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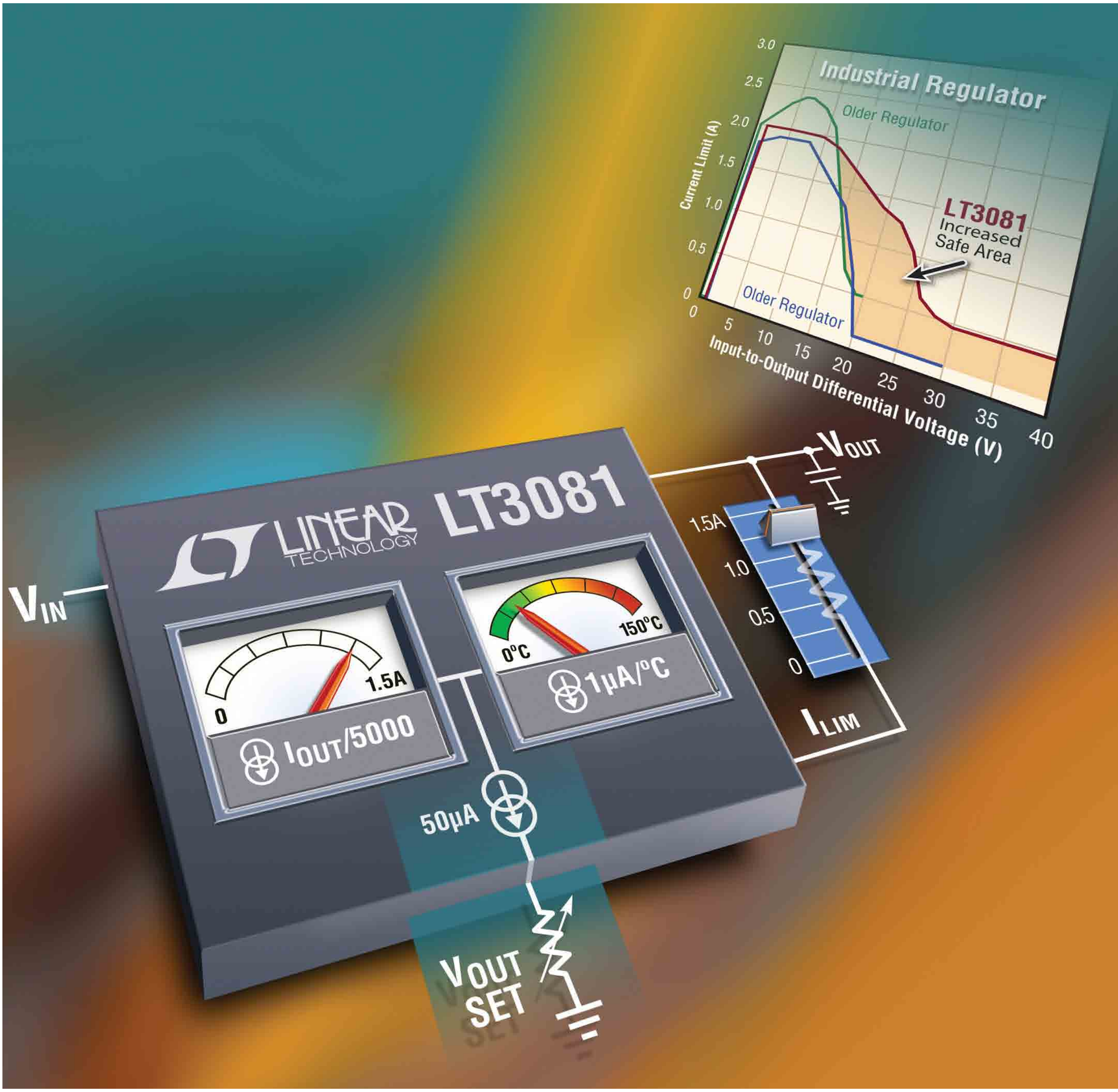

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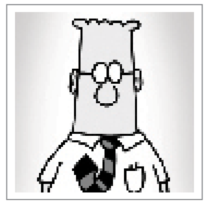

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Volume 10, Issue 7

Design philosophy as an expression of strategic vision

Every designer is trying to create a new solution to address the customer's needs, but how that solution is expressed should be a manifestation of not just your customer's needs, but your strategic vision of where that application space is headed and how you feel technology should be implemented to address it.

Short-term solutions

A short-term solution is just that, a band-aid placed on the application requirements to satisfy the customer's desires, but does nothing to address the deeper aspects of the market segment and the technologies and infrastructures involved. Many consumer devices fall into this trap, as companies create one-off short-term products that satisfy a market fad but do nothing to serve the general industry. This issue is not as great in B-to-B application spaces due to the slightly more practical nature of business, but it is still a real concern and drag on the industry.

One example rife in the industry is that many companies choose to field a proprietary solution to an application space that bridges many markets and industries. This may be done to make customer retention easier, or to avoid license fees on accepted connector and/or protocol and/or form factor issues. These "solutions" only help the immediate customer and do nothing for infrastructure compatibility and system interoperability.

Long-term solutions

Products and systems that solve industry-level concerns while addressing customer needs are the best. This is extremely beneficial to everyone, a true win-win. Not only does the customer get what they wanted, the manufacturer gains a solution that can be applied to multiple customers and applications. For example, implementing a smart-product solution that not only works for the customer but also uses industry-standard form factors, connectors, and protocols, will also ensure current and forward infrastructure compatibility as the industry migrates. A proprietary solution runs a significant risk of being left behind or leapfrogged as the industry moves forward.

Functionality focus

After interface and form factor, functionality must also be considered as an infrastructure consideration. How a system is deployed and its functionality focus has a great deal of influence on the solution itself. For example, Apple's iPod wasn't any different fundamentally in the hardware than its competition; its great advance was the focus on the device as part of a larger infrastructure. That infrastructure was proprietary, but since there was no other competition, Apple's solution won out because they had based their design on a larger vision that served the customer as well as the application space. A device created with a narrow focus will have a narrow application space; one created with the market and industry in mind and an idea of where that market is headed will apply to much more.

Best Regards,

Alix Paultre

Editorial Director, Power Systems Design
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Advanced source measure unit instrument sports an interactive touchscreen display

Keithley Instruments unveiled the first benchtop Source Measure Unit (SMU) with a capacitive touchscreen graphical user interface. The Model 2450 SourceMeter SMU Instrument combines a touchscreen and icon-based control so novice as well as experienced SMU users can access the device's versatility to learn faster, work smarter, and invent easier.

The Model 2450. It is based on the company's innovative "Touch, Test, Invent" design philosophy that reflects recent market changes, including shrinking product design/development cycles and fewer personnel devoted exclusively to test engineering tasks. At the same time, the profile of the typical instrument user has also evolved. In addition to electrical engineers, it now includes a growing number of non-engineers (such as electrochemists, physicists, materials scientists, etc.) who need fast access to data but sometimes have limited training in electrical measurement.

To accommodate all of these market and user changes, the Model 2450 incorporates numerous ease-of-use features that ensure a faster "time-to-answer" than competitive solutions, including a context-sensitive help function, "Quickset" modes that speed instrument configuration, and on-screen graphing capabilities that quickly turn raw data into usable results. The Model 2450 combines the functionality of a power supply, true current source, 6-1/2-digit multimeter, electronic load, and trigger controller in one tightly integrated, half-rack instrument. With all of these capabilities, the Model 2450 integrates the capabilities of I-V systems, curve tracers, and semiconductor analyzers at a fraction of their cost.

Benchtop Application Advantages

Many of the Model 2450's features help speed and simplify lab/benchtop work, like the full-color, 5-inch touchscreen user interface with large on-screen characters enhance legibility. A simple, icon-based menu structure allows reaching any measurement set-up panel with just a touch. An extended measurement range with new low current (100nA, 10nA) and voltage (20mV) ranges eliminate the need to add separate low-level instruments to a benchtop system. Back-panel triax cable connections eliminate the need for expensive cable adaptors, which can degrade low-level measurement performance.

A built-in context-sensitive help function provides information right where it's needed through the touchscreen, minimizing the need to review a manual. Error and event logging is easier, as the touchscreen displays error messages and an event log to simplify diagnosing instrument errors, for higher productivity.

In addition, KickStart start-up "no-programming" instrument control software simplifies taking and graphing data in minutes. For more complex analyses, data can be easily stored to disk, and then exported to Microsoft Excel or another software environment.

www.keithley.com

The role of the embedded power in the Smart Grid infrastructure

By: Conor Quinn, Emerson Network Power

I don't think that I'm alone in struggling with defining the role that the traditional power supply industry plays in the emerging "smart grid" infrastructure. This is not meant to imply that the power supply industry is not contributing to the smart grid, but that the terminology and concepts are too broad and expansive to be meaningful without added context.

I recently participated in a Smart Grid workshop organized jointly by Power Sources Manufacturers Association (PSMA) and Electric Power Research Institute (EPRI). A clever workshop title helped. It asked: "Are you smarter than the smart grid?" The message that I wanted to deliver was two-fold. The first was in regards to the state of the art in power supply technology and how far it has advanced in recent years – they're already smart; they already communicate with other devices and systems in their environment; and, they're already conserving energy when compared with performance levels of a few years ago. The second part of the message was that it's not obvious to me (and many in the industry, I believe), whether there are additional expectations on the power supply industry and what it should be doing to advance the goals of the smart grid.

Consider a power supply used in modern communications or computing equipment today and compare it with its counterpart five to ten years ago. From an energy-efficiency perspective, losses have been cut by a factor of three, i.e. the same power can be produced while generating approximately thirty per cent of the waste energy or heat that would have been generated previously. If one of the goals of the smart goal is to reduce the stress on the modern grid by reducing losses, our industry has contributed tremendously.

But, the modern power supply barely resembles its predecessors in many ways. It monitors and reports line status, energy consumption, temperature effects and load conditions. It adjusts its thermal environment, both independently and in response to system needs. And it modifies its own internal operating modes to maximize efficiency depending on external system conditions. Put simply, it is "Smart".

So, what are the future expectations in an area that is so vast in scope? Are large changes in store, or is it simply a matter of allowing these technologies to evolve based on the particular applications in which they are used? Efficiency will continue to increase incrementally, but cost-performance remains a constraint. Similarly, accuracy of reporting will probably continue to improve, but again within the constraint of cost. Perhaps the biggest changes will be in the integration of the power supply into the communication and networking methods associated with both the equipment and the grid? Whatever it may be, - the nexus of the Smart Grid and the Internet of Things and the Power Supply Industry – it won't be boring!

www.emersonnetworkpower.com

Grid stabilisation to drive battery and power management markets

By: Ryan Sanderson, HIS

Over the last decade, growth in population, and advances in technology and communications have placed a continuously increasing demand on power generation, distribution, control and storage. To meet global demands, the number of power stations has increased rapidly to provide power to those connected to the power grid. In recent years many regions around the world have invested in renewable energy sources in order to reduce environmental impacts related to energy produced from fossil fuels. This has created new challenges and opportunities in many related markets.

Batteries have been used in energy and infrastructure for many years. They provide reserve power and are also used to regulate power fluctuations, slow/start turbines safely and aid with grid stability. There is an emerging market for batteries for use in renewable energy generation and storage and to manage the challenges that an increasing number of sources feeding into the power grid bring.

Recent analysis of the global stationary battery market from IHS revealed that explosive growth is projected in the energy and infrastructure sector, owing largely to demand for batteries for renewable energy and storage, driving forecast growth of $6.3 billion from 2012 to 2017. This is predicted to bring many opportunities for battery packers and battery and power management solution providers as well as the obvious opportunities for battery manufacturers. It is also predicted that these opportunities will not just be confined to renewable energy storage solutions.

The market for stationary batteries used in traditional power generation, switch gear and control is also predicted to grow rapidly from $520 million in 2012 to $800 million in 2017. More than 90% of the market in 2012 was accounted for by lead-acid batteries with the majority of the small remainder accounted for by nickel cadmium batteries. Total market share for lead-acid is predicted to reduce slightly to account for 80% of the market in 2017. This is largely due to a predicted rapid increase in demand for lithium-ion batteries in this sector.

As there are a rapidly increasing number of renewable energy installations which feed directly in to the main power grid, fears of this producing grid instability are driving a market for stationary batteries used to regulate fluctuations and spikes during energy generation. While VRLA lead-acid batteries are suitable and strong growth is projected for their use for this purpose, the capabilities of lithium-ion batteries to charge rapidly following rapid discharge and to be able to cope with many more charge/discharge cycles throughout their lifetime, make them an attractive solution for this function. This is predicted to drive strong growth in the market for lithium-ion batteries used for grid stabilization in traditional power plants, growing from just $0.2 million in 2012 to $94 million in 2017.

www.ihs.com

Tapped boost converter modeling

By: Dr. Ray Ridley, President, Ridley Engineering

As mentioned in the last article of this series [1], Dr. Vatché Vorpérian developed the PWM switch model in 1986, which replaced the need for state-space averaging and greatly simplified the analysis process. It was a very elegant and intuitive modeling approach, which is easily grasped by new students in the field.

Figure 1 shows the PWM switch arrangement identified by Dr. Vorpérian in gold. Once this configuration of switch and diode is found in the power circuit, it can be replaced by one of three equivalent circuits, depending on what kind of analysis is to be done.

The equivalent circuit outlined in red is the nonlinear PWM switch model. This can be used in Spice to find both DC and AC analysis, if desired. The nonlinear model can also be used to generate distortion characteristics of switched-mode amplifiers and other circuits that operate over a large range of conditions. However, its nonlinear nature makes it unsuitable for hand analysis if you are trying to arrive at symbolic result for complete circuit understanding.

Tapped Boost Converter

To perform the PWM converter circuit analysis, it is crucial to find the switch and diode circuit structure shown in **Figure 1**. However, in some PWM circuits, it doesn't exist in the original circuit diagram. In the previous article, we showed how it could be found in isolated topologies, a straightforward process. In [2], it was shown how it can be found for the Sepic converter.

Figure 2 shows another interesting topology, the tapped boost converter. The power FET is connected to a middle winding of the inductor as shown, and the diode is connected to the end of the winding. This circuit is useful if a large step-up ratio is required from the circuit operation.

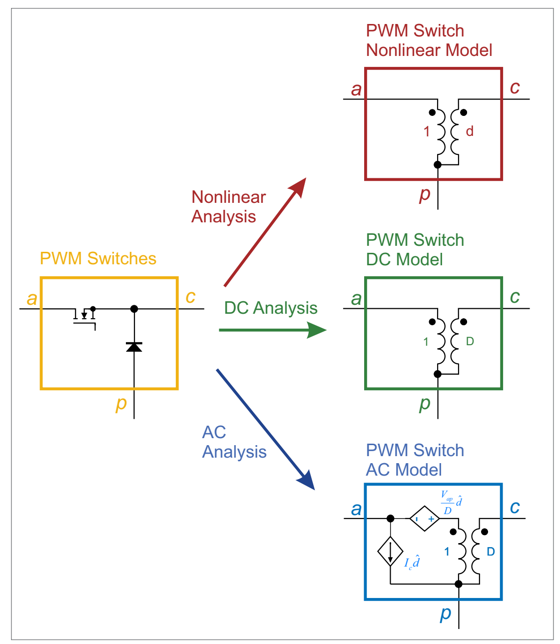


Figure 1: PWM switches and the three equivalent circuits used for different types of analysis

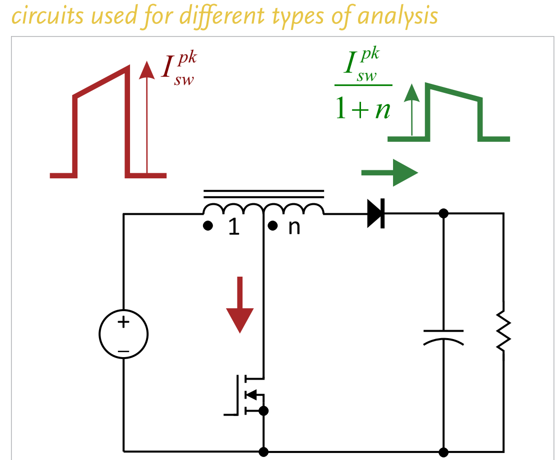


Figure 2: The tapped boost topology. This circuit can be useful for large step-up ratios, but the connection of the switch and diode is not present in the original circuit.

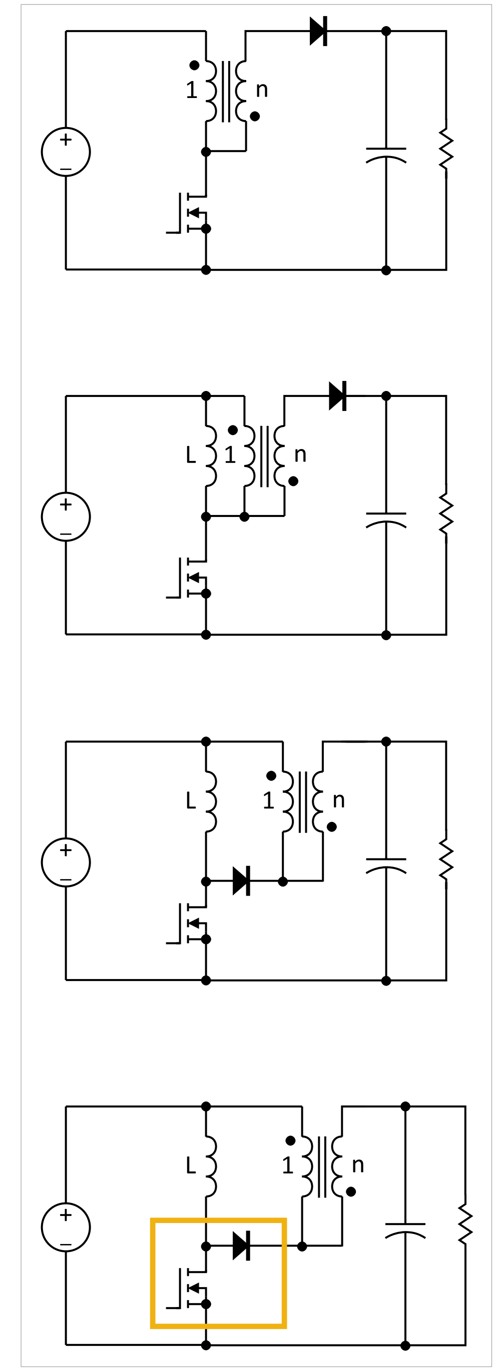


Figure 3: Rearrangement of the tapped boost circuit reveals the PWM switch structure, allowing analysis to be done using Vorpérian's switch model.

When the FET is on, the inductor has less than the complete number of turns connected, and the current shown in red results. When the FET turns off, the inductor now has the complete number of turns in series with the diode. The current is reduced by $1/(1+n)$ relative to the FET current, and the diode waveform is shown in green.

Figure 3 shows the sequence of circuit manipulations needed to find the PWM switch model. In the top circuit, no connections are changed, but the inductor is redrawn as a transformer with a 1:n ratio. This is not an ideal transformer, but it has a finite value of magnetizing inductance, which defines the energy storage inductor value. (This is similar to component always drawn for a flyback converter: the transformer is shown explicitly, but value of the magnetizing inductance is a critical design element.)

The inductor itself is explicitly shown in parallel with the transformer in the second circuit, and the value is that seen with just the left hand turns count. The 1:n transformer is now ideal with an infinite value of magnetizing inductance.

With an ideal transformer, the diode connected on the secondary side can now be moved to the primary. The direction is important to define proper operation of the circuit. In the original circuit, the diode only allows current to flow into the dot of the secondary winding. When the diode is moved to the primary, it can only allow current to flow out of the dot as shown in the third circuit of **Figure 3**. The PWM switch arrangement is now obvious, and it is framed in gold in the fourth circuit of **Figure 3**.

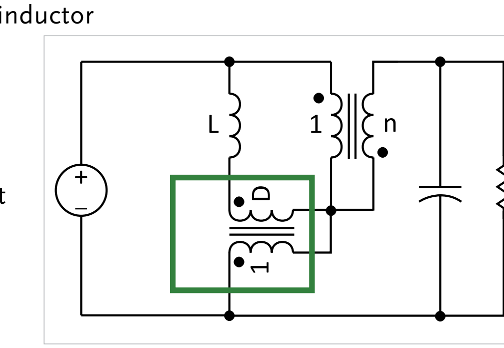
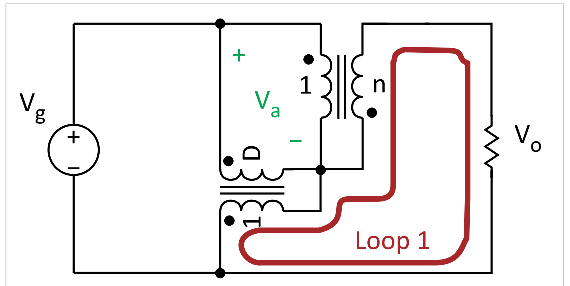


Figure 4: In order to solve for the DC gain of the circuit, the DC switch model is substituted for the original switching elements.

DC Analysis of the Tapped Boost Converter

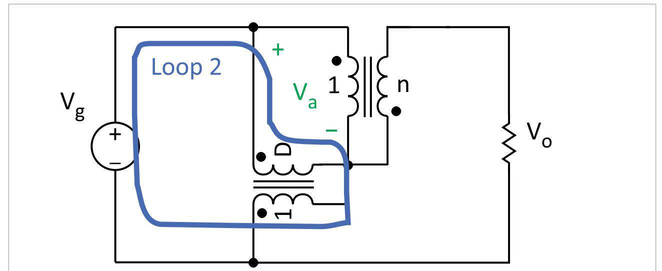
Now that the switch model has been identified, it is a simple matter to proceed with analysis of the circuit. **Figure 4** shows the DC switch model in green substituted for the switch-diode combination, and we use this



Writing KVL around Loop 1 gives:

$$V_o = -nV_a - \frac{1}{D}V_a \qquad \text{Eq. (1)}$$

Figure 5: Solving for DC gain by applying KVL around the first loop of the tapped boost circuit.



Writing KVL around Loop 2 gives:

$$V_g = V_a - \frac{1}{D}V_a = \left[1-\frac{1}{D}\right]V_a = \frac{D-1}{D}V_a = \frac{-D'}{D}V_a$$

or

$$V_a = \frac{-D}{D'}V_g \qquad \text{Eq. (2)}$$

Substituting (2) into (1) gives

$$V_o = -n\frac{-D}{D'}V_g - \frac{1}{D}\frac{-D}{D'}V_g$$

Gain of the Tapped-Boost Circuit:

$$V_o = V_g\left[\frac{nD}{D'}\right] + V_g\left[\frac{1}{D'}\right] \qquad \text{Eq. (3)}$$

Figure 6: Solving for DC gain by applying KVL around the second loop of the tapped boost circuit.

equivalent circuit to find the DC conversion ratio of the tapped boost circuit.

Notice that the 1:D transformer of the DC model is not connected in a way that allows simple inspection for the circuit to find the gain. Solving the DC gain of the circuit is an exercise in applying Kirchoff's voltage law. Two voltage loops are identified for the circuit as shown in **Figure 5.**

First, we assign a value of Va to the voltage across the two circuit transformers as shown in green. Then, moving around the loop in red, Equation (1) in Figure 5 gives the relationship between the output voltage and Va.

The second loop is shown in **Figure 6**, and this allows us to solve for Va in terms of the input voltage, Vg. Substitution of this equation into the first equation gives the gain of the tapped boost circuit, as outlined by Equation [3] in green. Notice that there are two terms making up the gain of the tapped boost converter. The second term, shown in blue in Equation [3], is the same as the gain of a normal boost converter. The first term, shown in green, is the same as the gain of a flyback converter, but without any inversion. If the secondary turns ratio is zero, we have just a normal boost converter, as would be expected.

With a turns ratio of one, at a 50% duty cycle, the gain of the circuit is 3, instead of the usual gain of 2 that would be obtained with just a boost converter. This demonstrates the advantage of this topology, giving increased gain. However, it does not come for free, and it has all the problems of transformer-isolated circuits. Most notably the effect of leakage inductance between the two windings causes voltage spikes on the power FET.

Summary

We described how to find the PWM switch model in the tapped boost circuit, which lets us find the DC gain of the circuit with ease, as has been shown. The ac analysis is also straightforward if we substitute the ac circuit model.

Tapped inductor circuits are often suggested as solutions to interesting power conversion problems. The tapped buck is useful if we want to arrive at large step-down ratios. For all of these types of converters, it is usually just a straightforward manipulation of the circuit to find the switch model. Not many designers practice this kind of circuit analysis these days, but it is a useful skill to have.

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4. To learn how to make control measurements, please visit http://www.ridleyengineering.com/analyzer.html
5. Join our LinkedIn group titled "Power Supply Design Center". Noncommercial site with over 2300 helpful members with lots of experience.

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New Linear Regulators solve old problems

Features include the ability for the regulator to operate down to zero output voltage

By: Bob Dobkin, VP & CTO, Linear Technology

Regulators regulate, but are capable of doing much more. The architecture of linear regulators has remained virtually unchanged since the introduction of the three-terminal floating voltage regulator in 1976. Regulators were either a floating architecture or an amplifier loop with feedback. Both of these architectures suffer from limitations on versatility, regulation, and accuracy.

The feedback resistors set the output voltage and attenuate the feedback signal into the amplifier, making regulation at the output a percentage of the output voltage, increasing regulation inaccuracy as voltages rise. In addition, since the loop gain is decreased, the bandwidth is decreased as well at higher output voltages. This makes transient response slower and ripple worse as output voltage goes up.

Older regulators fixed current limiting with no adjustment, are built into the IC, and different devices must be used for different output currents. If the current limit needs to be matched to the application or accurate current limit is needed, an external circuit must be used (see **Figure 1a**).

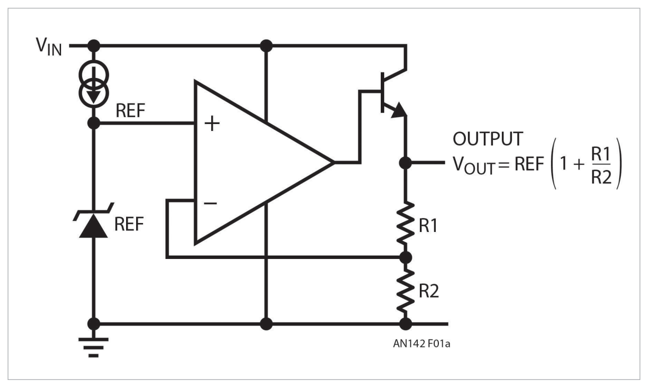

Figure 1a: Older Regulators

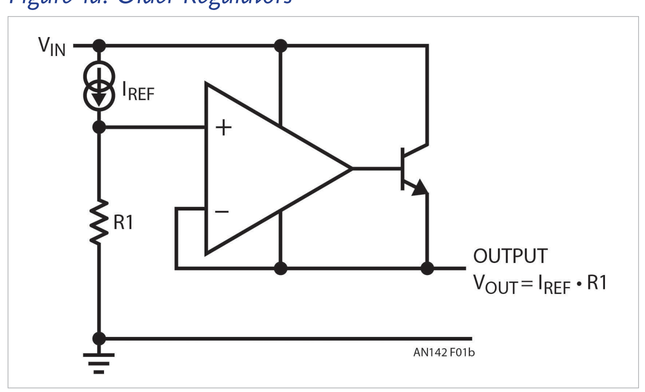

Figure 1b: New Architecture Regulator

New regulator architecture was introduced in 2007 in the LT3080, which used a current source for the reference and a voltage follower for the output amplifier. Advantages of this architecture include the ability to parallel the regulators for more output current, and the ability for to operate down to zero output voltage. The output amplifier always operates at unity gain, so bandwidth and regulation are constant. Transient response is independent of output voltage, and regulation can be specified in millivolts rather than a percent of output (see **Figure 1b**).

Along with different output current variations, these regulators were specifically designed to add functional features not previously available, such as monitor outputs for temperature and current as well as external control of current limit. One device (LT3086) also has external control of thermal shutdown. A new negative regulator provides monitoring and can operate as a floating regulator or an LDO. All of these new regulators can be paralleled for higher current, current sharing, and heat spreading.

A new industrial regulator

Providing 1.5A of output current, the LT3081 industrial regulator is adjustable to zero output voltage, is reverse protected, and has monitor outputs for temperature and output current. In addition, the current limit can be adjusted by connecting an external resistor to the device.

Temperature and current monitor outputs are current sources configured to operate from 0.4V above V_{OUT} to 40V below V_{OUT}. Temperature output is 1μA/°C per degree, and the current monitor is I_{OUT}/5,000. These current sources are measured by tying a resistor to ground in series with the current source and reading across the resistor. The current source has a range of –40V to 0.4V referred to the output and it continues to work even if the output is shorted. The dynamic range for the monitor outputs is 400mV above the output so, with the output shorted or set to zero, temperature and current can still be measured. Using a 1k resistor provides sufficient margin and ensures operation when the output is shorted.

The output is set with a resistor from set pin to ground and a 50μA precision current source set to the output. The internal follower amplifier forces the output voltage to be the same voltage as the SET pin. Unique to the LT3081, an output capacitor is optional. The regulator is stable with or without input and output capacitors. All the internal operating current flows through the output pin and minimum load is required to maintain regulation. Here, a 5mA load is required at all output voltages to maintain the device in full regulation.

The set resistor can add to the system temperature drift. Commercially available surface mount resistors have a wide range of temperature coefficients. Depending on the manufacturer, these can go from 100ppm up to over 500ppm. While the resistor is not heated by power dissipation in the regulator, over a wide ambient temperature range its temperature coefficient can change the output by 1 to 4 percent. Lower temperature coefficient thin film resistors are available for precision applications.

The benefit of using an internal true current source as the reference, rather than a bootstrapped reference, as in prior regulators, is not so obvious. A true reference current source allows the regulator to have gain and frequency response independent of the impedance on the positive input. With all previous adjustable regulators, such as the LT1086, loop gain and bandwidth change with output volt-age changes. If the adjustment pin is bypassed to ground, bandwidth also changes. For the LT3081, the loop gain is unchanged with output voltage or bypassing.

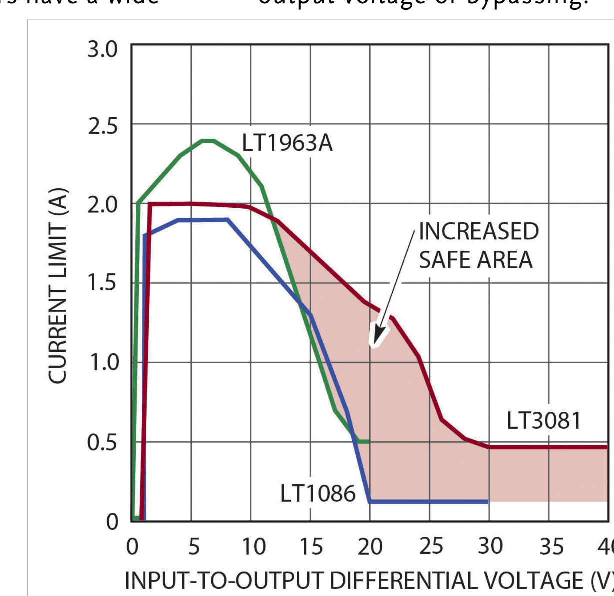

Figure 2: Comparative Safe Operating Area Performance

Output regulation is not a fixed percentage of output voltage, but is a fixed number of millivolts. Use of a true current source allows all of the gain in the buffer amplifier to provide regulation, and none of that gain is needed to amplify up the reference to a higher output voltage.

Industrial applications require large safe operating area. Safe operating area is the ability to carry large currents at high input-output differentials. The safe operating area for several regulators is compared in **Figure 2**. The LT1086, introduced in the mid-1980s, is a 1.5A regulator in which output current drops very low above 20V input/output differential. Above 20V only about 100mA of output current is available. This causes output voltage to go unregulated if the load current is above 100mA and transients on the input cause the high voltage current limit to be exceeded. The LT1963A is a low dropout regulator that also has a limited safe operating area. The LT3081 extends the safe operating area, offering nearly 1A of output current at 25V of differential. Even above 25V, the output current of 500mA is still usable. This allows the regulator to be used in applications where widely varying input voltages can be applied during operation. Wide operating safe area is obtained by using a large structure for the PNP pass device. Also, The LT3081 is protected (along with the load) for reverse input voltage.

There are three current sources — two that report output current and temperature, and a third that supplies the 50μA reference current. The LT3081, while not a low dropout regulator, operates down to 1.2V across the device — slightly better than older devices such as the LT1086. The internal amplifier configuration, in conjunction with well-regulated internal bias supplies, allows the device to be stable with no external capacitors. One caveat: it cannot be designed to tolerate all possible impedances in the input and load, so it is important to test the stability in the actual system used. If instability is found, external capacitors will ensure that the device is stable at all output currents. External capacitors also improve the transient response since it is no longer limited by the bandwidth of the internal amplifier.

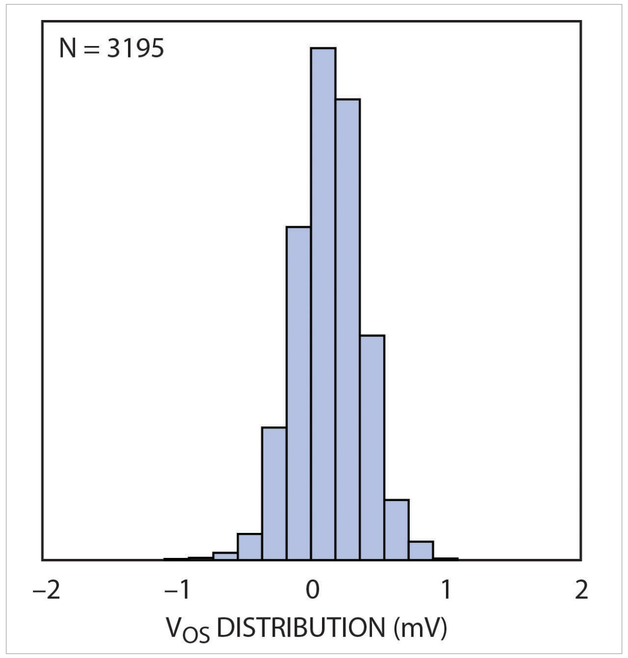

Figure 3: Offset Voltage

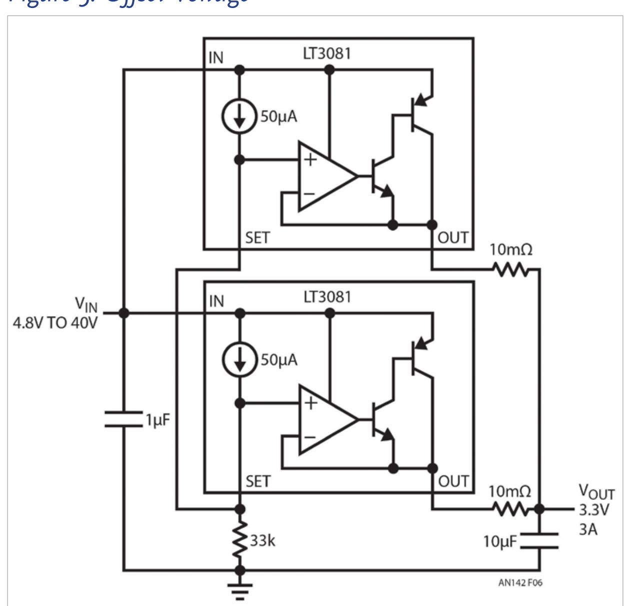

Figure 4: Paralleling Devices

Paralleling devices, usually a forbidden application with previous regulators since they do not share current, is easy with these current source reference regulators. Paralleling is useful for increasing output current or spreading the heat. Since it is set up as a voltage follower, tying all the set pins together makes the outputs the same voltage. If the outputs are at the same voltage, only a few milliohms of ballast are needed to ballast these devices and allow them to share current.

Figure 3 is a distribution of the offset voltage for the LT3081. The distribution is all within 1mV so to ensure sharing to 10%; 10mΩ of ballast resistance is more than sufficient. The ballast resistor can be less than an inch of a trace on a PC board or a small piece of wire, and provides good current balance from parallel devices. Even at 1V output, this degrades the regulation by only about 1.5%.

Figure 4 shows a schematic of two paralleled LT3081 devices to obtain 3A output. The set resistor now has twice the set current flowing through it, so the output is 100μA times RSET and the 10mΩ output resistors ensure ballasting at full current. Any number of devices can be paralleled for higher current. The ILIM pins can be paralleled (if used) so one resistor sets the current limit.

Figure 5 shows the LT3081 paralleled with a fixed regulator. This is useful when a system that has been designed has insufficient output current available. It provides a quick fix for higher output current. The output voltage of the fixed device is divided down by just a few millivolts by the divider. The SET pin of the LT3081 is tied about 4mV below the fixed output. This ensures no current flows from the LT3081 under a no-load condition. Then the 20mΩ resistors provide sufficient ballast to overcome this offset and ensure current matching at higher output currents.

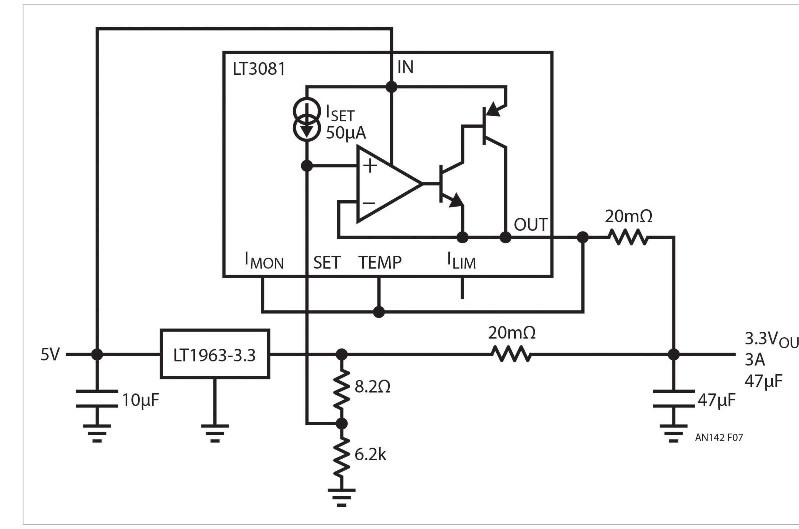

Figure 5: Increasing the Output Current of a Fixed Regulator

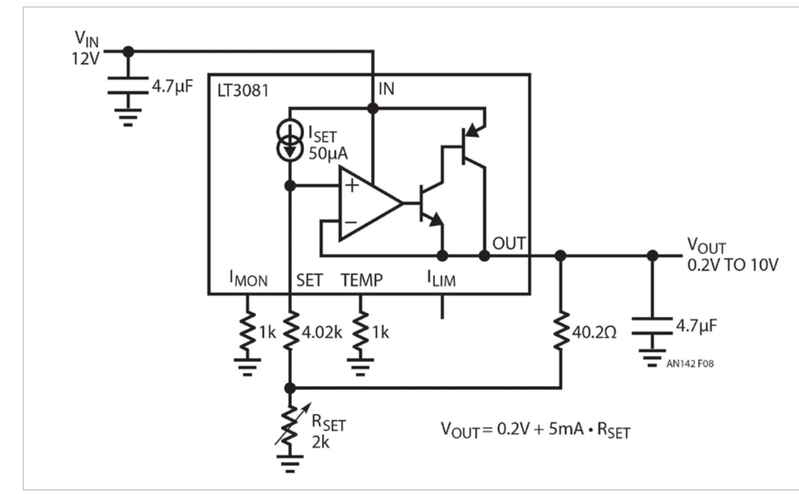

Figure 6: Using a Lower Value Set Resistor

With the 50μA current source used to generate the reference voltage, leakage paths to or from the SET pin can create errors in the reference and output voltages. Cleaning of all insulating surfaces to remove fluxes and other residues is required. Surface coating may be necessary to provide a moisture barrier in high humidity environments. Minimize board leakage by encircling the SET pin and circuitry with a guard ring tied to the OUT pin. Increasing

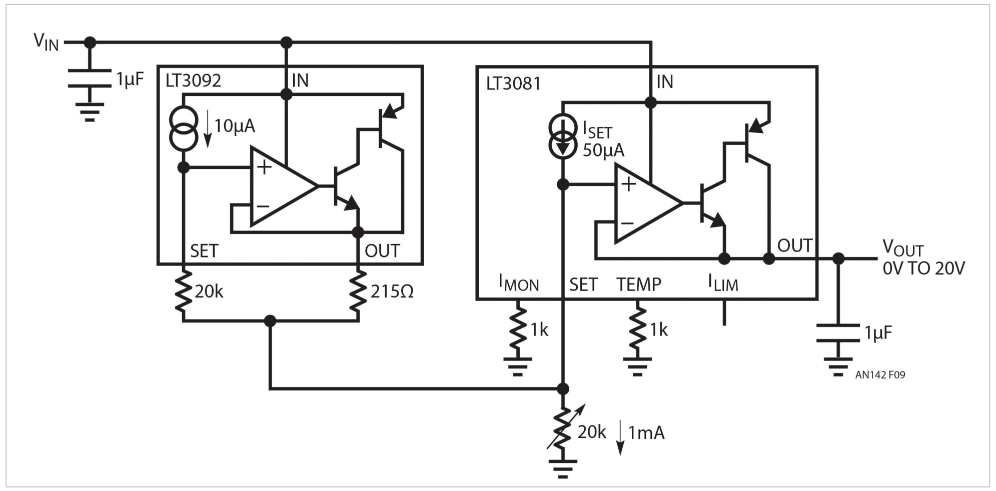

Figure 7: Using an External Reference Current

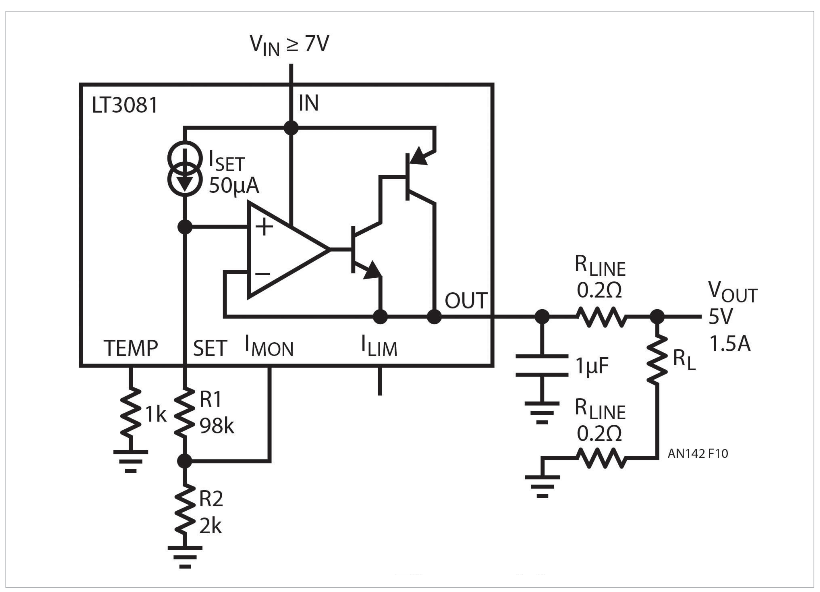

Figure 8: Using Current Monitor Output to Compensate for Line Drops

the set current as shown also decreases the effects of spurious leakages.

The low 50µA SET current can cause problems in some applications. High value film potentiometers are not as stable as lower value wirewounds. Board leakage can also introduce instabilities in the output. Problems can be minimized by increasing the set current above the nominal 50µA. **Figure 6** shows a solution using lower value set resistors. Here an increased current is generated through R2 and summed with the set current, giving a much larger current for adjusting the output. Set current flows through a 4k resistor, generating 200mV across R1. Then the current through R2 adds to the set current, giving a total of 1.05mA flowing through I_{SET} to ground. This makes the voltage less sensitive to leakage currents around the R_{SET}. Care should be taken to Kelvin connect R2 directly to the output. Voltage drops from the output to R2 will affect the regulation. Another configuration uses an LT3092 as an external current source of 1mA. This provides increased set current and allows the output to be adjusted down to zero.

Figure 7 shows an LT3092 current source used to provide the current reference to an LT3081. The 1mA generated reference current allows the adjustment set resistor to be much lower in value while still allowing the device to be adjusted down to zero.

The current monitor output can be used to compensate for line drops, as shown in **Figure 8**. Feeding the current monitor through a portion of the set resister generates a voltage at the set pin that raises the output as a function of current. The value of the comp resistor is $R2 = 5000 \cdot R_{CABLE(TOTAL)}$ and $V_{OUT} = 50\mu A (R_{SET} + R_{COMP})$. Several volts of line drop can be compensated this way.

www.linear.com

Enhancing RF system efficiency with bypass mode in hysteretic step-down converters

A key advantage over a fixed-frequency PWM converter is significantly improved transient response

By: Nancy Xiong, Maxim Integrated

A hysteretic DC-DC step-down converter has been widely used in 2G/3G/4G RF power amplifiers (PAs) as a replacement for a direct battery supply to the PA's DC supply. By dynamically adjusting the PA supply voltage and bias current, this approach dramatically improves PA efficiency and extends battery life. A bypass mode with bypass FET or bypass LDO also reduces the dropout voltages across the step-down converter and enhances the output current capability. Together, these functions lower the battery shutdown point and extend battery life.

The increased system efficiency by using a hysteretic step-down converter does, admittedly, involve a trade-off in voltage headroom. This article discusses how a bypass mode with a bypass FET or bypass LDO can be integrated into the hysteretic step-down converters to optimize PA performance.

Basics of a hysteretic step-down converter

A PA step-down converter differs from a traditional step-down converter that powers a digital processor core in several important ways. The PA converter offers dynamic output-voltage control for continuous PA power adjustment; high efficiency over a wide output voltage/current range; a fast turn-on time and settling time for output voltage change; low dropout and 100% duty cycle operation; and low output-voltage ripple.

Modern hysteretic step-down converters dynamically control the DC supply voltage to the PA. The converter output voltage is adjusted by an independent DAC-controlled analog input in proportion to different RF transmitting power levels. The converter uses output voltage ripple to control when the high-side and low-side switches are turned on and off. It uses an error comparator without a fixed-frequency clock instead of an error amplifier with compensation. Therefore, the hysteretic converter's key significant advantage over a fixed-frequency PWM converter is its major improvement in transient response. Unlike a fixed-frequency converter, the hysteretic converter reacts immediately to any output voltage/load transient without having to wait for a new clock pulse or for the error amplifier output to move. With high efficiency, high switching frequency, and a 100% duty cycle, the hysteretic converter is a perfect candidate to power the PA.

The importance of a bypass mode

Using a hysteretic step-down converter instead of the battery itself to bias the PA does, admittedly, raise one issue: the efficiency improvement sacrifices voltage headroom. Inserting the converter between the battery and PA usually removes at least

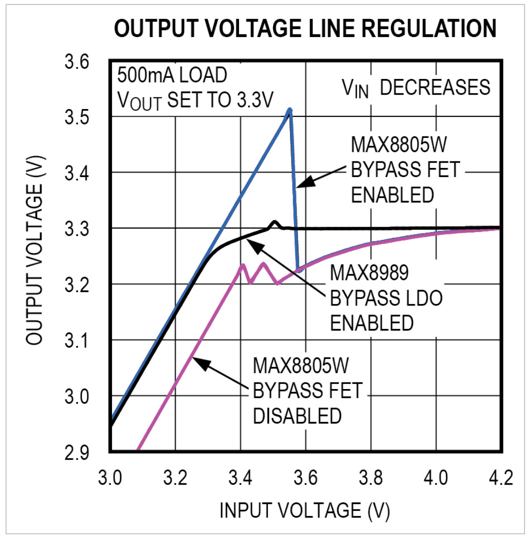

Figure 1: Data from the MAX8805W show how a bypass FET affects output voltage line regulation.

200mV or more of headroom.

Let's look at an example, the MAX8989 hysteretic step-down converter. To transmit 32dBm RF power on a certain PA module, the recommended VCC and ICC are 3.4V and 1130mA, respectively. Assume that the MAX8989 internal p-FET on-resistance (RON) is 175mΩ and that the inductor used has 200mΩ DCR. Then the total voltage drop across the p-FET and inductor is:

(175mΩ + 200mΩ) × 1.13A = 424mV

To sustain a 3.4V VCC voltage, the battery voltage must be above 3.824V, which shortens talk time. To overcome this issue, a bypass mode is implemented. Essential components of this bypass mode are the bypass FET and bypass LDO, and we will examine each in turn.

Use a bypass FET to lower the dropout voltage

The MAX8805W hysteretic step-down converter has a bypass mode with bypass FET. As the battery voltage drops and the converter approaches dropout region, its internal bypass FET connects the PA directly to the battery when VREFIN > 0.372 × VIN. **Figure 1** demonstrates the performance difference when the bypass is enabled or disabled.

Without the bypass FET, the dropout voltage after the converter enters 100% duty cycle is:

VDROPOUT = (RON-PFET + DCRIND) × IOUT

With the bypass FET on, the dropout voltage becomes:

VDROPOUT = (RON-BYP//(RON-PFET + DCRIND)) × IOUT w

Where RON-PFET is 180mΩ and RON-BYP is only 60mΩ. Using a 3.4V battery voltage, the MAX8805W's output voltage is 3.23V without the bypass FET on, and 3.37V with the bypass FET on. The bypass FET thus improves 140mV voltage headroom by lowering the dropout voltage.

The bypass FET increases the converter's output to battery voltage in the dropout region. The trade-off is a voltage jump at the transition from the regulation region to the dropout region instead of the smooth transition shown in **Figure 1**. To obtain a smooth transition from the regulation region to the dropout region, a low-dropout linear regulator (a bypass LDO) in parallel with the step-down converter is introduced into hysteretic converters.

Use a bypass LDO to remove voltage "jump"

Figure 1 also shows the improvement of a bypass LED over a bypass FET. This LDO provides a smooth transition between step-down regulation and operation in dropout. Two bypass LDO examples are presented using the MAX8989 and MAX8951.

We start by looking at the MAX8989, where the relation between the output voltage and REFIN voltage is:

VOUT = 2 × VREFIN - 0.5 × DCRIND × IOUT

When the MAX8989 output voltage drops by more than 50mV due to load regulation (0.5 × DCRIND × IOUT > 50mV) and the output voltage is above the linear bypass enable threshold (1.4V, typ), the bypass LDO supplies supplementary current to the output to keep the output voltage in regulation. **Figure 2** illustrates the effect of the bypass LDO on output voltage regulation. Here, the bypass LDO is disabled in the case of VREFIN = 0.4V; for VREFIN = 0.9V, the bypass LDO begins operation when the output voltage drops 50mV and the load regulation ramps down at a slower rate. Two inductors (a TOKO® DFE252012C-4R7 and a TDK® VLS252015ET-4R7M) are used and noted in **Figure 2**. With different inductors, the bypass LDO starts at the same 50mV point. But since the TDK inductor has bigger DCR and causes a higher voltage drop across the inductor, the bypass LDO begins operation at a lower output current.

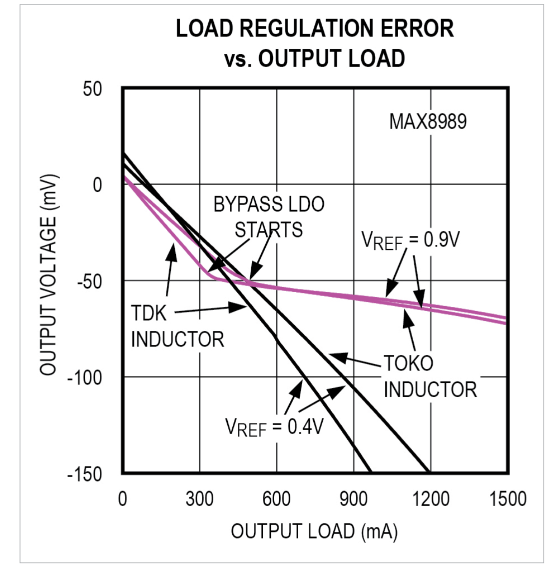

Figure 2: Data show the load regulation error vs. output load for the MAX8989.

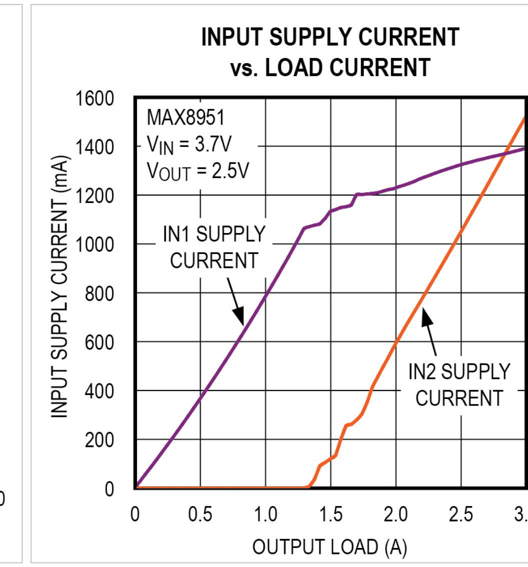

Figure 3: Data show the input supply current vs. load current for the MAX8951.

When the output current exceeds the step-down converter's current limit, the bypass LDO provides supplementary current to the output, thereby ensuring a stable output voltage. The bypass LDO does not provide any supply current before the step-down converter gets to its current limit. While the linear bypass regulator is sourcing current, the step-down converter continues to supply most of the load to maximize efficiency.

The MA8951 has separate input supplies for the hysteretic step-down converter (IN1) and bypass LDO (IN2). **Figure 3** illustrates the IN1/IN2 supply-current delivery versus output load. The converter reaches its current limit at 1.3A load. Above a 1.3A load, the IN2 supply picks up the load and provides the supplemental current to the output. Therefore, with a bypass LDO, the inductor with a lower saturation current rating can be used in higher-current PA applications.

A bypass LDO also enables a faster outpu`t voltage-transient response. Using the same setup for the MAX8989 described above, tests are done by stepping the REFIN voltage to get a 1V to 3V output voltage change. After the output voltage rises above the bypass-enable

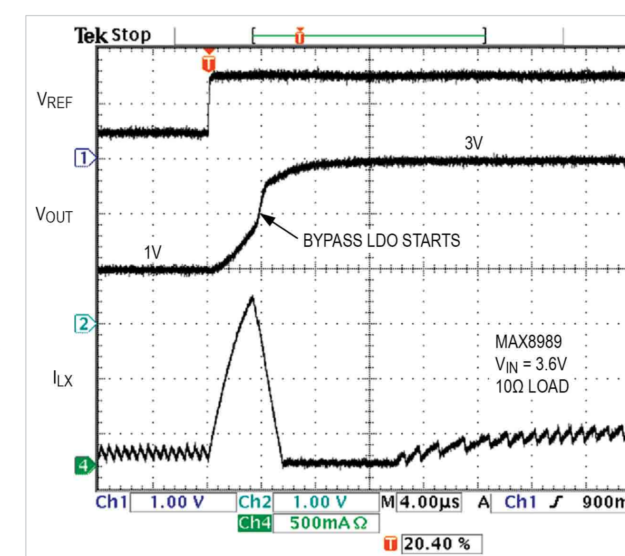

Figure 4: The output voltage transient response for the MAX8989 shows a settling time of less than 8µs.

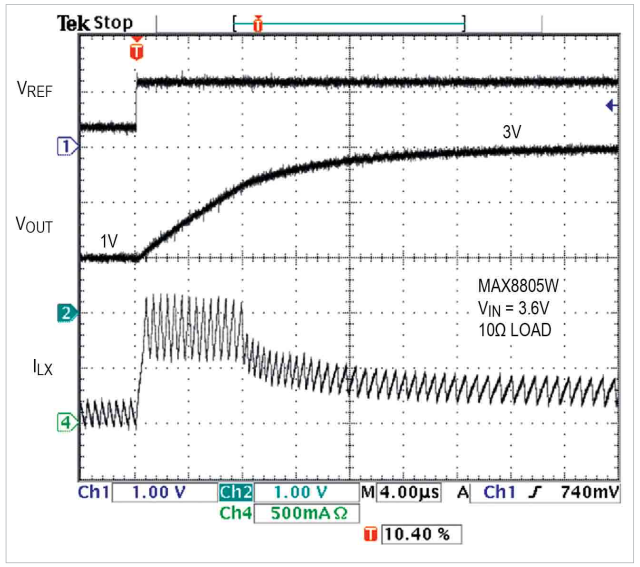

Figure 5: The output voltage transient response for the MAX8805W shows a settling time of more than 16μs.

threshold, the bypass LDO starts and ramps up the output voltage at a faster rate. The MAX8989's overall settling time from 1V to 3V is less than 8μs, while this time for the MAX8805W is more than 16μs. Compare **Figure 4 and Figure 5** for the devices' difference in output voltage-transient response.

Conclusion

Hysteretic step-down converters with either a bypass FET or bypass LDO both optimize the PA performance and improve the system efficiency which extends battery life. A bypass LDO offers advantages over a bypass FET, specifically a smoother transition between step-down regulation and dropout and a faster transient response. These performance benefits make a step-down converter with a bypass LDO an ideal candidate for PA power applications.

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Urban Legends about Thermal Interface Materials

Proper thermal design in power electronics is critical to device performance

By: Dr.-Ing. Martin Schulz, Infineon Technologies

Proper thermal design in power electronics is the necessary fundamental to ensure that the final application will operate throughout the predicted lifetime. Thus, it remains a key element in the design process. Thermal transfer, including the thermal interface materials (TIM) is the core of power electronic systems. Inadequate handling of these materials or inaccuracies during the design phase can lead to fatal consequences when operating the equipment.

Whenever new developments or optimizations of existing designs are ongoing, the developer has to consider what power semiconductor to combine with a certain heat sink. The thermal interface material, connecting the semiconductor to the heat sink, usually is not a major consideration. Most often, materials are in use simply because they have been there for years; what was ok for the last decade cannot be wrong today.

This however is the first misjudgment. Just like semiconductors, thermal interface materials have been significantly enhanced over the last several years.

When the developer searches for alternative materials, he is facing a nearly unmanageable variety of possible candidates. This leads to the question of how to evaluate and compare the different materials.

The myth about datasheet values

After extensive research and collecting the data for possible alternatives, the developer takes a well known approach: Take the datasheet given by the manufacturer, compare different materials in regards of thermal conductivity and start a simulation to estimate chip temperatures. A typical scenario usually consists of

- The maximum ambient temperature expected
- The known thermal resistances connecting the chip to the module's base plate R_{thJC}
- The heat sink's thermal resistance to ambient R_{thHA} determined through measurement
- The thermal conductivity of a homogenous layer of grease as described in the datasheet
- Most likely, the semiconductor's manufacturer added to the datasheet a typical resistance base plate to heat sink R_{thCH} assuming a common grease is in use

This leads to a simplified ther-

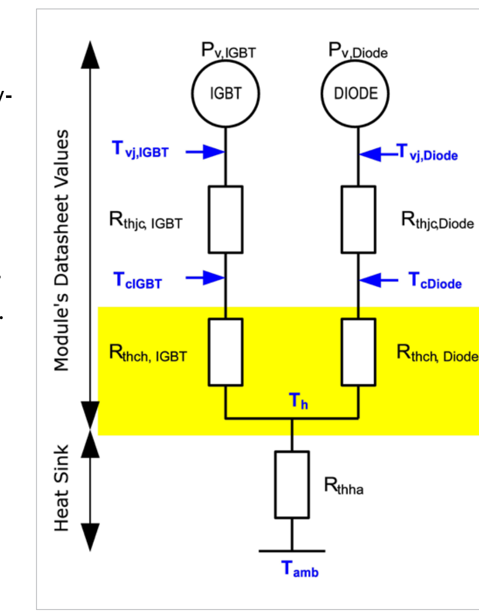

Figure 1: Simplified thermal model using datasheet values. The thermal interface material is hidden inside the yellow area

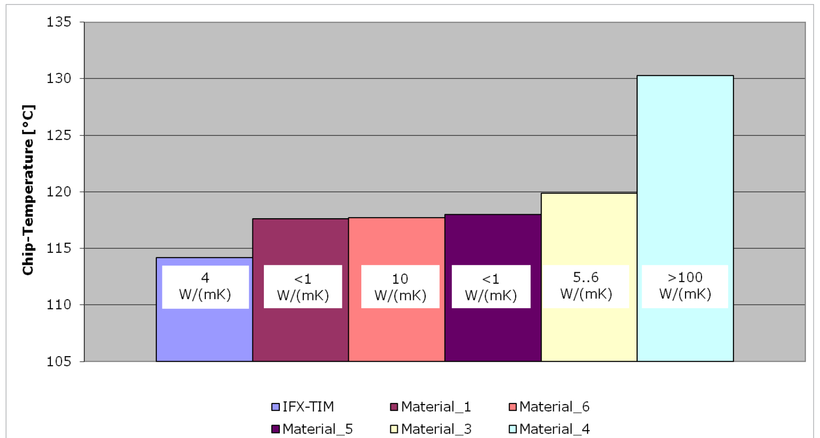

Figure 2: Comparison of thermal results using different thermal interface materials

mal model as given in **figure 1**. In case the losses P_V generated are known exactly, the chip temperature results from bare math.

The lack of accuracy of such simplified models becomes obvious if the calculated results are compared to measured data. In our case the test bench was designed dedicated to measuring the effectiveness of thermal interface materials. Screen printing was used to apply thermal greases to power modules that were then mounted to heat sinks. The setup consisted of six identical units and provided an insight to chip temperature development throughout an eight month test period.

It was expected that the thermal interface with the highest conductivity would achieve the lowest chip temperature and in turn the longest life time. Throughout the eight months test, daily measurement of the maximum chip temperatures was recorded. As the final result, the average value of these measured temperatures is considered. **Figure 2** summarizes the stress test that was conducted for more than 100.000 cycles.

The diagram clearly shows that there is no correlation at all between the chip temperature achieved in the test and the datasheet value given for thermal conductivity. The material with the highest conductivity leads to the worst result. At the same time, materials that deviate by a factor 10 in conductivity achieved similar chip temperatures. Comparing and evaluating the thermal quality of thermal grease purely based on datasheet values is futile.

What's causing this dilemma is the way the datasheet value is determined. The test setup described in the standard ASTM5470-12 features properties that are incompatible to power semiconductors. It is rather suitable to describe the situation found in discrete parts or processors. Surface structures and mounting forces coming from screws are disregarded, just like the fact that a noteworthy portion of heat is transferred by metal-to-metal contact especially in the area the screws are located in. Further important parameters, like flow characteristics and wetting abilities of interface materials, are either missing in the description or are very difficult to pinpoint within comparable numbers.

The developer is left with one possibility only; copious in-situ tests of the material under consideration in a particular application.

The Glass Pane Saga

A recurring experiment consists of mounting a module with thermal grease applied to a glass pane to observe the way the material spreads inside the setup. What appears to be a clever idea in first place turns out to be highly questionable as no knowledge regarding thermal qualities can be derived from this attempt. A glass pane does not feature the microscopic channels that are common to heat sinks with a milled surface. However, it is this structure that enhances the flow characteristics of paste-like greases. Therefore the view through a glass pane leads to dubious statements.

Instead of mounting a module to a glass pane, the glass can be mounted to a heat sink with thermal grease in between. Though the heat sink now provides the microscopic structure, the glass does not feature the cavities found in power modules. This configuration too does not generate a reliable statement regarding the flow characteristics of thermal greases. **Figure 3** is a photo taken from such a setup.

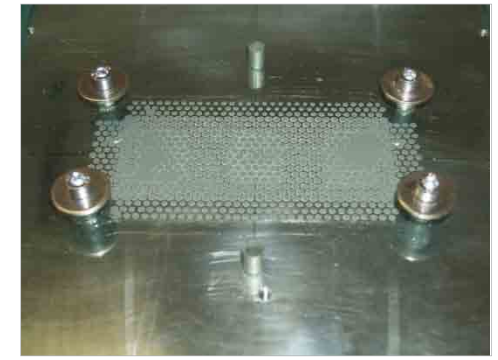

Figure 3: Glass pane with TIM applied mounted to a heat sink

The photo clearly shows that, due to the planar surface, the glass applies homogeneous pressure even in cold condition. This behavior is different compared to what is seen using a power module. Starting at room temperature, the setup shams a wrong impression that gets even worse if higher temperatures would be considered.

The base plate of power modules changes in shape at elevated temperature levels due to bimetallic effects. As it lowers towards the heat sink, it applies large mechanical forces to the thermal interface material applied and in turn to the heat sink.

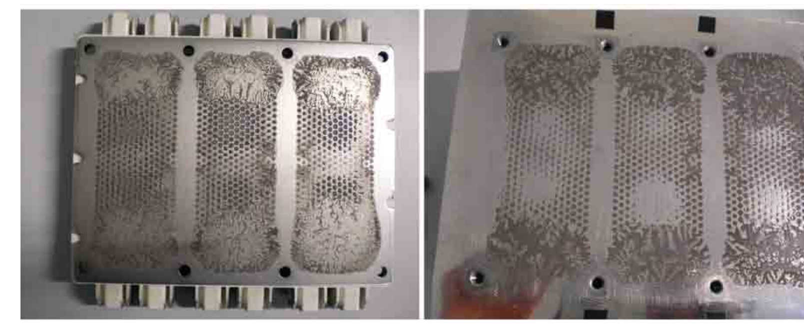

Figure 4: optical appearance of the interface material after cyclic load. The module is on the left side, the heat sink to the right.

Heating up the module mounted to the glass pane is not a viable option, as the glass cannot withstand the thermal or mechanical stress and would be destroyed during the test. Thus, it can be concluded that the experiment is not capable to simulate the behavior of the real application and therefore is of no relevance.

The Imprint Legend

An evenly delusive idea is the art of interpreting imprints. A power electronic system, consisting of module, grease and heat sink, is operated for a certain time and disassembled afterwards. The remaining imprints on module and heat sink are taken as a hint for the thermal quality of the tested material. This approach represents guessing the properties of an assembled structure, usually operating at high temperature and under high pressure, by looking at the disassembled components at room temperature. It is self-evident, that this approach will not lead to credible statements.

The picture of the imprint on an EconoPACK + as shown in **figure 4** may be used as an example. The usual interpretation of such an imprint would come up with findings regarding the poor spreading of the grease, obviously caused by too little material being applied, concluding that the thermal transfer clearly was disastrous.

The measurement of the actual chip temperature during the test was done using an IR-Camera. In contradiction to the interpretation, the thermal transfer was excellent as no other material in the test achieved similarly low chip temperatures.

Many things regarding thermal interface materials a rather believed in than measured. There is only one important parameter – the chip temperature – and the advice can only be to observe this parameter as closely and accurately as possible.

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Mechanical Ventilation and Heat Recovery Makes Sense

MVHR systems are becoming increasingly necessary as the UK nears Zero Carbon goals

By: Mike Farrer, Stadium Power

In general, legislation exists for good reason in any industry. In the building industry legislation provides regulatory requirements that deliver a safer and increasingly more sustainable end product. The drive towards sustainability isn't restricted to the building industry, of course; it now touches and influences every industry and permeates the entire supply chain.

Legislation also drives innovation; out of necessity, manufacturers who are obliged to comply with legislation must continuously strive for ways to differentiate their product or service, in what can be viewed as an increasingly homogeneous landscape. However, invariably legislation and regulation exists to protect consumers from the 'worst-case scenario'; imposing upper limitations that allow significant room for improvement. And it is here where real innovation can shine through.

Sustainability and 'going green' is a case in point. While opinions will always conflict, it's a fact that the decision from global governments to adopt 'greener' and more sustainable practices now spans design, manufacturing, distribution, and end-of-life across practically every industry at some level. The use of harmful chemicals and base materials in now highly restricted in the electronics industry, for example, while European Directives now dictate how manufacturers must also make provision for the disposal of such products.

In the building industry the focus is less on end-of-life and more on its preservation; specifically, buildings constructed today are expected to be in use for many decades and so it is their impact on the environment over their 'working life' that is now coming under closer scrutiny.

MVHR makes sense

With a target of making all new UK homes Zero Carbon by 2016, an important aspect of new builds is their efficiency in heating and/or cooling. Modern homes must now comply with legislation that requires them to be air tight, maximising their ability to lower heating costs through insulation and efficient windows/doors. Targets propose a roadmap of waypoints in improving insulation and heating systems, leading to the eventual Zero Carbon goal.

This isn't happening in isolation, of course; other aspects of legislation also dictate the restricted use or cessation of harmful components in building materials, coupled with a reduction in the contribution to CO_2 emissions. On the face of it, an airtight building that neither harbours or vents harmful materials, or contributes any CO_2 to the environment would provide the ideal solution.

However, this presents its own problems, specifically in dealing with the affects of stale air and condensation. The solution to this is to vent stale air to the outside and replace it with fresh air. However, while not harmful to the environment, it is clearly wasteful in terms of the heat lost by venting warm and replacing it with cooler albeit fresher air.

Mechanical Ventilation and Heat Recovery (MVHR) helps overcome this problem, by recovering the heat from the warmer internal air and using it to heat the fresh air from outside, before it is introduced in to the property. MVHR systems are relatively simple but provide an important part of the Zero Carbon building. (See **Figure 1**)

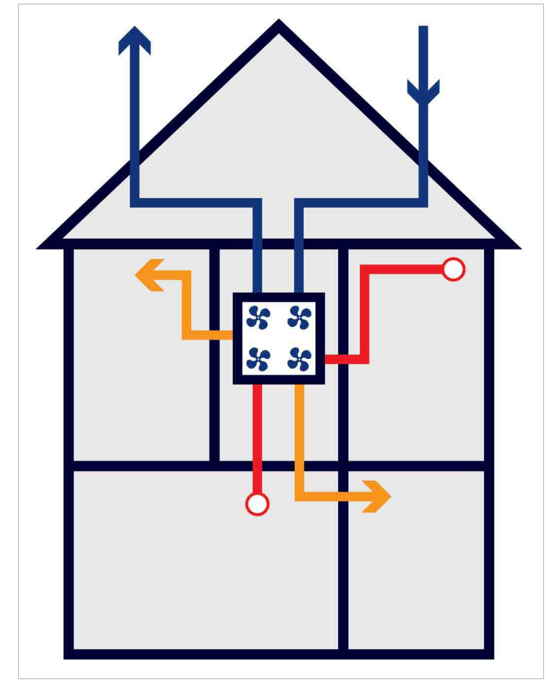

Figure 1: MVHR systems are relatively simple but provide an important part of the Zero Carbon building

In order to preserve the overall goal of reducing emissions, the performance of an MVHR system is also subject to inspection. Specifically, their performance can be submitted in accordance to the Standard Assessment Procedure Appendix Q, which makes performance data for installations of specific equipment available to energy performance assessors. It uses tests and methodologies that integrate within the applicable SAP calculation version.

This data contributes to the overall energy performance of a dwelling and is becoming increasing relevant as the Zero Carbon objectives of 2016 draw closer. There are now a number of MVHR equipment manufacturers and equipment listed on the Appendix Q website, allowing specifiers to select the most appropriate solution for their needs.

Driving Efficiency

The performance of an MVHR installation is dependent on number of parameters, some of which are installation-dependent — such as using rigid or flexible ducting — and some which are determined purely by the equipment and components used, like the kind of fans employed, their power supplies and control systems.

Predominantly, the components that make up the electronic subsystems are developed and assembled by a range of manufacturers, such as those listed in the database of performance data maintained by SAP. This database of performance data describes key aspects of an MVHR system's operational parameters measured using SAP's own criteria. These include (and are largely defined by) the power needed to (re) circulate a given volume of air based on the number of (wet) rooms in the dwelling. By example, the tested airflow for a kitchen is 13 Litres/second and for wet rooms (bathrooms, for example) it's 8L/s.

The SAP Appendix Q specification measures this airflow in terms of electrical energy, or Watts. The result is a figure measured in Watts/Litre/second, referred to as the Specific Fan Power (SFP). The current specification calls for fairly modest SFP figures; <1.5 W/L/s and heat recovery efficiency $> 70\%$. Already the database of performance data lists equipment/manufacturers that achieve much better figures.

The challenge these manufacturers face, however, is improving these already impressive performance figures under the variable airflow rates required by SAP Appendix Q; something that is almost entirely dependent on the fan type used. Inevitably the requirements will get tougher.

Powering MVHR

Fans are, generally speaking, relatively cheap. However, their cost is directly related to their efficiency, which in turn is dependent on their operating method. The cheapest and

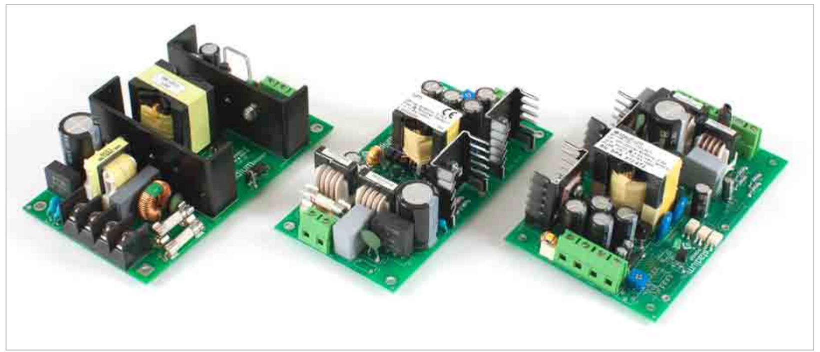

Figure 2: power supply manufacturers such as Stadium Power are now developing power supplies that meet MVHR's exacting requirements.

simplest fans run directly from an AC mains source but they are also the least efficient. Electronically Commutated Fans (EC-DC or ECM fans) take the AC mains source and convert it to a high voltage DC (direct current) which delivers a more efficient use of the power source, but significantly increases cost.

Low voltage DC fans use a power supply to convert the AC mains voltage to a low voltage to operate the fan. These can be more efficient and cost effective.

However, the low power and low flow rate requirements of Appendix Q can have a negative impact on the efficiency of Electrically Commuted Fans, which are normally designed to run most efficiently over a given flow rate range.

The problem is actually in how the fan converts the power into mechanical movement; as ever, cost is a factor so the power conversion stage is normally designed to be efficient over a limited window of operation. With MVHR systems, the performance of the fan is largely dependent on the prevailing conditions, number of (wet) rooms and even seasonal climate.

As a result, the most efficient MVHR systems — those that can deliver low power consumption and high efficiency (<1.5W/L/s and >70% heat recovery) over a wide operating window — need a more efficient and typically bespoke power conversion stage. In response to this growing need power supply manufacturers such as Stadium Power are now developing power supplies that meet these exacting requirements. (See **Figure 2**)

Given that a typical dwelling may have one kitchen and between 1 and, say, five wet rooms, and each of these rooms may have variable ventilation needs (perhaps controlled by external sensors such as humidity, temperature or occupancy), the load on the power supply could vary between 25% and 100%. For this reason, Stadium Power has designed a range of MVHR PSUs to deliver greater than 90% efficiency at 25, 50, 75 and 100% load, achieving >87% between 10 and 100% loads. For example, Stadium Power now offers five variants in a range developed specifically for MVHR applications; delivering between 75W and 120W @ 24V DC with a 'flat' efficiency of >90% between 25 to 100% load.

Conclusion

MVHR systems are becoming increasingly necessary as we near the Zero Carbon goals for dwellings by 2016. However, looking at system efficiency requires MVHR manufacturers to consider the environmental and financial impact of the variable power requirements such systems exhibit.

In order to not only comply with the requirements of SAP Appendix Q but to also differentiate themselves amongst the competition, MVHR manufacturers should look closely at the PSU sub-components and strive to provide the highest possible efficiency over a wide operating window; parameters many ECM fans aren't designed to deliver.

Though designing in high efficiency power supplies designed specifically to help meet SAP Appendix Q will enable MVHR manufacturers to deliver the right solution in the face of mounting demand and competition.

www.stadiumpower.co.uk

A UPS topology to manage the arrival of Big Data

Data center operators need a strategy for large and sometimes unpredictable growth

By: Kenny Green, Uninterruptible Power Supplies Ltd

Big Data - an explosion in data generated from multiple sources - is expected to affect most organizations if it has not done so already. While this can present opportunities as well as challenges, data center operators need a strategy for this large and sometimes unpredictable growth. Today, Uninterruptible Power Supplies (UPSs) are essential to such strategies. Here, Kenny Green, technical support manager at Uninterruptible Power Supplies Ltd, a Kohler Company, looks at the UPS topologies that help data centers meet the challenges of Big Data.

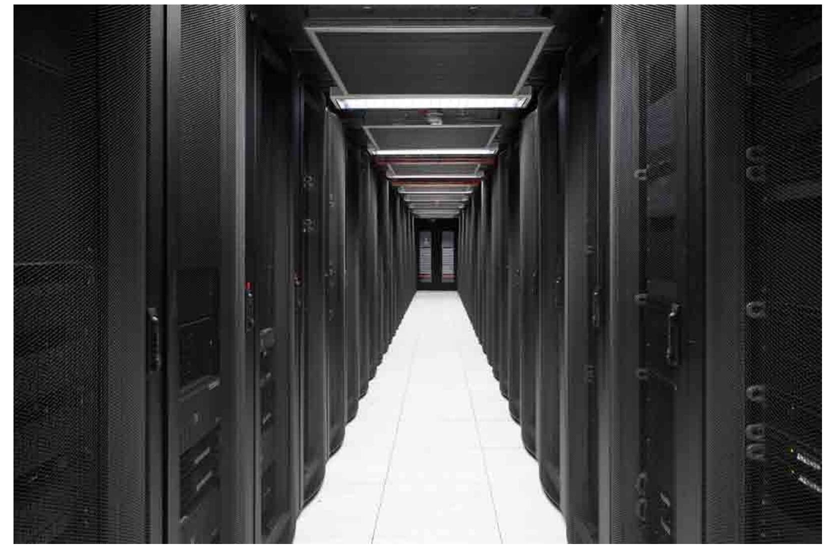

Figure 1: Most organizations have yet to properly consider their forward capacity planning

According to IBM, we create 2.5 quintillion (10^{18}) bytes of data every day, with growth so fast that 90% of the data in the world today has been generated in the last two years. Much of this data, in terms of its size and rate of growth is unstructured, unrelated and unpredictable as it is generated by sources as varied as climate sensors, trading data, blogs and social media as well as customer records and other more traditional content. Some corporations are seeing this as an opportunity as well as a challenge; with the right tools, the emerging availability of this data provides possibilities for deeper insights into their operation, allowing better-informed, more accurate business decisions to be made.

However, handling this growth in data, and applying new computing solutions to extract the required intelligence, calls for a significant increase in computing power and its associated infrastructure. A report commissioned by Cable & Wireless Worldwide highlights that companies studying Big Data applications have discovered that over the next two years, capacity requirements will grow by 40% to 50%. However, in spite of this, most organizations are yet to consider this within their forward capacity planning (see **Figure 1**).

As data center managers seek to accommodate this fast, sometimes unpredictable growth, they must ensure that their infrastructure expansion keeps pace with that of their data processing equipment, without compromising its reliability or availability. The uninterruptible power supply (UPS) is one critical component of this infrastructure – and it's an area in which Uninterruptible Power Supplies Ltd (UPSL), a Kohler company, can help significantly. They have significant experience in developing and supplying UPS topologies that can be rapidly scaled to handle fast-changing load requirements.

Scalable UPS Topology
UPSL's scalable topology benefits from major advances in semiconductor technology. UPS industry peer systems were built around a phase-controlled rectifier inverter and output transformer. Using modern IGBT semiconductors, more recent systems comprise a fixed rectifier followed by a DC converter. This converter boosts the rectifier output voltage fed to the inverter, allowing it to produce an AC output voltage sufficient to drive the load directly, thus eliminating the transformer.

Transformerless design has several important advantages over transformer-based implementations. Efficiency is immediately improved by about 5%, which, in turn, substantially reduces heat loss and operating costs. Other benefits include improved input power factor, reduced input current harmonic distortion, lower audible noise. However, another key benefit is a substantial reduction in the UPS's size and weight. This arises because this approach not only eliminates the transformer, but also the 12-pulse rectifier previously needed to improve input THDi performance. As an example of the savings possible, a transformer-based 120 kVA UPS would weigh 1,200 Kg and occupy a footprint of 800 mm x 1650 mm, while its transformerless 120 kVA equivalent would weigh 310 Kg and occupy 750 x 850 mm.

This reduction in size and weight has had a profound impact on UPS design, because it means that UPS systems – even three-phase types - can realistically be built using rack mounting modules rather than monolithic floor standing units. Great new opportunities in flexibility, space saving and scalability become possible. UPSL's PowerWAVE 9000DPA UPS, for example, comprises a vertical racking frame that accepts up to five modules, available in ratings from 10 kVA to 50 kVA that can be added or removed incrementally to efficiently keep pace with the data center load as it changes over time.

For example a data center load could initially be 50 kVA, serviced by a single 50 kVA module mounted in the rack. A second 50 kVA module could be added to provide N+1 redundancy. More modules can be added as the load grows, until it reaches 200 kVA; this would be serviced by five 50 kVA modules, with N+1 redundancy maintained. Note how this incremental growth allows redundancy as well as capacity to be achieved very efficiently; two stand-alone systems of 200 kVA each would be needed to support a 200 kVA load with N+1 redundancy, whereas the modular topology achieves the same redundancy with 250 kVA.

The flexibility and easy scalability afforded by modular UPS topology are valuable tools for data center operators engaged in managing Big Data. By using vertical scaling within a UPS rack as described, they make efficient use of their data center room, adding UPS capacity without increasing floor space. The PowerWAVE 9000DPA can achieve up to 342 kW/m² power density in this way. Just as importantly, increases in the UPS's capacity can be deferred until required, eliminating unnecessary hardware expenditure. When needs do arise, new modules can be simply mounted into the frame without even interrupting power to the load – there is no disruption, building or engineering work involved.

If the capacity demand forecast has led to sufficient power cabling and floor space allocation, expansion beyond the original frame's capacity is also fast and simple (see **Figure 2**). More frames can be provided to accept further UPS modules, with up to five frames being parallelable for up to 1 MVA N+1 capacity in a process referred to as horizontal scaling. The frames contain all of the input protection, input and output isolation required by the UPS modules. This means that any associated switchgear panels can be smaller, more easily installed and lower cost than those essential for standalone UPS systems. It is also why no additional electrical installation work is required when more capacity is added.

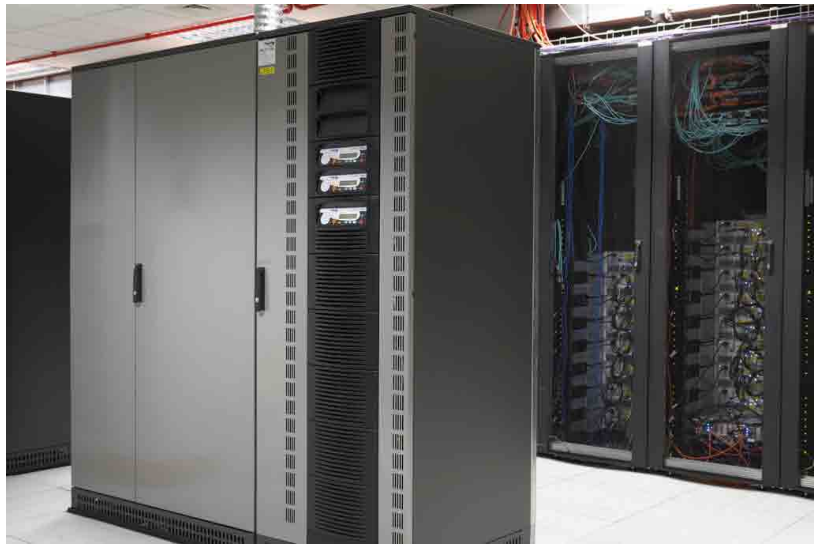

Figure2: A proper demand forecast will lead to sufficient power cabling and floor space allocation

Maintaining high availability
With modular UPS' easy vertical and horizontal scalability, data center operators can effectively plan for expected future growth in the critical load, and accommodate it as it happens. However it is essential that they can do so without compromising the availability of clean power, which justifies the UPS' existence. In fact, modular UPS topology has a multipart approach to maximizing availability, which we can explain by looking at how availability is defined:

Availability A=MTBF/(MTBF+MTTR)

Where MTBF = Mean Time Between Failures and MTTR = Mean Time To Repair. From this we can see that Availability can be improved both by increasing MTBF and by decreasing MTTR. The PowerWAVE 9000DPA is so-called because it features Decentralized Parallel Architecture, in which all of the UPS modules feed the critical load directly. With no single points of failure, the UPS modules operate in a truly redundant mode. The failure of a single module will not affect the continued operation of the others. Modular UPS topology also reduces MTTR, because a faulty module can be quickly and easily replaced, rather than attempting repairs in situ. This can cut repair times from six hours to about half an hour. The overall result is a UPS system that can achieve 99.9999% availability.

A scalable solution to Big Data growth
To summarize, there are many reasons why modular UPS topology offers an attractive way forward for data center operators needing to accommodate or plan for Big Data and its associated impact on capacity demand. Provision can be made for large scale and unpredictable growth, without having to purchase hardware unless or until it is needed. When extra capacity does become essential, it can be installed quickly, easily and without disruption to the critical load.

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Considering COTS connector solutions for solid-state lighting design:

Connector selection, a significant design challenge, is often and mistakenly taken for granted

By: Tom Anderson, Connector Product Manager, AVX

Now that the color, quality, and cost issues often associated with early solid-state lighting technologies have been addressed and overcome by so many leading manufacturers, consumers are adopting it at an ever-increasing rate. As a result, the market for SSL luminaries has expanded dramatically in recent years. Designing SSL luminaries poses several challenges for engineers and, throughout the industry, a great deal of effort has been put into solving challenges such as: selecting the right LED, integrating the best optical solution, choosing the best driver, and maximizing thermal management. However, connector selection, another significant design challenge, is often and mistakenly taken for granted.

Considerations for Connector Selection

Cost and size have been the driving factors behind connector selection in most SSL luminaire designs. However, although these factors are important and do affect the ultimate success of end products, there are several other factors that engineers should consider prior to specification. Operating at elevated temperatures in harsh environments requires careful connector selection if the design is intended to last. Consequently, engineers need to dig deeper into the design and construction of connector options, considering each connector's contact material, contact plating, plastic selection, and ease of use during assembly and disassembly.

A few of the questions design engineers should consider when specifying connectors for SSL luminaires include: Which connectors have the best materials for high-reliability performance and a long useful lifespan? Which connectors provide the desired mechanical stability and meet the current requirements of the device? Would a small, sleek connector or a large, robust one better suit the design? And, of course, does the connector solution meet the customer's cost targets? Such questions are critical when designing SSL luminaires, as each unique design can necessitate the prioritization of different parameters.

COTS Connector Solutions for SSL Applications

SSL luminaires demand high-performance, high-reliability connectors capable of supporting the efficiency and long lifespan of these devices. An abundance of commercial off-the-shelf (COTS) connectors that meet these two requirements are available across a broad range of price points. However, many (if not most) of these existing connector solutions are not ideal for use in SSL designs.

Although a host of COTS high-reliability connectors may be adequately durable and resistant to heat, the fact that they weren't developed with the specific needs of the SSL industry in mind typically results in their only meeting a portion of the specifications desired in today's continuously evolving lighting designs. As such, specifying COTS connectors that were developed years ago for either a different market, or even an earlier iteration of this one, often requires design engineers to make concessions regarding mechanical or electrical performance, size, and/or cost.

For example, if an SSL design requires a high-reliability wire-to-board (WTB) connector capable of handling high current (up to 10A), compatible with automatic placement, and able to withstand the harsh environment of an SSL luminaire, a surface-mount insulation displacement connector (IDC) like AVX's 9176 Series IDC would suffice. Providing a high-reliability, gas-tight, WTB termination that is resistant to automotive levels of temperature, shock, and vibration, the 9176 SMT IDC would meet the current, placement, environmental, and reliability requirements of the design but, having initially been developed for harsh automotive and industrial applications, would not be the most size- or cost-effective solution possible.

Consequently, as consumer adoption of solid-state lighting continues to expand and LED technology continues to advance, SSL design engineers are beginning to turn to the connector industry with increasing frequency in search of specialized solutions.

Specialized Connector Solutions for SSL Applications

In response, a number of components manufacturers have begun to develop connectors that are not only specifically designed to provide engineers with performance specs tailored to the unique environmental and reliability demands of SSL applications but that also, through critical materials selections or design configurations, attempt to satisfy the cost vs. performance outcome that is such a critical concern for SSL engineers. Achieving the ideal combination of these parameters isn't easy, though, especially for components manufacturers that remain focused on designing traditional connector solutions.

Utilizing input from myriad SSL engineers seeking COTS solutions for what initially appeared to be custom applications, a team of innovative design engineers at a leading global interconnect manufacturer closely examined the broader SSL market and was able to identify several common requirements among the disparate requests. In general, SSL designers require smaller, more cost-effective connectors that are just as capable of handling high current, as compatible with automatic placement, and as easy to assemble and disassemble as standard connectors – a discovery that has enabled the interconnect engineering team to develop more than 25 unique new COTS connectors designed specifically for SSL applications since the beginning of the LED revolution.

Challenge/Solution: Developing COTS Connectors for SSL Applications

Although the performance and cost requirements for SSL connectors are fairly standard across all applications, the various types of connections necessitated by certain designs require an equally varied assortment of connector architectures capable of fulfilling said requirements. For example, one of the primary interconnect challenges in linear LED strip lighting is coplanar board-to-board connection, which is typically achieved using hard soldering or connectors. Hard soldering the boards together tends to meet the cost model in low labor rate markets, but is a manual – and therefore time-consuming and inconsistent – process that doesn't allow for quick and easy PCB disconnection. As such, SSL designers typically prefer to use connectors, which enable quick and easy PCB assembly and disassembly. However, due to the size and budget constraints typical of most SSL applications, existing connectors are often too big for and/or fail to meet the cost targets of SSL designs. Similarly, SSL applications utilizing wire-to-board connections often require different connector architectures than board-to-board solutions and must not only meet the general cost and performance specifications for SSL applications, but must also be made available in several iterations compatible with a range of standard AWG wire sizes.

Faced with the challenge of designing unique new SSL connector solutions for these very applications, that same inventive design team broke the problem down to its most basic elements. Knowing that the critical functionality of a connector is concentrated in its contact, the team pushed itself to think well beyond the boundaries of existing solutions and status-quo connectors and challenged itself to create a single contact solution that functions just like a connector during the mating, un-mating, and wire termination processes. As a result, the team successfully developed several stripped down, insulator-less connector solutions capable of providing SSL designers with all of the critical functionality of a connector, but without the cost of the insulator and assembly, effectively satisfying the SSL industry's performance and cost targets.

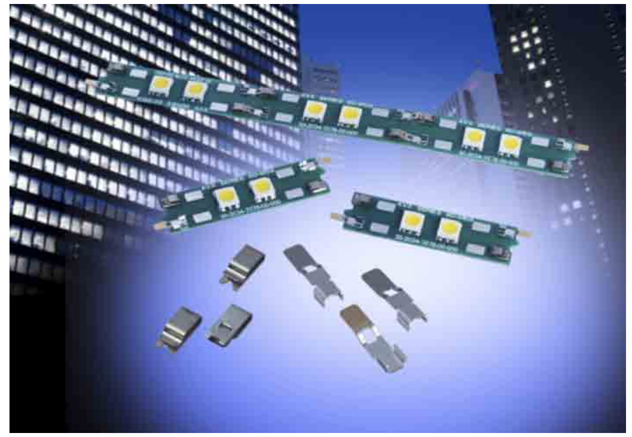

Figure 1: AVX's 70-9159 coplanar contact system

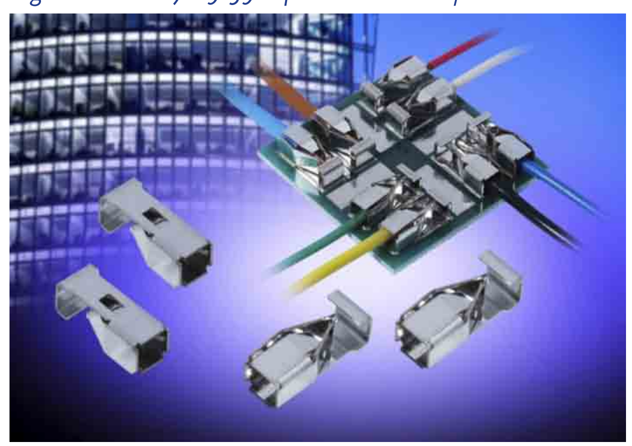

Figure 2: AVX's 9296 SMT single poke, dual-beam, closed-boxed contact system

For the linear LED strip lighting application, the team developed an innovative, insulator-less coplanar contact system (see **Figure 1**) that allows LEDs to be placed in the center of the PCB, effectively minimizing LED pitch densities and maximizing light output, and contacts to be individually placed on the outer edges of the metal core or FR4 boards, effectively utilizing what is typically free space. Designed with a compression beam on the horizontal plane to absorb maximum X- and Y-axis assembly tolerances (1mm on each axis), compensate for placement errors, and optimize final lateral PCB alignment, the novel contact system also has a minimal 1.2mm Z-axis height, which enables it to be placed close to LEDs without impacting light output. Featuring gold-plated phosphor bronze socket contact and gold plug contact with tin tails, the 70-9159 contact system provides maximum contact and signal integrity both in the harsh environment and over the long lifetime of the LED fixture. It also meets the required 5A, 125°C, and automatic placement performance specifications and is capable of supporting both board-to-board and wire-to-board applications.

For the wire-to-board application, the team was challenged to develop a connector solution capable of supporting the high power (up to 20A) and ground requirements of up to a 12AWG solid or stranded wire while still satisfying all of the general SSL connector requirements with regards to size, cost, power, placement, and ease of assembly and disassembly. In response, the team created a unique surface-mount, closed-box contact system (see **Figure 2**) that provides simple, reliable poke home wire insertion and maximum wire retention with dual opposing high spring-force contact beams. In order to function like a connector, the box was designed with top and bottom contact tines that guide a stripped wire into the center of the contact zone and an integral end-stop to ensure proper insertion depth. There, the dual contacts mechanically hold and make constant electrical contact with the wires. In addition to facilitating wire guidance and high force retention, the novel, single-position, 9296 closed-box contact also features an enhanced solder pad for maximum mechanical stability on the PCB, enables easy twist-out wire removal, and is packaged on tape and reel for automated SMT placement. Effectively providing all of the benefits of a full-function connector in an insulator-free solution, mitigating both labor and materials costs, as well as contributing to smaller and more cost-effective SSL designs, the 9296 SSL contact solution currently accepts 12-20AWG; a smaller 18-24AWG option is under development.

Figure 3: AVX's 9176 IDC contact

The team also developed a smaller and more cost effective single-contact iteration of its high-reliability, gas-tight, wire-to-board 9176 surface-mount insulation displacement connector (see **Figure 3**). Despite its stripped-down appearance, the 9176 contact makes no concessions with regards to mechanical or electrical performance; it is capable of handling high current (up to 10A), compatible with automatic placement, and able to withstand the harsh environment and match the extended lifetime of an SSL luminaire. Developed for SMT termination to the PCB, the singular SSL contact provides robust PCB attachment, supports 18-28AWG, and fulfills all of the standard SSL connector requirements.

Conclusion

Cost and size have long been and will continue to be driving factors behind connector selection in most SSL luminaire designs. However, there are several other factors that engineers should consider prior to specification, including: contact material, contact plating, plastic selection, and ease of use during assembly and disassembly, all of which are critical for high-reliability performance, mechanical stability, and a long useful lifespan. As consumer adoption of solid-state lighting continues to expand and the technology continues to advance, SSL design engineers will continue to turn to the connector industry in search of specialized solutions. In general, SSL designers require smaller, more cost-effective connectors that are just as capable of handling high current, as compatible with automatic placement, and as easy to assemble and disassemble as standard COTS connectors. However, these common denominators, while helpful for interconnect engineers, will never extinguish the need for the continuous development of innovative new contact solutions that both expand the industry's perception of connectors and provide SSL design engineers with ideal solutions for their cutting-edge designs.

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Special Report: Serving the Smart Grid

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Inside:

Smarter Energy Monitoring

If you don't collect the data, you can't measure your impact

By: Felix Lipov, Enertiv

Nowadays we have become accustomed to being deluged with data that outline every bit of our lives, from the amount of money we have in our bank accounts, to the number of unread email messages, to how many friend requests we might have. Yet one aspect of our lives where data still tends to remain a black box is the amount of energy we use. How much energy did your lights consume? Your heating and cooling? Your plug loads? How much is all that energy costing and what can be done to minimize one's energy waste? It all starts from a simple maxim – if you don't collect the data, you can't measure your impact, and hence can't manage it.

Currently the market place is working to fill that gap, to give additional insights into the heart-beat of a building, which subsequently can allow for optimizing the comfort and productivity of individuals, while minimizing one's carbon footprint. Sensors collecting data and sharing it in the cloud are the future of things to come. The various existing approaches to capture and present that data tend to take one of two angles – that of the hardware approach and that of the software approach. A hardware approach can begin at the high-level by providing real-time measurement of the electrical mains of a building and thus an instant view of energy consumption. That can be further enhanced with submeters, breaking the energy usage down as well as by adding additional meter readers that can capture data for other resources, such as water, gas, oil, etc. There are several options out there, a popular one being the products offered by the energy solution provider Obvius and the automation solution provider Veris. The data is solid, yet the bundled software leaves something to be desired. Accessibility to information is hindered by a poor user interface, which can very often leave you wondering what information you are looking at and whether the data being presented displays a good or a bad picture of your facilities' performance. Most Building Management Systems, despite expensive and powerful software, fall short due to the complexity of their own functionality. Most BMSs are not accessed beyond once a week and sometimes once a month. Many of the basic outputs generated by hardware-focused companies provide data, but are lacking in understanding.

Software-based approach takes a different angle. Rather than being focused on generating and acquiring high quality data, the goal is to provide a slick user-interface which can make already available energy data accessible, in turn allowing you to gain quick insights and act to improve those metrics of managed buildings. Software as a service versus on-premise software provides a lower total cost of ownership, managing the large volumes of data, while providing regular product updates without expensive hardware/software upgrades. Companies such as FirstFuel, WegoWise, Retroficiency, and others lead in this space, focusing on providing a means for analysis of the available utility or user-supplied data. A software-based solution does have its own shortcomings, with the analysis being only as effective and detailed as the data provided. Statistical approaches can accomplish much even with a single meter, but assumptions in the statistical approach can many times lead to unreliable conclusions. Despite the growth in smart meters, very often the data will still fail to provide an effective level of depth for truly insightful analysis.

Figure 1: The Enertiv One data acquisition system

The next generation approach is a combined software and hardware approach. On the hardware level, by generating sub-second interval data on equipment and their circuits, it is possible to get a new level of insight that is not available from purely statistical analysis. An installation which is managed by focusing all of the work in a traditional electrical panel keeps the solution localized. From there, software which is built to process this valuable data-stream can present a graphical picture and actionable insights that have not been previously available with utility or user-supplied data. That is the approach that Enertiv has taken with its Enertiv One (E1) data acquisition system (see **Figure 1**). Using the E1 it is possible to individually monitor up to forty-eight circuits. The E1 then works along with the cloud based Enertiv Energy Monitoring Suite to provide access to the data and the relevant insights.

Enertiv has developed an end-to-end solution which allows for retrofitting old as well as new electrical panels to provide a rich perspective on energy usage. Utilizing split-core current transformers, the solution can be installed without an interruption of power. Once in place, a metadata rich layer is created, tagging each piece of equipment, which allows one to understand electrical consumption, both from the perspective of the electrical panel, as well as that of the building's facility manager. With a fully customizable view, one can break down energy consumption into their requisite sublocations and easily identify various pieces of equipment that draw power. A typical case where this is advantageous is how an electrical panel can be divided between different consumers for separate reporting and billing purposes, despite the idiosyncrasies of building layout versus wiring layout. The software focuses on more than just producing charts outputting demand (kW) and consumption (kWh), but takes analysis to the next level – an approach that is only possible with the level of detail provided

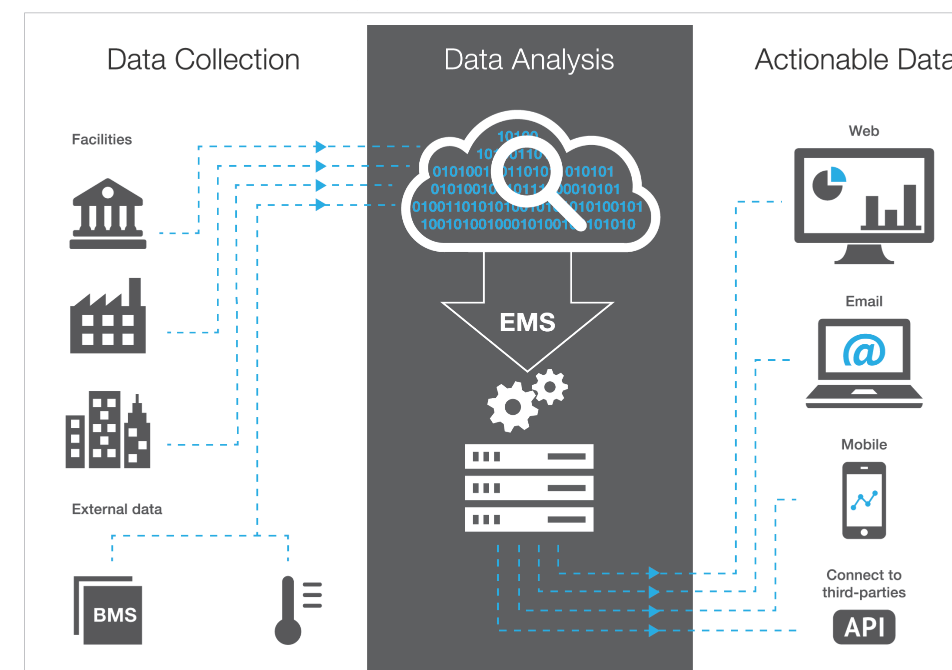

Figure 2: The E1 system integrates hardware and software for enhanced system management

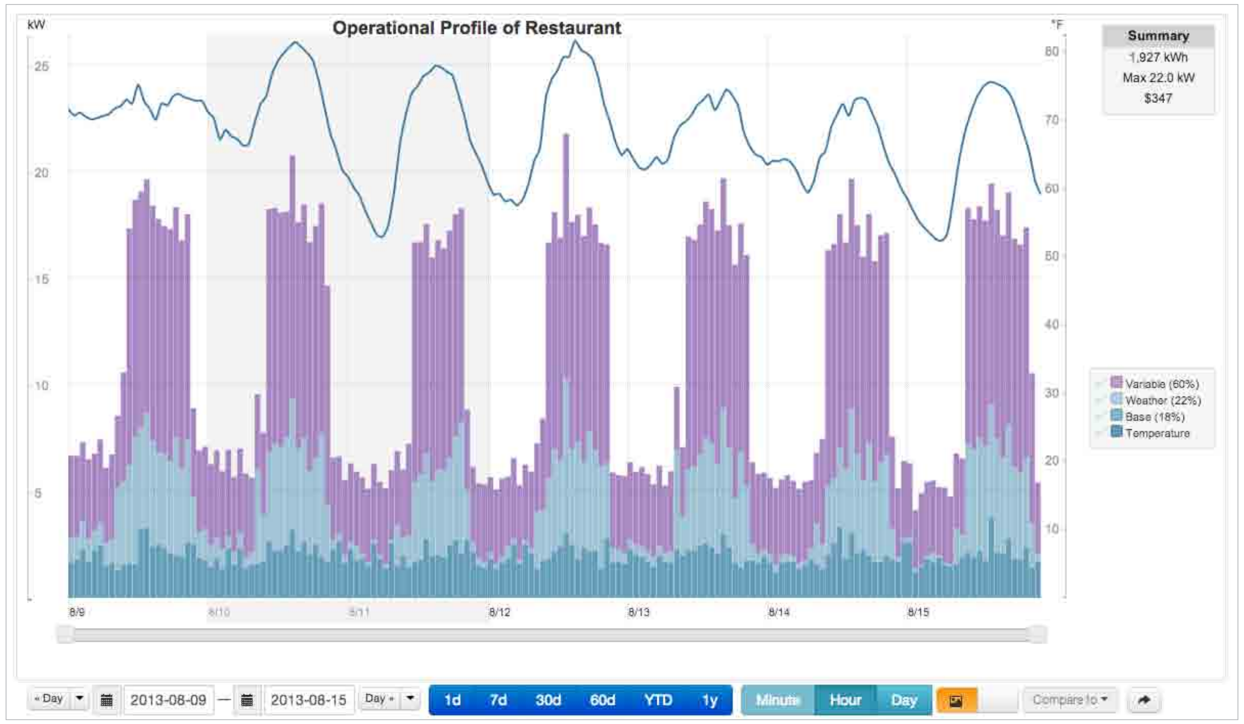

Figure 3: Facility energy summaries enhance system management

by the hardware and the close integration of the hardware along with the software (see **Figure 2**).

The Enertiv EMS, despite having access to a large amount of accurate data, does not strive to simply provide that information back in visual and tabular form. The goal rather is to facilitate analysis that allows for actionable activities and tangible results. Typically within a week, a client can see a whole new rich picture of their energy data in real-time. Within a month, concrete and personalized recommendations can be provided that facilitate the execution of conservation measures. That data can be integrated with other data sources, such as external weather providers. Generally clients note early savings of between 10%-40% as unnecessary loads are identified, wasteful BMS settings are corrected and a clearer picture of energy usage is formed. Anomaly detection is available out of the box as the data is scanned for irregular activity using machine-learning techniques. Measurement and verification tools allow for the creation of financial analysis to determine whether an HVAC upgrade, lighting retrofit, etc. are true value creators. Overall payback periods tend to range in the 6-18 month range.

It is typical for a large facility to commission energy audits and the recently introduced laws in major cities like New York and San Francisco have mandated energy consumption reporting for buildings of a given size. Continuous data collection makes compliance with these regulations easy, at a cost comparable with time-limited audits. Once the Enertiv E1 system has been installed, a facilities/energy manager can review multiple properties from one console and stay constantly informed with email notifications and regular energy summaries and reports that are automatically provided by the system (see **Figure 3**). Together with the Enertiv Pulse (EP), it is possible to tie in electrical data along with other forms of resource consumption, such as oil, water, and gas to achieve a full real-time perspective on the health and well being of a building. Typical facilities which can best benefit from this system are office buildings, light manufacturing facilities, municipalities, schools, universities, data centers, hotels, hospitals, and fast food restaurants. In effect one can perfect a continuous energy audit, recognizing existing energy savings plans and minimizing drift from expected performance targets. Just as a trading algorithm can analyze market data to help give buy and sell recommendations, the algorithms driving the Enertiv EMS can do a holistic analysis of a facility and recommend targeted actions to ensure that the building is running at its best. Information is available via a web client or just as easily via a smart phone.

Today's energy management requires leveraging a great deal of data to create awareness and insights that can lead to the successful execution of conservation measures leading to effective energy and resource usage. Pure hardware solutions currently available are heavily focused on data capture, without providing an understanding of the data collected. Pure software solutions, despite the use of advanced statistical techniques, lack granular, short-interval data in a well-integrated fashion to allow for more than the most basic of analyses. Enertiv seeks to provide a hardware and software solution, which through a non-intrusive installation allows for the capture of granular, circuit-level, metadata-rich energy and resource consumption information allowing for the execution of actionable savings. Enertiv has its sights set on revolutionizing the way operators and occupants view and interact with energy data. Today, the technology to break open the black box of energy data exists, and in the not too far future, one's energy footprint will become just another common statistic we take for granted. The tools to facilitate that are here now and they're evolving rapidly.

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Selecting the Right MOSFET for Power Factor Correction Applications

Device choice impacts a PFC circuit on the line current and its harmonics

By: Philip Zuk, Vishay

Power factor is the ratio of the real power (P = Watts) to the apparent power (VA = Volt Ampere); the goal is to achieve a power factor as close to 1 as possible. A load with a lower power factor draws more reactive current than a load with a higher power factor for the exact same output power. The higher current increases the energy lost within the system, and for utility companies, results in excessive wasted power in transmission.

For this reason, a power factor correction (PFC) circuit block, shown in **Figure 1**, is an important, and often mandatory, sub-system of any power supply with an output power of 75 W or more (per EN61000-3-2). A PFC circuit block is used to align the input line current with the AC voltage waveforms, and in most cases boosts the output voltage to a common 400 VDC. **Figure 2** shows the impact of a PFC circuit on the line current and its harmonics.

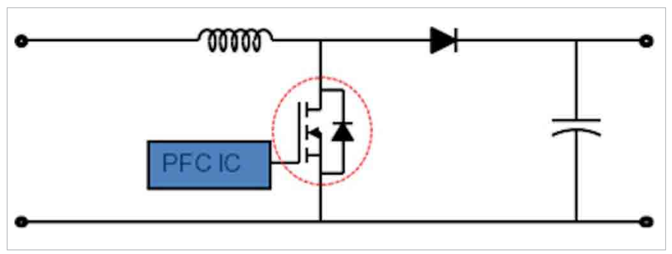

Figure 1: PFC schematic

In **Figure 2A**, current is drawn from the AC supply only for a short duration of the cycle. This results in a poor power factor and excessive harmonics of 115%. While the system draws only 158 W of usable power, 272 Volt-Amperes are circulated in the transmission system to deliver it. **Figure 2B** shows the benefits of implementing PFC using the same input power profile. With a power factor of 99.9%, harmonics are down to 3%. Current is drawn from the AC line throughout the cycle and no excessive Volt-Amperes are wasted.

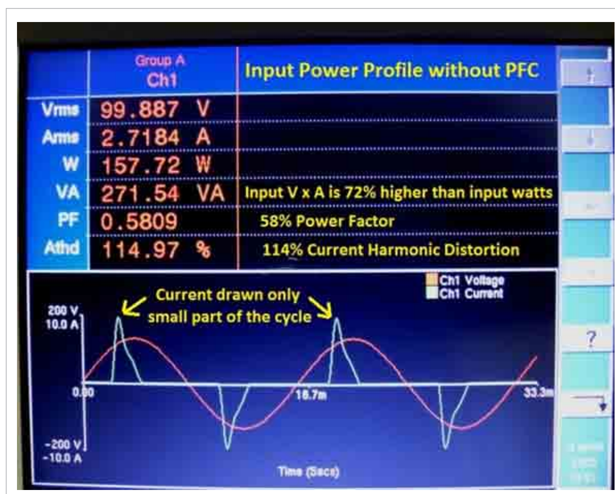

Figure 2A: Line voltage and current without PFC

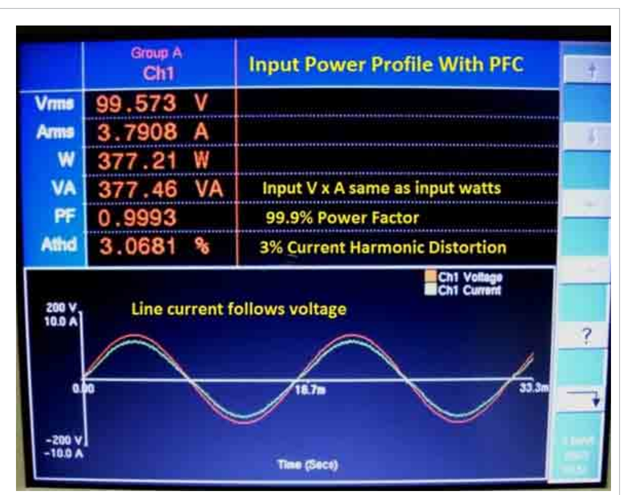

Figure 2B: Waveforms with PFC

It should be noted that PFC and harmonic current reduction are not synonymous. For example, in a highly inductive load, the current may be a perfect sinusoid lagging the voltage. It will then have a poor power factor and high reactive power without any harmonics at all. Whereas a distorted waveform, rich in harmonic currents, usually has all the undesirable features. The PFC circuit corrects more than just the power factor; it reduces the harmonics. Today, there are different standards specifying the quality of power drawn by electronic equipment. EN61000-3-2 requires harmonic current reduction on all systems with input power of > 75W. The 80 Plus power supply certification requires a power factor of 0.9 or more.

In a PFC circuit, the MOSFET is responsible for approximately 20% of all losses. By choosing the correct device, PFC efficiency can be greatly increased. One way to select the right MOSFET for a PFC circuit is by using an application-specific Figure of Merit (FOM) that is focused on minimizing total losses in the device. While it includes on-resistance ($R_{DS(on)}$) for conduction losses and gate charge (Q_g) for switching losses, the FOM is not a simple product of the two. In order to account for switching losses, a portion of the device's Q_{gs} and Q_{gd}, along with its output capacitance (C_{oss}), are used.

The four stages of a standard AC/DC power supply

- Input
- PFC front end
- Converter
- Secondary

To meet 80 Plus Gold efficiency standards, the combined loss for all stages is ~ 12% of the rated output power. The PFC MOSFET alone should be limited to around 2% of the total output power or the package power limit, whichever is lower.

The maximum power loss limits of "TO" packages:

- PowerPAK SO-8L (5x6): 5W
- PowerPAK 8x8: 7W
- TO-220 / TO-220F: 10W
- TO-247: 20W
- Super TO-247 / Tmax: 25W

So, the maximum package power limits that consist of both conduction and switching losses should not exceed the above levels. Conduction loss is a simple $I^2 * R$ calculation that takes into account the $R_{DS(on)}$ of the device as well as its temperature coefficient. The switching losses need to take into account not only Q_g, Q_{gd}, and Q_{gs}, but also Q_{oss}, which is an integral function of C_{oss}.

The traditional FOM, $R_{DS(on)}$ (typ) * Q_g (typ), does not take into account the C_{oss}/Q_{oss} of the device, which is a very important loss, especially at light loads where switching losses trump conduction losses. This component of the switching loss is incurred both ways, as C_{oss} is charged when the device turns off and discharged when it is turned on, and has to be taken into account in the design. The larger the C_{oss}/Q_{oss}, the larger the switching losses. In addition, the Q_{oss} loss is fixed and independent of load, as can be seen by the standard equation $P_{oss} = ½ CV^2 \times F_{sw}$, where F_{sw} is the switching frequency.

In universal input power supplies, the PFC MOSFET is always subjected to the bulk DC bus voltage of 380 VDC to 400 VDC. As a result, the output switching loss can be a significant portion of the total losses. The C_{oss} of a high-voltage MOSFET (HVM) varies considerably with the applied VDS. This variation is much wider for high-voltage Super Junction power MOSFET than for planar types. To account for the non-linearity of the output capacitor, $P_{oss} = ½ C_{oer} \times V^2 \times F_{sw}$ may be used as the loss equation. C_{oer} is the effective capacitance that has the same stored energy and same losses as the integrated C_{oss} of the MOSFET, and is provided in the datasheets. So, the new FOM will now look like $R_{ds(on)}$ (typ) * (Q_{switch} (typ) +

Recommended Power Levels Based on Package Type	
Packages	**Recommended Maximum Ratings***
DPAK (TO-252)/ PowerPAK® SO-8L (5x6)/ PowerPAK® 8x8	Up to 25W
IPAK (TO-251)/ PowerPAK® SO-8L (5x6)/ PowerPAK® 8x8	Up to 75W
D2PAK (TO-263)/ PowerPAK® 8x8	Up to 150W
TO-220	Up to 350W**
TO-220F	Up to 350W**
TO-247AC	Up to 1000W
TO-247AD	Up to 1000W
Super TO-247	Up to 1500W

Table 1: Maximum power levels based on package type

Q_{oss}), where Q_{switch} is a combination of Q_{gd} and Q_{gs}.

As an example, we'll use a TO-220 / TO-220F device with a maximum package power loss of 8W, and contribute 4W to conduction losses and 4W to switching losses. The C_{oss}/Q_{oss} losses would contribute to approximately 20% of the overall package loss, or 40% of the total switching losses, which is a large loss that is not taken into account with the standard FOM equation.

With many package options available, **Table 1** lists the recommended maximum power rating for the different package offerings. Note that there will be a range of devices available in each package, which is why the same package may be recommended over a wide range of output power. To realize the maximum possible power dissipation of SMT packages like PowerPAK SO-8L (5x6) and PowerPAK 8x8 it is necessary to maintain PCB temperature at required application needs under worst case conditions. The Recommended Maximum Ratings are therefore limited by system thermal considerations rather than the package loss.

Recommended Power Levels Based on Package Type

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Understanding power factor and the need for power factor correction

Due to international legislation governing power factor and harmonic distortion, PFC is now a serious industry concern

By: By Arun Ananthampalayam, CUI

Until the era of switching power supplies, Power Factor – and power factor correction – wasn't a big concern for all but a handful of electrical engineers working with large electric motors, and other, generally high-power and industrial, electric loads. Now, thanks to international legislation governing power factor and harmonic distortion, this subject is high on the list of concerns for many engineers designing systems for global use.

A Quick Introduction to Power Factor

Power factor (pf) is the ratio between real power (P) flowing to the load, and the apparent power in the circuit (S): pf = P/S. It is a sinusoidal waveform and therefore expressed as a dimensionless number between -1 and 1.

Real power is measured in watts (W) and apparent power in volt-amps (VA). For a purely resistive load, the two figures are identical; for a reactive load the arithmetic for the apparent power produces the same figure, that is, the product of the RMS values of voltage and current. However, to find the actual (real) power delivered to the load, the instantaneous product of voltage and current must be integrated over the complete sine-wave cycle (see **Figure 1**).

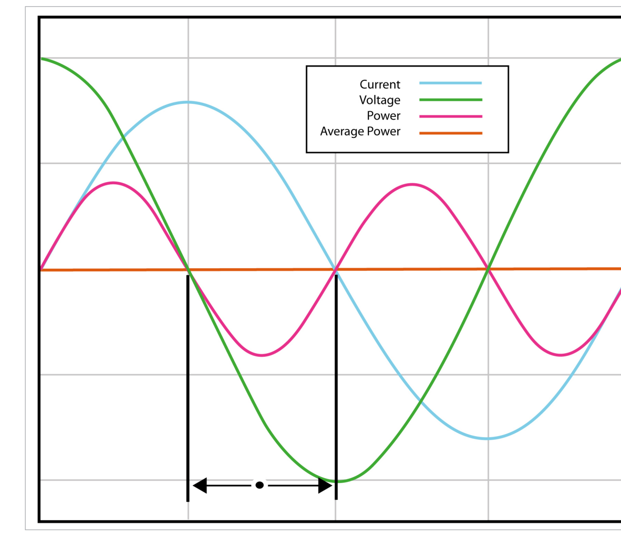

Figure 1: An ideal waveform with a power factor of 0

When current is leading or lagging voltage, the value of that integral will always be less than the value for the in-phase case over the same interval. This reflects the attribute of an inductor or a capacitor to act as an energy store; at various points through the AC cycle the reactive component is either storing energy, or returning it to the system.

The apparent power is the vector sum of the true power and the reactive power (Q), measured in reactive volt amperes (var); conventionally, this relationship is expressed as:

$P = S \cos\Theta$ or P2+Q2=S2

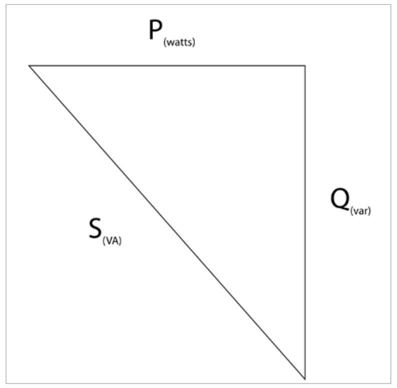

Figure 2: Traditional triangle vector diagram

The relationship is conventionally visualized in a right-angled triangle vector diagram (see **Figure 2**). This is a basic definition and works for pure sinusoids; non-sinusoidal waveforms are more complex, but can be represented by a series of harmonic sinusoids and therefore the same basic principles apply.

The Implications

Power supply utilities and generating bodies require their customers to present a load to the power grid that is as near to unity power factor as possible. The main, but not the only reason, is fiscal. The customer expects to pay for the "real" work done on his premises – in other words, the value of W, above.

Electric utilities must provision to deliver the peak voltage and current values in the waveform at any time. A power factor of less than one is effectively an increase in their costs, and one that they pass back to customers by imposing an increased tariff for customers with low power factor loads. Achieving maximum power factor is therefore a "win-win" for all concerned.

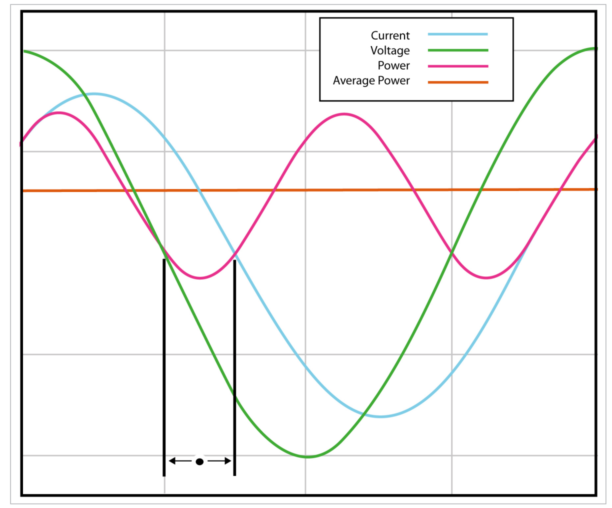

Figure 3: Poor quality wave form with a lagging power factor of 0.71

There are further effects that power generators must contend with that make a unity-power-factor load highly preferable. Rotating plant generating power is more difficult to manage and to keep stable when supplying a low power factor, and there can be heating or overload hazards for transformers and transmission equipment in the supply grid; grid stability is also more difficult to maintain with low-power-factor loads attached to the system. Low power factor also tends to be associated with other negative attributes for a well-behaved electrical load. Highly-distorted current waveforms drawn from the mains can inject high-order harmonics back into the supply grid (see **Figure 3**).

Transmission equipment has higher losses at higher frequencies leading to heating problems; if the higher frequencies are present in the load placed directly on the generating plant, they can manifest themselves as destructive vibrations leading to excessive wear on components such as bearings. Current distortion can lead to out-of-balance currents in the neutral lines of 3-phase distribution networks, which in turn can take the neutral away from ground (voltage) and give rise to a multiplicity of problems.

The first attempt to legislate for mains power interference came over 100 years ago, in 1899, to prevent incandescent lamps from flickering, but one of the key regulations came in 1978, with IEC 555-2 requiring power factor correction be incorporated into consumer products.

More stringent legislation is being enacted around the world. For example, the EU currently legislates EN61000-3-2 for equipment that implements a power supply with a rating between 75 and 600 W. This sets limits to the 39th harmonic for equipment with input currents less than or equal to 16 A per phase. Split into four classes, A, B, C (for appliances, power tools, and lighting) and the most stringent class, D (for computer monitors and TVs), similar regulations have been implemented in China, Japan, and Australia.

Although the US does not have the same level of legislation as the European Union, the Energy Star program operated by the US Department of Energy, as well as schemes such as 80 PLUS for computer and data-center power systems, are placing increasing emphasis on maintaining a high power factor; calling for a power factor of 0.9 or higher at 100 percent of rated output in the system's power supply.

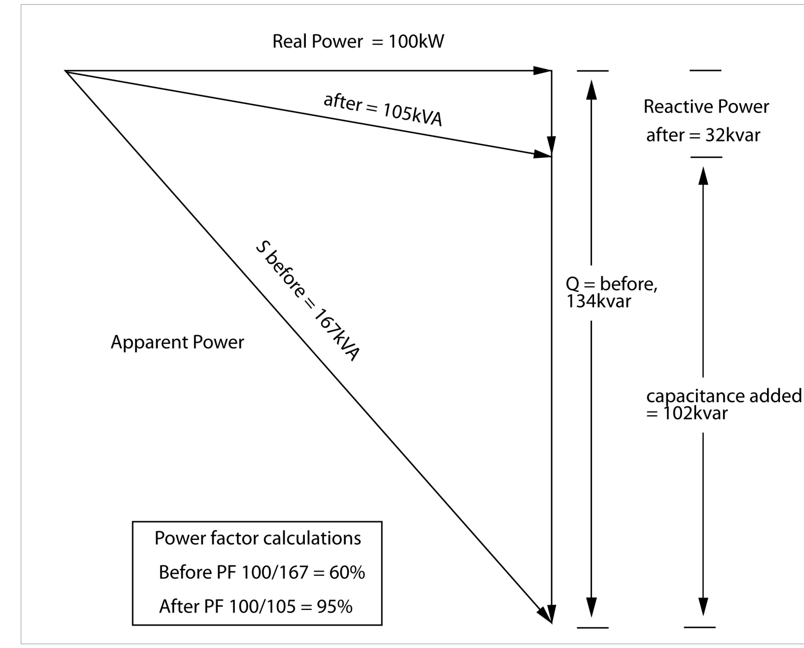

Figure 4: Triangle vector diagram showing the effect of power factor correction

Power Supplies for Electronic Systems

Even when most electronic equipment was supplied by power supplies that used linear regulation, power factor (and waveform distortion) was often less than ideal, but was rarely addressed for anything other than the largest supplies. The typical, conventional off-line arrangement was that of a transformer followed by a bridge rectifier, feeding a reservoir capacitor. Conduction through the rectifier would take place when the DC voltage on the output line had sagged below the instantaneous value of the transformed AC supply, which could be for the complete cycle at full load, or only at the peak of the AC waveform under light load.

Switching power supplies can significantly worsen the situation. The off-line part of the design may not change, still comprising a transformer/rectifier and capacitor, but now feeding one or more switching regulators. The input rectifier continues to generate poorly-shaped current waveforms, but now with the added burden that some of the higher-frequency switching noise from the regulation stage can find its way back into current drawn from the wall socket.

Not only does this shift the effective current peak away from that of the voltage waveform in time, it also introduces high-harmonic-content switching waveforms that potentially worsen the distortion of the current waveform. The arrival of this class of supply broadly coincided with the widespread deployment of PCs and other IT products in great numbers. Such trends led directly to today's legislative environment.

Power Factor Correction

The solution to excess harmonics is to use power factor correction (PFC). This shapes the input current of the power supply to maximize the real power level from the mains and minimize harmonic distortion (see **Figure 4**). Ideally, the electrical appliance should present a load that resembles a linear load, such as a simple resistor, rather than the reactive load of an uncorrected switching power supply. This corrected waveform minimizes

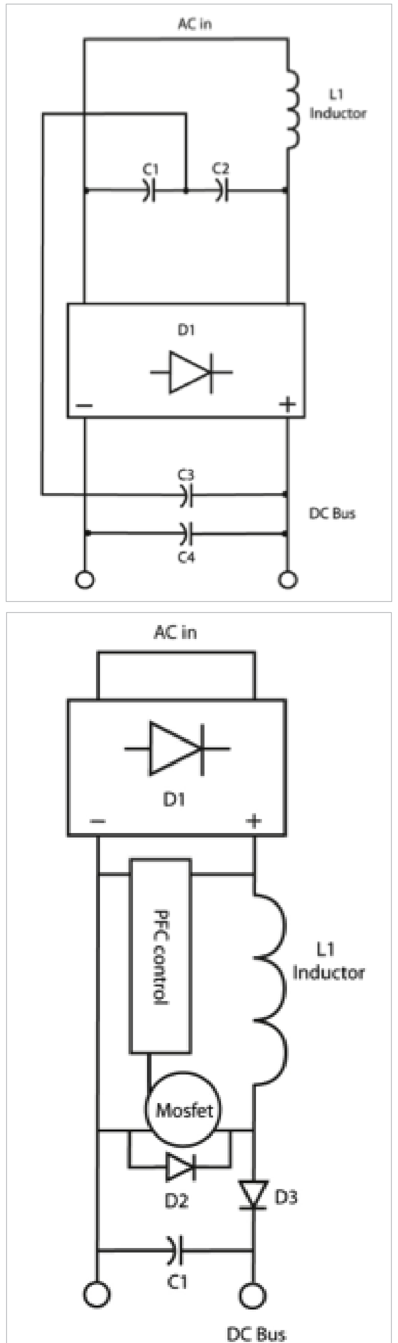

Figure 5: Examples of passive and active power factor correction circuits

losses as well as interference with other devices being powered from the same source.

Compensation for low power factor can be by passive or active devices. The simplest case is highlighted in electric motor applications. Naturally, as wound machines, they provide a highly inductive load, and adding capacitors to the supply network has long been standard practice. However, even this case may not be entirely simple. For example, the designer of such a network has to take care not to create unwanted resonant effects. Variable power factor in the load may be accommodated by an adaptive scheme to connect reactive elements as required and in high-power contexts (MW scale) rotating-machinery solutions can be applied.

Passive power factor correction in the form of filtering can be effective, within limits, and has the effect of reducing the higher-order current harmonics that, as noted above, contribute to degraded power factor. Such techniques involve putting a low-pass filter in the input side of the power supply to suppress higher-order harmonic components, and then compensating lead/lag characteristics as with conventional power factor. The downside to a passive PFC design is that large (both by value, and physically) inductors and/or capacitors may be required. Additionally, there are limitations to the input range and power rating when implementing this scheme (see **Figure 5**). Passive PFC circuits are generally able to achieve a power factor in the range of 0.70-0.75.

The existence of, and rapid progress in, high-speed, high-current capacity semiconductor switches now make available the option to achieve a power factor up to 0.99. Active power factor correction is the scheme that is most widely applied in present-day designs. A switching pre-regulator stage is placed in the input current path of the supply. That regulator is designed not only to maintain a constant DC voltage to feed the main converter stage of the power supply, but also to draw current from the input in-phase with the incoming AC voltage waveform. And while adding a switching stage does impose some extra losses, and some extra cost, there are compensating savings in the form of smaller passive filtering components, and in the supply's main converter.

Summary

Power factor is on the list of concerns for designers of virtually every device that draws significant power from a mains socket, as well as for engineers in heavy-electrical sectors. The power factor target, based on legislation, plus efficiency, component cost, and volume/board space, needs to be considered.

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What is the Smart Grid, really?

Definitions of the "Smart Grid" range from highly technical descriptions to purely commercial interpretations

By: Richard Ord, Amantys

The Smart Grid – a changing landscape of supply, demand and storage

Definitions of the "Smart Grid" range from highly technical descriptions to purely commercial interpretations, but whichever one you may follow, it implies a major re-engineering of all aspects of infrastructure, usage pattern and business models across the whole electricity supply industry.

As a result, the management of the network is one of the biggest challenges facing suppliers and one significant challenge is how to observe effectively how each cell and part of the network is performing, placing network sensing and communications at the center of innovation.

From central to distributed generation

The distributed nature of the Smart Grid sets it apart from the historical unidirectional flow of power, where nuclear or fossil fuel power stations of up to 3GW generated power to distribute outwards through the grid. The very name of the UK's former nationalized generating body of the day gives the clue to the system

Figure 1: Escalating installations of renewable energy sources are likely to be distributed far and wide

structure – the Central Electricity Generating Board, or CEGB. Those power plants were typically based in low population areas or close to the fuel supply resource. Escalating installations of renewable energy sources are also likely to be distributed far and wide – whether onshore or offshore - and these too will typically be a long way from the existing grid infrastructure (see **Figure 1**).

Key differences

There are a number of key differences between a smart grid and the more traditional 'national grid' approach, affecting all aspects of generation, transmission, storage and consumption, and with a bidirectional flow of energy throughout according to local and national variations of supply and demand. A smart grid may also include features such as digital sensing, control and communications across the entire network and a 'cellular' type structure of regional grids.

A modern cell within the smart grid will include industrial and consumer energy consumption, as well as renewable energy generation from wind and solar energy sources. These sources may themselves be under industry, government or private ownership. Even at the smallest level, any factory site, business premises or private household could be drawing power from the grid or supplying energy into it at different times of day or night. As a result the smart grid network isn't predictable, demand can vary depending on weather conditions, and supply may come from different sources at completely different times each day.

Changing dynamics of power switching

The implications at the level of power switching are enormous: as well as the need to monitor supply and demand at a micro level, the intersection of power transmission between each cell will need a level of robustness and reliability not previously engendered in the national grid. A power station ready to boost output at the half-time break in national sports events will no longer suffice.

The need for resilience and robustness

Homeowners with their own solar panels perhaps represent the smallest unit of power ebb and flow, drawing from or feeding back into the grid. Offshore wind farms face a similar challenge, dealing with wide day-to-day variations of power generation, and the management of how this is fed into the grid.

At a national or macro-geographic level, there are already links between grids, whether across the English Channel, between different European countries, or across North America and China. At each of these junction points, energy flow is bi-directional, but the imperative is that failure or instability in one region cannot propagate into the other and shut down the neighboring region. This same imperative will also apply at the cell boundaries in the Smart Grid, demanding power switching systems that can isolate neighboring areas from varying energy flow and frequencies.

Digital techniques at the core of the switching system

At each of these stages, the level of performance monitoring available is still what we'd expect from the older national grid. When the network becomes much more complex, there's a clear demand for real-time observability at every level from the power switch to the national grid. In Germany there have been documented challenges in managing the supply generated though solar and this reinforces the need for something new. Whether that's in a warehouse hundreds of miles away from the nearest engineer or at a more local level, using digital techniques to monitor power switching can make smart grids much more manageable.

Visibility across the network

New monitoring systems will satisfy the need at a higher level of operational performance, but such systems will be better informed if information is available right from the power switch. The operator can then assess real-time data in light of changing power stack performance, environmental conditions and as critical components age. This performance intelligence helps to build a profile of how the system operates and reacts in different conditions, and this can then be rolled back into new developments and installations, reducing test time and cost. When there are faults or failures, current systems flag a failure but without context of what happened or the conditions leading up to the failure. Understanding what causes faults and failures is essential in improving the efficiency and the resilience of the smart grid.

Getting renewable energy back into the grid

Getting power back from the offshore wind farms or remote areas presents another challenge in power switching and it's here where HVDC (High Voltage DC) has proven to be more efficient and less expensive than AC transmission when these links are underground, underwater, or across hundreds of miles over-ground. A typical modern HVDC switching hall will be populated with rack after rack of power stacks, each comprising dozens of IGBT modules mounted on a cooling plate, and filling the space of a medium-sized warehouse.

Yet this move presents another set of challenges, with a facility including tens of thousands of high power IGBT modules, each with a gate driver circuit, and, until now, the switching signals available from these modules was limited

Figure 2: By integrating intelligence with the system, the operator can program and modify the flow of data

to on, off or fault. In a facility such as this, once the system is powered up, the operator won't want to open the doors for many months or even years, so any techniques that can help provide performance monitoring from within the switch to the outside control domain is welcome. This is particularly important when the facility is likely to be miles away from the nearest engineer; spotting faults early is critical to maintaining reliability.

Intelligence in Smart Grids

At Amantys our approach is all about intelligent monitoring of power switching and understanding more than just a simple on/off/fault reading from each IGBT. Amantys Power Insight provides a hardware and software infrastructure to observe and monitor power switching from its foundation, providing the basis for a robust and resilient system. By integrating intelligence with an ARM Cortex® M3 processor at the core of the system, the operator can program and modify the flow of data from the switch as a function of performance and environment in real-time (see **Figure 2**).

Smart Grid and the "internet of things"

In the Smart Grid the biggest challenge is still managing and balancing the network. It seems almost backward that while techniques for generating and transmitting power may have changed, the level of insight into its performance and reasons behind faults and failures is lagging far behind. For the Smart Grid to be truly smart, understanding how it's working at its very core is essential to improve the efficiency and resilience of the system.

www.amantys.com

User tracking in the Internet of things

By: Alix Paultre, Editorial Director, PSD

Among the many concerns we have as individuals in the information society, one of the most pressing to us is our privacy. Once upon a time, protecting your privacy only required a small amount of operational security; shred important documents, don't give strangers your information, and don't lose your wallet. Today, there are aspects to our identity that we can't even control ourselves anymore.

The "how" in the "who" online

We all know (or should) that your activity can be tracked online using tracking chits called "cookies". Most people know that if they want some privacy, they should disable the cookie functionality in their browser, to prevent websites from collecting user data and other personal information. This is an aspect of our online identities that we can control to some degree.

However, many organizations are starting to use powerful information warfare techniques to the world of online activity, removing a lot of the control people had on their identities. One of the most powerful tools one can use involves pattern and traffic analysis. One can discover a great deal about you just by tracking who you talk to and where you go, without having to even listen to what you say when you talk, or what you do when you get there. Pattern analysis is now becoming a major weapon in the online arsenal.

Internet of things

But what happens when the Internet moves into the real world, and we live in an environment full of connected intelligent devices? This will enable the creation of even more comprehensive pattern analysis, to the point where your actions and activities can be tracked whether you want them to or not. Just like the old Morse-code senders of old, your behavioral "fist" in the Internet of things will betray you to the skilled observer.

Just as companies are currently beginning to track people cookie-free online just through their behavior and the "fingerprint" of user settings in their browser, they will track people through the real world by their interactions with the devices and systems around them. It will probably get to a point where your actions to mask your activity will actually highlight you to the system as a depression in the data patterns.

The good side

This is not necessarily a bad thing, if individual information is protected while the system is allowed to use the macro market and usage data to optimize infrastructure operational efficiencies by leveraging the information to better control power, lighting, traffic, and signal management (among the many facets of societal infrastructure that could be improved through Big Data) to significantly reduce waste and increase operating efficiencies.

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	1.0	210	240	0.51°C/W	AUIRFS8408-7P
	1.3	150	240	0.65°C/W	AUIRFS8407-7P
D²PAK	1.2	300	195	0.40°C/W	AUIRFS8409
	1.6	216	195	0.51°C/W	AUIRFS8408
	1.8	150	195	0.65°C/W	AUIRFS8407
	2.3	107	120	0.92°C/W	AUIRFS8405
	3.3	62	120	1.52°C/W	AUIRFS8403
TO-262	1.2	300	195	0.40°C/W	AUIRFSL8409
	1.6	216	195	0.51°C/W	AUIRFSL8408
	1.8	150	195	0.65°C/W	AUIRFSL8407
	2.3	107	120	0.92°C/W	AUIRFSL8405
	3.3	62	120	1.52°C/W	AUIRFSL8403
TO-220	1.3	300	195	0.40 °C/W	AUIRFB8409
	2.0	150	195	0.65 °C/W	AUIRFB8407
	2.5	107	120	0.92 °C/W	AUIRFB8405
DPAK	1.98	103	100	0.92 °C/W	AUIRFR8405
	3.1	66	100	1.52 °C/W	AUIRFR8403
	4.25	42	100	1.90 °C/W	AUIRFR8401
IPAK	1.98	103	100	0.92 °C/W	AUIRFU8405
	3.1	66	100	1.52 °C/W	AUIRFU8403
	4.25	42	100	1.90 °C/W	AUIRFU8401

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