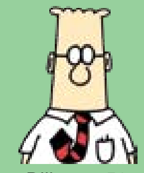

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Volume 6, Issue 10

Let's Look Forward

Welcome to the December issue of PSD Europe. It's been quite a year. Challenging some might say. I believe I'm not alone in saying that we, in this industry - as well as many others, have all suffered a full repertoire of difficulties from short-time working in addition to the ever present threat of job losses. Companies are brutally aware of the need to make profits to pay their way forward and to give an attractive return for their investors, which gives us all an additional stress-factor on top of the 'normal' challenge of just 'doing the work' in these difficult times.

Hopefully next year will see a continuation of the much-publicised resurgence in industry confidence, a timely return to investment and an improvement in real and sustainable business.

In this issue we have another bumper crop of articles, news features and interviews - as well as further reading in our growing online magazine. Also, look out for our recently-introduced regular news bulletin, PowerSurge, which delivers timely industry and product news direct to your inbox.

But heartening news is now coming in: Although global semiconductor revenue is set to decline in 2009 for the second consecutive year, quarterly year-over-year growth is expected to finally return to the market in the fourth quarter, signaling the start of the industry recovery, according to iSuppli Corp. Revenue is expected to rise by 10.6% in the fourth quarter of 2009 compared to the same period in 2008. The fourth quarter will mark the first quarter in 2009 that revenue has risen compared to the same period a year earlier. Meanwhile, semiconductor inventories returned to more normal levels in the third quarter after chip suppliers shed stockpiles by slashing costs dramatically in order to reduce unsold inventory carried since the beginning of 2009.

Thin-film solar cells are rapidly taking market share away from the established crystalline technology, with their portion of Photovoltaic (PV) wattage forecast to more than double by 2013. Thin-film will grow to account for 31% of the global solar panel market in terms of watts by 2013, up from 14% in 2008.

But while the electronics market is visibility improving, considerable uncertainty lingers regarding the market outlook in the first half of 2010. Most suppliers are likely to continue to hold off on significant capacity increases until their outlook improves.

So with this overall positive news coming in, coupled with our indestructible collective industry optimism, we should experience a better year in 2010 than we did in 2009. I still firmly believe that the power industry is the place to be and that we will see continued advances, and a return to investment and stability.

I hope you enjoy the issue, keep the feedback coming and check out our fun-site, Dilbert, at the back of the magazine.

All the best!

Cliff Keys

Editor-in-Chief, PSDE
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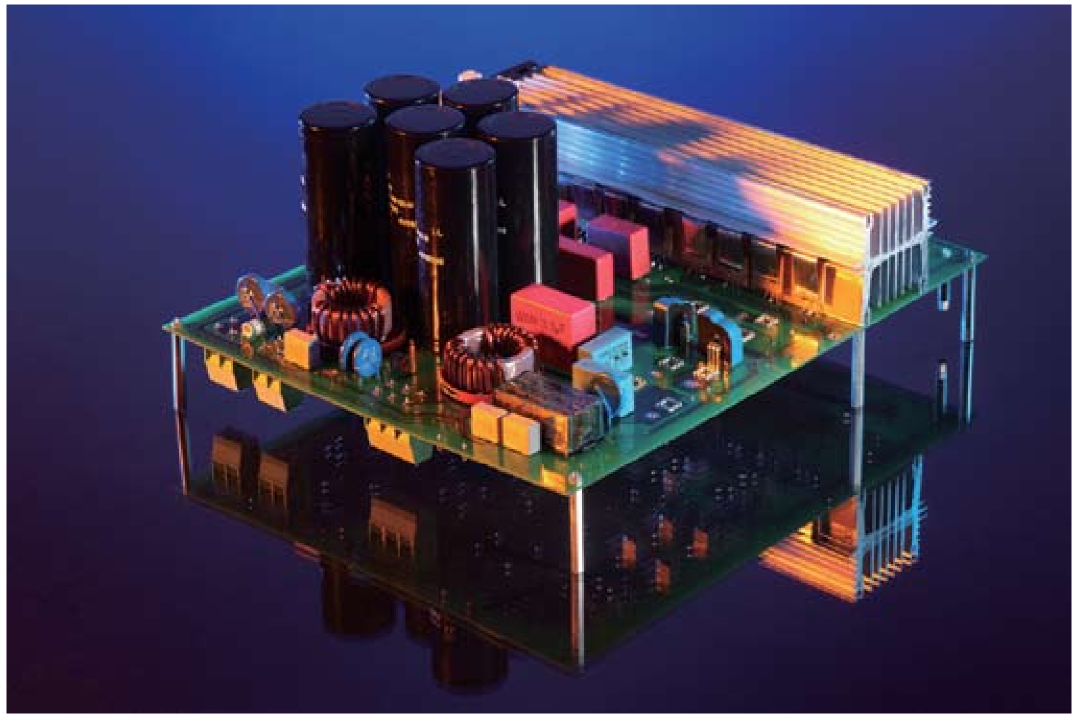
VAC Nanocrystalline Chokes Maximize Solar Inverter Efficiency

Vacuumschmelze GmbH & Co. KG (VAC) has demonstrated its materials expertise in future-oriented technology. The Fraunhofer Institute for Solar Energy Systems (ISE) has established a new world record for the efficiency of inverters in photovoltaic systems, a remarkable 99.03 percent. Losses have been slashed by one third compared to their previous best result by employing new components and improved circuit technology. Vital new components helping to achieve this are VAC's common mode filter chokes.



The ISE's record-breaking PV inverter contains an EMI filter incorporating Vacuumschmelze common mode chokes. Thanks to the high permeability of VITROPERM® 500F, the nanocrystalline material used for the choke cores, only a very low number of turns is required to achieve the required filter characteristics. Because of this, the wire diameter can be increased for a predefined construction volume, thus reducing the resistive copper losses of the choke and improving the overall system efficiency. In comparison to conventional materials for chokes, the core material from Vacuumschmelze generally enables the overall volume of the choke to be reduced, or, for a given volume, the cross sectional area of the windings to be increased for maximum efficiency as demonstrated by the Fraunhofer inverter design. Since VITROPERM® is mainly composed of inexpensive iron (Fe content about 75%), VAC chokes are less susceptible to the significant fluctuations in raw material price of other common metals such as copper and nickel as have been recently seen.

Other benefits of nanocrystalline common mode chokes are their broadband damping properties, thanks to the optimum blend of high material permeability in the low-frequency range and a low winding capacitance for good high frequency properties. Thanks to these properties, in many cases, the value of EMI filter capacitors can be reduced or which may reduce the number of passive components necessary. In other cases it is even possible to reduce two stage filters to single stage designs. Another major advantage of VITROPERM® common mode chokes is the virtually temperature-independent performance up to 150°C and beyond, assuring stable filter characteristics in high ambient temperature applications.

www.vacuumschmelze.com

The Power to Move Ahead

By Peter Sontheimer, Vice President R&D and Marketing, Vincotech

With the current financial climate, it's a challenging time for all companies in our industry. Demand suffered greatly in markets that contracted, instead of showing further growth-rates as experienced between 2005 and 2008. The first three quarters in 2008 were overheated to a certain extent and the lower demand situation led to significant capacity reductions in staffing and plant in all sectors of the electronics industry.

But sometimes it takes an industry a financial crisis to forge a new and improved mode of operation. This is exactly what Vincotech accomplished in 2009.

There are now indications that markets are coming back. Vincotech observes a remarkably better situation in order books coming from all strategic markets.

Focus change

In 2009, Vincotech challenged the meaningfulness of its key processes and removed significant administrative backlogs. The manufacturing strategy was scrutinized and the company changed from its former conservative thinking to leaner production principles that lead to a "fewer pieces more often" way of thinking, increasing its flexibility tremendously. As a consequence, the company is now able to react to customer needs in a much faster and more flexible way, which in turn helps customers to get to market faster.

Market focus and customer profile

In particular, the motion control markets suffered from an all-embracing decline in demand due to cost-saving initiatives in end customers as well as from investment policy changes. In parallel, engineering programs of market

players started to ramp-up as customers changed their strategies and began new innovation programs, resulting in strategies to gain market share by differentiation.

The slogan "make the difference" is shouted out loud. Firms which have an absolute need to be flexible and be able to customize their end products to differentiate themselves from the 'one size fits all' offerings from the well known industry giants, fit perfectly in Vincotech's customer profile.

There is a great deal of hype and misinformation around in the buzzwords "energy efficiency" at the moment. Vincotech prefers not to enter into this rhetoric. The buzzwords and hype are to be seen all around us – to the extent where the term itself becomes diluted to the point of meaninglessness.

Vincotech concentrates on the task of sustainable loss reduction, which is a much clearer and tangible definition of what the company achieves with its product developments. The solar power market appreciates this approach and has opened its doors for power modules that help significantly in reducing power losses during operation.

Products and market access

Vincotech continuously improves its value proposition to customers. The result is an outstanding product offering for all manufacturing preferences with complete, fully integrated modules, rectifiers and intelligent power modules which are a perfect fit for the motion control market. Medium and high voltage modules are available up to power levels of 200kW. Additionally, high efficiency topologies have been developed for the solar power and allied markets such as UPS or welding equipment. Loss-reduction is the focus.

Conclusion

Crisis periods offer opportunities. Many people have unfortunately been affected by cost-saving initiatives. However, the situation can be reversed for those who are able to leverage the potentials that are born out of the crisis. Vincotech is now stronger than ever before, both financially and strategically, and has reached a higher level of operation. The focus is aligned to markets that offer a perfect fit for a quick, flexible and independent power electronics vendor. The company's target is two-fold: To help the customer to sustainably reduce power losses; and to create added value to the customer application.

Out of the crisis we have the power to move ahead.

www.vincotech.com

Solar Market Suffers but Outlook Still Bright

By Ash Sharma, Research Director, Power & Energy Group, IMS Research

The final quarter of the year always seems to bring huge uncertainty in the solar power market, and this year things are no different. Last year, following the explosive growth in the Spanish PV market, the main concern was what would happen once this market was capped. Where would all those extra PV modules go and which markets would drive growth? This year, the uncertainty concerns different issues: how much further will module prices fall? Will Q4's strong demand counteract the slide in revenues seen in the first half of the year? And looking further ahead, what will happen after 2010, once incentives are inevitably cut in Germany and Italy?

IMS Research estimates that the PV market declined year-on-year by 30% in the first half of 2009. This is based on inverter shipments and it also showed that dollar revenues fell by even more – some 38%. This was mainly caused by the collapse of the Spanish market which eliminated nearly 2GW of demand, but also by the lack of access to financing, and speculation over future module price decreases.

Strong incentives remain in place in many countries. Others, including China and the US, have announced major plans for renewables, including PV, yet these markets have been relatively slow to develop.

Discussions at the recent PVSEC conference revealed that invariably, PV

companies were expecting a huge fourth quarter in 2009. The second half of the year is typically much stronger than the first, with companies rushing to get projects constructed and connected to the grid before annual reductions to the FIT occur in certain countries. This year, the 4Q rush looks set to be compounded by existing pent-up demand and easing credit conditions, which may lead to a massive fourth quarter.

Strongest growth (in absolute MW terms) is anticipated to come from Germany and Italy, whilst emerging markets such as Bulgaria, Czech Republic and Belgium also show promise. Similarly, much greater demand is anticipated in the US and China, and also in Canada, now that a feed-in tariff has been approved in Ontario.

One interesting development that has been attracting significant media attention is distributed PV systems using micro-inverters, AC modules and other distributed maximum power point (MPP) solutions. Some companies, such as Petra Solar have seen good initial success by promoting their product's ability to distribute PV generation with intelligence and communications throughout the grid to improve grid reliability.

Other companies, such as SolarEdge and National, are marketing their new products and apparently seeing good success, on the basis that they can help to improve yields by distributing MPP tracking across the entire array to counteract the negative effects of shading and module mis-match.

Despite the current uncertainty surrounding the industry, IMS Research predicts that shipments will reach 5GW in 2009, around 15-20% down on 2008. Despite this fall, more than 7GW of new PV systems are anticipated to be installed in 2010, resuming the industry's strong double-digit growth.

www.imsresearch.com

Leakage Inductance Can be Good For You

Transformer design for low leakage

In this article, Dr. Ridley shows how the leakage inductance of a transformer can sometimes be too low, resulting in increased stress and losses, and decreased reliability. Sometimes it pays to increase the leakage inductance of your power transformer

By Dr. Ray Ridley, Ridley Engineering

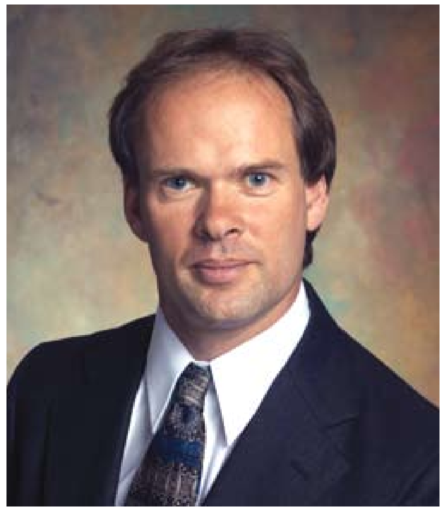
Most power supply designers strive for low leakage in their transformer designs, especially as power levels climb. They do this because they are aware that a high leakage inductance leads to high voltage spikes on both primary and secondary semiconductor devices. High leakage is also associated with high proximity losses in a transformer, raising the temperature of the windings.

Leakage inductance is minimized by reducing the primary-secondary separation as much as possible, and by minimizing the number of turns. We usually design a transformer with the lowest number of turns possible without having the transformer core saturate. This is in accordance with the nonsaturation constraint of the transformer given by:

$$B_s n A_e > E_i T_n$$

where
B_s is the maximum flux allowed in the core material;
n is the number of turns;
A_e is the minimum core area;
E_i is the voltage applied; and
T_n is the on-time of the switch.

Using the minimum number of turns leads to the lowest value of leakage for a given core size. There is some design freedom in selecting the maximum



allowable flux which give flexibility is reducing the turns count. Sometimes, however, the leakage inductance becomes so low that further reductions result in increased stress on the semiconductors.

Two-Switch Forward Converter Example

Figure 1 shows a two-switch forward converter. Specifications for the converter were as follows:
Input: 180 – 280 VAC
Output: 30 V at 10 A

Over the course of development, more than 5 different transformers were tested, each using different combinations of wire sizes and turns to experiment with different winding arrangements.

The current waveform Id of Figure 1, and the output diode waveform Vd were monitored to see the effect of different designs. There were no snubbers on the primary side of the converter. The two-switch forward topology has the feature of primary side diodes that reset the core, and also return any leakage energy to the source. This clamping action

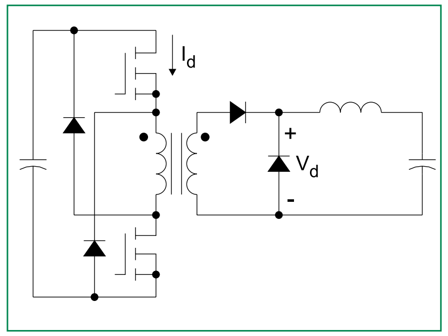


Figure 1: Two-Switch Forward Converter.

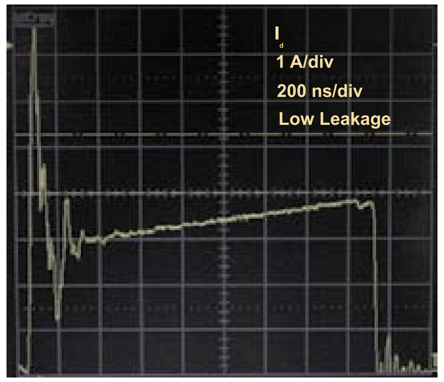


Figure 2: Switch current for low-leakage transformer design, 180 VAC Input.

protects the main power switches from overvoltage.

The secondary diodes each had RC snubbers across them, and the free-wheeling diode across which the voltage was measured, also had an RCD clamp which allowed a 200 V schottky to be used.

Figure 2 shows the current waveform in the primary switches with a low-leakage transformer. With an input voltage of 180 VAC, the initial turn-on spike reached an amplitude of 7.6 A. The main part of the current ramped up to just below 4 A. The initial spike increased with higher input voltages, and with increased temperature of the devices. This spike is due to capacitive discharge of the transformer, plus the recovery and capacitance of the secondary diodes. A higher spike of current results in increased switching losses.

A second transformer was built with approximately three times the leakage of the first, and the results are shown in Figure 3. The winding layout of the transformer was kept constant, but the number of turns was increased beyond the minimum required to keep the core away from saturation.

The peak of the turn-on current spike was reduced to just above 5 A.

The leakage inductance also has an impact on the secondary side waveforms. Figure 4 shows the voltage across the catch diode on the secondary. There is an initial short-duration turn-on spike of about 50 V. This adds to the clamp voltage value of about 135 V, resulting in a peak stress of close to 200 V. At higher input lines, the rating of the output schottky diode would be exceeded. The value of this spike increases with increased temperature of the semiconductors.

Figure 5 shows the same diode voltage with a high-leakage transformer design. The leading edge spike is reduced, and the total stress is now about 30 V lower than the low-leakage design

For both the voltage and current waveforms, the leakage inductance slows down the waveform transitions. The primary current increases more slowly, and this gives the secondary diodes more time to turn off due to the slower rise of the secondary voltage.

The spike on the secondary diode is of a very short duration. In fact, if you use a low bandwidth oscilloscope, you

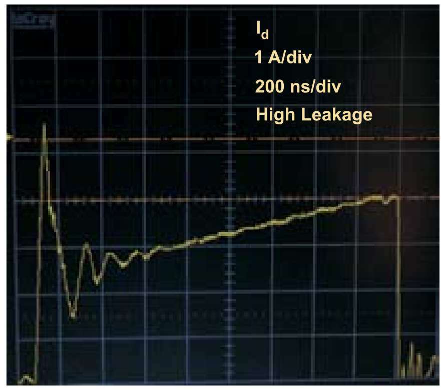


Figure 3: Switch current for high-leakage transformer design. Note the decrease in leading-edge spike.

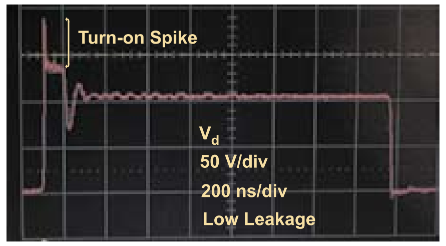


Figure 4: Secondary diode voltage for low-leakage transformer design.

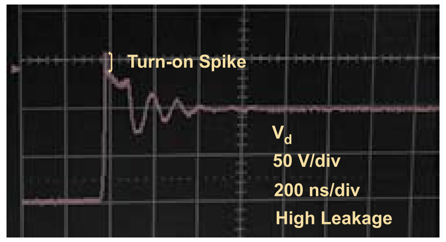


Figure 5: Secondary diode voltage for high-leakage transformer design. Note the decrease of the turn-on spike.

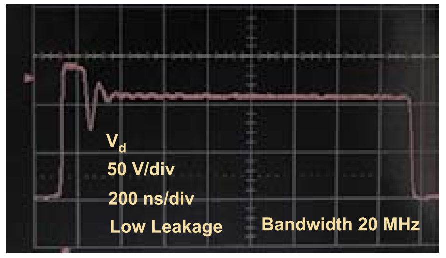


Figure 6: Secondary diode voltage for low-leakage transformer design with 20 MHz bandwidth rather than 200 MHz. Note the turn-on spike is no longer visible.

cannot see the spike at all. Figure 6 shows the secondary waveform with the scope bandwidth reduced to 20 MHz. Without proper instrumentation, potentially damaging short-term repetitive events like these can be missed entirely.

Figure 6: Secondary diode voltage for low-leakage transformer design with 20 MHz bandwidth rather than 200 MHz. Note the turn-on spike is no longer visible.

Summary

This article shows that decreasing transformer leakage inductance beyond a certain point can result in increased stress in the power semiconductors. A higher value of leakage is actually beneficial in many cases. For the two-switch forward converter, the higher leakage inductance does not affect the primary voltage stress due to the primary clamp diodes.

Two transformers were compared, with a 3-to-1 difference in leakage inductance. Note, however, that both transformers were still low-leakage designs, following proper high-frequency transformer design procedures. The point of this article is to stress that striving for ultra-low leakage can actually be harmful to the design. There is a limit as to how much the leakage should be reduced.

This effect can also be seen on other converters, even if they do not have clamped primary waveforms. For example, continuing to reduce the value of a flyback inductance beyond a certain will allow fewer turns and lower leakage. Normally this is good, but if the leakage becomes too small, switching losses begin to dominate the operation of the converter, and efficiency can drop.

There is no general equation that determines which leakage inductance is optimum. The best design approach is to build multiple transformers with different constructions to see which one produces the best waveforms.

www.ridleyengineering.com

On the Road

Reported by Cliff Keys, Editor-in-Chief, PSDE

National Semiconductor

I had the great pleasure of talking with Werner Berns, National's Manager for the PowerWise Design Lab in Europe, who told me about the company's latest development in its WEBENCH design tool. For many years, engineers have enjoyed this powerful design tool and the usage has shown remarkable growth in that time.

National Drives Ease-of-Design

New WEBENCH Visualizer enables real-time comparison of power solutions across multiple criteria

National is renowned and well respected by designers for its leading suite of web-based design tools and has now introduced WEBENCH® Visualizer, a powerful comparison and selection tool that enables engineers to rapidly select an optimal power system design. WEBENCH Visualizer creates a graphical snapshot of options across multiple criteria, such as power efficiency, footprint and system bill of materials (BOM) cost. Drawing from 25 different switching power supply architectures and 21,000 components, engineers can navigate through billions of power supply design alternatives in seconds. Design criteria can be modified and the real-time effects observed, allowing engineers to select the best DC-DC power supply based on their unique needs.

"With WEBENCH Visualizer, National has enabled analog experts to be superior business decision makers because we've given them all of the tools to produce the best possible design in the shortest time," said Phil Gibson, Vice President of Technical Sales Tools at National Semiconductor. "We've also given non-power experts the ability to do extraordinary things with analog power designs."

I tried the tool for myself and found it easy to use and wondered what made the tool so fast and interactive. Werner Berns explained, "Last year, National introduced its Flex version (Flash-client) of WEBENCH, which is downloaded to the engineer's desktop, presenting the tool as a local client. That enables the WEBENCH interface to execute extremely fast".

Werner Berns, Manager, PowerWise Design Lab, National Semiconductor.

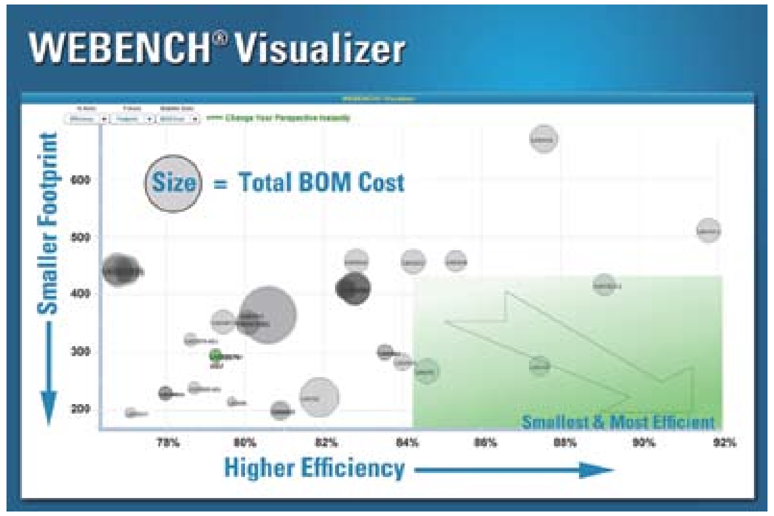
Werner added, "At one single glance, the engineer can see dozens of solutions and can directly compare them based on three out of a selection of several key characteristics. The tool is extremely visual and offers an unmatched transparency to the designer. Working with the WEBENCH Visualizer will cut down design time dramatically".

National's WEBENCH Visualizer tool supports a variety of power supply topologies such as buck, boost, buck-boost, SEPIC and flyback. Several alternative circuit configurations are also available to address specific needs like fixed-frequency and constant-on-time architectures as well as current-mode and voltage-mode control loops. With the broadest power parts library from 110 manufacturers, designers can specify a wide range of parameters:

- V_{IN} from 1V – 100V
- V_{OUT} from 0.6V – 300V
- Power up to 300W
- Efficiency up to 96%
- Frequency up to 3MHz
- Footprint from 14mm by 14mm

How WEBENCH Visualizer works

The WEBENCH Visualizer tool features an optimizer dial that enables engineers to "dial-in" their preference for footprint, system BOM cost and power efficiency. The tool instantly creates 50-70 designs from 48 billion possible design options. It then highlights the smallest and most efficient designs, with one recommended as a starting point for further optimization.



A second visualizer control panel allows engineers to adjust their design options for voltage, current and temperature. In seconds, an updated set of solutions appears, highlighting each design's topology, schematic, footprint, efficiency, operating values and BOM cost/count. The tool's interactive filter allows engineers to further fine-tune the power supply design to meet the target system's exact requirements.

Once a design is selected, National's WEBENCH design environment offers the ability to further tune and optimize that design through additional component options and electrical and thermal simulation. With the "Build It!" feature, National promptly ships a custom power supply prototype kit. To view a video demonstration or begin an analysis with the WEBENCH Visualizer tool, go to www.national.com/visualizer.

The WEBENCH Visualizer tool is an extension of National's award-winning WEBENCH tools for LEDs and power design. These tools offer instant access to the latest simulation models, parametric data and package information, enabling designers to simultaneously compare the performance of multiple devices in multiple circuit requirements.

I found WEBENCH Visualizer hugely user friendly, fast and easy to navigate. With power designers under immense pressure to find a superior and cost-effective solution, this tool will, for sure, ease the burden.

www.national.com

European Power Supply Manufacturers Association

I was invited to attend the annual general meeting of the EPSMA (European Power Supply Manufacturers Association) which was founded in 1995. It was an uplifting and interesting meeting where I could see first hand the good work for our industry that this dedicated group is involved in.

EPSMA Meets in London

Power industry professionals work for us all

The EPSMA facilitates the power supply industry to cooperate in areas where they have a common interest – e.g. legislation, common technical/educational issues. It is run by a small Management Committee of currently twelve member companies who hold meetings four times per year which can be attended by any member.

The EPSMA Technical Committee conducts projects and produces technical documents and white papers in areas identified or reported as being of concern to EPSMA members.

There are thirty full, supplier and affiliate members currently and interest is growing as the EPSMA provides a valuable conduit to enable members to gain access to usually 'difficult to navigate' European bodies such as CENELEC.

I met the team and spoke with Lars Thorsell, Chairman of Technical Committee of the EPSMA. He took the group through the year's progress and gave an outline of project progress and achievements.

A selection of the running projects and their status was presented by Lars:
- General Safety Guidelines
- Energy Efficiency
- Harmonized Temperature Measurements

New projects in development were then outlined and discussed:

Lars Thorsell, Chairman, Technical Committee, EPSMA.

Ryan Sanderson, EPSMA Secretariat.

- MSL (Moisture Sensitive Levels) for packaged products
- Datasheet Parameters
- Reliability Issues on Lead-Free Soldering

There were also Design Notes recently distributed to EPSMA members:
- Safety for DIN Rail applications
- Safety for applications in hazardous locations.
- Safety for Railway applications

In the pipeline there were still more papers:
- Medical Approvals for Power Supplies
- Safety for Telecom applications

Several companies within both manufacturers and users have made contributions with material covering areas such as semiconductor solutions, digital power, energy efficiency, remote powering, high voltage converters, and much more.

This active and dynamic group is now well set for 2010 with a good outline of what it needs to achieve. For me it was indeed a privilege to see the workings of this association and was inspiring to see a group of real industry professionals, experts in their respective fields who were making time in their busy schedules for the good of our industry.

For further information on the EPSMA visit www.epsma.org

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Linear Lights Up

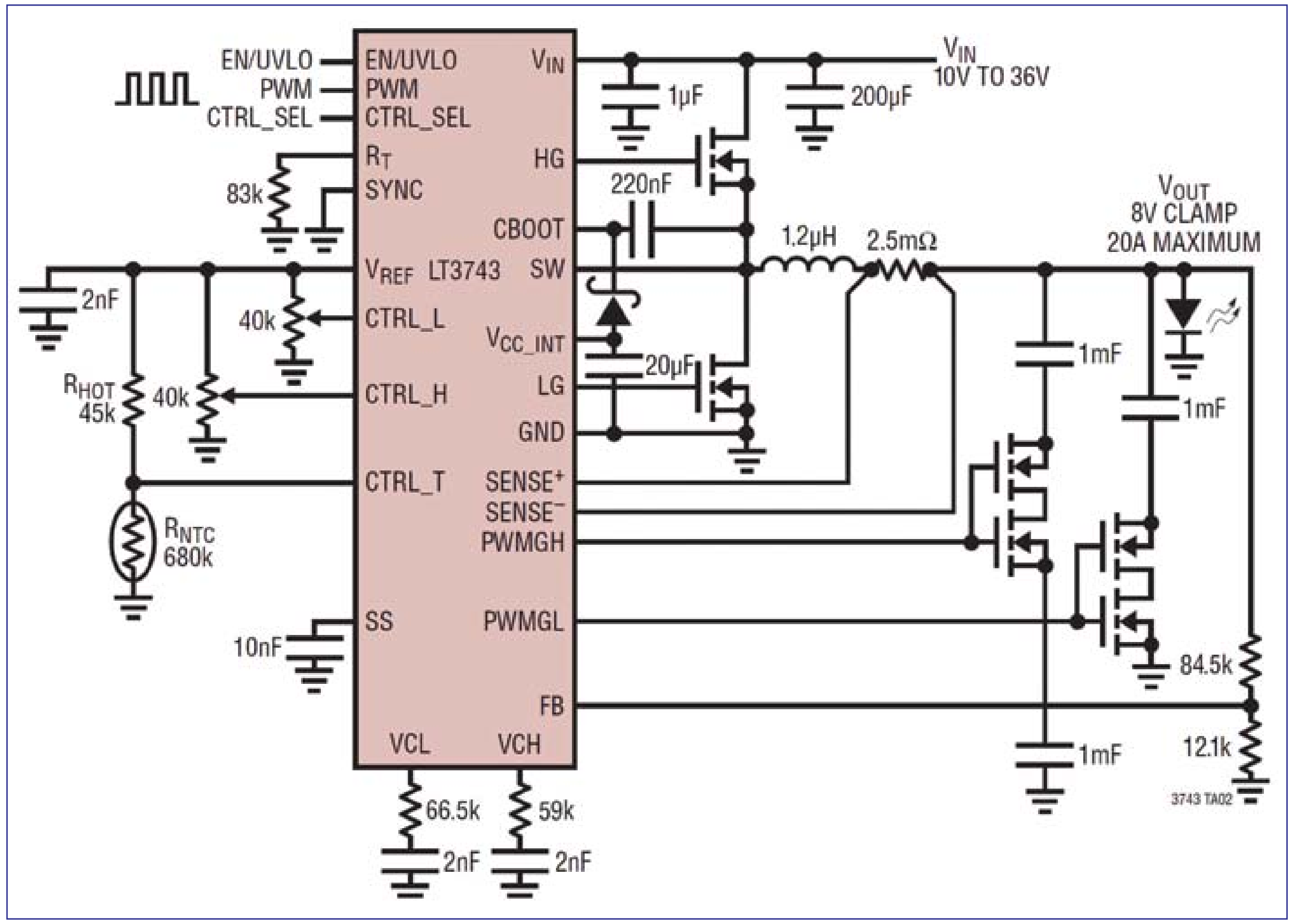
Over 20A continuous LED current from new driver

I talked with Tony Armstrong, Director of Product Management and Bryan Legates, Design Manager at Linear about the company's new synchronous step-down LED driver that delivers over 20A continuous LED current suitable for but certainly not limited to, industrial applications, professional DLP projection and architectural lighting.

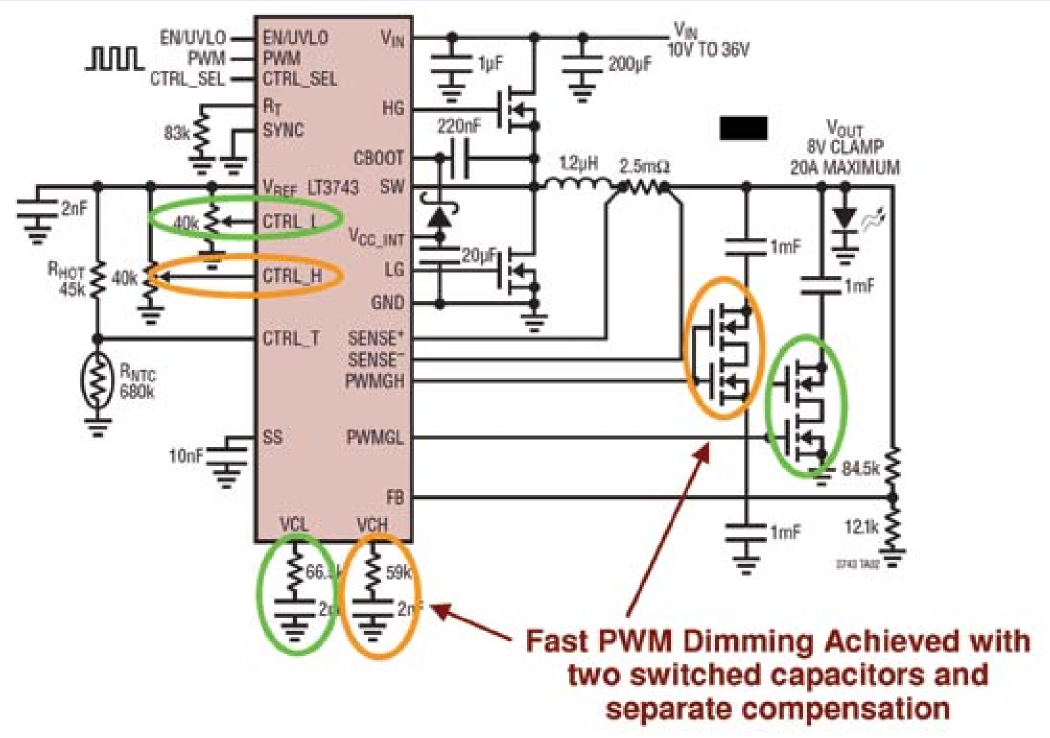
Reported by Editor-in-Chief, PSDE, Editorial Director, Power Systems Design Franchise

Linear Technology recently launched the LT3743, a synchronous step-down DC/DC converter which designed to deliver constant current to drive high current LEDs. The device's 5.5V to 36V input voltage range makes it ideal for an increasingly wide variety of applications.

The LT3743 provides up to 20A of continuous LED current from a nominal 12V input, delivering in excess of 80 Watts. In pulsed LED applications, it can deliver up to 40A of LED current or 160 Watts from a 12V input. Efficiencies as high as 95% eliminate any need for external heat sinking and significantly simplify the thermal design. A frequency adjust pin enables the user to program the frequency between 100kHz and 1MHz so designers can optimize efficiency while minimizing external component size. Combined with a 4mm x 5mm QFN or thermally enhanced TSSOP-28 package, the LT3743 offers



Full-featured LED controller delivers over 80W of LED Power.



LED dimming is achieved through analog dimming on the CTRL_L, CTRL_H and CTRL_T pins and with PWM dimming on the PWM and CTRL_SEL pins. Through the use of externally switched load capacitors, the LT3743 is capable of changing regulated LED current levels within several µs, providing accurate, high speed PWM dimming between two current levels. The switching frequency is programmable from 200kHz to 1MHz through an external resistor on the RT pin.

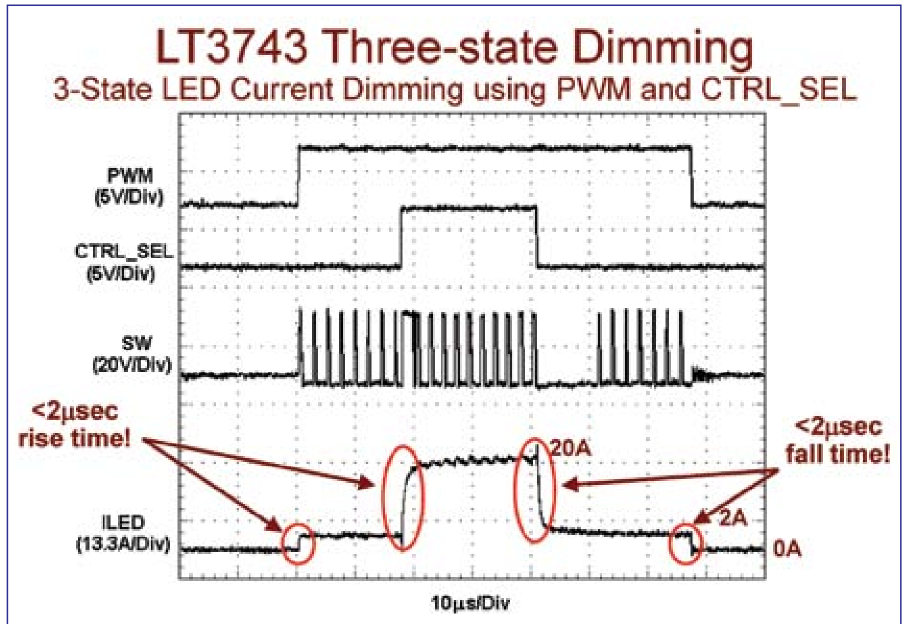
an extremely compact high-power LED driver solution.

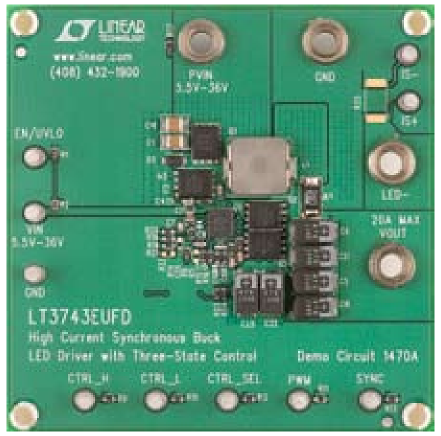
The LT3743 offers both PWM and CTRL_SELECT dimming, offering 3,000:1 dimming capability at three LED current levels, making it ideal for color mixing applications such as those required in DLP projectors.

The LT3743's unique topology enables it to transition between two regulated LED current lenses in less than 2µsec, enabling more accurate color mixing in RGB applications. LED current accuracy of +5% is maintained in order to ensure the most accurate luminosity of light from the LED. Additional features include output voltage regulation, open-LED protection, overcurrent protection and a thermal derating circuit.

The debut of this device will for sure open up new and diverse applications other than lighting and projection. Interest is reported in driving laser diodes, used extensively in industry for precise and clean cutting of metal or fabrication.

The LT3743EUFD is available in a 28-pin 4mm x 5mm QFN package, whereas the LT3743EFE is available in a thermally enhanced TSSOP-28. Pricing starts at $4.80 and $4.95 each, respectively in 1,000-piece quantities. Extended temperature versions, or "I" grades, namely the LT3743IUFD and LT3743IFE are also available. Pricing starts at $5.65 and $5.82 each respectively in 1,000-piece quantities. All versions are available from stock.





LT3743 Demo-board.

www.linear.com

Solar Perspective

Is the solar energy glass half full?

The question of whether the glass is "half full" or "half empty" is often answered based on whether you are optimistic or pessimistic. Solar energy critics generally come from the economics of solar energy installation. Once the installation is completed, the fuel cost is nearly zero. We will discuss the difference between considering $/W and $/W-h, and how module electronics can help optimize the system's total energy.

By Dave Freeman, TI Fellow and Engineering Manager; Nagarajan Sridhar, Technologist at TI's Solar Lab and Chris Thornton, Power Systems Designer, Texas Instruments.

Recently, another Moore's Law-like prediction was cited by Bill Sweet (Photovoltaic Grid Parity, November 2009, IEEE Spectrum Energy Wise News): The cost of solar installation comes down about 20 percent for every doubling of installed capacity. Because this is not happening yet, the glass appears to be half empty.

The solar industry admits it needs help to reduce installation cost. However, they want the comparison based on $/kW h. The website www.solarbuzz.com tracks prices and trends. They draw a distinction between residential and industrial solar energy. Residential cost is about $0.35/kW h, whereas industrial is closer to $0.20/kW h. These numbers still indicate "the glass is not half full," but getting close.

Rather than compare solar energy costs to other sources, shouldn't the question be: "Do you want to live in a house powered by solar energy only?" This question was pondered by the Solar Decathlon, a competition in which 20 teams of college and university students competed to design, build, and operate the most attractive, effective, and energy-efficient solar-powered house. Each participant constructs a livable house and is judged on everything from market appeal, day-to-day home activity, and engineering solution. Talking to the vari-

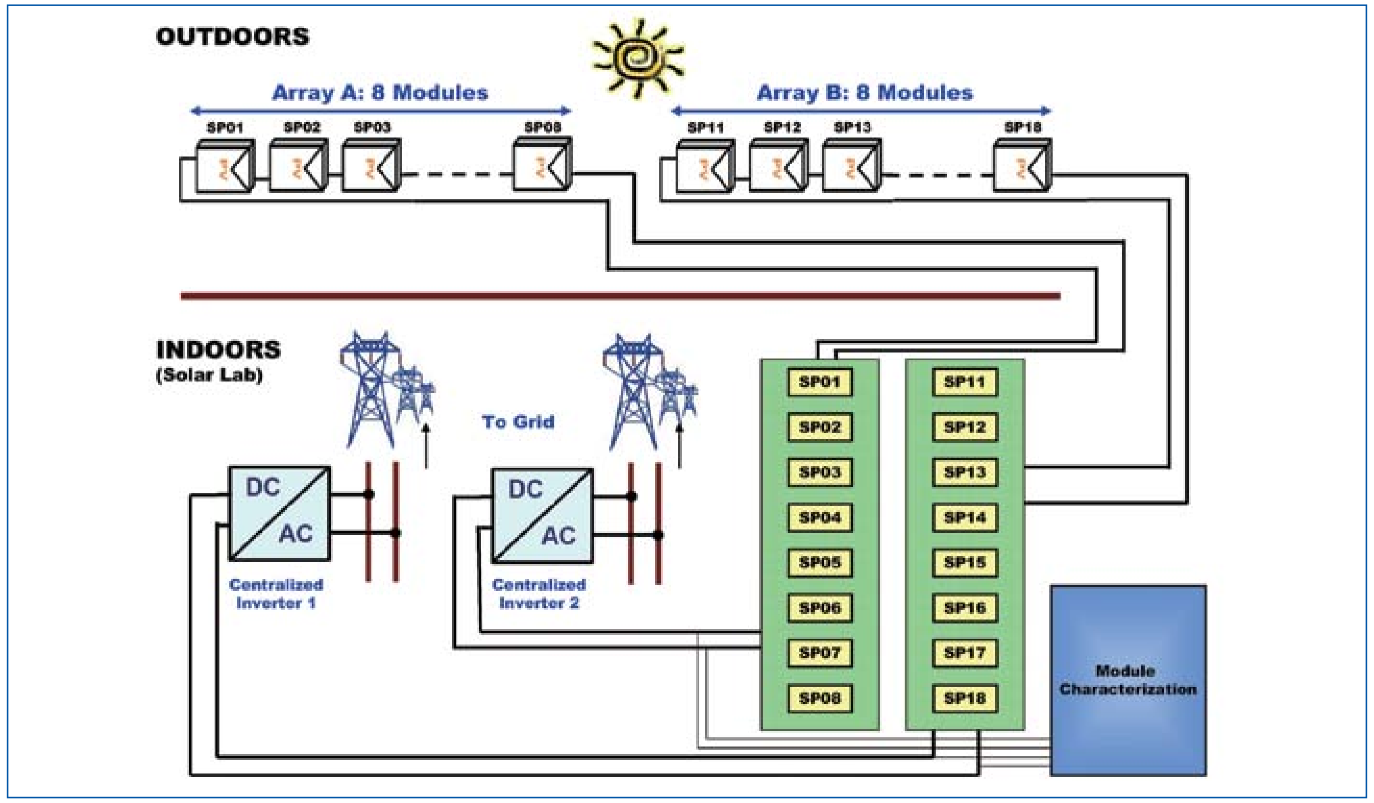


Figure 1: PV array and testing block diagram.

COVER STORY

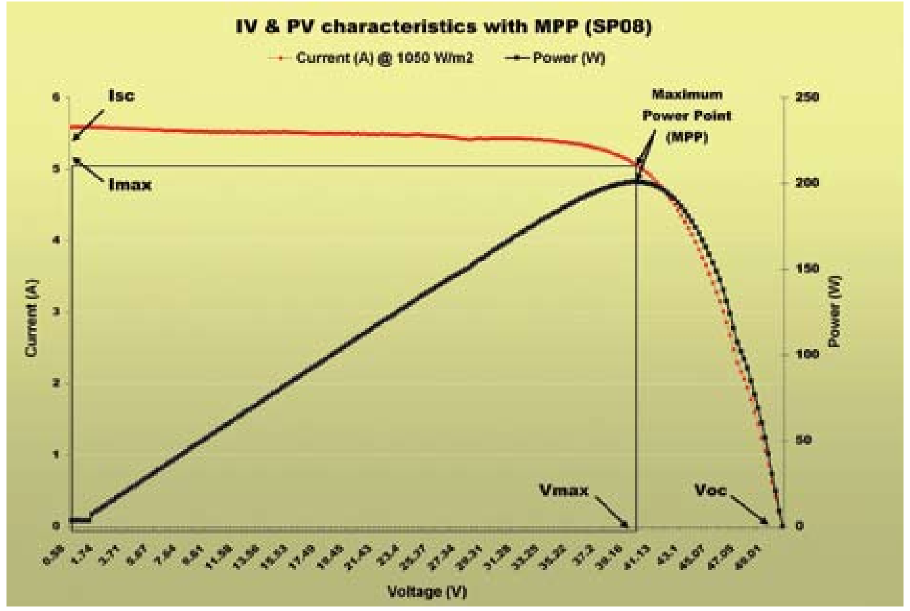


Figure 2: IV and PV curve for a PV module shows maximum power delivered for that condition.

ous student competitors, they think the glass is half full. They believe powering a house with solar energy makes more sense when energy-efficient appliances are used. Consider the desirability of a completely solar-powered house and corresponding efficient appliances, then indeed solar may be considered half full. Let's look at the solar energy system and consider what can be done to improve performance.

Behavior of photovoltaic modules

Solar cells, when connected together in series or parallel, comprise to form a photovoltaic (PV) module. In a typical residential or grid-tied application, the PV system has one or more PV modules connected in series to form a string to increase the overall system voltage. Each string is connected in parallel to form a PV array and increase the system current. The goal of this system or array is to deliver maximum power to the load. Since power delivered by a solar cell/module/array is the product of the current and voltage under DC conditions, it is critical to ensure that power delivery occurs at the point of the IV curve where the IV product is maximized. This is the maximum power point (MPP).

Assuming one MPP for a string may be incorrect due to mismatches and varying irradiance from module shading. Module electronics can address this performance mismatch. To design and build the module electronics optimally, it is important to characterize and understand the behavior of PV module parameters under different irradiance and ambient conditions.

Photovoltaic array configuration

Before understanding the behavior of the module parameters, one must understand the PV array configuration (see Figure 1).

Eight modules (SP01–SP08) are connected in series that are connected to a string inverter 1. Similarly, another eight modules are connected to a string inverter 2. All sixteen modules are made of mono-crystalline silicon solar cells from the same manufacturer, and rated at 215W at standard operating conditions of 1000 W/m^2 and 25°C. AC power from the inverters is sent back to the local grid. The behavior of each module can be individually monitored for MPP operation.

Module IV and PV Characteristics

Figure 2 shows an IV (current voltage) curve and a PV (power voltage) curve generated from one of the modules (SP08) for an irradiance condition of 1050 W/m^2. The MPP is located close to the knee of the IV curve where the current and voltage product is maximized.

Changing the irradiance condition reduces the ISC and, to a lesser extent, the VOC (see Figure 3).

Most commercial IV units take two to three seconds to sweep using a quick diagnostic tool. This prevents any false peaks and valleys in the curve that could occur from any moving cloud condition.

Module-to-module mismatch

Figure 4 shows the mismatch for all modules for a given irradiance condition. The mismatch varies from –0.9% to +1.25%. A static or passing cloud or any other realistic condition could increase the mismatch. This is where module electronics can pay off.

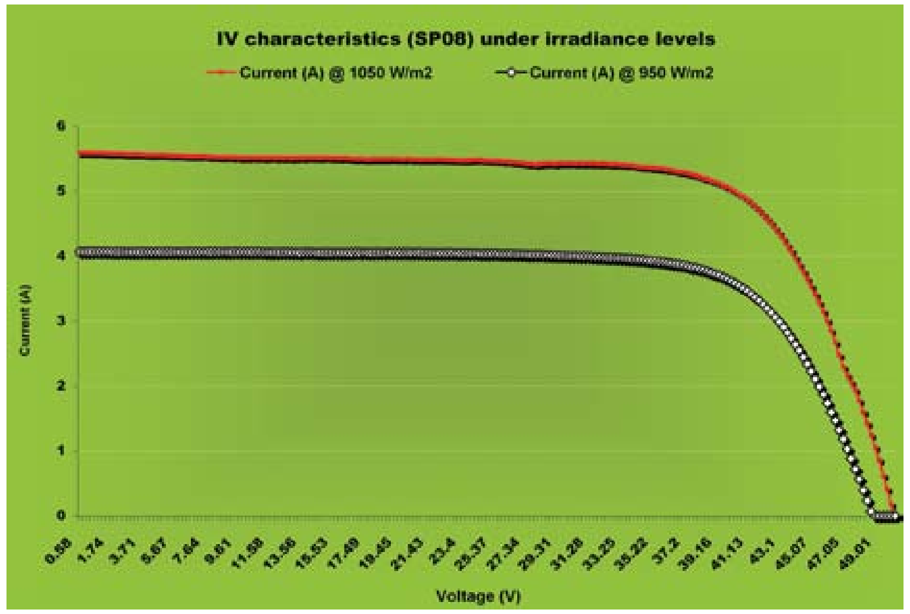


Figure 3: IV curve under different irradiance conditions.

Under no mismatch condition, total maximum power from an array (eight modules connected in a string) is equal to the sum of the individual module power. Without module MPP and mismatch condition, the total maximum power delivered by the array is always less than the sum of the individual module's maximum power because some modules are operating below their maximum power point. Under irradiance condition of 1015 W/m^2, taking the array connecting modules SP01–SP08, the percentage mismatch is 2.4 percent, or a loss of 37W.

Module electronics advantages

Many small and some large companies use module electronics to improve energy performance and monitor / manage the solar module. Module electronics fall into two categories: micro-inverters (dc/ac), or micro-converters (dc/dc). A micro-inverter converts the power so it can be applied directly to the ac-line to connect to the utility grid. Alternatively, a micro-converter converts the variable current from the PV module to match the common output current shared with other modules in a series string connection. The combined string output is used by a larger string or central inverter to deliver ac-line power to the grid. For either a micro-inverter or a larger central inverter, an operating grid offers infinite demand. Irrespective of the module electronics type, the principle is the same: operate each individual solar module at an IV point that delivers maximum electrical power for a given level of solar irradiation.

PV modules produce a relatively constant output voltage for a given temperature. However, their output current varies with irradiation. When connected in a typical series string configuration, the string current is constant for each module. This is not a problem, if all the modules have the exact same IV output characteristic and are exposed to the same level of solar irradiation.

Nevertheless, if PV modules' are different, or current generated by one or more of the modules differs due to shade, the whole string output is impacted because the modules have limited compliance to accommodate any differences between the common string current and their own individual output current. This causes the output voltage from a shaded module to be significantly reduced or even reversed. Protective diodes are placed across the PV modules to prevent this. As a result, the total amount of power produced by the string drops significantly for even one module under partial shade.

Adding a micro-converter to PV modules provides two benefits:

1) It continually operates each module at maximum power point (MPP) by increasing or decreasing its module current so the product of module current and voltage remains at maximum value.

2) It converts the module's variable power produced to a variable output voltage, accommodating whatever current is flowing in the series string. This allows the MPP of each PV module to be reflected through the voltage it contributes to the string, irrespective of its IV characteristic or solar irradiance level.

Figure 5 shows a typical micro-converter block diagram that attaches to a single solar PV module. Three principal elements are: H-bridge power circuit, micro controller, and bias supply. The H-bridge power circuit provides a micro-converter the flexibility to operate in both buck (voltage step-down) and boost (voltage step-up) switching conversion modes. The buck leg is formed by the synchronous switch pair, S1–S2, and the boost leg by S3–S4. When $V_{PV} \geq V_O$, the buck leg is active. When $V_O \geq V_{PV}$, the boost leg is active. Whichever leg is active, the opposite side is idle with its top switch permanently turned on.

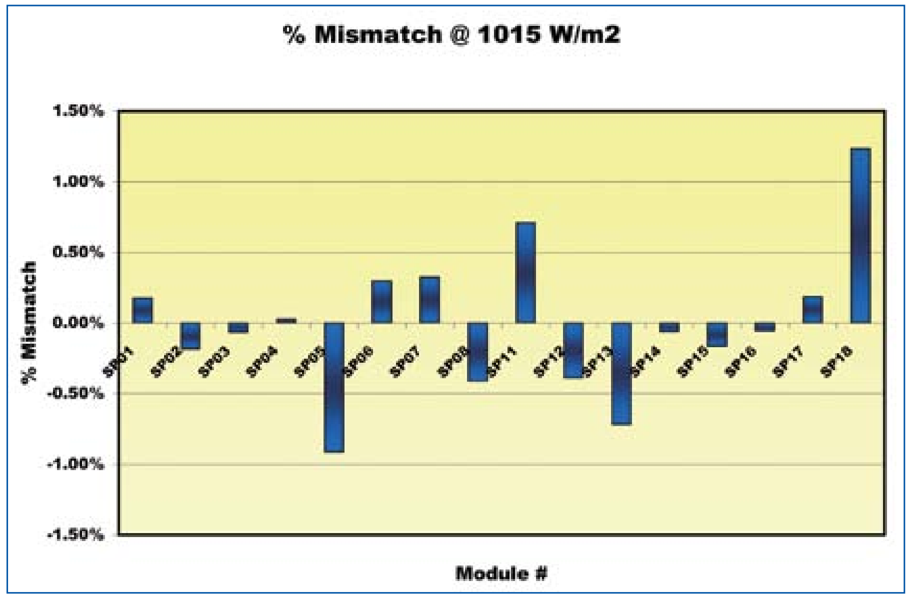


Figure 4: Mismatch at 1015 W/m^2.

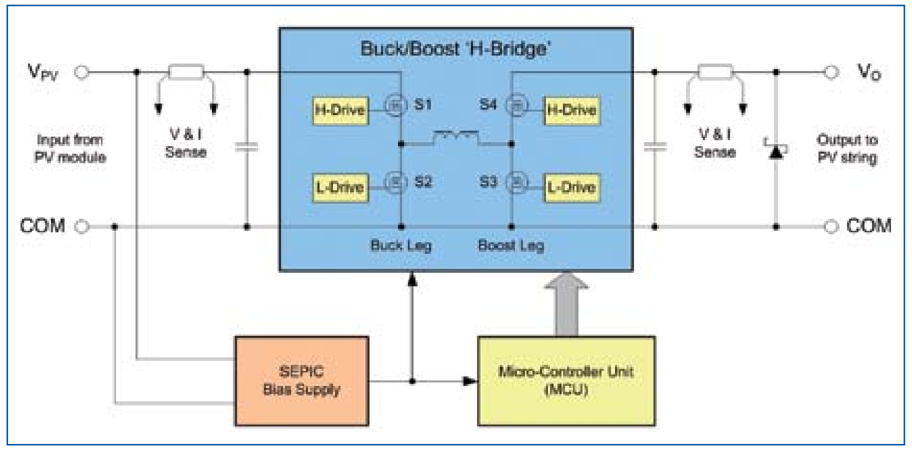


Figure 5: Solar micro-converter block diagram.

Controlling the H-bridge is complex. It has to provide a seamless transition between buck and boost conversion modes, each of which has its own distinct control compensation. It must continually monitor the voltage and current at both the input and output terminals. This determines the operating mode, as well as the IV condition that correlates to the module's MPP. Performing maximum power point tracking (MPPT) makes this an appropriate application for embedded digital control. A microcontroller unit (MCU) is in Figure 5. The power conversion must be done at a very high efficiency.

Several methods are used to identify the MPP for a PV module. Techniques include simple constant voltage operation, perturb & observe (P&O), and methods that calculate the MPP using additional module temperature and solar irradiance measurements. The two most popular methods provide good accuracy using just the VPV and IPV module measurements during normal operation: the optimized P&O and incremental conductance.

Optimized P&O averages several module power samples, while perturbing the module current. It uses this information to identify the operating point and dynamically adjust the perturbation magnitude and direction. This method provides the best performance versus cost.

The incremental conductance method compares the instantaneous conductance (I_{PV}/V_{PV}) to the incremental conductance (dI_{PV}/dV_{PV}). When the I_{PV}/V_{PV} $= -dI_{PV}/dV_{PV}$, the PV module is operating at its MPP. Basically, the system increments and decrements the module current to find the point where there's a proportionate change in the module voltage. This method offers the best performance at high irradiance levels, and has a fast response to rapidly changing conditions. However, it is not as accurate as the optimized P&O at low-irradiance conditions (<30 percent).

The economic benefit of module electronic assemblies can be analyzed only in terms of recovered electricity cost. Energy recovered for the entire string as a result of one mismatched or shaded module can be significant. A micro-converter can recover as much as 50 percent of the power from a partially shaded module whose voltage contribution might otherwise be reduced to zero. While a shade condition might exist for a couple hours during the day, mismatched modules are a permanent condition. Once you estimate the amount of energy recovered, savings can be calculated in dollars. Equation 1 calculates the annual savings G ($), from ESAVED or the energy recovered per day (kW h), and RATE or the local electrical tariff ($/kW h):

$$G(\$) = 365 \times E_{SAVED} \times RATE$$

Electrical savings must be offset by annualized cost of the module electronic assembly. The loan installment to purchase the assembly, A ($), assuming it is paid off over its useful life is calculated using the capital recovery factor (CRF) in Equation 2:

$$A(\$) = PE(\$) \times \frac{i \cdot (1+i)^n}{(1+i)^n - 1}$$

Where, PE ($)=initial cost of assembly
i = interest rate (APR% ÷ 100)
n= loan term or useful life in years

In the final analysis the economic justification requires that A ($) ≤ G ($).

Example: Assuming energy recovered per day is 0.06 kWh, Equation 3 shows the break-even cost for a micro-converter assuming fixed 12¢/kW h local retail tariff, and a loan interest of seven percent APR over a 25-year lifetime? (See Equation 3)

$$PE(\$) \le 365 \times E_{SAVED} \times RATE \times \left[\frac{(1+i)^n - 1}{i \cdot (1+i)^n}\right]$$

Answer: PE($) ≤ $30.63

This evaluation is the benefit provided by just one module electronic assembly fitted to one PV module in the string. Figure 4 reflects the typical benefit a micro-converter provides in a good installation and after accounting for power conversion efficiency. It is equivalent to three-to-seven percent of the module' s total energy generated. The amount recovered is higher in the string for adversely mismatched modules or those periodically in partial shade.

Safety, monitoring and management benefits

Once module electronics are added, they can provide other functions beyond power conversion and MPPT such as safety, monitoring and management. In a traditional string installation the individual string series elements can not be disconnected in the event of a fire. The local fire department knows to disconnect the grid, but this only turns off the string inverter output. Many cities have inspection requirements for proper installation, but disconnects are not currently required. At some point as system numbers increase awareness kicks in and insurance companies get involved. MCU-controlled systems can accommodate these regulations.

Monitoring and management are desirable functions. Module problems like fouling the module surface or encroaching shadows from trees and new construction can be detected and service can be requested.

Conclusion

Is the solar energy glass half full? It depends on your perspective. If you only look at the cost per watt, it does not compete well and likely will not get there soon. However, if you consider the smart grid and the ability to manage many distributed power sources of intermittent performance, then solar energy may be the answer. Installing a 4kW solar system on your house or business is certainly more attractive than installing a 4kW pulverized coal plant. Solar when combined with energy efficient use can be even more attractive. Solar energy is not new, but the attention it is getting is. Previously, installation focused on cost with little concern for management at a module level. When the integrated module electronics is brought down to a cost of about $30, then solar module management will become accepted. We think the glass is half full and well on its way to adding more in the glass.

For more information about solar energy, visit: http://www.ti.com/solar-ca

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Managing Multiple Supply Voltages

Reliable reset generation for TI TMS320C6XXX ('DaVinci') processors

Modern fabrication technologies facilitate the acceleration of processor throughput by enabling the integration of board-level functions, such as SERDES interface, memory interface and multiple types of processors, on a single chip. One of the direct results of fine transistor geometries is lower core power supply voltages, such as 1.2V. However, peripherals require their own power supply levels, depending on the communication interface type. As a result, multiple supply voltages are required to power these devices. Texas Instruments' fixed and floating point DSPs, like the TMS320C6x family, also require multiple supply voltages.

By Shyam Chandra, Product Marketing Manager for mixed signal products, Lattice Semiconductor

Every microprocessor or DSP requires a reset generator circuit or IC to perform two functions: (1) start up from a fixed condition after the supplies are turned on, and (2) prevent the processor from mis-executing instructions and causing flash memory corruption when their power supplies are lower than the specified operating level. Traditional, simple, single-supply reset generators were adequate for single supply processors, but no longer are sufficient to guarantee reliable operation of multiple supply processors like the TMS320C6x. This article examines some of the challenges associated with resetting modern day processors.

TMS320C6XXX Processor power requirements

Increasingly, newer members of the TMS320 DSP family integrate multiple peripherals within the processor chip. Because of these peripherals, these processors have additional power supply requirements. For example, the integrated DDR memory interface requires a 1.8V supply and a 0.9V reference voltage for a SSTL18 interface. In addition, all processors require a standard 3.3V I/O interface supply and core power supply.

The TI Design Guide for the TMS320 DSP specifies that the core power supply be capable of sourcing 1.0V, 1.05V, 1.1V, 1.14V, 1.2V or 1.26V to be compatible with future releases of the devices. The voltage rating of these supplies should be 3%. In addition the reset generator is required to wait for the clock to be stable before releasing the reset.

Most TMS320 processors also provide emulation support. As a result, two types of reset signals must be provided:

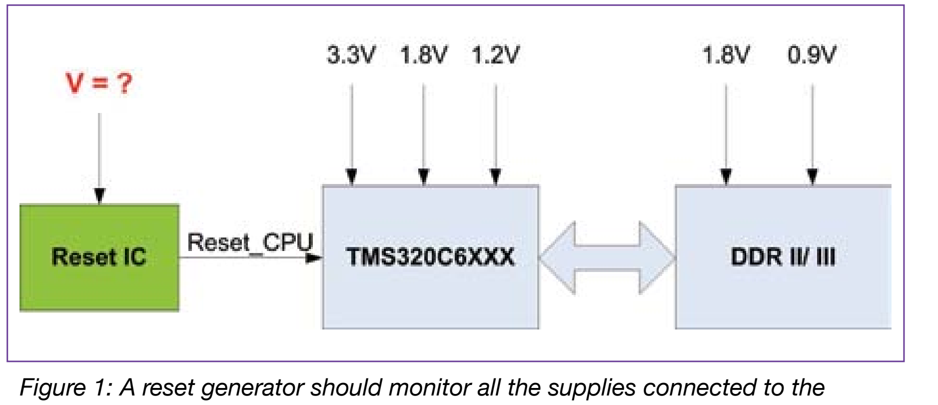

Figure 1: A reset generator should monitor all the supplies connected to the processor and memory.

Power on reset (POR pin) and Warm reset (RESET pin). The Power on reset signal is activated when both the processor and the emulation sections are to be reset. The Warm reset, however, resets only the processor and not the emulation section. The reset generator should support both reset signals. The datasheet also specifies that the Warm reset (RESET pin) should be activated when an external watchdog timer expires.

Traditional reset generation circuit drawbacks

A traditional reset generator IC has one analog voltage monitoring input and a digital output that resets the microprocessor. The threshold is set 5% or 10% below the nominal voltage level. For example, the threshold voltage of a reset generator monitoring a 3.3V supply is 3.3 – 10% = 3V. This device holds the processor in reset condition until the supply voltage is above 3V. During operation, the reset generator reactivates the reset signal of the processor when the supply voltage drops below 3V. This is fine for a processor that requires only a 3.3V supply.

Figure 1 shows a TMS320 processor connected to a DDRII memory interface. As a result, there are four supply voltages in this system: 3.3V, 1.8V, 1.2V and 0.9V.

A single supply reset IC clearly cannot deterministically reset the processor. This system requires at least 3 supply monitoring reset ICs. The most reliable system will require monitoring of even the 0.9V supply.

Need for higher monitoring accuracy

Typical range for the core supply voltage for a processor (e.g., 1.2V) is +/-5%. The reset generator should monitor for a voltage of 1.14V. So, a reset generator with 0% error will be able to monitor a voltage of exactly -5%. But if the error of the reset generator is 1%, it will activate the reset to CPU from 1.2V-4% to 1.2V-6%. Usually this is acceptable. But if the reset generator has an error of 3%, then it will flag errors from 1.2V-2% to 1.2V-8%. So, it will flag error prematurely and, with potential danger, allow the processor to operate when its supply is faulty.

In order to reliably reset the processor, the reset generator should monitor all supplies with an accuracy of 1% or better to meet the specifications of the processor.

Internal or external watchdog timer?

The TMS320 processor provides a 64-bit watchdog timer to support a wide range of watchdog timer delays. This watchdog timer value is set by software to a required value during the initialization phase. However, many designers feel that an external, slower hardware watchdog timer, which cannot be changed by the processor; is necessary as a backup The backup watchdog timer reactivates the processor in case the on-processor watchdog timer setting is corrupted due to software misexecution .

An ideal companion device for modern processors and DSPs is one that integrates multiple supply monitoring and reset generation and provides reprogrammable logic and timers. This is because such a device increases reliability by providing expanded supply monitoring, external watchdog timer circuits and improved accuracy.

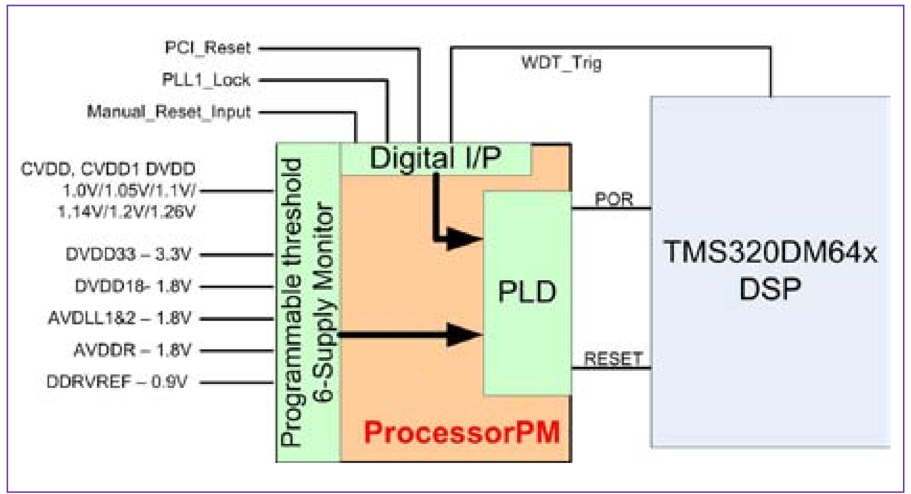

Figure 2: Reset generation for a TMS320 processor using ProcessorPM.

Proposed reset generation circuit

Here is a summary of the requirements for a reliable reset generator for a TMS320C6XXX ("DaVinci") processor:

- Wait for all four supplies and clock present signals before releasing the power on reset (POR pin)
- Activate Power-on reset if any of the supplies are below their respective thresholds, or if the clock is removed
- After power on, if manual reset input is activated, activate only the warm reset (RESET pin)
- If the watchdog timer expires, activate warm reset (RESET pin)

All these features are supported by Lattice Semiconductor's ProcessorPM POWR605 device. Figure 2 shows the reset generation for a TMS320C6XXX ("DaVinci") processor.

The ProcessorPM device is a low-cost, 6-supply voltage monitoring device with two digital inputs and five digital I/O pins. The logic to control the output pins is implemented in the on-chip 16-macrocell PLD. The ProcessorPM device can be used as a standard reset generator and watchdog timer IC across a wide range of processors and DSPs. The ProcessorPM device also integrates multiple timers, which can be used to implement watchdog timer delays of milliseconds to minutes. Board-specific design can be programmed into the device using the JTAG interface.

The voltage monitoring thresholds can be programmed into the 6-supply monitor block. The exact value of the monitoring threshold can be selected using 192 steps. The accuracy of the voltage monitoring thresholds is 0.7%. In this example, the thresholds are set to 0.9V-5%, 1.8V-5% (3 separate supplies), 3.3V-5% and 1V-5%. The core voltage threshold can be changed to meet the actual core voltage value, depending on the version and speed of the processor.

The digital inputs of the ProcessorPM device are connected to manual reset input, PLL_Lock signal (input clock frequency is correct), PCI_reset and watchdog timer trigger. The ProcessorPM device generates the POR signal as well as the RESET signal. The PCI_Reset and the Manual Reset input signals activate the RESET signal. The RESET signal is also activated when the watchdog timer expires. The POR signal is activated during power-up and power fault conditions.

Software-based design and evaluation hardware

Reprogrammable devices like the ProcessorPM are designed via software tools rather than static external circuits like pin straps. Software interfaces provide a means to vary threshold voltages, watchdog timer period and output logic. This ensures the device can be adapted to various TMS320 models. This versatility is attractive both to designers and procurement managers who are seeking ways to reduce the variety of power management devices to be stocked and qualified. The ProcessorPM provides a JTAG programming interface, making in-system changes easy.

ProcessorPM designs can be implemented with Lattice's user friendly, intuitive PAC-Designer software. This software also supports simulation capabilities that let the designer verify the design before programming the device. The PAC-Designer software can be downloaded for free from the Lattice semiconductor website.

The ProcessorPM Development Kit can be used to verify the design in hardware before implementation in the actual circuit board. The development kit also is available from the Lattice on-line store.

Advantages of the proposed reset generation solution

Multiple single voltage reset generator ICs are required to provide a reliable reset solution for the TMS320C6XXX ("DaVinci") processors. The drawback of most low-cost off the shelf single supply ICs is unacceptably high voltage monitoring error. Accurate voltage supervisor ICs are expensive. Designers have to use a different reset generator IC to monitor different core voltages, depending on the version and speed of operation of the TMS320C6XXX (DaVinci) processors.

The ProcessorPM devices provide the most reliable, low-cost, single chip solution as they cover all the supply rails for accurate fault monitoring and offer multiple outputs to support Power-on-reset and Warm reset functions. In addition, the same device can be used to monitor a different core voltage when a different TMS320C6XXX processor is used.

www.latticesemi.com

Power Supplies

Optimizing Operation Under Real-World Conditions

Clock sources with integrated power supply noise rejection simplify power supply design in FPGA-based systems

By their nature, FPGAs are power hungry devices with complex power delivery requirements and multiple voltage rails. A single chip commonly consumes multiple watts of power while operating from 1.8V, 2.5V and 3.3V rails. Activating high speed on-chip SERDES can increase power consumption by several watts and complicate the power delivery strategy. When FPGA power consumption increases, performance requirements on sensitive analog and mixed-signal subsystems also increase. Chief among these are the clocking subsystems that provide low jitter timing references for the FPGA and other board-level components.

By Juan Conchas, Timing Marketing Manager, Silicon Laboratories

Power hungry systems cannot be free of power supply noise. In general, system designers try to use low noise linear power supplies whenever possible. However, excessive power dissipation usually prevents the use of linear regulators. When using a linear device, regulating from 3.3V input to 1.8V output is only 54% efficient regardless of the load current. Low conversion efficiency burns power in the regulator instead of the load and makes linear devices unsuitable for many high performance applications.

The use of low dropout regulators (LDOs) helps improve efficiency by reducing the input to output voltage difference that the regulator produces. For example, 2.5 to 1.8V regulation yields 72% efficiency for all loads. This is generally a good practice for loads up to 500mA. However, when the load consumes 1 to 3A of current, LDOs are less helpful. When a regulator enters dropout, it no longer regulates effectively. Its pass element behaves like a resistor, unable to respond to changes in load current or input voltage. This effect diminishes the noise rejection of the regulator, defeating the purpose of using it to provide power to sensitive circuit blocks. To maintain good regulation and noise rejection, LDOs must be powered by considerably higher input voltages than their dropout specification dictates, decreasing efficiency. To avoid dropout conditions, multiple LDOs can be placed in parallel to reduce the load current through each regulator. Complicated and costly, this alternative is not an attractive solution.

A more practical way to increase efficiency and maintain regulation over a wide load current range is with the use of switching regulators. The high 85 to 95% efficiency of switching regulators often makes them the only power conversion alternative for FPGAs. The boost in efficiency comes with a noise penalty, with as much as 50 to 100mVp-p of peak-to-peak voltage ripple. Due to the high power consumption of FPGA logic and I/O, switching ripple lower than 50mVp-p is generally expensive and impractical.

Another noise source is the FPGA itself. The fabric system clock may run at tens to hundreds of megahertz. When high power digital logic operates, it generates noise transients that ripple through the various power planes. Fast transients create high energy spurs that power supply filters struggle to smooth out. Since most power supply decoupling is optimized to present low impedance around one or a few frequencies, it is difficult or even impossible to clean up all high frequency noise on the power supply rail. This noise tends to propagate to other subsystems through the power supply, especially those in close proximity with the FPGA.

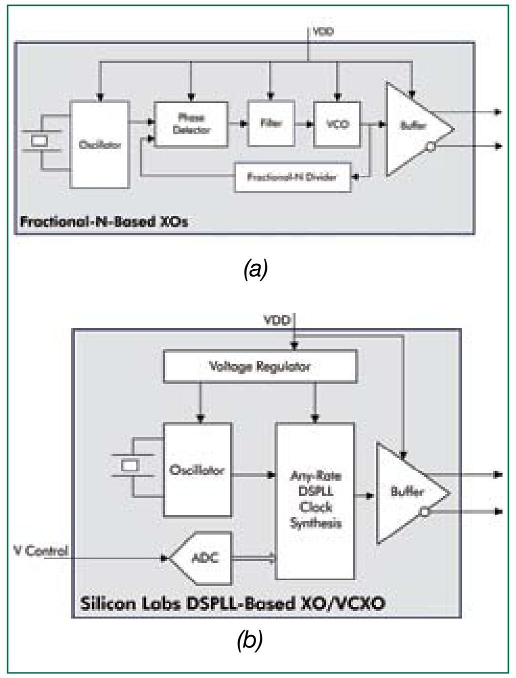

Figure 1: (a) The most common way to generate high frequency clock signals, the fractional-N based XO has multiple VDD vulnerabilities. (b) The Silicon Labs Si5xx DSPLL-based XO/VCXOs employ an all-digital approach with on-chip regulation that rejects noise on the power supply and eliminates sensitive VDD nodes.

FPGAs present another challenge. When blocks of logic or I/O switch between low and high power operating states, the load current fluctuates dramatically. As the logic blocks enter a high power operating state where the logic undergoes intensive processing, the power supply tends to experience a load droop. As the logic block transitions to a lower power state, the load droop disappears and the power rail returns to a nominal state.

Multiple events can create such a load droop and the overall interaction of these events is generally impossible to predict or control. Such load variation creates a low frequency envelope on the rail that is generally much less than 100kHz. This noise envelope can be cleaned up using additional regulators, but this adds cost and board space and may reduce power supply operating margin.

For these reasons, sensitive analog components tend to present a challenge when sharing the same power rails as FPGAs. In many cases, users may experience unexplained performance degradation or anomalous, unpredictable behavior. The traditional solution is to isolate each sensitive timing subsystem on its own power island using linear regulators to filter low frequency noise and extensive LC filtering using ferrite beads and ceramic decoupling capacitors to cover higher frequencies. However, this is not an ideal solution because it adds cost and increases layout complexity. Further, it breaks up the power planes, reducing their effectiveness in providing low impedance and tightly coupled ground return. A better solution is to maintain a continuous power plane that remains as intact as possible throughout the board. However, in order to take advantage of this, each subsystem must be able to tolerate noise on the power supply.

Today's FPGAs depend heavily on low jitter clock sources to meet end application requirements. FPGAs may drive backplanes, optical modules, or GMII/XGMII interfaces, all of which require extremely low jitter timing references. Operating in the noisy environment that FPGAs create has become a major challenge for FPGA reference clocks.

Figure 1a and Figure 1b shows two types of crystal oscillators. Crystals have been used for decades to set the heartbeat of most electronic systems. They provide low phase noise, good frequency accuracy, and adequate performance for many high performance applications. Despite these advantages, crystals have a major limitation: Fundamental frequency oscillation is limited to frequencies lower than 50MHz. For most high performance applications, the crystal must be followed by a PLL that multiplies the low frequency reference by the appropriate amount to generate the output frequency of interest. PLLs are used to multiply the initial frequency by an integer value such as 3 or a frac-

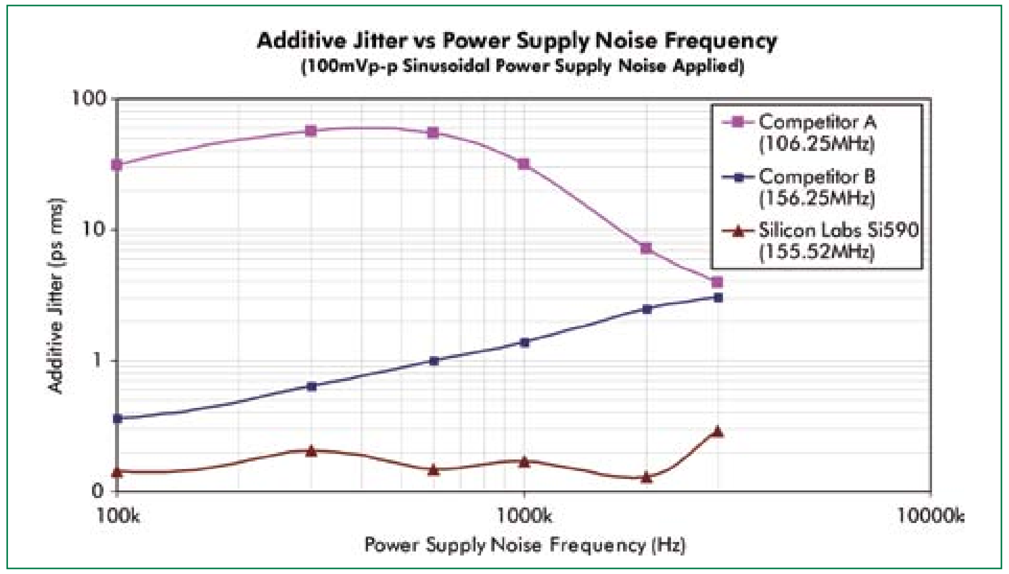

Figure 2: Many XOs have sensitive VDD inputs and struggle to meet output jitter specs in noisy environments. Two traditional XOs with 1ps and 0.9ps maximum data sheet jitter specifications violate spec, adding up to 50ps of jitter with 300kHz noise ripple. The Silicon Labs DSPLL-based XO/VCXOs adds less than 1ps of jitter under all power supply noise conditions.

tional value such as 3.125.

The fractional-N topology of Figure 1a is comprised of a crystal oscillator followed by an analog phase detector, analog compensation filter, analog VCO, and a fractional-N feedback divider. The output frequency equals the input frequency scaled by the ratio 1/N. A low noise buffer is used to drive the external load circuitry. Many applications such as Gigabit Ethernet, Fibre Channel, and High Definition Serial Digital Video (HD-SDI) rely on low jitter clock sources with output frequencies ranging from 100 to 156.25MHz. Under ideal supply conditions, a fractional-N PLL can be designed to provide good jitter performance of less than 1 ps RMS integrated over the 10 kHz to 20 MHz band. In contrast, in an environment with a noisy power supply, an oscillator may struggle to meet the phase jitter specified in the datasheet. Using analog sub-circuits creates vulnerable nodes where noise can be injected. When noise enters the system, it often becomes amplified, generating output phase jitter.

In contrast, the Silicon Labs DSPLL-based approach uses digital processing to implement a PLL that multiplies the crystal reference frequency to a higher frequency. The crystal is never pulled. All frequency control and trimming is carried out using digital commands. The compensation filter is based on a digital signal processor that does not use capacitors or other passive components. Finally, the VCO is controlled digitally without using analog circuitry. To offer additional VDD isolation, an on-chip linear regulator and in-package power supply decoupling capacitor are used to further ensure noise rejection. Due to these advancements, every Silicon Labs DSPLL-based XO/VCXO has the ability to generate high frequency clock signals with sub-picosecond jitter performance in noisy real-world environments.

Figure 2 shows the power supply rejection ratio performance of fractional-N PLL-based XOs compared to Silicon Labs DSPLL-based XOs. Although fractional-N PLL-based XO is rated to achieve 0.9ps maximum RMS jitter, suitable for high data rate FPGA SERDES, the rated specification applies only in ideal environments. With 100mVp-p of power supply noise, competing solutions generate up to 40 ps RMS of additive jitter, becoming unusable in high-speed serial links. Silicon Labs DSPLL-based XO/VCXO products do not suffer from this limitation, adding only 0.1 to 0.3ps RMS of jitter across the tested frequencies.

Other DSPLL timing devices offered by Silicon Labs are low jitter integrated PLLs used for jitter attenuation and clock multiplication. These devices also employ a DSPLL-based architecture that eliminates VDD noise sensitivity. When using the Si5xx XO/VCXOs or Si53xx family of any-rate clock multipliers, designers can take advantage of high efficiency switching power supplies while maintaining excellent jitter performance. In addition, designers are free to implement continuous power and ground planes without the need to sprinkle linear regulators around the board, offering the lowest impedance, least interrupted ground plane design. On-chip power regulation enhances system performance, minimizes board area, reduces system cost, simplifies design and improves time-to-market.

In conclusion, today's FPGA–based designs require improved clocking with greater immunity to power supply switching noise observed in real-world applications. With low jitter that meets high speed serial link requirements and integrated power supply noise rejection that optimizes operation under real-world conditions, Silicon Labs' family of DSPLL-based clocks and oscillators is an ideal complement to FPGAs in high performance applications.

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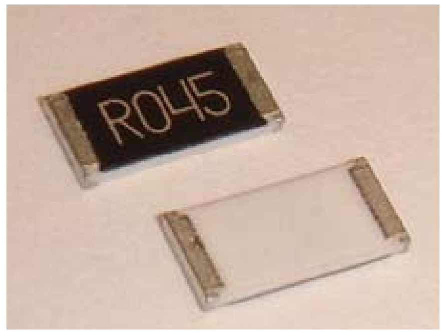
Current Sensing Solutions

Surface mount current sense resistors for power system design challenges

Current sense resistors remain one of the largest growth areas in the resistor market today. As power systems continue to push the technological envelope for higher power ratings, better electrical stability, smaller chip sizes, and lower component counts, current sense resistors help enable designers to create more powerful devices in smaller packages at a lower cost.

By Kory Schroeder, Director of Marketing, Stackpole Electronics Inc

The three main surface mount current sense resistor technologies all have their strengths and weaknesses that must be carefully weighed by the power system designer to ensure the proper component is chosen for a given set of design parameters.



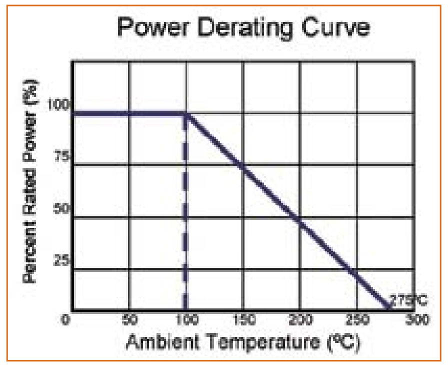
Thick film technology is the most commonly used current sense resistive element today, mainly due to its low cost and high availability. Thick film processes have been greatly improved in the recent years, such that the only major cost drivers for thick film current sense chips are the specialized low TCR and high power handling thick film materials. A major strength of thick film current sense chips is the ability to achieve small case sizes. The portable PDA, cell phone, and MP3 player market continues to strive for higher efficiency and smaller case sizes. These two needs are at odds with each other. Higher efficiency means lower resistance values required to minimize the power lost during the current sensing operation. However, these low resistance values are limited as the chip size is reduced. At higher resistance values, the efficiency drops as the power dissipated in the current sense operation increases. Higher power dissipation makes it difficult to use small case size chips without exceeding the temperature handling limits of the resistors and of the PCB.

Another property of thick film current sense chips that can be beneficial is their inherent fusible performance under excessive overloads. This could provide a level of protection for both the power supply circuitry as well as the rest of the electronics. However, film resistors will begin to degrade if subjected to significant overloads even if they don't fail. With each successive pulse, more of the film is compromised, usually in the form of lower resistance values. This shift in resistance value lower leads to increased current through the part during successive overloads which causes increased heat generation and more damage to the film until ultimately the film is completely burned away and the device fails open. Surge handling for metal plate resistance elements is much better because of the relatively higher mass of resistance element. The other major weaknesses of thick film current sense chips are the limited ability for precision, electrical, and environmental stability. Commodity current sense chips will typically have TCR's of 200 ppm / degrees C to 500 ppm / degrees C. This means that for temperature fluctuations of 100 degrees C, which is not uncommon in some high power system designs, the current sense resistor value can fluctuate by 2% to 5% respectively. While many commercial and consumer devices can allow for and design around such fluctuation, many power systems simply don't have that much tolerance built into them.

Size	Lowest R	Future Development	TCR
0402	0.02	lower resistance values will require longer term development	200 ppm
0603	0.02	0.01 ohms available in 3 to 6 months	200 ppm
0805	0.01	0.005 available in 6 to 9 months, (with metal plate technology)	50 ppm

Metal plate resistive elements provide a good combination of low resistance values, electrical precision, high power handling, surge handling, and high temperature handling. This technology is the best choice when low resistance values are required along with very low TCR's such as 25ppm / degrees C to

50ppm / degrees C or when tolerances less than 1% are needed. Thick film materials simply can't match that stability at low resistance values, mainly due to the necessity of using high TCR metals in the thick film inks. Thin film current sense chips can also achieve low TCR's and tight tolerances, but their resistance values are limited usually to 50 milliohm and higher. Use of a solid piece of metal provides a very robust resistance element in terms of high temperature handling as well. Unlike thick film and thin film resistive elements, metal plate elements can operate up to 275 degrees C safely and some can remain at full rated power up to 100 degrees C.



This ability to handle high temperatures makes them ideal for higher power current sensing applications of 3 watts and higher. High continuous and surge currents which would quickly fuse a film resistive element are no problem for a metal plate based current sense chip. For example, a 2 watt 2512 size chip with a 5 milliohm resistance value can withstand 20 amps continuously whether it is a film element or a metal plate. However, any surges that may occur would cause significant degradation to the film element while the metal plate chip would experience very little resistance shift at all. This robust performance however requires consideration for over power conditions; the metal plate chip will not fuse, so the temperature will continue to increase until the board or neighboring components begin to burn. Power systems with this potential issue can be protected either with a PTC thermistor or resettable fuse. Metal plate current sense chips are typically more expensive than most thick film based chips to such a degree that if there are no high temperature, low TCR, or tight tolerance requirements, thick film current sense chip are usually chosen first. Because they are entirely metal, they are unable to achieve resistance values above 0.2 typically. Finally, metal plate resistors are difficult to make in small chip sizes. It is difficult to find many manufacturers with metal plate based elements smaller than 1206 and chip sizes smaller than 0603 are currently non-existent.

Thin film resistive elements are relatively new to the current sensing resistor market. Thin film resistors are well known for their ability to achieve low TCR's and tight tolerances. What they have not been known for in the past is low resistance values. However, recent technological developments have allowed the use of thin film materials for resistance values down to around 50 milliohm. Thin film technology also lends itself well to smaller chip sizes, currently down to 0402 with 0201 in development. Typically, thin film current sense chips have lower power ratings for a given chip size. This means that using thin film resistors for current sensing requires consideration for power loading to ensure the devices are kept in a safe zone of operation. Thin film current sense chips can bridge the gap between low cost thick film current sense chips with limited tolerance and TCR capability and metal plate based chip resistors with limitations on high resistance values and limited ability to do small case sizes. Time will tell whether this technology will become a significant factor in the current sense chip resistor world.

Whatever the power system design calls for, the resistor market has responded with technological advances and improvements. For small size, low cost, and relaxed electrical stability, thick film technology continues to push for lower resistance values in smaller case sizes while improving the TCR on the existing value range. For high power, high temperature, and high stability, metal base current sense resistor elements are under development in smaller case sizes, in lower resistance values, and even in larger case sizes with the ability to handle 5 watts. But it is clear that current sensing is still the preferred method of power management by most power system designers.

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Selecting the Right Power Module

flowSEL – enhancing the designer's toolkit

Vincotech already offers a very powerful tool for the simulation of power modules under operating conditions with its successful flowSIM. But what about finding which power module is the right one for a given application? For motor drive applications, the tool flowSEL offers an easy way. Based on a short list of application parameters, flowSEL returns a useful selection of suitable power modules.

By Andreas Johannsen, Product Marketing Manager, Industrial Products, Vincotech

The market of power semiconductor components offers a broad selection of solutions for industrial drive applications from different suppliers and with different characteristics. For example Vincotech, a German power module supplier, offers about 20 different product families of standard frequency inverter applications, with about 120 different modules. How does the designer choose the right solution for a given application?

The common way is to compare the data sheets of different modules. But if you have the choice between a few dozen modules, this will certainly be a very drawn-out activity. Another issue is the dynamic characteristics of motor drive applications. The behaviors are changing several times a second and depend on several external influences. To check if a power semiconductor achieves all the requirements is only possible by doing complex calculations. Doing this manually is very time consuming and exhausting.

SPICE – The universal approach

One way to solve these issues is the usage of simulation tools. A very common tool for simulation of electronic circuits is SPICE. It contains numerical models of electronic components and enables the possibility to simulate electronic circuits under dynamic conditions. The first issue is to get accurate numeric models of the used power semiconductors. Only a few suppliers are offering SPICE models of their products. Another issue is that SPICE is a very universal tool. For an accurate simulation, the whole application has to be reproduced in SPICE. For power semiconductor applications not only the electronic, but also the thermal behavior is very important. To build up a complete electrical and thermal model of a motor drive application in SPICE might be a very complex challenge. Another issue is the needed simulation time. The switching time of an IGBT is a few nanoseconds. To make conclusions about the thermal characteristics of a power module multiple seconds have to be simulated. According to the Nyquist –Shannon sampling theorem, a few billion of simulation steps have to be proceeded to get an adequate result which results in extensive simulation time.

Proprietary simulation tools – The better choice

Some suppliers of power components providing simulation tool, which are customized for the special requirements of applications for power semiconductors. An example is *flow*SIM from Vincotech. It contains the characteristics of most of their power modules by measured data. This makes it possible to create very accurate simulations with all important parameters of a typical power module application at very comprehensive simulation time. The short simulation time allows the simulation of multiple modules at different application parameters and still maintaining the development schedule.

***flow*SEL – The combination of simulation and selection**

With tools like *flow*SIM, the simulation issue seems to be solved and the module verification can be done early at the design cycle before even building up hardware. But how to know which of the dozen of power modules that can be simulated are the most promising for the given application? To answer this question Vincotech offers a very unique tool called flowSEL. It's focused on the selection process of power modules for motor drive applications. To get a list of usable power modules only a few application parameters are necessary. (See also the box at the upper left side of Figure 1).

- DC link current
- Inverter switching frequency (PWM frequency of the power semiconductors)
- Output frequency (motor frequency)
- Output voltage (RMS motor voltage)
- Output current (RMS motor current)
- Motor power factor (ratio between effective and apparent power)
- Heatsink temperature

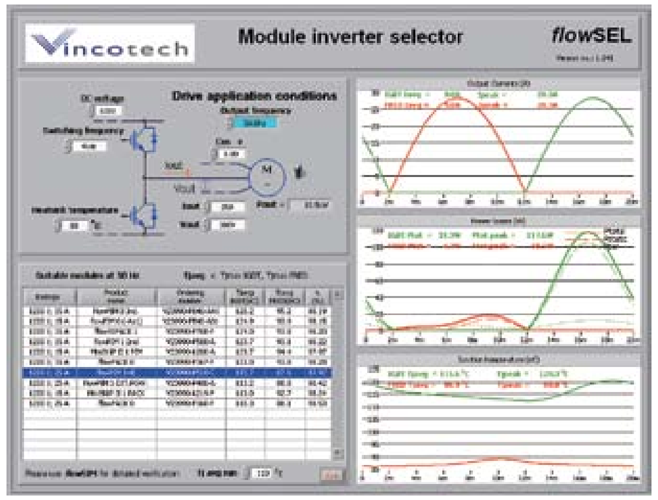

Figure 1: The flowSEL screen.

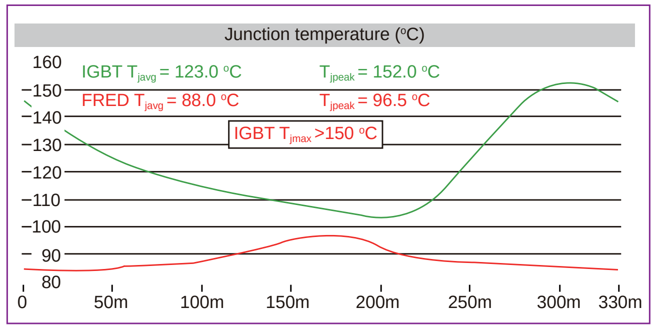

Figure 2: Tj max warning.

Based on these parameters and the measured semiconductor characteristics stored in the tool, flowSEL creates a list of usable power modules in real-time. The items in the list display module name, order code, nominal chip ratings, the averaged surface temperature of the IGBTs and FREDs and the efficiency of the power section simulated (ratio between input and output power). The rectifier stage is not simulated, as it is normally not the limiting factor within a power module.

$T_{j\,avg}$ – The yardstick for the power module

By selecting a module from the list, the graphs on the right hand side are showing the current, power loses and junction temperature of the IGBT and FRED over the time of one phase (see Figure 1). This enables the possibility to see where the losses are generated and if the selected module fits to the application requirements. The most important criterion for the module selection is the averaged junction temperature $T_{j\,avg}$. The maximum acceptable $T_{j\,avg}$ for a power module is determined by the maximum chip rating given in the module data sheet and a certain margin for lifetime reliability normally around 25 °C. Only modules where the calculated $T_{j\,avg}$ is equal or below this value are shown in the selection table. Also important for the selection is the maximum junction temperature. The maximum recommended junction temperature again is limited by the technology of the semiconductor and given in the datasheet (generally 150 or 175°C). flowSEL shows a warning, when the calculated maximum junction temperature exceeds the recommended value (see Figure 2).

Optimize trade-off between module price and lifetime

To narrow the module selection, the minimum value for $T_{j\,avg}$ can also be specified (see value for $T_{j\,avg}$ min at the bottom left in Figure 1). The difference between $T_{j\,avg}$ and Theatsink describes the load cycles during short power cycles and the difference between $T_{j\,avg}$ and ambient Temperature describes the thermal swing during start up and long power cycles with full power swing. Therefore the higher this parameter the higher the stress for the power module will be. By increasing the minimum value for $T_{j\,avg}$ the larger modules will disappear and only smaller power modules will be shown in the short list, being closer to the predefined design limit of $T_{j\,max}$ minus 25°C Finally this results in the smallest available modules and in line normally lowest in cost still fulfilling the given limits.

Close to 0Hz - Simulation of very low output frequencies

In some power module data sheets the power dissipation and maximum current rating are specified for an output frequency of 50Hz. But for some applications, the behavior at frequencies down towards 0Hz is relevant and therefore becomes more critical. At higher frequencies, above 30Hz the load is distributed over the three phases and the maximum power capability of a module is determined by the averaged power dissipation. But if the motor moves very slowly, every single phase is stressed for a longer time. The heat can not be distributed and the junction temperature will be higher therefore these conditions need to be checked. With flowSEL it is possible to simulate motor frequencies down to 100mHz, a sufficient approximation of 0Hz conditions.

The power comes back – The motor as a generator

When a motor is slowed down, energy is pushed back into the frequency inverter. This could be also an important operating condition for industrial drives. When the motor is accelerating, most losses are generated by the IGBT. When decelerating, the current is conducted by the FRED diodes and its maximum power capability is limiting the application. With flowSEL, it is possible to switch the simulation between “Motor”-mode for acceleration and “Generator” -mode for deceleration. This enables the user to simulate both operating conditions.

After preceding the simulation with flowSEL, the customer gets a selection of power modules, which seem to be suitable for his application. In the next step the needed form factor and functionality (inverter only, inverter with rectifier, brake, power factor correction etc.) has to be selected. And with the simulation tool *flow*SIM, a more detailed simulation is possible.

Conclusion

The selection process for a power module is a challenging task. With ubiquitous tools like SPICE, the simulation costs a lot of effort and can take very long time. With *flow*SIM, the simulation can be processed in real-time with minimum effort. This enables the ability to compare several power modules under different conditions and makes the selection process significantly easier and more thorough.

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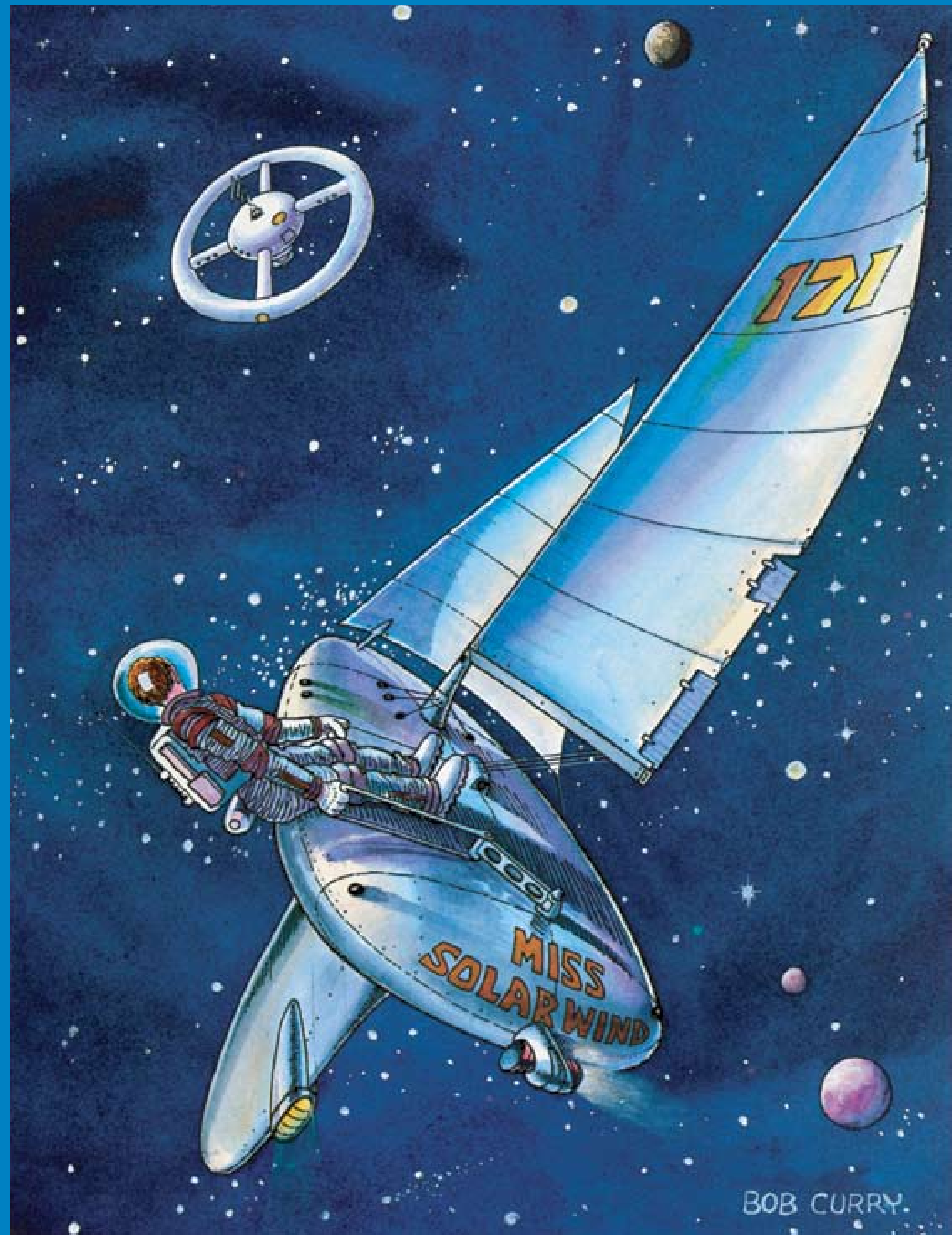

Image courtesy Omni Magazine / Bob Curry (circa 1984)

Full Power Conversion

Power semiconductors for wind turbines

The increased requirements in grid code standards, use of permanent magnet synchronous generators and the possibility to reduce wear-out of gear boxes are important factors favouring the use of full converters in wind turbines. This has been hampered in the past by limitations in the required power semiconductors. Nevertheless, recent advances in the semiconductor technologies have reduced these disadvantages and make the full converter a viable solution for wind turbines application.

By Björn Backlund, ABB Switzerland Ltd Semiconductors, Lenzburg, Switzerland

The doubly Fed Induction Generator (DFIG) is today the dominating solution for wind turbines. Since the generator must operate fairly close to the line frequency and the possibilities to control the power are limited, systems using converters for the full generated power are increasing their share of the market. This is due to the fact that the generator frequency gets de-coupled from the line frequency, enabling simplifications and savings in the mechanical drive chain including both the generator and the gear-box. In addition, the better control possibilities makes compliance with the grid code standards easier. The full converters has the disadvantage that all the power have to flow through power semiconductor devices which due to the device characteristics will have a large influence on the system performance. Recent developments in the power semiconductors have enabled the reduction of these limitations and it is now possible to build compact converter units with decent efficiency also at a switching frequency needed for an acceptable harmonic content on the output voltage.

Topologies and voltage ratings

Due to the better availability of asymmetric and reverse conducting turn-off power semiconductors compared to symmetrical devices, the VSI-topology (Voltage Source Inverter) has achieved a dominant position in the field of frequency conversion. For low voltage conversion the 2 level VSI, figure 1 to the left, is the solution of choice but this simple inverter topology is also used for medium voltage circuits. However, the voltage ratings of the available power semiconductor components remains a limiting factor, since serial connection of power devices is a complex issue with many related technical difficulties, and therefore the output voltage of the 2-level VSI with commercially available components is limited to about 2400Vrms.

To accomplish a higher output voltage without series connection of power devices other topologies are needed and the most common is the 3-level NPC inverter, figure 1 to the right which enables an output voltage that is twice as high as a 2-level inverter with the same power semiconductor voltage rating. This topology is the main solution for the Medium Voltage Drives (MVD) on the market since with existing devices it is possible to achieve output voltages of up to 4.16kV without series connection of devices and/or converters.

Power semiconductors for medium voltage wind applications

For full converters there is basically a choice between two families of turn-off devices, the IGBT (Insulated Gate Bipolar Transistor) and the IGCT (Integrated Gate-Commutated Thyristor) where the IGCT is mainly developed for medium voltage applications only.

Insulated Gate Bipolar Transistor IGBT

The IGBT is a well established device for power conversion and is available in many different types of packages, mainly with an insulated base plate and made for low voltage applications. Nevertheless, for medium voltage systems the number of possibilities is reduced to a few package types. For the comparison in figure 2 we have used the common module type HiPak. When comparing 3 different voltage ratings we see that higher voltage devices that require thicker silicon with the associated higher switching losses will have a stronger frequency dependency of the possible output power then low voltage devices. Hence, this will reduce their possible usage for applications requiring high switching frequencies.

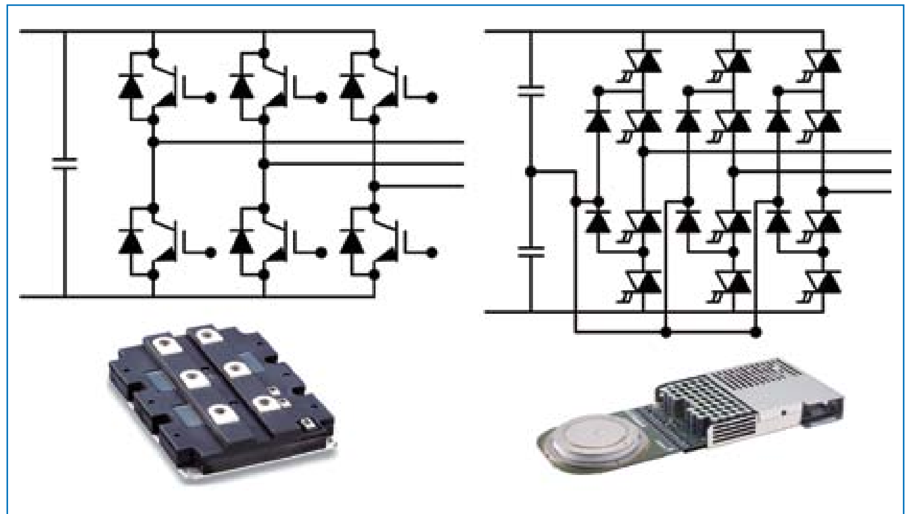

Figure 1: The 2 and 3 level topologies.

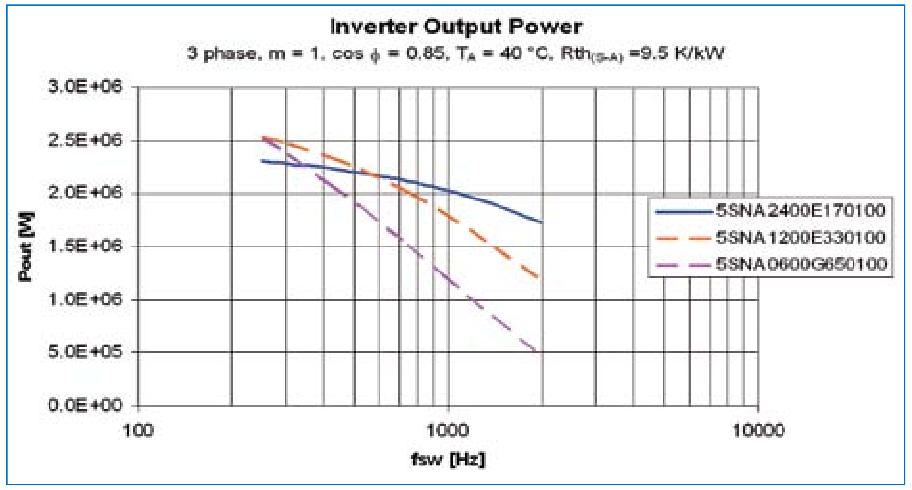

Figure2: 2-level inverter output power for HiPak IGBT modules at given conditions.

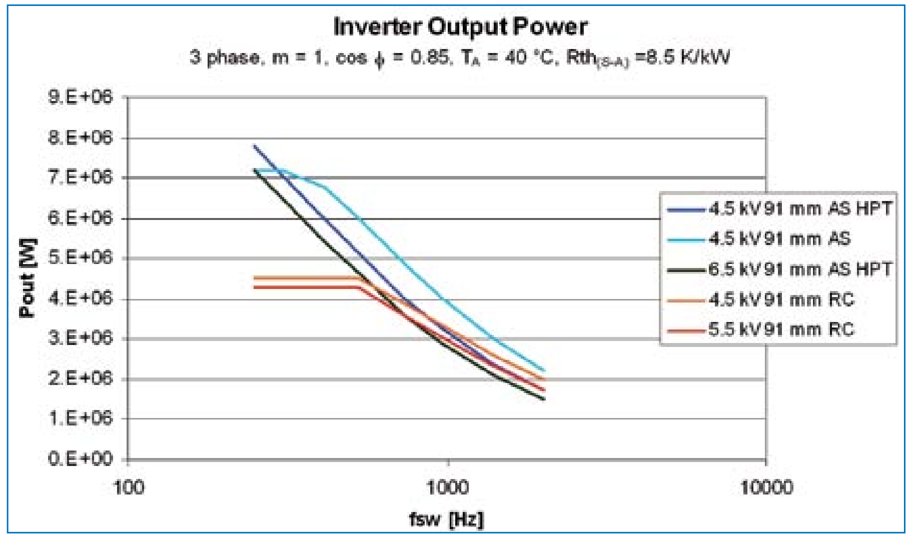

Figure 3: 2-level inverter output power for large IGCTs at given conditions.

Although among the largest module sizes on the market, the HiPak needs parallel connection of devices or inverters to reach the main stream power levels of 1.5 – 2MW, but with a well designed modular system of inverters these power levels can be reached.

The recent introduction of the SPT+ platform has increased the power density in the HiPak IGBT modules with up to 20%. Due to the improvement it is possible to either increase the output power of the inverter without making any changes to the circuitry and without sacrificing the robustness and controllability that has become a trademark for the SPT-chip family, thus shifting the curves in figure 1 on the direction of the upper right corner.

The quest for improved ratings has not stopped by the introduction of the SPT+. Further possibilities to improve the IGBT performance were explored and a very promising technology is in the pipeline. The Reverse Conducting IGBT (RC-IGBT, referred to as the BIGT (Bi-mode Insulated Gate Transistor) in its advanced design), promise another performance increase in at least the same magnitude as the change from SPT to SPT+ thus shifting the curves in figure 1 even further. By using the same die both as diode and as IGBT the power density can increase significantly since the available chip area within a module is more efficiently utilised.

Integrated Gate Commutated Thyristor IGCT

The IGCT has since its introduction in 1997 established itself as the device of choice for Industrial MVDs but it is also used in wind energy applications. The IGCT is available only as press-pack devices as asymmetric and reverse conducting devices where the latter has an integrated free-wheel diode. Figure 3 shows a comparison between the available asymmetric IGCTs in form of possible output power for a 2-level inverter at common conditions. The bending of the curves at low frequencies is due to SOA-limitations of the devices. Included in the figure is the new HPT-IGCT which gives an increase in the IGCT-SOA (Safe Operating Area) of up to 50% which opens new perspectives for control and fault handling compared to the standard devices.

As can be seen many wind turbine sizes could be covered with 2-level inverters using IGCTs. Nevertheless, it is more advantageous to use the IGCT in a 3-level connection since such a topology gives a better output voltage without the need to having very high switching frequencies. Such an inverter would also cover all of the currently available sizes of wind turbines without the need for series or parallel connection of the power semiconductors.

Furthermore, the technology development of the 10kV IGCT and diode, enabling voltages in a 3-level configuration of up to 7.2kV open up new fields for the use of power semiconductors in power conversion. By using the advanced corrugated p-base design from the HPT-IGCT, the envisaged turn-off capability is much higher than what could be previously expected for a turn-off device of this voltage level. 91mm 10kV IGCT and diode technology demonstrators have been produced and show very promising results and good switching behaviour.

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Special Report – Renewable Energy

Transformerless PV Topologies

High efficiency single phase PV Inverters

PV electricity is expensive and because of this, feed-in tariffs are used to make PV installations attractive. In countries with low insulation like Germany, the tariff is up to 0.43 € per kWh and in countries with high insulation like Spain or California, the tariff is in the range of 0.20 € to 0.30 € per kWh.

By Bruno Burger and Dirk Kranzer, Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany

In Germany, the electricity costs increase by 4% to 6% per year and the feed-in tariff is reduced by 8%-10% per year. Therefore grid parity will be reached between 2011 and 2016, depending on different electricity tariffs (households or industry) and different feed-in tariffs (rooftop or freestanding).

High efficiency single phase inverters

Today most solar modules are manufactured according to safety class II, so that there is no need for an additional galvanic isolation with a transformer in the inverter. A transformer causes approx. 2% additional losses and also component costs and weight. So inverters without transformers are the better solution. They achieve higher efficiencies, are cheaper and have less weight than inverters with a transformer. Additional safety mechanisms like isolation resistance tests and residual current measurement (RCD) make the transformerless inverters even safer than the inverters with transformers.

In all basic circuits that are presented, ideal switches are printed. In practice, IGBTs MOSFETs or JFETs can be used. The IGBTs and JFETs need external antiparallel diodes, whereas the MOSFETs can use their internal body diode. Fig. 2 shows the ideal switch and the practical realizations with the same polarity.

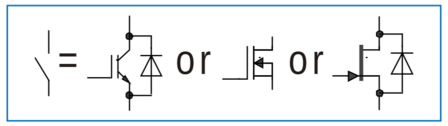

Figure 2: Ideal switch and real switches like IGBT, MOSFET and JFET.

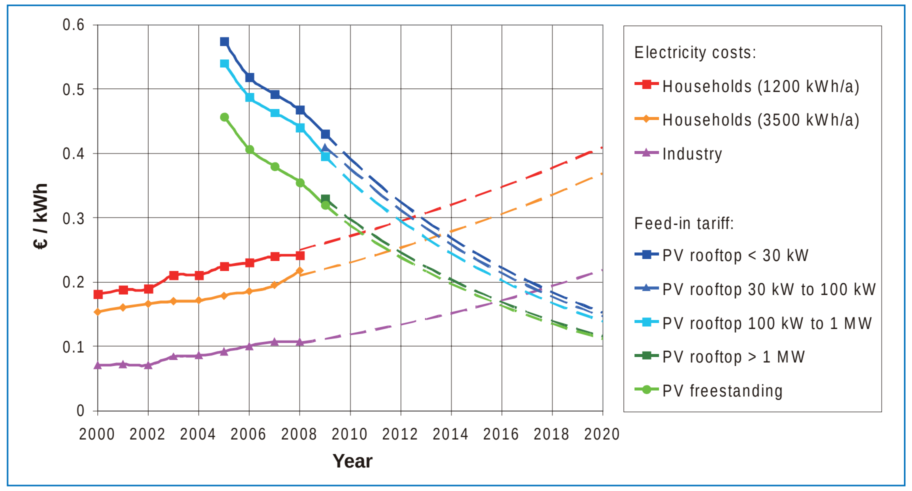

Figure 1: Electricity costs and feed-in tariffs in Germany.

Figure 3 shows a single phase inverter with H4 topology. In principle, there are three switching methods for the bridge: bipolar switching, unipolar switching and single phase chopping. Additionally there is the possibility to use only one inductor or two split inductors. But out of these six possibilities, only one, the bipolar switching with two inductors, can be used in practice. The five other possibilities cause rectangular common mode voltages from the solar generator to earth and since the parasitic capacity of the solar generator to earth is quite high, high capacitive leakage currents occur.

Circuits with an additional freewheeling path with zero voltage have been developed to reduce switching and inductor losses. The first circuit of this category is the HERIC® topology. It uses two additional switches for the freewheeling path, one for positive inductor current with D1 and S5 and one negative inductor current with D2 and S6 (Fig. 4). During freewheeling, the four switches S1 to S4 are switched off and the solar generator is floating.

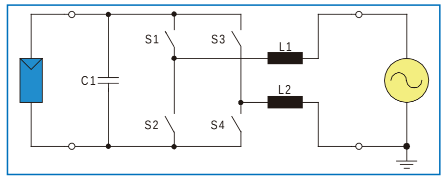

Figure 3: Single phase inverter with H4 topology.

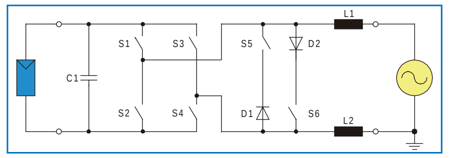

Figure 4: HERIC® inverter.

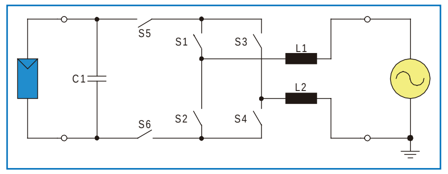

Figure 5: H6 inverter.

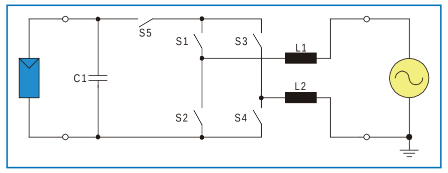

Figure 6: H5 inverter.

Since the HERIC topology was very successful on the market, other topologies with similar behavior have been developed. One possibility is to shift the additional two switches S5 and S6 of the HERIC topology from the right side of the H4 Bridge to the left side. For a positive output voltage, S1, S4, S5 and S6 have to be switched on. Negative voltage is switched with S2, S3, S5 and S6. For zero voltage, S1 and S3 or S2 and S4 can be switched. Additionally the solar generator has to be disconnected to avoid voltage steps in the voltage from solar generator to earth. So when switching zero, S5 and S6 have to be switched off. This topology can be called H6 topology, since it uses 6 switches.

The H5 topology uses the switches S1 and S3 for switching zero voltage, while the switches S5, S2 and S4 are switched off to disconnect the solar generator (Fig. 6). By using the switches S2 und S4 for the disconnection of the negative pole of the solar generator, switch S6 can be saved.

The last three circuits are nearly similar in performance and achieve up to 98% efficiency in series products with IGBTs as switches.

Single Phase Inverters with normally-off SiC JFETs

The first SiC diodes were introduced in PV inverters in research projects in 2001 and in series products in 2005. Now MOSFETS, normally-on JFETs, normally-off JFET and Bipolar Junction Transistors (BJTs) are available as engineering samples. Especially normally-off JFETs are very promising.

Fig. 4 shows the efficiency of a HERIC® inverter with SiC JFETs. The switching frequency of the inverter is 16 kHz. The losses caused by the on board power supply, relays, control circuit and DSP were included in the efficiency measurement.

The achieved efficiency curve shown in Fig. 7 is quite remarkable. A maximum efficiency of 99% at 350 VDC was achieved with the HERIC® topology. Commercial HERIC® inverters with Si-IGBTs achieve 98% efficiency. So in this case the losses have been halved from 2% to 1% by the use of the SiC JFETs.

Efficiency ratings

The inverter efficiencies are strongly related to the topology of the power electronics circuit used in the inverter. Highest maximum efficiencies up to 99% are achieved with tree level topologies like HERIC®, H5 and H6 topologies and SiC transistors. With Silicon IGBTs, these circuits reach up to 98% efficiency. Inverters with bipolar switching (H4 bridge) achieve maximum efficiencies in the range of 96% to 97%. Additional boosters in the input stage cause additional losses in the range of 1% to 2%, depending on the level of the input voltage.

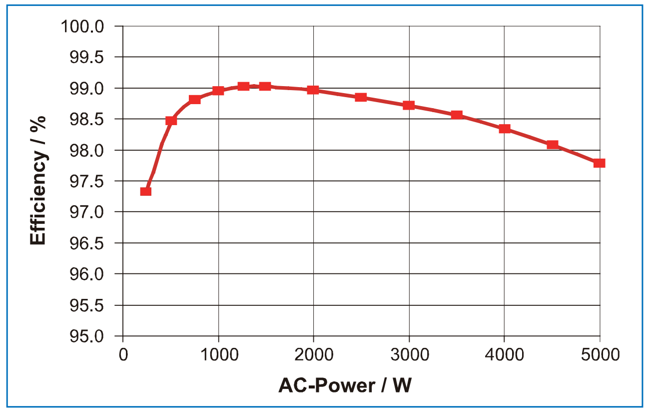

Figure 7: Efficiency versus AC-power of a HERIC® inverter with SiC JFETs and unipolar switching.

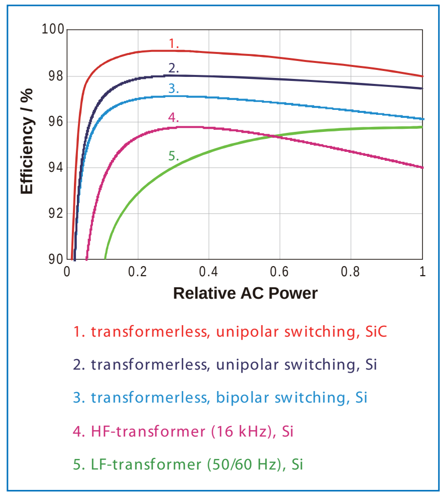

Figure 8: Typical inverter efficiency curves for PV inverters.

Inverters with line frequency transformers achieve 94% to 96% maximum efficiency, depending on their rated output power. Inverters with high frequency transformers achieve 93% to 96% maximum efficiency, depending on their output power and topology. Fig. 8 shows typical efficiency curves for all different inverter types.

Trends in PV inverters

There is a trend towards inverters with increasing efficiency ratings. Therefore, special transformerless inverter topologies for single phase inverters like HERIC®, H5 and H6 will increase their market shares.

The market shares for transformer-based inverters will decrease. These inverters have approx. 2% lower efficiency than transformerless inverters.

New semiconductor materials like SiC or GaN will be introduced in PV inverters first, since the electricity costs of PV are quite high and higher efficiency will pay off earlier for PV inverters than for UPS inverters or drives. Besides higher efficiency, new semiconductor materials like SiC or GaN offer the possibility of higher switching frequencies up to several hundred kHz, meaning the large and expensive inductors used today could be replaced by much smaller ones.

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Power LEDs - Reading Between the Lines

Accurate performance assessments from datasheets

Understanding and comparing LED performance appears straightforward. Get the datasheets, compare numbers for light output, efficacy and lumen maintenance, and make a decision. Unfortunately, any purchase and design decision based simply on the top line numbers – the specs on the early pages – without analysis of how the LEDs will perform in the desired application under operating conditions can lead to unsatisfactory results, expensive redesigns and significant business risks.

By Rudi Hechfellner, Director of Applications and Steve Landau, Director of Marketing Communications, Philips Lumileds

The excitement - even hype - about the potential of power LEDs to revolutionise the lighting industry has been joined by scepticism among some lighting designers and architects. This is likely the result of the failure of some early solid state lighting solutions to live up to their promises in terms of light output, efficiency or operating lifetime. In many cases, assumptions that the performance of an LED as stated on a datasheet would translate directly to that level of performance in a luminaire. In fact, this is never the case and the performance numbers quoted by LED manufacturers are not the same as what will be realized in an application that functions in a completely different environment.

As this article will show, there is no alternative for the lighting equipment manufacturer to a rigorous examination of the relevant data in the datasheet. This analysis will uncover the actual performance and lifetime of a power LED under the conditions that will apply in the luminaire's operating environment.

Range of lighting fixtures featuring Power LEDs.

Why all LEDs are not born equal

A 60W GLS light bulb is a standard, commodity product. Power LEDs, by contrast, are not commodities that adhere to a single industry standard. Even if power LEDs from different vendors shared identical packaging and pinout (which few do), differences in performance would mean that one brand could not be simply interchanged with another.

There are a number of reasons why LED manufacturers' products differ considerably. Solid-state lighting is a young and developing industry, and innovations are constantly being introduced by manufacturers to improve performance characteristics and to give their products a competitive edge.

Some of the factors that result in product differentiation are:

• The design, manufacture and materials used to create the LED.

• Phosphor development. Different phosphors react differently to heat and to light.

• LED packaging can affect how light exits the package, how much heat can be dissipated and how optics are attached.

So multiple and complex factors within the control of the power LED manufacturer affect the raw performance of their LEDs, with the result that no two brands of LED will perform identically in a luminaire.

This is important to understand, as superficial descriptions of power LEDs can give the impression of a standard output analogous to the standard wattage label applied to GLS bulbs. When two different LED manufacturers describe parts as providing 'min. 100lm at 350mA', it is true that, in certain tightly defined circumstances, including but not limited to an input current of 350mA, both power LEDs will produce at least 100lm.

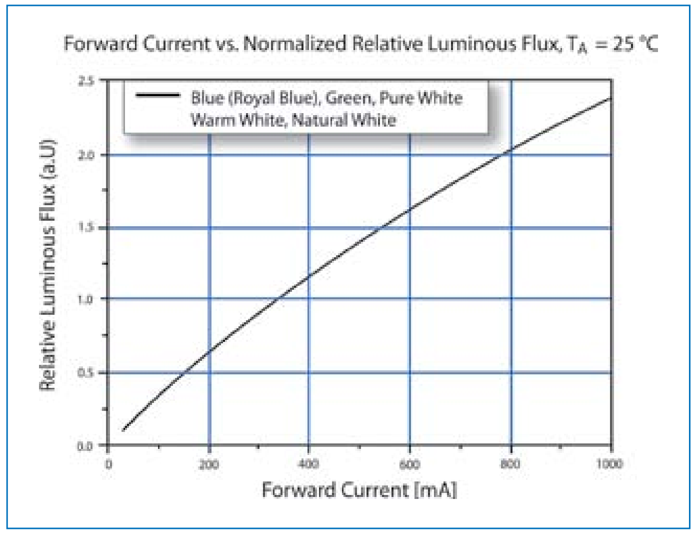

Figure 1: Example of Flux Normalisation graph.

But change those circumstances even a little and the performance of the two LEDs can begin to diverge significantly. The two potentially conflicting key parameters that affect the performance of an LED are:

• Drive current – up to a certain threshold, the higher the current applied to an LED, the more light it will produce and the hotter it will get.

• Operating temperature, the hotter an LED gets, the less light it will produce.

These two factors combine to affect light output (lm), efficacy (lm/W), lumen maintenance and ultimately the actual performance of a lighting solution.

No matter which brand of LED a lighting manufacturer uses, luminaire design decisions for drive current and thermal management will entail trade-offs. For instance, a decision to choose a high drive current for higher light output could cut the number of LEDs required to hit the target for light output, which will have a helpful impact on BOM cost. But there will be a trade-off in terms of lower efficacy for the LED and higher operating temperature.

All brands of LED will be subject to these trade-offs. But the size of their effect – the amount of pain they inflict, if you will – is very different from one brand of LED to another. This is where the factors described earlier – differences in LED design and manufacturing – show their impact.

The fact that stark differences in performance between one LED and another will emerge once they are embedded in a real luminaire is very far from obvious from the first page of a power LED's datasheet. But the tools to make an informed choice do exist in the datasheet. The designer simply needs to know how best to find and use them.

This is perhaps best illustrated by example. For our example we will calculate for a simple, single LED desk lamp in order to make the figures as easy to follow as possible. But the principles and methods shown here can be applied to

	Data sheet Min. Flux	Data sheet drive current	Data sheet test temp	Data sheet test time
MFR 1	91lm	350mA	T_A 25C	25ms
MFR 2	107lm	350mA	T_J 25C	25ms
MFR 3	130lm	700mA	T_A 25C	25ms
MFR 4	100lm	350mA	T_{Pad} 25C	25ms

T_A: Ambient Temperature T_J: Junction Temperature
T_{Pad}: Solder Pad Temperature

Table 1: Headline product specifications for miniature power LEDs.

any solid-state lighting design in any application.

So let us imagine that you are the lead project engineer at a lighting equipment manufacturer, and you have to work to the following brief. You are to design a desk lamp with the highest possible light output. The lamp must be capable of producing light output after 50,000 hours of operation at a level that is at least 70% of output when the lamp was new.

A key part of this design project will be to choose an appropriate brand of power LED as the light source. The first stage in evaluating LEDs is to compare the raw light output figure as shown at the front of the datasheet issued by the manufacturer. Since the application is a desk lamp, space for mounting LEDs in the lamp will be constrained. Therefore this example compares high performance power LEDs from four leading suppliers, identified here as MFR 1-4. This example uses only publicly-available datasheet information as provided for its own LEDs by each of the manufacturers.

This first-stage comparison is shown in Table 1.

This data does not allow a like-for-like comparison, as the MFR 3 part is specified at 700mA. This explains the much higher light output value. Interestingly, different manufacturers adopt a different approach to specifying the temperature at which the device was tested, and this gives further scope for confusion. The effect of such differences emerges quite clearly as we progress further into the evaluation.

For the purposes of the design brief, however, this data is only a starting point. The brief was to maximise light output consistent with the lifetime goal of 50,000 hours. By driving the LEDs at 350mA (as per the datasheet figures), we would not be maximising light output, so let us instead compare all four LEDs at the higher figure of 700mA (see Table 2).

Manufacturer	Data sheet Min. Flux	Normalize to drive current	Normalized Min. Flux @700mA	Data sheet test time	Data sheet test time
MFR 1	91lm	700mA	164lm	T_A 25C	25ms
MFR 2	107lm	700mA	182lm	T_J 25C	25ms
MFR 3	130lm	700mA	130lm	T_A 25C	25ms
MFR 4	100lm	700mA	165lm	T_{Pad} 25C	25ms

Table 2: Raw comparison of LEDs at 700mA drive current.

Manufacturer	Data sheet Minimum Flux	Actual Drive Current	Normalized Min. Flux@25C	Data Sheet TJ max.	Operating TJ (calculated)@25CA, Rth50K/W	Determine Flux De-rating Factor	Actual Flux
MFR 1	91lm	700mA	164lm	145C	135C	72%	118lm
MFR 2	107lm	700mA	182lm	150C	128C	78%	142lm
MFR 3	130lm	700mA	130lm	125C	141C		
MFR 4	100lm	700mA	165lm	150C	130C	81%	133lm

Table 3: Comparison of light output under real operating temperature conditions.

Manufacturer	Calculated Lumens	Lumen Maintenance L70 Claim	Data sheet TJ max	L70 / 50Kh conditions	Actual Operating TJ (calculated)	Calculated current to achieve lumen maintenance	Final Calculated Lumens
MFR 2	142lm	50,000 hours	150C	TJ ≤ 85C TA ≠ 25C	128C	407mA	107lm
MFR 4	133lm	50,000 hours	150C	TJ ≤ 135C & If ≤ 700mA TA N.A.	130C	700mA	133lm

Table 4: LED output consistent with 50,000-hour lifetime requirement.

For three of the parts, this means applying the Flux Normalisation graph found in each datasheet (see Figure 1 for a typical example). The graph will provide a factor to use for each specific LED to calculate the light output produced at the higher current.

As we now see in Table 2, the MFR 3 emitter is no longer the leader in light output but the comparisons here are still some way from being apples-to-apples and in the actual operating environment.

So how do we calculate the actual light output we will get at the operating temperatures our desk lamp will experience in real life? For this we need the Temperature De-rating graph provided in every manufacturer's datasheet. First, we must specify the conditions in which our LEDs will operate: the ambient temperature (in degrees Centigrade); and the thermal performance of the luminaire, expressed as a value for thermal resistance. Thermal performance will be strongly affected by any thermal management methods applied, such as heat-sinking.

Using conservative assumptions (a high ambient temperature, which puts a relatively high stress on the LEDs, and a modest amount of heat-sinking), the light output comparison in Table 3 has changed strikingly when compared with Table 2.

The first interesting point to note is that the MFR 3 part cannot be used at all under these conditions: the high ambient temperature drives the temperature at the LED up to 141°C, 16°C above its maximum rated value.

Also interesting is the rate at which the output from the MFR 1 part declines under these conditions, when the LED's temperature rises to 135°C: while the part boasted an impressive 164lm output at 700mA before taking operating temperature into account, in real conditions it produces 118lm, markedly less than the two remaining emitters.

We now have a much more realistic basis for comparing different brands of LED. But we still have not taken into account at all the requirement for 70% lumen maintenance after 50,000 hours.

Again, all datasheets provide lumen maintenance graphs showing the rate at which light output declines over time.

But it is important to look carefully at the operating conditions that apply to valid data sets (see Table 4). For the MFR 4 emitter, these operating conditions are consistent with the lumen maintenance graph's conditions: the device is able to provide 50,000 hours of use at a junction temperature of 135°C; in the desk lamp example, the LED will actually run at 130°C. So we now know that the MFR 4 LED will produce 133lm when new, and will still provide at least 70% of peak output after 50,000 hours.

Table 4 also shows the conditions under which the MRF 2 part can provide 70% lumen maintenance at 50,000 hours: the junction temperature – the temperature at the LED itself – must be 85°C or less.

But in our example, when driving LEDs at 700mA for high light output, the MFR 2 device runs at a much higher 128°C. The simplest way to compare the MFR 2 emitter with the others in our example while achieving a 50,000-hour lifetime is to lower the drive current to a value at which junction temperature is 85°C. To achieve this, current must be reduced to 407mA, and at this low current the LED only produces 107lm, versus the 133lm from the MFR 4 LED at the full 700mA. Additionally LED drivers are typically available for 350 mA or 700 mA. Since 407 mA is not standard, a customer solution would likely have to be created which could add cost to the solution.

This is not the only approach that can be taken. Other options include:

- Easing the specification, either by reducing the product's lifespan to less than 50,000 hours or reducing the lumen maintenance requirement to less than 70%
- Improving the thermal management of the device, perhaps by increasing the heat-dissipation capability of the heat-sink Clearly, any such measures carry a cost, either in BOM (for a bigger heat-sink for instance) or in reduced product performance.

Conclusion

The conditions that apply in the raw statements of performance shown in Table 1 and typical of LED datasheets are very different from those that apply in real luminaires. When all operating conditions are taken into account – a realistic drive current for those applications that need bright light, the real temperature at which the device will operate, and compliance with lumen maintenance requirements – the actual light output, and the comparison between different brands of LED, look very different. Only through analysis of the LED performance metrics based on the actual application and intended environment can an appropriate selection decision be made.

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Increasing Lifetime - Reducing Cost

IGBT Module with 6th Generation IGBT

The insulated gate bipolar transistor (IGBT) is very popular semiconductor component for the output stage of power electric systems such as in inverter, power supply, and motion control applications. In the case of IGBT modules where the power chip is integrated onto an insulated package, it is possible to offer a wide power capacity range from less than 1kW to more than 1MW. The 1st step of NX series was to offer a higher degree of package flexibility. However minimizing the power dissipation of an IGBT module is also a key point for users who demand a total system cost down, which includes suppressing EMI irradiation noise, and increasing long term lifetime. By improving its carrier stored trench bipolar transistor (CSTBTTM) chip technology as a 2nd step in the NX series development, Mitsubishi is able to offer a suitable solution.

By Taketo Nishiyama and Yuji Miyazaki, Power Device Works, Mitsubishi Electric Corporation, Japan

IGBT module "NX series"

Generally, IGBT modules are designed in various sizes to meet space and cost performance requirements. Furthermore, an IGBT module range consists of many different package elements i.e. case, base plate, terminal, insulator and power chips. In the NX series range some unified package parts and common assembly processes are utilised which allows us to offer a wide capacity range and various circuit modules, not only single, but as a 2-in-1, 7-in-1, CIB (converter-inverter-brake) pack etc. Mitsubishi is also able to offer other unique configurations as applications demand. Some examples of package types are shown in Figure 1. Flexibility is offered for both circuit configuration and terminal layout.

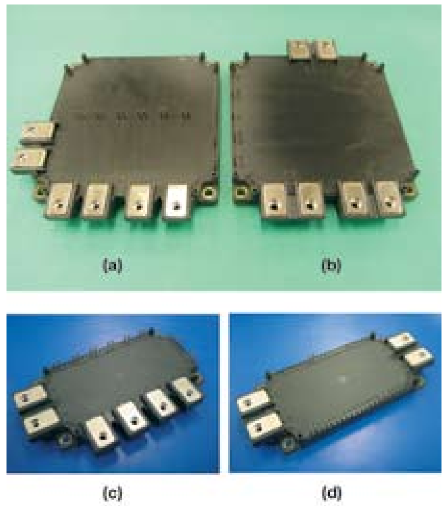

Figure 1: Example of NX series package (a)(c)7in1, (b)(d)2-in-1.

Chip technologies

Progress of IGBT chip

Figure 2 shows the Figure of Merit (FOM) which indicates the transition of IGBT performance. The FOM is defined as the chip current density (J_c), divided by the product of the saturation voltage ($V_{CE(sat)}$) and the turn off energy loss (E_{off}) per pulse per unit current in inductive switching at T_j=125°C. CSTBTTM technology has better FOM than trench IGBT technology. The FOM of the Mitsubishi 6th generation IGBT is 30% higher than that of the 5th generation.

6th Generation IGBT

The 6th generation IGBT chip is based on an advanced CSTBTTM technology.

Figure 3 compares the cross-sectional views of the 6th generation IGBT with the conventional 5th generation IGBT. Both types share a common concept of CSTBTTM technology using the carrier stored (CS) effect. As a first step in the 6th generation IGBT development, the wafer structure was modified from a NPT (Non Punch Through) type to a LPT (Light Punch Through) type by the development of a thin wafer process technology. Secondarily, the unit cell

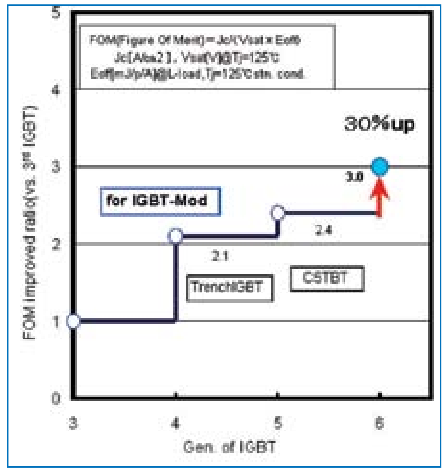

Figure 2: FOM of IGBT.

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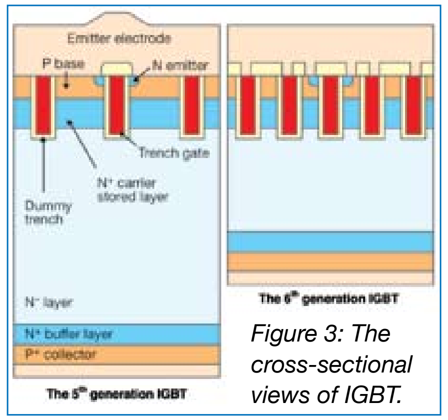

Figure 3: The cross-sectional views of IGBT.

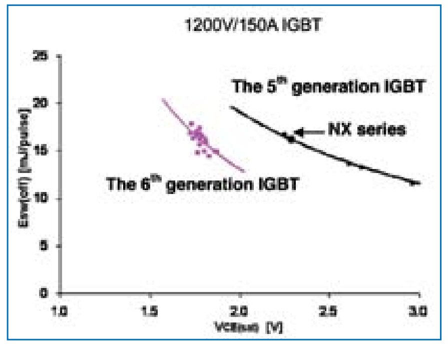

Figure 4: Relationship between $V_{CE(sat)}$ and $E_{sw(off)}$ (@T_j=125°C).

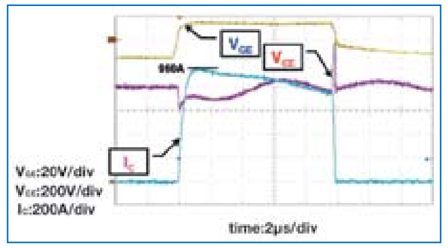

Figure 5: SCSOA wave form (1200V/150A rating device V_{CC}=800V, V_{GE}=+15V/-15V, R_G=30Ω, t_p=10μs, T_j=125°C).

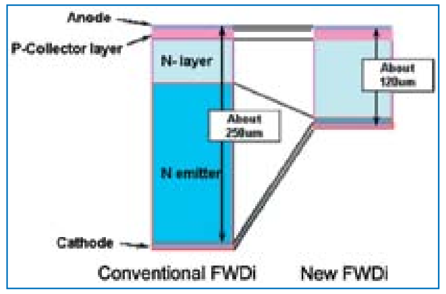

Figure 6: The cross-sectional views of FWDi.

design was optimized for the purpose of improving the $V_{CE(sat)}$ -$E_{sw(off)}$ trade-off relationship.

Narrowing the trench pitch of the unit cell using fine pattern technology and optimizing the doping profile of the CS-layer enhances the CS effect on the carrier stored layer. As a result, and as shown in Figure 4, drastic improvement is achieved in the $V_{CE(sat)}$-$E_{sw(off)}$ trade-off relationship. One other important consideration is that the IGBT power loss performance has a trade-off relationship with the SCSOA (Short Circuit Safe Operation Area). Figure 5 shows measured data of the SCSOA waveform of the 6th generation IGBT chip. Optimization of the CS layer and unit cell design results in more than a 10μsec short circuit withstands capability without sacrificing the IGBT power loss performance.

New designed FWDi

Figure 6 shows the structure of a newly designed Free Wheel Diode (FWDi) compared to a conventional FWDi. As shown in Figure 7, the thin wafer process technology contributes to an improvement of trade-off relationship between the forward voltage VF and the recovery switching loss $E_{sw(rec)}$.

Turn-on behaviour

Reducing the dv/dt at the turn on switching waveform often helps in suppressing the EMI irradiation noise from equipment. Generally, by controlling the gate drive speed in an external circuit, the turn-on dv/dt can be reduced, otherwise, reducing the dv/dt will increase the turn-on switching loss ($E_{sw(on)}$) in the IGBT chip. Figure 8 shows the trade-off relationship between $E_{sw(on)}$ and dv/dt. Switching speed can be controlled by changing the gate resistance. The $E_{sw(on)}$ of the 6th generation IGBT is 20% lower than that of the conventional IGBT at the point of dv/dt = 7.5kV/μs, which is taken as an assumption for the condition of the user.

Softness of the reverse recovery current on the FWDi and the reverse transfer capacitance (Cres) on the IGBT contribute to improve the $E_{ssw(on)}$-dv/dt trade off. This result means that 6th generation IGBT has wider selection range and good controllability of power loss vs. noise performance.

Turn-off behaviour

At the point of turn off, there are a lot of electron hole pairs and free electrons in the N- layer and so the collector current cannot be suddenly stopped. The collector current gradually decreases over a time, which depends upon the lifetime of the electron. Incidentally, the 6th generation IGBT improves the tail current because of the optimization of the LPT structure. Figure 9 shows the turn off waveforms. The tail current of the 6th generation IGBT is lower than that of the 5th generation. Lower tail current leads to lower $E_{sw(off)}$ loss.

Power loss performance

Power loss in general PWM inverter drive applications has been estimated for both 5th and 6th generation IGBT

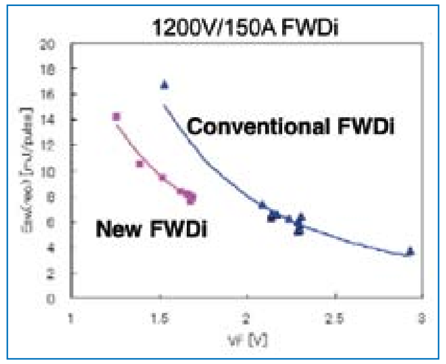

Figure 7: The relationship between V_F and E_{sw} (@T_j=125°C).

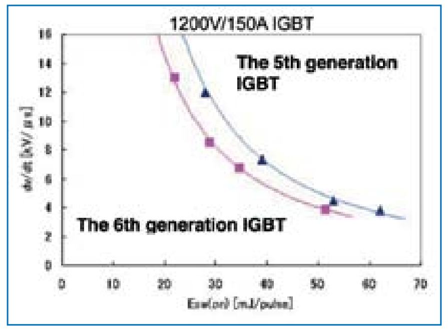

Figure 8: Relationship between $E_{sw(on)}$ and dv/dt (@T_j=125°C).

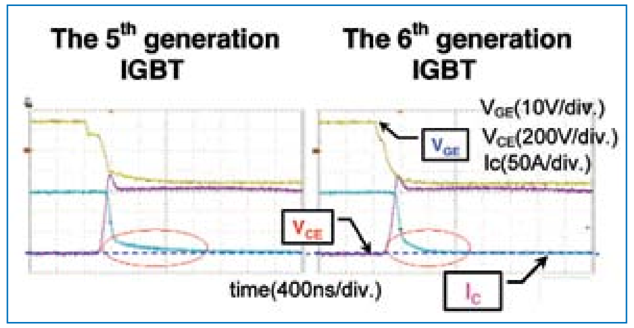

Figure 9: Turn off waveform @Ic=150A, V_{CC}=600V, Tj=125°C.

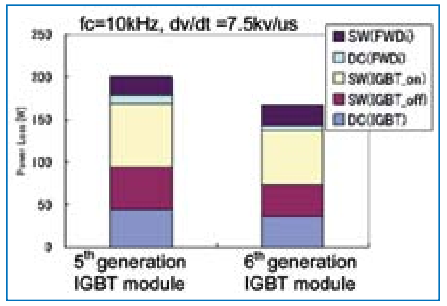

Figure 10: The simulated loss.

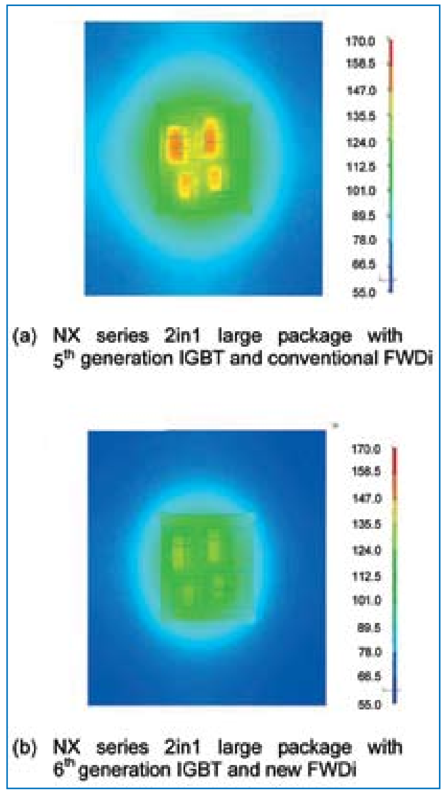

Figure 11: The thermal profiles simulation of NX series output current 420Arms, carrier frequency 2.5kHz, power factor 0.85 and 3-phase modulation.

modules (Figure 10) for a 1200V/150A rated module as used in a 30kW capacity full load at 400VAC. The gate resistor was selected in each device so that dv/dt at the turn-on switching waveform gave the same value (7.5kV/μs). Total power loss in an IGBT/FWDi chip consists of switching loss and static loss. Calculations show that losses of the 6th generation IGBT module are about 20% lower than those of the conventional module.

Thermal simulation

The thermal simulation of the NX series is shown in Figure 11. The simulation was executed assuming a 1200V/1000A rated device with a large NX series 2in1 package and 400V input, running a 185kW capacity inverter at full load operation. The Junction temperature (T_j) of 6th generation IGBT is an average of 25°C lower than that of the conventional IGBT. The new FWDi Tj is an average of 21°C lower than that for the conventional FWD. It is therefore possible to reduce space, weight and cost for the cooling system.

Reliability limits

In many cases the lifetime of IGBT module is dominated by the junction temperature cycling in the intermittent operation mode. Figure 12 shows the power cycling lifetime of the latest NX series module compared to the old type of module (H series). The NX series with its 6th generation IGBT has the same power cycling lifetime as the current NX series and is better than that of H series. Incidentally, an increase in the T_j maximum limit is also seen as a requirement when considering new power equipment designs. The NX series with its 6th generation IGBT allows the operation of the Tj maximum limit up to 175°C. The NX series has been tested under two operating conditions ($T_{j(max)}$=125°C and $T_{j(max)}$=175°C). At $T_{j(max)}$=175°C the 6th generation IGBT shows a lifetime performance somewhere between $T_{j(max)}$= 125°C of the current NX series and $T_{j(max)}$=125°C of the H series.

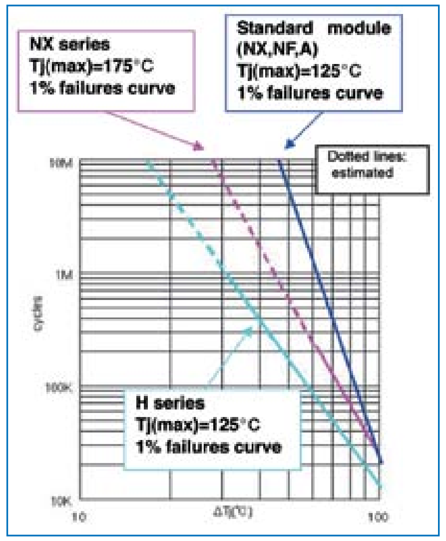

Figure 12: Power cycling lifetime.

Conclusion

With the development of a 6th generation IGBT chip and a new FWDi, Mitsubishi's NX series IGBT module range will lead to improvements in power losses for power applications. For the IGBT module user this will mean better system efficiency. Furthermore, NX series will have high package flexibility and improved device characteristics which will extend the application range. The new NX series will have great potential for the development of future power electric systems.

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Clean Success

Analog Devices helps Northern Power Systems' wind turbines generate clean energy

Northwind 100 wind turbines utilize ADI's broad portfolio of technologies including precision ADI components and SHARC digital signal processors to maximize energy extraction and optimize system controls

Reported by Cliff Keys, Editor-in-Chief, PSDE

As environmental and economic concerns associated with fossil fuel production and consumption continue to grow, so too does the market for clean, renewable energy. Wind power in particular is gaining wide popularity as an inexhaustible means to offset oil, coal and gas-centric energy production. Over the past ten years, global wind power capacity has continued to grow at an average cumulative rate of over 30 percent annually, owing to growing global demand for emissions-free power generation infrastructure that can be installed quickly, virtually everywhere in the world.

A Northwind 100 powers the McGlynn Elementary School in Medford, Massachusetts.

Northern Power Systems (Barre, Vermont, USA) is positioned at the forefront of the wind power technology movement, offering community and utility-scale wind turbine systems differentiated by their innovative 'gearless' turbine designs, efficient energy capture capabilities, and low maintenance requirements.

The company's flagship Northwind 100 wind turbine is designed for community-scale wind power generation installations, enabling municipalities, businesses, farms, schools and other organizations to produce power at the source of the need, even in locations where wind speeds are relatively low. To help ensure that Northwind 100 systems deliver the highest possible energy yield and return on investment, Northern Power Systems relies on precision ADI digital signal processors, data converters and other components along with ADI's technical support to maximize system management efficiencies.

Elegance in design

Northern Power Systems' wind turbine technology is based on its proprietary permanent magnet direct drive (PMDD) design architecture, which precludes the need for a gearbox in between the turbine's rotor and generator. By directly coupling the rotor with the generator, Northern Power Systems' engineering team significantly reduced the number of moving parts within the system, which ultimately yields a more reliable machine that requires less maintenance than traditional gearbox-based turbines. This 'less is more' design approach epitomizes Northern Power Systems' engineering philosophy, and ultimately led the company's engineering team to seek out a similarly elegant signal processing platform that wouldn't compromise performance or functionality. They found what they were looking for in Analog Devices.

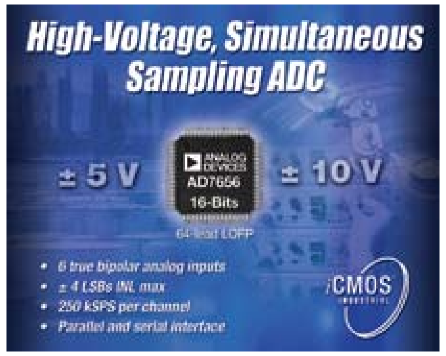
ADI SHARC digital signal processors, data converters and other advanced components ensure high-performance system operation.

Leveraging ADI SHARC digital signal processors, data converters and other advanced components to ensure high-performance system operation, Northern Power Systems' Northwind 100 delivers 100 kilowatts of rated power for community wind applications such as schools/universities, businesses, farms, and municipalities. ADI's expertise in next-generation energy infrastructure assures that companies like Northern Power Systems are equipped with advanced components across the entire signal chain to enhance the value, performance and innovation of their system designs.

High-performance signal processing

Within a Northwind 100 turbine, wind capture and energy conversion functions are facilitated by the system's rotor, generator and power converter components. The rotor converts the wind's aerodynamic energy to mechanical shaft torque; the generator converts the mechanical shaft power to electrical power at variable frequency and provides reaction torque to the rotor; and the power converter converts the variable frequency generator output to constant frequency for feeding into the grid.

The Northwind 100 generator's power flow is regulated by the power converter to compensate for variable wind speeds, which helps to maximize energy extraction. An electrodynamic braking system managed by the turbine and power converter embedded software allows the generator to apply reactive torque to the rotor when needed to regulate power output. This capability ultimately enables a Northwind 100 wind turbine to provide a steady flow of clean power to a local grid, simplifying grid interconnect infrastructure and maintaining grid stability. Eliminating the need for a gearbox transmission dramatically reduces lifecycle maintenance and increases system reliability.



ADI's 16-bit analog-to-digital converter.

At the heart of this system is ADI's 32-bit floating point SHARC 21363 digital signal processor, which hosts real-time closed-loop control algorithms to efficiently control the Northwind 100's generator and power converter subsystems, based in part on incoming data provided by the ADI AD7656 16-bit analog-to-digital converter (ADC) embedded in the data acquisition hardware and ADI dual-axis iMEMS® ADXL203 accelerometer sub-assembly part affixed to the turbine's nacelle. Delivering core processing performance up to 333 MHz/2 GFLOPS with support for IEEE 32-bit/40-bit floating point and 32-bit fixed point operations, SHARC 21363 processors employ an enhanced Single Instruction, Multiple-Data (SIMD) architecture to provide the real-time processing bandwidth and atomicity required to keep these subsystems running in precise coordination.

SHARC 21363 processors feature integrated 3 Mb SRAM/4 Mb ROM on-chip memory and a rich peripheral set to accommodate a wide range of configuration options. The Northwind 100's data acquisition platform hosts the ADI AD7656, which provides the high-speed signal sampling and data conversion that feeds into the system's real-time closed-loop control algorithms. This is facilitated by the SHARC 21363's six high-speed serial ports (SPORTs), yielding a seamlessly connected signal chain that helped minimize design complexity.

ADI powers innovation

Analog Devices' VisualDSP++ easy-to-install, easy-to-use software development and debugging environment for the ADI processor family enabled Northern Power Systems to streamline the product development process. VisualDSP++ is a member of ADI's CROSSCORE family of software and hardware tools, which also features the EZ-KIT Lite evaluation kit, all of which helps developers shorten design cycles and speed time to market.

With high-performance Analog Devices components at the core of the Northwind 100 wind turbine, Northern Power Systems' customers are assured ultra efficient power generation that reduces energy costs and minimizes the community's environmental footprint. For utility-side and consumer-side applications, Analog Devices enables technology developers like Northern Power Systems to design intelligent systems that promote energy efficiency and maximize investments in clean, renewable power.

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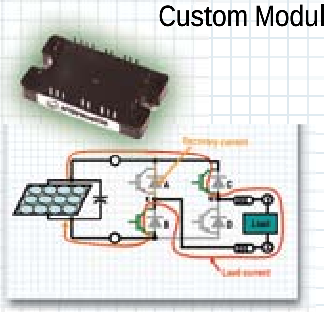

PSDE Green Power ENERGY EFFICIENCY

Accuracy Enables Efficiency

Miniature Iso-Amp measures current and voltage in small wind power systems

Isolation amplifiers (iso-amps), working in conjunction with shunt resistors, provide accurate current measurements in power converters even in the presence of high switching noise. When used with a resistive divider, they work as precision voltage sensors. The current and voltage information is required by the controller for calculation and effective control in order to achieve optimum conversion efficiency in typical small wind power systems. Featured with high common mode noise rejection, high isolation voltage, built-in safety insulation, and very small footprint, miniature iso-amps provide an ideal solution for small wind power turbines.

By Hong Lei Chen, Technical Marketing Engineer, Isolation Products Division, Avago Technologies, Singapore.

As one of the most promising alternative energy resources, wind power will continue to grow fast, despite the financial crisis and economy recession, at an annual rate of 22.4% average for the next five years. Large wind power farms are expanding to offshore deep water regions, such as the 25-megawatt Arklow Bank Wind Park in the Irish Sea, and the Cape Wind, America's first offshore wind farm, coming with 420-megawatt capacity.

Despite the attention given to large multi-megawatt wind turbines, which are projected to continue growing both in size and number of installations, most of the opportunities for power inverter manufacturers are in the small wind turbine market (<100kW). Although the market for wind power inverters is small compare to the solar photovoltaic market, the small wind market is experiencing a number of significant developments, including the emergence of Building Integrated Wind Energy (e.g., the 1kW AVX 1000 and the 60kW WindCube®) and the further development of Vertical Axis Wind Turbines (e.g., UGE 10KW VAWT).

Focus market for small wind turbines

The US market for small wind turbines grew 78% in 2008 with an additional 17.3MW of new capacity. This compares to 53% capacity growth worldwide with 38.7MW new installations in the same period. US manufacturers accounted for 49% of global small wind sales in 2008, maintaining their historically dominant position.

For the commercial segment of the US small wind turbine market (21-100kW), the growth was due largely to increased private equity investment that allowed manufacturing volumes to increase. The residential segment (1-10kW), the largest segment of the market, was driven by both investment and cost down with volume up. The rising residential electricity price and increased public awareness of the technology also played a part behind the growth.

In Europe, there are more than 40 established manufacturers active in

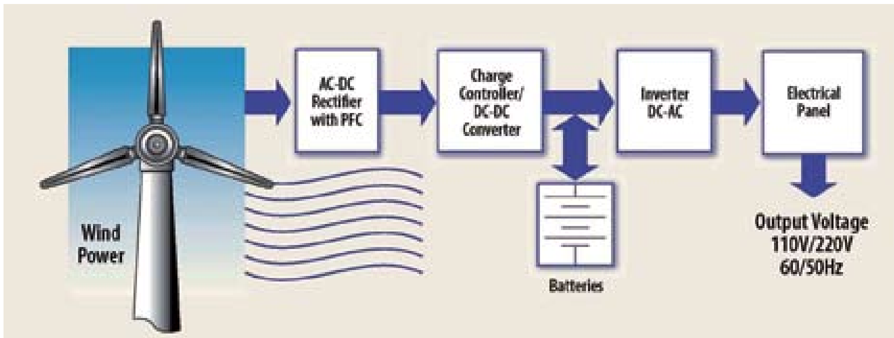

Figure 1: Simplified block diagram for small wind power generation system.

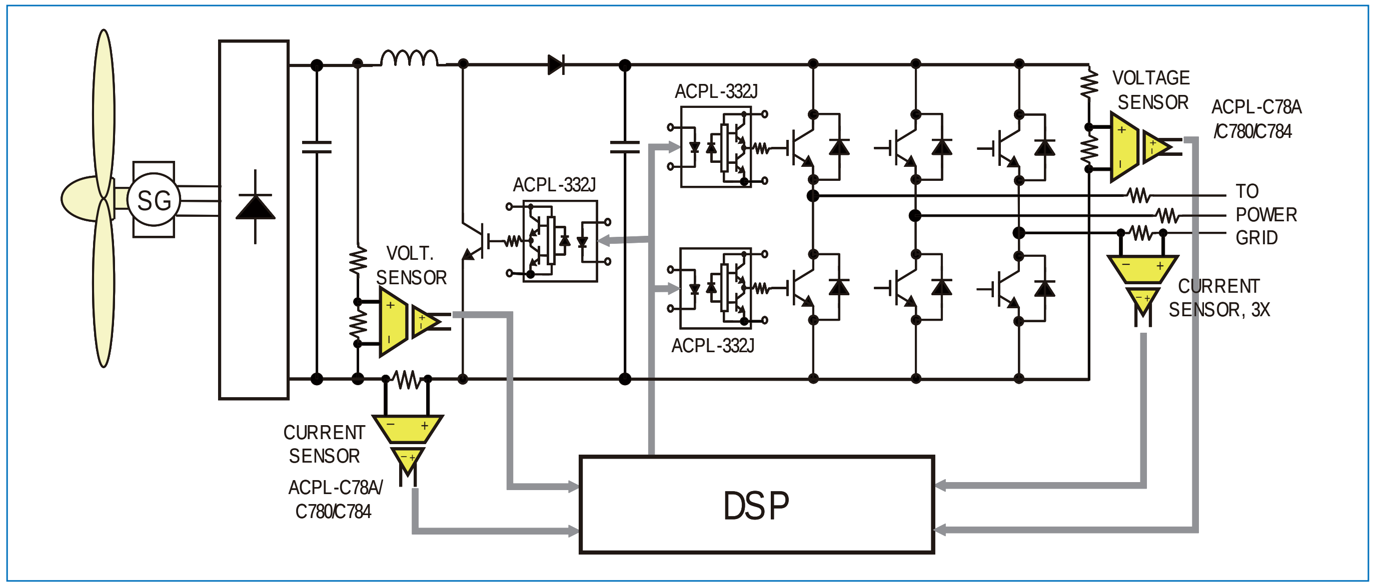

Figure 2: Block diagram of a small wind turbine using AC-DC-AC converter.

the small wind power industry. Mainly located in Germany and Spain, these manufacturers produce small wind generators with power ratings from sub-kW to a few hundred kW.

A small wind system

A small wind system (Figure 1) usually includes a turbine, a generator, an AC-DC rectifier, a charge controller and a rechargeable battery module, an inverter, wiring, and a tower supporting the whole system. The charge controller and battery module are often required to meet the needs of off-grid wind energy systems in difficult and remote locations.

Efficiency is the key

Due to the variable wind speed characteristics, many wind solutions feature variable speed control technology to maximize energy capture from the wind and minimize turbine drive-train loads. Different variable speed control strategies have been proposed and discussed in the industry, with a common goal – optimum efficiency.

Besides the speed control section, the inverter plays a crucial role in enabling the power conversion process in a wind power system. In the case of wind turbines, variable-speed generation devices, an inverter is essential for the devices to connect to the grid and supply code-compliant power. Inverters can be either single (commercial) or three-phase (industrial) discrete components or modules and are controlled by a DSP to provide high-efficiency power conversion. High-performance inverter systems require precision timing control of power devices as well as safety isolation to prevent hazardous high voltage switching transients from damaging the controller and operator.

As an example, in a 30kW power conversion system, a simple AC-DC-AC converter and modular control strategy for grid-connected wind system was implemented.

Figure 2 shows a similar block diagram of the power converter. As the voltage and frequency of generator output vary along with the wind speed change, a DC-DC boosting chopper is utilized to maintain constant DC link voltage. The input DC current is regulated to follow the optimized, predetermined current reference for maximum power point operation of the turbine system. On connecting to the grid, PWM signals control the IGBTs through ACPL-332J gate drivers to supply currents into the utility line by regulating the DC link voltage of the inverter.

In order to achieve optimum system efficiency, the converter illustrated in

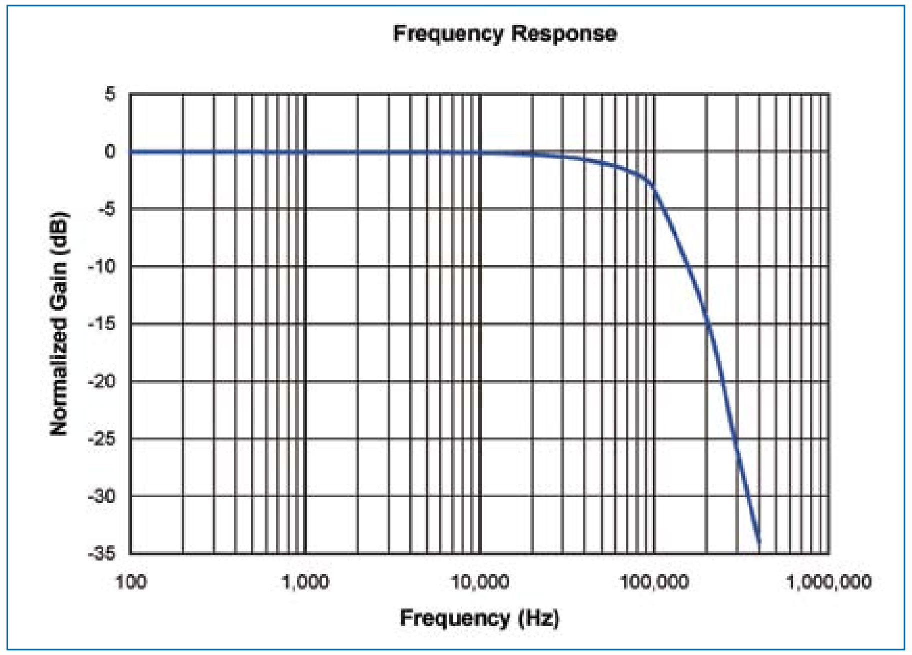

Figure 3: Gain-frequency response of the ACPL-C78X.

Figure 2, and many others show that important current and voltage information must be fed back to the DSP for calculation and effective control. This information may include DC link current, generator phase currents, inverter output phase currents, and DC link voltages. This need poses opportunities for current/voltage sensors with requirements of not only sufficient accuracy, response speed, but also high switching noise rejection and safety insulation, at a competitive cost.

Iso-amp measures current and voltage

With advantages of better linearity, low cost, and design flexibility, shunt current sensing is a classical method for current measurement despite the drawback of power loss on the shunt. From developments of better thermal performance and lower resistance in shunt technology, power loss can be minimized by reducing shunt signal level.

Specifically designed to meet the stringent requirements in power conversion systems, the ACPL-C78A/C780/C784 miniature iso-amps accept signal of ±200mV, which is ideal for direct connection to shunt based current sensing applications. By choosing an appropriate shunt resistance, any range of current can be monitored, from less than 1A to more than 100A.

The ACPL-C78X family uses advanced sigma-delta A/D converter technology and fully differential implementation to realize 1% gain accuracy (ACPL-C78A), 0.004% extremely low nonlinearity and DC to 100kHz wide bandwidth (Figure 3). Available in a stretched small outline-8 (SSO-8) package with 8mm clearance and creepage (Figure 4), the ACPL-C78X offers robust galvanic isolation with safety approvals of 1140V working voltage per IEC/EN/DIN EN 60747-5-2,

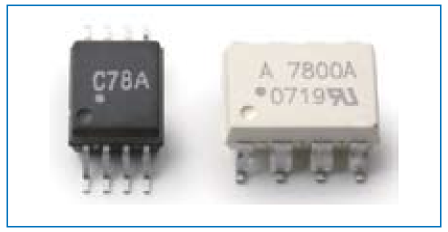

Figure 4: SSO-8 package (left), 30 percent smaller footprint vs. DIP-8 package.

5kVrms/1min double protection per UL 1577, and 15kV/µs common-mode rejection.

Conclusion

Though the market forces driving the wind energy industry vary from region to region, from feed-in tariffs successfully implemented in Europe, to a combination of regulations, subsidies and tax incentives employed in North America and Asia, this industry is set to grow quickly. Despite the eye-catching multi-megawatt wind machines going offshore into deep water regions, most of the opportunities for power inverters are in the small wind turbine market.

The ACPL-C78X miniature isolation amplifiers provide accurate current and voltage measurements that are required in typical small wind power designs to achiever optimum efficiency. The high switching noise rejection and high insulation voltage capabilities ensure smooth inverter operation and safety of the controller and operator.

www.avagotech.com

Making the Most of Efficiency Growth

Optimising inverter design for high-efficiency solar generation

The photovoltaic (PV) cell has come a long way since the days of solar-powered calculators. Conversion efficiency has steadily improved – the Fraunhofer Institute for Solar Energy Systems recently operated an experimental n-type silicon cell at over 23% efficiency. Combined with increasing open-circuit voltage, now reaching 1.75V for the best designs, solar power is a practical proposition for everyday applications such as heating and lighting.

By Wibawa T. Chou, Senior Applications Engineer, International Rectifier Corp., El Segundo, California

Still, however, the energy from each cell is precious; the DC/DC converter and DC/AC inverter stages that convert the low-voltage DC output into high-quality mains power must also be carefully designed to achieve the maximum possible efficiency. As far as the inverter is concerned, valuable efficiency gains can be achieved by optimising operating principles and carefully selecting components.

Inverter design

The inverter is required to produce a sinusoidal single-phase AC voltage of suitable quality to be put onto the grid for distribution, or to drive a local load. Its input is the boosted voltage produced by the DC/DC converter connected to the output of the solar panel. The main functional block within the inverter (figure 1), which produces the sinusoidal output and is also responsible for most of the inverter's losses, is a full-bridge switching network comprising four power transistors. A controller IC co-ordinates the switching of these devices, and subsequent inductive filtering produces a smooth sinusoid with low harmonic content.

IGBTs are the power switch of choice for solar inverters. The voltage-controlled gate is as easy to drive as a MOSFET, but the IGBT has superior current carrying capability and conduction properties. The latest devices also have good switching performance, and have a co-packaged ultra-fast recovery diode to speed up the turn-off characteristic. Further advantages include the IGBTs wide safe operating area (SOA) and high degree of ruggedness. However, IGBT device designers must usually trade turn-off time against voltage drop. Since the voltage drop translates into energy loss, this has important implications when seeking maximum efficiency for a solar inverter.

IGBT constraints

Since the IGBT is a minority carrier device, its turn-off speed is determined by the time for the minority carriers to recombine. The recombination time is adjusted using lifetime-control mechanisms, but these tend to impose a higher voltage drop (VCEon) as the trade off for a shorter recombination time.

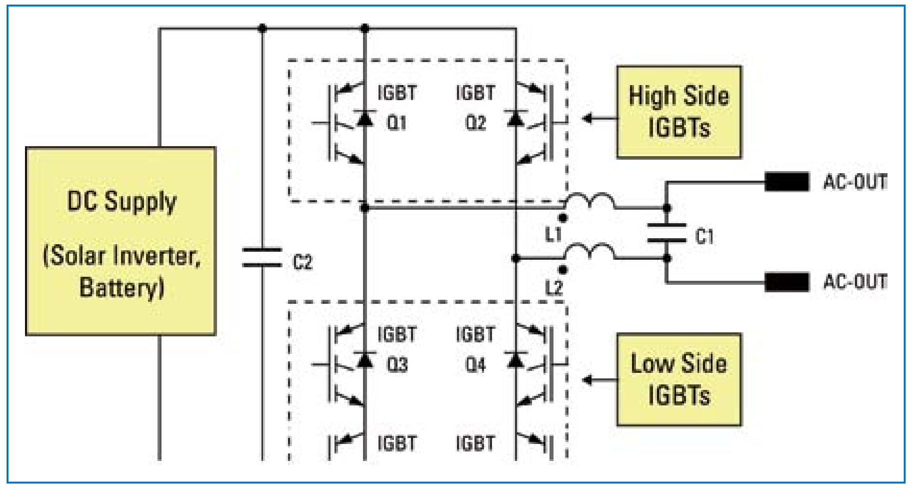

Figure 1: Main functional block within the inverter.

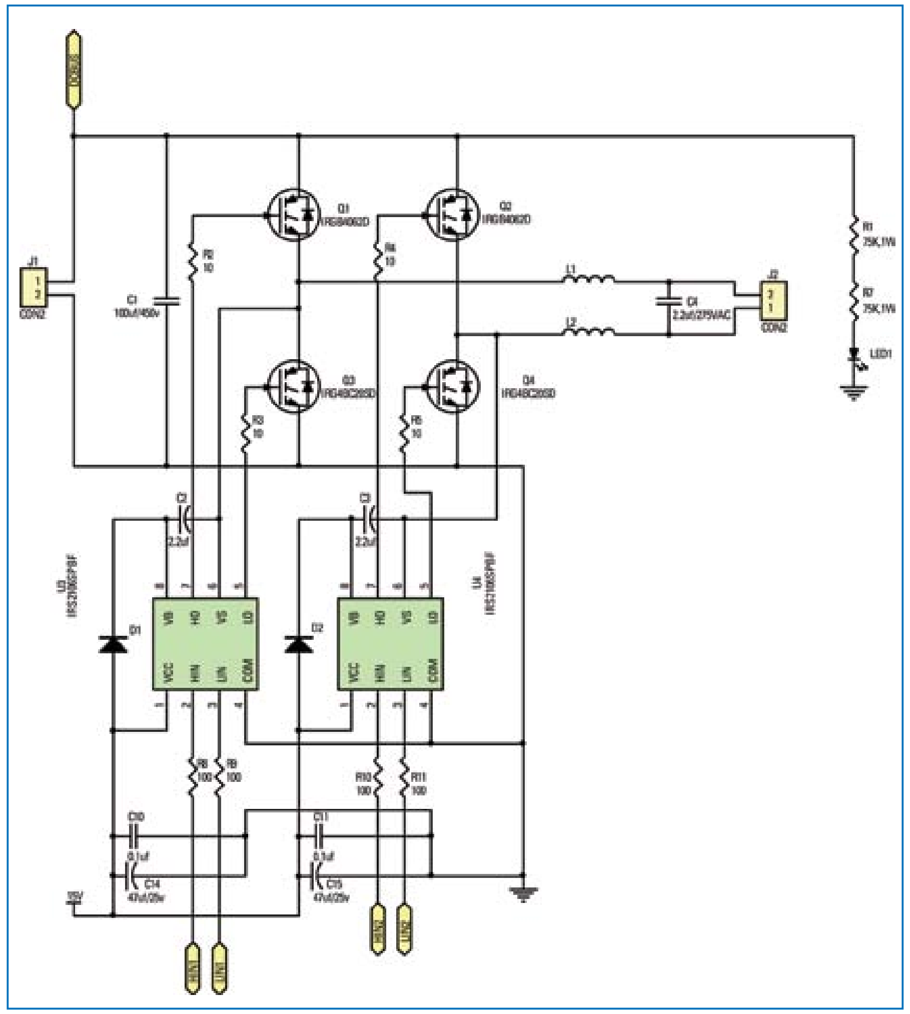

Figure2: System-level design for a 500W full-bridge inverter circuit.

This aspect of IGBT behaviour must be considered when designing a full-bridge inverter for solar power conversion. The inverter's output waveform must have a low harmonic content. This can be achieved by pulse-width modulating the two high-side IGBTs at a relatively high frequency while commutating the low-side IGBTs at the desired AC frequency; typically 50Hz or 60Hz. The PWM frequency is usually set at 20kHz. This provides a practical trade off between IGBT switching losses and the size of the inductors necessary for effective filtering. Audible noise is also avoided, as the switching frequency is above the human hearing spectrum.

A bridge of two halves

Operating the IGBTs at different frequencies imposes different performance requirements on the high-side and low-side devices. High-side IGBTs tend to be optimised for minimum losses at 20kHz. To ensure that both conduction and switching losses are kept to a bare minimum the ideal high-side IGBT is a high-voltage (600V) ultrafast trench device optimised for low VCEon and low total switching energy (Ets). This class of IGBTs are also highly rugged, having a square reverse-bias operating area, 175°C maximum junction temperature, and typically four times the rated current of a conventional planar device. Devices such as the IRGB4062DPBF are also typically 100% tested for clamped inductive load. The co-packaged ultrafast soft recovery diode also plays an important role in minimising switching losses.

Note, also, that a short-circuit rating is not required for the high-side IGBTs since the output inductors L1 and L2 act to restrict current transients when the inverter output is shorted, thereby allowing time for the controller to react appropriately. This is important for device selection, since short-circuit rated IGBTs tend to have higher VCE(on) and higher Ets than non short-circuit rated IGBTs of the same dimensions and would therefore contribute higher power losses; hence reducing inverter efficiency.

On the other hand, switching losses are of almost negligible consequence when selecting the low-side IGBTs since these are commutated significantly more slowly, at 50/60Hz. Instead, conduction losses dominate the inverter designer's concerns. Standard-speed, planar IGBTs such as the IRG4BC20SD are ideal. This is a fourth-generation IGBT optimised for minimum saturation voltage and operating frequencies below 1kHz. Its typical VCEon is 1.4V at 10A. In addition, the co-packaged ultrafast, soft-recovery, anti-parallel diode is tailored for extremely low forward voltage drop and reverse leakage current. This minimises losses during freewheeling and reverse recovery.

Performance analysis

Figure 2 illustrates a system-level design for a 500W full-bridge inverter circuit producing a nominal 110V AC output. Q1 and Q2 are IRGB4062DPBF ultrafast trench IGBTs, while Q3 and Q4 are IRG4BC20SD planar devices. Since the co-pack diodes of Q1 and Q2 are not subjected to the freewheeling current, and Q3 and Q4 have low conduction loss and very little switching loss, the overall system losses are minimised leading to high conversion efficiency. Additionally, because the switching is implemented on diagonal device pairs (Q1 and Q4 or Q2 and Q3), there is no possibility of cross conduction. Another important advantage is that the inverter operates from a single DC bus supply, hence eliminating the need for a negative DC bus.

The diagram also shows the high-speed gate-driver ICs, which have independent low- and high-side driver channels. The driver used in this example, the IRS2106SPBF, also permits bootstrap power supply operation for the high-side power transistors, thereby eliminating the need for an isolated power supply for the high-side drive. Overall, this inverter design enables improved efficiency and also saves parts

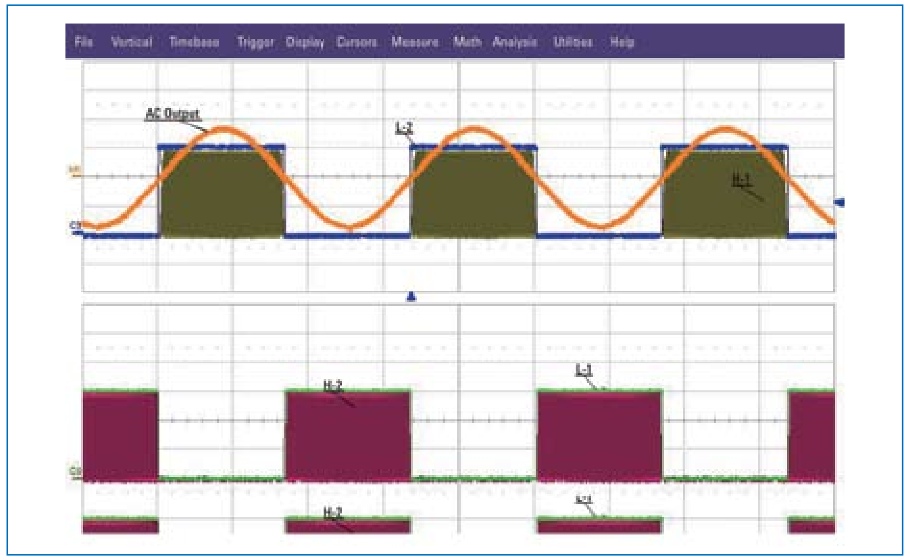

Figure3: Inverter output waveforms.

count for the overall system.

Figure 3 shows the output waveforms for the inverter. During the positive-output half cycle, the high-side IGBT Q1 is sine PWM modulated, while the low-side Q4 is kept on. Similarly, during the negative output half cycle, the high-side Q2 is sine PWM modulated while the low-side Q3 is kept on. This switching technique produces a smooth AC sine wave across the output capacitor C4, following the output LC filter.

The table shows the measured output voltage, current, power and losses for this inverter at 500W and 200W operation. This shows how careful attention to device selection enables very high inverter efficiency over a wide range of operating conditions. In fact, efficiency is continuously above 97% from 500W down to 100W.

System-wide efficiency gains

It is worth noting that the high efficiency of this design also helps to avoid thermal management challenges, delivering an important extra advantage in the pursuit of maximum efficiency. The low internal losses keep measured junction temperatures for the high-side and low-side IGBTs below 40°C at 100W, reaching a maximum of 83°C at 500W. These temperatures are well within the specified maximum of 175°C. Hence reliable operation up to 500W is possible without the additional power drain of a cooling fan.

This approach to inverter design, blending optimised low- and high-side high-voltage IGBTs with suitable high-voltage drivers, delivers consistently high conversion efficiency complementing the efforts of PV-cell research to make solar power a major element of future low-carbon energy policies.

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2009 GreenPower Leadership Awards

Winners and Finalists Announced at PCIM Europe

For the past year the readers of Power Systems Design Europe have been voting for the best editorial contribution in the area of "energy efficiency". The 2009 GreenPower Leadership Awards program has been made possible by the financial contributions of our two Gold Sponsors: Intersil and Linear Technology.

The Winner is: Company: Fairchild Semiconductor, Article: "Solar Power Shines", Author: Alfred Hesener.

The four finalists (in alphabetical order by company) are: Company: Coilcraft, Article: "Designing for Efficiency at the Component Level", Author: Len Crane • Company: Linear Technology, Article: "Solving Current Source Design Challenges", Author: Robert Dobkin • Company: Microsemi, Article: "SiC Impacts 'Greening' of Power", Authors: Philip C. Zuk & Bruce Odekirk • Company: Philips Lumileds, Article: "Avoiding Current Spikes with LEDs", Author: Pat Goodman.

Educational Donation. A significant component of the *2009 GreenPower Leadership Awards* program is an educational donation, given to the European Engineering University of choice by the article author. This year's donation is awarded to: The Institute of Robotics at the University of Maribor, Maribor, Slovenia. The University conducts research on motion control solutions.

2010 GreenPower Leadership Awards. Voting has already begun for our expanded *2010 GreenPower Leadership Awards Program* and will continue through the April 2010 issue of Power Systems Design Europe. If you want to summit editorial content on "energy efficiency" to be judged for next years program, contact Cliff Keys, Editor-in-Chief, **cliff.keys@ powersystemsdesign.com** • For sponsorship opportunities, contact Julia Stocks, Publisher, **julia@powersystemsdesign.com.**

intersil
LINEAR TECHNOLOGY
Power Systems Design EUROPE

Where will it come from?

Reported by Cliff Keys, Editor-in-Chief, PSDE

The topic of renewable energy is sure to continue to be centre-stage for many years to come. The idea of us all using only energy derived from clean renewable sources is a long way off and will likely never be achieved. At best we can strive to consume less wastefully and to be sensitive to the policies of our governments regarding future sources of energy.

Policy statements drafted by the UK's Energy and Climate Change Secretary outline an energy future that focuses on a 'trinity of fuels' as a reliable source of low carbon energy: nuclear, renewables, and 'clean' fossil fuels. The UK has shortlisted ten sites as suitable for new nuclear power stations. Eight would be on or next to the sites of existing or decommissioned facilities and two further proposed stations would be on new sites. The new power plants would create up to 90,000 jobs in their construction and operation phases.

The PV inverter market staged a strong recovery in the third quarter of 2009 with shipments reaching record levels and the outlook for the market becoming increasingly positive.

Over 2.5GW of PV inverters were shipped in the third quarter of 2009 according to IMS Research, marking an impressive recovery for the industry, which had stalled in the first half of the year. Global revenues are estimated to have reached over €600m, 30% up on the same quarter in 2008 and nearly double the previous quarter. Germany showed very strong growth with over 1.2GW of inverters shipped in the third quarter alone - almost twice the amount that was shipped in the first half of the year.

Demand is anticipated to remain very strong in the fourth quarter but is now limited by the availability of inverters and other components with most suppliers now unable to deliver products until 1Q2010. Prices of PV inverters have fallen around 10% over the last year, a relatively small amount compared to the severe price declines experienced by PV module suppliers.

Naturally it is a complex issue. In Europe there has been widespread implementation of PV due to incentives given by governments. Wind is also high on the agenda with a proliferation of offshore wind farms. It will be interesting to see where governments specify the source-mix of our power for the future.

www.powersystemsdesign.com/greenpage.htm

Same Package, 60% More Current

Part Number	B_{VDSS} (V)	$R_{DS(on)}$ (mΩ)	I_D @ 25°C (A)	Qg typ (nC)	Package
IRFS3004-7PPBF	40	1.25	240*	160	D2PAK-7
IRFP4004PBF	40	1.7	195*	220	TO-247AC
IRFB3004PBF	40	1.75	195*	160	TO-220
IRFS3004PBF	40	1.75	195*	160	D2PAK
IRFS3006-7PPBF	60	2.1	240*	200	D^2PAK-7
IRFB3006PBF	60	2.5	195*	200	TO-220
IRFS3006PBF	60	2.5	195*	200	D^2PAK
IRFS3107-7PPBF	75	1.85	195*	380	TO-247AC
IRFS3107PBF	75	2.6	240*	160	D^2PAK-7
IRFP4368PBF	75	3.0	195*	160	D2PAK
IRFB4115PBF	100	2.6	195*	360	TO-247AC
IRFS4010-7PPBF	100	4.0	190	150	D^2PAK-7
IRFS4010PBF	100	4.7	180	143	D^2PAK
IRFS4127PBF	150	5.9	171	151	TO-247AC
IRFS4115-7PPBF	150	11	104	77	TO-220
IRFB4127PBF	150	11.8	105	73	D^2PAK-7
IRFS4115PBF	150	12.1	99	77	D^2PAK
IRFP4668PBF	200	9.7	130	161	TO-247AC
IRFP4568PBF	200	20	76	100	TO-220
IRFP4468PBF	200	22	72	100	D^2PAK
IRFP4768PBF	250	17	93	180	TO-247AC

* Package limited

International Rectifier has expanded its portfolio of high performance MOSFETs with a new series of HEXFET Trench MOSFETs ranging from 40V to 250V. The new devices feature a package current rating of up to 195A, delivering a 60 percent improvement over typical package current ratings. The new MOSFETs also provide improved on-state resistance ($R_{DS(on)}$) compared to previous offerings and are available in the popular TO-220, D^2PAK, 7 pin D^2PAK, TO-247 and TO-262 packages.

Applications

- Industrial battery
- Power supply
- High power DC motors
- DC to AC inverters
- Power tools
- Synchronous rectification
- Active ORing

Features

- Industrial grade
- Moisture sensitivity level 1
- Lead-free
- RoHS compliant

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