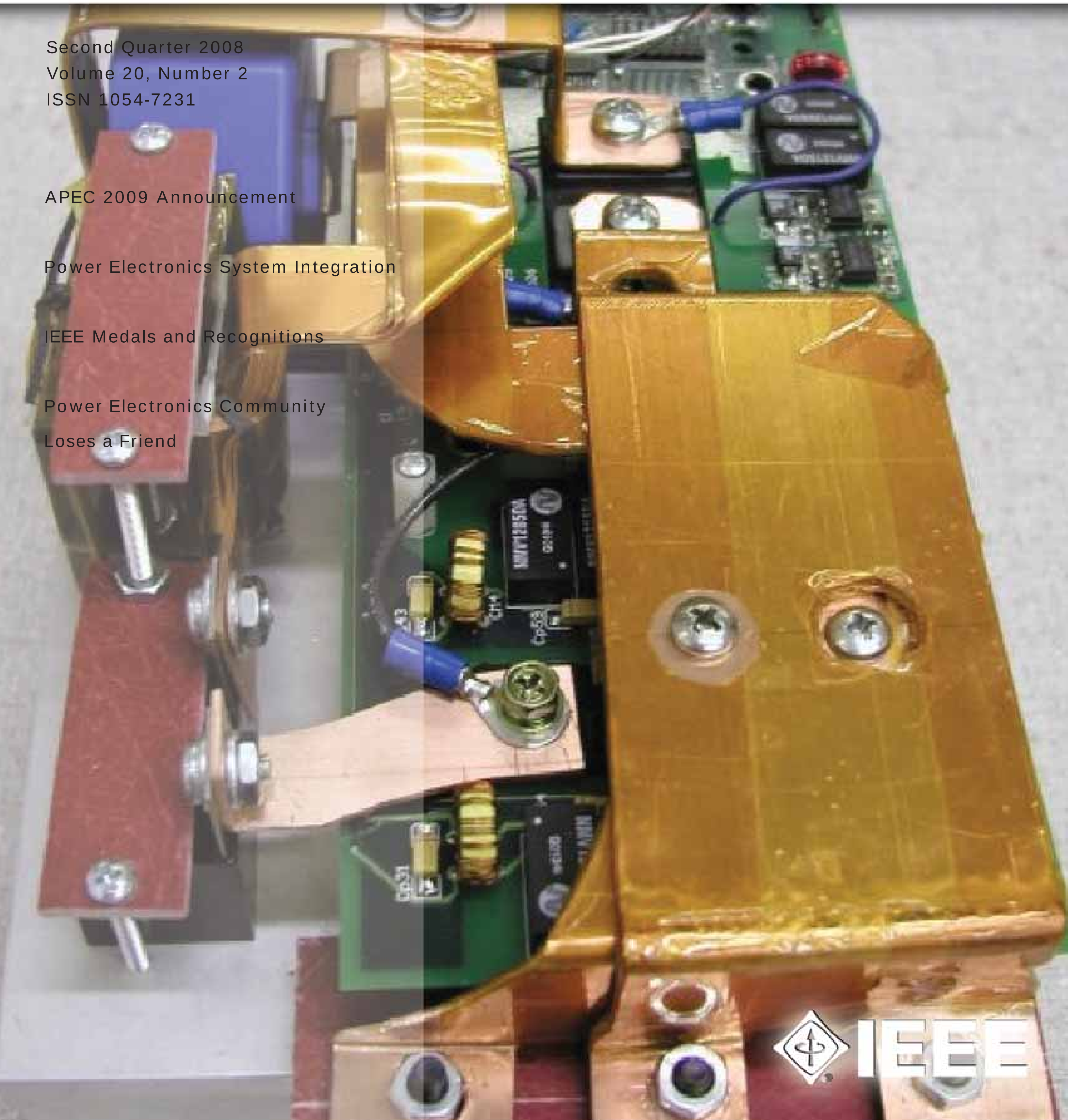
POWER ELECTRONICS SOCIETY

NEWSLETTER

Second Quarter 2008
Volume 20, Number 2
ISSN 1054-7231



APEC 2009 Announcement

Power Electronics System Integration

IEEE Medals and Recognitions

Power Electronics Community Loses a Friend

IEEE

Table of Contents

From the Editor 3
President’s Message 4
Detroit-Area Man to Receive National Engineering Award 6
The 2009 International Future Energy Challenge™ 6
APEC 2009 Call for Papers 7
Status Review and Suitability Analysis of Cell Equalization Techniques for Hybrid Electric Vehicle Energy Storage Systems . .8
PESC 2008 Announcement 12
APEC 2008 Breaks Records - Again 13
Power Electronics System Integration - A CPES Perspective . .14
Redundant Power Supplies - Considerations When Paralleling Power Supply Outputs for Redundancy 20
Combined Thermal and Electrical Simulation of Power Electronic Systems with PLECS 22
Book Review 24
Seeking Nominations for IEEE Medal and Recognitions 24
Meetings of Interest 25
Obituary 26

The IEEE Power Electronics Society Newsletter (ISSN 1054-7231) is published quarterly by the IEEE Power Electronics Society of the Institute of Electrical and Electronic Engineers, Inc. Headquarters: 3 Park Avenue, 17’th Floor, NY 10016-5997. An assessment of $1.00 per member per year (included in Society fee) for each member of the Power Electronics Society is made. Postmaster: Send address changes to IEEE POWER ELECTRONICS SOCIETY NEWSLETTER, IEEE, 445 Hoes Lane, Piscataway, N.J. 08855-1331.

News Items should be sent to: Dr John M. Miller, PELS Newsletter, Editor-in-Chief, J-N-J Miller Design Services, PLC, 3573 East Gatzke Road, Cedar, MI. 49621, USA; TEL:+1 231 228 5011; EMAIL: pelsnews@ieee.org. Deadlines for copy are March 15, June 15, September 15 and December 15. Email submission of items in MS-Word or plain-text format are preferred. MS-Word and plain-text (straight ASCII) submissions on CDROMs are welcome and should be accompanied by a backup hardcopy. Fax submissions are acceptable, but are least desirable. Include caption with all photos identifying event and individuals in a back-row, left to right, front-row, left to right, etc method. Full-page calls for papers and announcements of PELS-supported conferences are welcome and should be sent as both high-quality hardcopy and MS-Word files. Please indicate all trademarked items, such as INTELEC®, APEC® with the registered trademark symbol, “®”.

Technical items should be sent to: Prof Babak Fahimi, PELS Newsletter Associate Editor, University of Texas at Arlington, 416 S. College St., Arlington, TX 76019 USA; TEL: +1 817 272 2667; FAX: +1 817 272 5040; EMAIL: fahimi@uta.edu

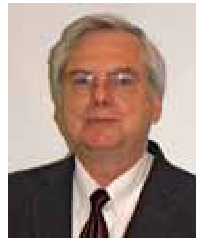
Advertising queries should be sent to: Tom Flynn (West and Central USA & International) TEL: +1 770 645 2944; FAX: +1 770 993 4423; EMAIL: flynntomga@yahoo.com
Or
Walter Chalupa (Eastern USA), TEL: +1 973 626 3412; FAX: +1 973 835 1602; EMAIL: wchalupa@aol.com

The Newsletter in PDF format is posted at the PELS website approximately three weeks sooner than paper copies can be delivered. To receive email notification when the internet version is available, go to http://www.pels.org/Mailing/MailForm.html and provide your email address. Additionally, the email notification sometimes includes timely announcements that are not in the printed newsletter.

Periodicals Postage paid at New York, NY, and at additional mailing offices. PRINTED IN THE U.S.A.

From The Editor

John M. Miller



Welcome to the second issue for 2008 and the start of new content in the form of short articles on product technical tips from our advertisers and companies wishing to describe some unique solutions to power electronics implementation issues. Also, we continue to look for news items of recent happenings such as the news from IEEE-USA citing the Professional Achievement Award to one of our members. Other than these features the content remains relatively unchanged.

The editorial staff of PELs newsletter is pleased to include in this issue an article presenting a ten year synopsis of the Center for Power Electronic Systems from the principals of CPES at Virginia Tech. I hope everyone will find this summary very informative and the accomplishments of the CPES team at the leading edge in power electronic systems.

John M. Miller, EIC
pelsnews@ieee.org

A 33kW zero-voltage, zero-current-transition (ZV/ZCT) phase-leg Power Electronic Building Block (PEBB) module developed by the Center for Power Electronic Systems (CPES). Photo art courtesy of CPES.

President’s Message

Dear PELS members:

I am writing this article in a flight from Austin to Tokyo after attending the PELS AdCom (Administrative Committee) meeting on Feb. 24, 2008 and the 23rd IEEE APEC in Austin Convention Center. It was warmer in Austin than I had expected in Tokyo. I did not use the coat I brought from Tokyo when I walked around the city.

First of all, I would like to extend a warm welcome to the following new PELS AdCom members, Jaime Arau, Fanny Björk, Jon C. Clare, Annette Muetze, Regan Zane, and Richard Zhang as the Member-At-Large for 2008-2010, and Ponci Ferdinanda as the Liaison to Women in Engineering. Moreover, I am pleased to inform you that our President-Elect in 2008 (PELS President from Jan. 2009 to Dec. 2010) is Deepak Divan who is serving now as VP (Vice-President) Operations in 2008. Three scenes in the form of photographs are picked up from the AdCom meeting.

Our Society membership was 6337 as of Feb. 6, 2008, which increased by 3.6% at the same time last year, under the leadership of VP Meetings, Ralph Kennel and Membership & Publicity Chair, Duhsan Boroyevich. I expect that our Society activity continues to grow by leaps and bounds with a “fair wind” from wind turbine generators and pure/hybrid electric vehicles that are intended for mitigating global warming and climate change.

The APEC has been cosponsored by three organizations: the IEEE PELS and IAS, and PIMC. The 2008 APEC was a successful and active conference, not only in terms of the number of more than 2000 participants, but also in terms of more than 200 booths (a record number) displayed in a huge exhibition hall. Oral and poster presentations of about 300 technical papers selected from a base of over 650 digest submissions were made, along with the plenary session, professional education seminars and so on.

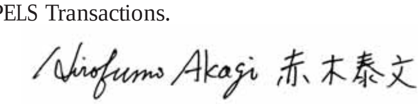
In addition to attending the technical sessions, I walked around the huge hall back and forth, and stopped to talk with some exhibitors of my favorite booths. They gave me the latest information on power electronic components and devices. I really enjoyed the whole conference including the exhibition. On behalf of the Power Electronics Society, I deeply thank all the conference committee members for their excellent team work led by the General Chair, Steve Karakem.

One week before the AdCom meeting, the IEEE TAB (Technical Activity Board) meeting was held in Louisville, where I saw small blocks of iced snow outside the window of my room in a hotel. Usually, the TAB meeting lasts two days, Friday and Saturday from the morning to the evening. We discussed common issues among more than 40 societies and councils formally, and specific topics between two or three societies informally.

One of the common issues was the so-called “no-show papers” in IEEE conferences. This means that neither author nor co-author of a paper included in the conference CD-ROM makes oral or poster presentation at the conference. The TAB has already established a sub-committee to solve the issue, in which the committee members are collecting various data related to it. Although some interesting data were presented at the meeting, the TAB has not yet reached an effective solution.

Judging from my observations through the last several years, no-show papers have not been serious at major conferences sponsored or cosponsored by PELS. However, all the PELS members should strive to reduce no-show papers except for those resulting from unavoidable illness, family emergency and so on. If a principal author found his/her paper to be “no-show” before submitting it to an IEEE conference, I would suggest that the author does not submit it to the conference but uploads his/her full paper for review process in the PELS Transactions through internet (Manuscript Central).

The online version of the PELS Transactions will have 12 issues per year and the print copy will have six issues per year from 2009. This change will make it possible to publish the accepted papers in the online version with a less waiting time in a queue, and will contribute to improving an impact factor of the PELS Transactions.



Hirofumi (Hiro) Akagi
IEEE PELS President
Professor, Tokyo Institute of Technology
E-mail: akagi@ee.titech.ac.jp

Presenting a certificate of appreciation to Ron Harley (right).

Presenting a certificate of appreciation to John Shen (right).

CHOKES

POWER LINE CHOKES

RL-1282, 1283, 1284, 1288

- Inductance range 1.0µH - 100mH
- Current rating 39mA - 6A
- 204 Values, 4 Sizes
- Axial leads available straight, pre-formed, tape and reel

RADIAL LEADED POWER LINE CHOKES

RL-1256

- Inductance range 1µH - 100mH
- Current rating 800mA - 70A
- 365 Values, 8 Sizes
- Radial leads for easy PCB mount

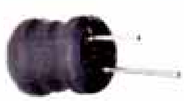
BAR CHOKES

RL-1281, 1285

- Inductance range 0.22µH - 12.5µH
- Current range 4A - 6A
- 42 Values
- Radial leads for easy PCB mount

24 SAMPLES WITHIN HOURS

MINI-DRUM INDUCTOR



RL-5480

- Inductance range 3.9µH - 270mH
- Current rating 15mA - 4A
- 259 Values, 5 Sizes
- Staggered lead length for easy PC insertion

AXIAL LEADED HIGH FREQUENCY INDUCTORS

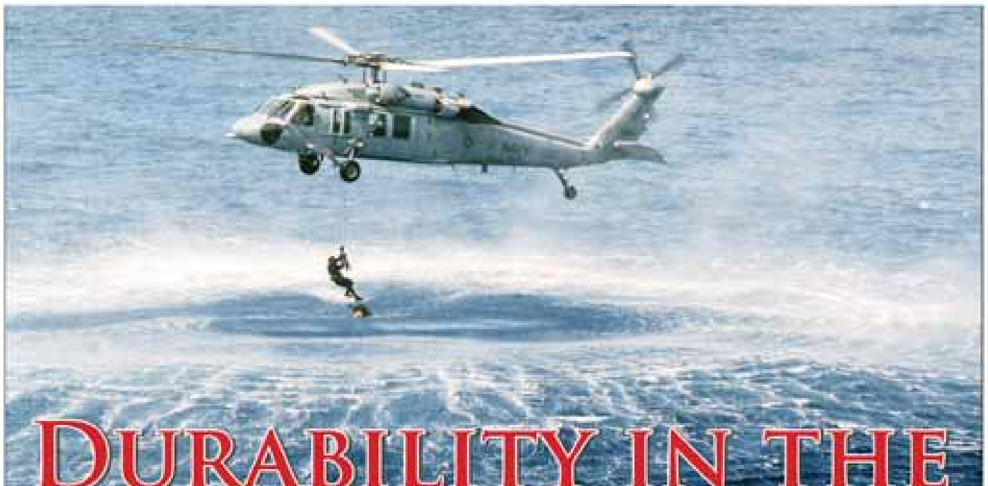
RL-1292, 1293, 1294

- Inductance range 3.9µH - 150mH
- Current range 39mA - 6 Amps
- 155 Values, 3 Sizes
- Axial leads available straight, pre-formed, tape and reel

AXIAL LEADED HIGH FREQUENCY INDUCTOR

RL-1295

- Inductance range 3.9µH - 150mH
- Current range 16mA - 1.3 Amps
- 56 Values
- Axial leads available straight, pre-formed, tape and reel



DURABILITY IN THE HARSHEST ELEMENTS

Desperate times call for desperate measures. When an accident becomes a life threatening situation, and rescues could take days or weeks if you're not prepared. With high saturation current and low loss core, the Renco Electronics choke provides split second accuracy during an emergency.

Choke applications include GPS tracking systems, power supplies, power amplifiers, SCR/ triac control circuits, switching regulators, high voltage line filtering, surge suppression, filters, DC-DC converters, and buck/boost topologies. The use of high saturation material makes the coils ideal for use in switching regulated power supply applications. The shielded coils withstand a temperature rise of up to 130°C and provide an inductance range up to 270,000µH.

Renco has remained a leading inductor manufacturer for half a century and can determine the best solution for handling your diverse power needs. They know the importance of receiving the high-quality products you need when you need them. Regardless of quantity, Renco can rapidly fulfill all of your orders.

Renco Electronics offers a complete line of ROHS Compliant products FOB direct from Hong Kong or the United States. For no-charge samples please call our **Engineering Hotline** at 1.800.645.5828 or email us at Engineering@rencousa.com.

ISO 9001:2000 Certified

POWER-DISC™ INDUCTOR

RL-6600

- Inductance range 2.2 µH - 6.8mH
- Current range 1.4 A - 44 Amps
- 114 Values, 3 Sizes
- Radial leads for easy PCB mount

SHIELDED RADIAL CHOKE COIL WITH STAND-OFF

RL-8054

- Inductance range 10 µH - 1.0 mH
- Current range .23 A - 3.51 Amps
- 71 Values, 3 Sizes
- Radial leads for easy PCB mount

MOLDED RADIAL CHOKE COIL

RL-8064

- Inductance range 1.0 µH - 15.0 mH
- Current range 0.13 A - 8.80 Amps
- 61 Values, 3 Sizes
- Radial leads for easy PCB mount

Over 50 years of Excellence

GENUINE RENCO SINCE 1955

RENCO ELECTRONICS

Detroit-Area Man to Receive National Engineering Award

NEWS from IEEE-USA
1828 L Street, N.W., Suite 1202
Washington, DC 20036-5104

WASHINGTON (12 February 2008) -- Kevin Taylor of Warren, Mich., has been selected to receive an IEEE-USA Professional Achievement Award.

Taylor, a member of the IEEE-USA Career & Workforce Policy Committee, is being honored for conceiving and coordinating the Future Energy Technologys Employment Challenge career program in Detroit in October of 2006. The event drew 150 attendees to the NextEnergy Center, Michigans nonprofit alternative energy accelerator.

Dr. Leonard J. Bond, IEEE Region 6 director-elect and a Laboratory Fellow at the Pacific Northwest National Laboratory in Richland, Wash., was the keynote speaker. Dr. Bond spoke about the U.S. energy system, energy technology trends and the challenges and opportunities U.S. organizations face in meeting their needs for a talented energy workforce.

Taylor received word of his award from 2007 IEEE-USA President John Meredith, who wrote, You have honored IEEE with your contributions and services in the area of professional activities, and the IEEE-USA Board of Directors is very pleased to recognize your efforts by the presentation of this award.

Taylor will be honored with 21 other award recipients during the IEEE-USA Annual Meeting at the Hyatt Regency Hotel in Indianapolis on 26 April.

Taylor is the IEEE Southeast Michigan Section technical chapter chairman for the IEEE Power Engineering, Industry Applications, Industrial Electronics and Power Electronics societies.

IEEE-USA awards are presented in recognition of professional, technical and literary contributions to public awareness and understanding of the engineering profession in the United States. They are administered under the IEEE-USA Awards and Recognition Committee and approved by the IEEE-USA Board of Directors.

Nominations are being accepted for IEEE-USAs 2008 awards. See http://www.ieeeusa.org/volunteers/awards/index.html for more information or contact Sandra Kim at sandra.kim@ieee.org. The deadline is 31 July 2008.

IEEE-USA advances the public good and promotes the careers and public policy interests of more than 215,000 engineers, scientists and allied professionals who are U.S. members of the IEEE. IEEE-USA is part of the IEEE, the worlds largest technical professional society with 370,000 members in 160 countries. See http://www.ieeeusa.org.

Contact: Chris McManes
IEEE-USA Public Relations Manager
Phone: + 1 202 530 8356
E-mail: c.mcmanes@ieee.org

The 2009 International Future Energy Challenge™

Sponsored by the IEEE Power Electronics Society, and the Power Sources Manufacturers Association (PSMA).

About the 2009 International Future Energy Challenge

The International Future Energy Challenge (IFEC) is an international student competition for innovation, conservation, and effective use of electrical energy. The competition is open to college and university student teams from recognized engineering programs in any location. The 2009 competition addresses two broad topic areas:

Topic (A) Integrated Starter/Alternator-Motor Drive for Automotive Applications: The main purpose of this challenge is to conceptualize, design, and develop a 1 kW, 3000 rpm electromechanical energy converter for operating efficiently (not less than 75% at cruising speed) as an alternator and motor. It is also desired to have a (cold) stand still torque of 30 N-m and to reach rated speed of 3000 rpm within 3 to 5 seconds.

Topic (B) Low Cost Wind Turbine Energy Maximizer: The objective of this topic is to foster innovation in low power wind turbine generation systems for remote, rural and small urban applications. The goal is to construct a power electronic interface converter for a wind generation system that will support and protect system operation under all operating conditions; achieve maximum energy transfer when charging a 12 V battery over a wide range of wind speeds without overcharging or damaging the battery; reliably operate without significant user support over many years of use; and be a leading-edge solution in the areas of performance, reliability, and safety. The design is supposed to be for minimum weight, minimum component cost and count, to achieve reduced high volume manufacturing cost.

Participation is on a proposal basis. Those schools that are interested must submit a proposal no later than May 2nd, 2008. Proposals will be judged by a distinguished panel of volunteer experts from the IEEE and from industry. Schools with successful proposals will be notified by May 12th , 2008. The major sponsor of the 2009 competition is the IEEE Power Electronics Society (PELS). For more information please visit: http://www.energy-challenge.org/

Babak Fahimi
Chair, IFEC 2009

Dr. Babak Fahimi is currently with the department of electrical engineering at University of Texas-Arlington. He is the director of the power electronics and controlled motion laboratory and is responsible for research in adjustable speed motor drives and advanced power electronics areas. Dr. Fahimi is also actively involved in development of a series of new courses in his area of research. For more information please visit: http://www.uta.edu/pecm.

Status Review and Suitability Analysis of Cell-Equalization Techniques for Hybrid Electric Vehicle Energy Storage Systems

Pablo A. Cassani, Student Member, IEEE, and Sheldon S. Williamson , Member, IEEE
P. D. Ziogas Power Electronics Laboratory
Department of Electrical and Computer Engineering
Concordia University
1455 de Maisonneuve Blvd. W.
Montreal, Quebec H3G 1M8, Canada
Phone: +1/(514) 848-2424, ext. 8741
Fax: +1/(514) 848-2802
EML: sheldon@ece.concordia.ca
URL: http://www.ece.concordia.ca/~sheldon

Abstract–*In order to augment gas mileage and to meet stringent CO2 emission targets, automakers have recently started making serious advances towards hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and all-electric vehicles (EVs). The main obstacle remains the same as it was 10 years ago; the energy storage system. Although in recent years, lithium batteries, in the form of lithium-ion or lithium-polymer, have been intensely explored, they still do not meet the requirements for an HEV. The main issues include, cost, cycle life, calendar life, energy density, power density, and lately, safety. Some of these issues can be addressed successfully using a more practical approach, using a battery cell voltage equalizer. The purpose of this paper is to find a way to improve the overall cost per kilometer of an HEV. The lithium rechargeable cell has been widely touted as a leading candidate, but there are no cost analyses of the benefits of using advanced electronics to protect and equalize the cells. In order to do that, it is essential to characterize the degradation of lithium batteries, in order to demonstrate the usefulness of the battery cell voltage equalizers. This paper will explore and contrast several cell equalizer configurations, and propose the most adept configurations for future use, for EV as well as HEV/PHEV applications.*

Index Terms–*Battery storage, cell equalizers, electric vehicles, energy storage, power electronic converters.*

I. INTRODUCTION

Battery energy storage is by far the main stumbling block to fast commercialization of electric/hybrid electric vehicles. In fact, the common issues related to lithium rechargeable cells can be summed up in one simple topic: cell equalization. Typically, a battery pack of an HEV consist of a long string of cells, where each cell is not exactly equal to the others, in terms of capacity and internal resistance, because of normal dispersion during manufacturing. However, the most viable solution for this problem might not originate from mere changes in battery properties. The aim of this paper is, firstly, to explain the role of power electronics based battery cell voltage equalizers and their role in improving cycle life, calendar life, power, and overall safety of EV/HEV battery energy storage systems. In addition, this paper will also comprehensively review and contrast popular cell equalizer topologies and will propose a novel equalizer design for future work.

It is imperative that most studies related to ESS for HEV applications must follow a cost-conscious approach. For instance, taking into account that lithium batteries cost about $500/kWh, a small 16kWh battery is capable of providing about 50 miles (80 kms) of autonomy to a small-sized vehicle (simulated and tested under the Federal Test Procedure, FTP driving pattern) [1]-[4]. This amounts to a surcharge of about $5000 over the price of a standard vehicle, exceeding the reasonable budget for a medium consumer.

Moreover, issues related to cycle life and calendar life cannot be ignored. Depending on the intensity of usage, an average battery holds about 500 cycles at 80% of its capacity, before losing 20% of its initial capacity. If the battery is replaced at that point and the cost of electricity is added, the expenses rise to $0.1/km. Consequently, the existing scheme makes the EV option more expensive than the traditional gasoline based vehicle. It is worth pointing out here that the low calendar life of batteries is mainly due to the high temperature and high voltage conditions both during charging and after being fully charged. These issues can be addressed simply by guaranteeing the right temperature, lower charge voltage, and a "per cell" charge voltage control.

Even though lithium batteries possess high energy densities, the use of long strings of cells for applications such as on-board storage for PHEVs, downgrades their overall capacity. In addition, their overall power density is also affected negatively by the use of long string of cells. Nevertheless, the use of battery-cell voltage equalizers, which work on the simple principle of drawing more current from the highest capacity cells compared to those having lower capacity, help increase the overall capacity and power availability of the entire string. In the ensuing sections, the paper will examine the critical characteristics of lithium batteries and their cycle-life, in particular.

II. ISSUES RELATED TO LITHIUM BATTERIES FOR HEV APPLICATIONS

Lithium rechargeable batteries are today at the top of their wave. For instance, a 20 kWh Li-ion battery pack weighs about 160 kg (at the rate of 100-140 Wh/kg), which is acceptable for HEV applications. In contrast, current HEV Nickel-Metal Hydride (Ni-MH) batteries weigh between 275-300 kg for the same application. Moreover, Li-ion batteries also depict excellent power densities (400-800 W/kg), allowing more than 2C discharge rate (at the rate of 40-80 kW peak power in a 20 kWh pack) [4]. However, they also suffer from many drawbacks. One of them is the cost (projected at about $250-$300/kWh), which is the most expensive of all chemistries [4], [5]. The second drawback is that lithium is a very flammable element, whereby its flame cannot be put off with a normal ABC extinguisher. Finally, Li-ion batteries have a cycle life between 400 to 700 cycles, which doesn't satisfy HEV expectations [5], [6]. Therefore, finding a solution to these issues is crucial.

With reference to cycle life, the battery can suffer significant degradation in its capacity, depending on its usage. Furthermore, the internal resistance also increases with each charge cycle. Also, according to the chemistry and the quality of the cells, a battery typically loses about

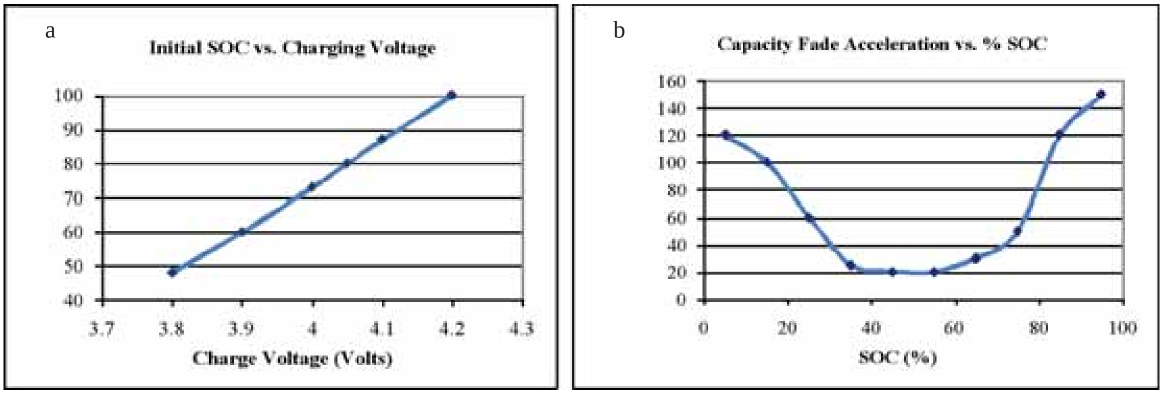


Fig. 1 (a). % SOC vs. charge voltage; (b) Capacity fade acceleration (ppm/10% SOC) vs. % SOC

20% of its initial capacity after about 200 to 1000 full cycles, also known as the 100% SOC (State of Charge) cycles. The cycle life can be greatly increased by reducing the SOC span, by avoiding complete discharges of the pack between recharging or full charging. Consequently, a significant increase is obtained in the total energy delivered, whereby the battery lasts longer. In addition, over-charging or over-discharging the pack also drastically reduces the battery lifetime.

A. Capacity Fade vs. SOC

In order to estimate capacity fade over cycle life, the capacity fade acceleration per cycle vs. state of charge (SOC) is introduced in Fig. 1(b). This plot is based on the tests performed in [8]-[11]. The integral of capacity fade acceleration, starting from the initial to the final SOC, will give the permanent capacity fade per cycle, in ppm. The high values of capacity fade acceleration near the complete charge and discharge represent the higher damage of the cell when operated close to those regions.

In the context of this paper, 100% SOC is the state of a cell after being fully charged at 4.2V per cell, and 0% SOC corresponds to the state of a fully discharged cell (3V per cell). The capacity during the first few cycles, from 100% to 0% SOC, is termed as C. Cycle life is the amount of cycles after the cell loses 20% from initial C. Furthermore, if the charging voltage is lower than 4.2V, the available energy will be reduced. This can be expressed as a reduction in %SOC at the end of the charge cycle (i.e. the beginning of the discharge cycle), as shown in Fig. 1(a), which is extrapolated from tests performed in [7] and [8].

Given a certain charging voltage, the initial %SOC can be obtained from Fig. 1(a). Thereafter, the curve in Fig. 1(b) is integrated between this initial %SOC and the final %SOC per cycle (obtained from an estimator algorithm), which represents the accumulated permanent capacity fade per cycle, in ppm. It is important to note that the plots in Fig. 1 are obtained by extrapolating cycle life tests and depict a general trend in the capacity fade acceleration per cycle vs. %SOC.

Some interesting facts can be deduced from Figs. 1(a) and 1(b). First of all, they reveal the fact that a much better cycle life can be obtained by charging at about 4.05V (80% SOC) and discharging to 30% SOC, completing a total of 50% SOC (half the initial capacity), whereby a notable 1400 cycles could be completed, before losing 20% of the initial capacity. Moreover, the total lifetime capacity that can be delivered would be 700 C (initial, 1 cycle capacity) vs. 300 C, which represents more than twice the total power and almost five times the cycle life. This fact is well known in satellite applications and in the Mars Rover Project, where battery lifetime is critical [8], [12]-[13]. Furthermore, additional improvements in the cycle life can be achieved using even lower SOC swing.

B. Economical Analysis

Due to the uniformity created by cell voltage equalizers, SOC would tend to be equal in all cells. Thus, the equalized battery pack will tend have cycle life of the average capacity cell, instead of that of the lower capacity cell. Furthermore, several combinations of SOC utilization and battery capacities can be achieved, in order to obtain about 30/50 miles autonomy in HEVs, which could be without doubt, extended to recently proposed PHEV applications. Table 1 can be obtained assuming that the cost of a lithium battery is in the range of \$300/kWh, electricity costs about \$0.1/kWh, the cost of an adequate equalizer is about \$1000, and the average cost of gasoline is \$3.5/gallon. From Table 1, it is evident that only the smallest cycle battery with a suitable equalizer (last column), has a payback mileage equal to the lifetime of the battery. When gasoline becomes even more expensive, coupled with government-aided programs and improvements in battery cycle life, substantial improvement in payback mileage could be experienced.

Another key conclusion could be that, for batteries with a long string of cells, individual cell voltage monitoring would be needed. In fact if, during one of the charge or discharge cycles, the battery is pushed close to 0% or 100% SOC, there could be few cells in an over charge or under-voltage situation, even though the total voltage is within the limits. As stated earlier, in order to maintain the safety of the pack, individual voltage monitoring becomes an absolute necessity. In the next section, popular battery cell voltage equalizer topologies will be analyzed in detail and an advanced multi-cell equalizer design will also be introduced.

III. OPERATIONAL CHARACTERISTICS OF CLASSIC AND ADVANCED MULTI-CELL VOLTAGE EQUALIZERS

A battery cell voltage equalizer is an electronic controller which takes active measures to equalize the voltage in each cell. In addition, by some more complex methods, such as measuring the actual capacity and internal resistance of each cell, it equalizes the SOC of each cell. As a result, each of the cells will have the same SOC during charging and discharging, even in conditions of high dispersion in capacity and internal resistance. This causes each cell of the pack to act as an average cell. In the example presented in the previous section, instead of 282 cycles, the pack would last 602 cycles, an increment of more than 100% in the cycle life. For the same application, the requirement of current though the equalizer at a discharge of 50A, over a 100Ah pack, would be 6A drain/source, over the extreme capacity cells (the ones with bigger and smaller capacity), and a total transferred power of 350W (in the entire chain), over the complete charging/discharging time. In addition to the increment in cycle time, depending on the internal resistance of each cell, the equalizer also has the potential to improve the output power. This requires a detailed analysis of the internal resistance vs. SOC, in order to have precise improvement. In the following analyses of various equalizers, it will be realized that only a few of them are capable of accomplishing this requirement.

In principle, there exist 3 basic families of equalizers; resistive, capacitive, and inductive. Resistive equalizers have inherent heating problems, because they tend to have low equalizing currents in the range of 300-500mA, and work only in the final stages of charging and flotation. On the other hand, the main drawback of capacitive equalizers is that they cannot control inrush currents, when big differences in cell voltages exist. Finally, inductive or transformer based equalizers use an inductor to transfer energy from the higher voltage cell to the lower voltage cell. In fact, this is the most popular family of high-end equalizers, and because of its capability to fulfill most of the needs expressed above, it is explored in more detail in the forthcoming sections of this paper.

A. Basic Inductive Equalizer

A basic inductive equalizer is shown in Fig. 2. These equalizers are relatively straightforward and can transport a large amount of ener-

Table 1. Payback mileage analysis of an HEV (with and without equalizer).

Battery Capacity	16	16	16	16	20	20	KWH
SOC usage	72	72	52	52	40	40	%
Autonomy	46	46	33	33	32	32	miles
Autonomy	74	74	54	54	52	52	km
Cycle life	280	600	900	1550	1600	2700	Cycles
Lifetime Battery	12902	27648	29952	51584	51200	86400	miles
Battery Cost	0.372	0.174	0.160	0.093	0.117	0.069	\$/mile
Battery + Elect. Cost	0.397	0.199	0.185	0.118	0.142	0.094	\$/mile
qualizer payback mileage	No eq.	5040	No eq.	14880	No eq.	20945	miles
Payback mileage vs. gas	No	No	No	101847	182857	86897	miles

gy. At the same time, they are also capable of handling more complex control schemes, such as current limitation and voltage difference control.

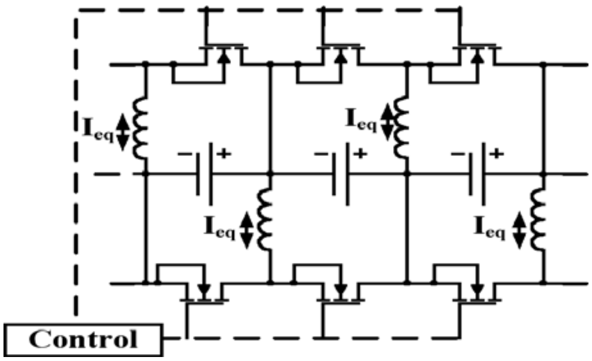


Fig. 2. Schematic representation of a typical inductive equalizer.

On the other hand, it takes some additional components to avoid current ripples from getting into the cell. Typically, this requires 2 switches (and control) per cell. Also, due to switching losses, the distribution of current tends to be highly concentrated in adjacent cells. Hence, a high-voltage cell will distribute the current largely among the adjacent cells, instead of equally in all cells. In this case, the switching scheme could be replaced by a more complex, global scheme, with the additional cost of more processing power.

B. Transformer Based Equalizer

The solutions provided by transformer-based equalizers permit the right current distribution along all cells. One such popular arrangement is depicted in Fig. 3.

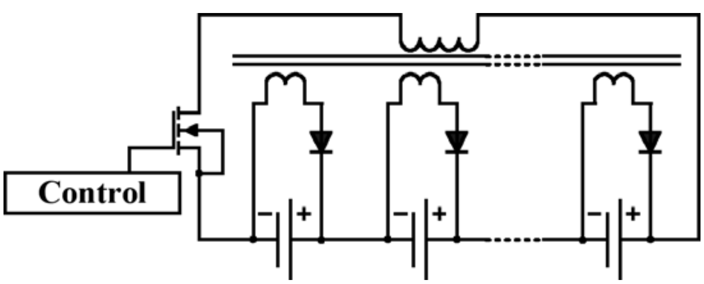


Fig. 3. Schematic representation of a multi-winding transformer equalizer.

This topology poses an additional issue of a very complex multi-winding transformer. This transformer is very difficult to mass produce, because all windings must have the compatible voltages and resistances. Hence, it is not a practical solution for high-count HEV cell packs, and moreover, it also lacks the capability of handling complex control algorithms such as current and voltage control.

C. Multi Cell Equalizer

Keeping the various drawbacks of classic cell equalizers in mind, a novel design of a multi-cell equalizer, more specific for HEV energy storage applications, is being explored. A simplified block diagram representation, that primarily highlights the basic principle of operation of a multi-cell equalizer topology, is shown in Fig. 4. This main advantage of this equalizer circuit is its capability to share current accurately. Furthermore, this equalizer has standard manufacturing requirements, which makes the overall design process uncomplicated. The only obvious drawback foreseen is the need for added processing power. The high current carrying capability and the possibility of advanced control based on instantaneous battery state of charge (SOC) estimation, makes this equalizer configuration highly attractive for EV/HEV energy storage applications.

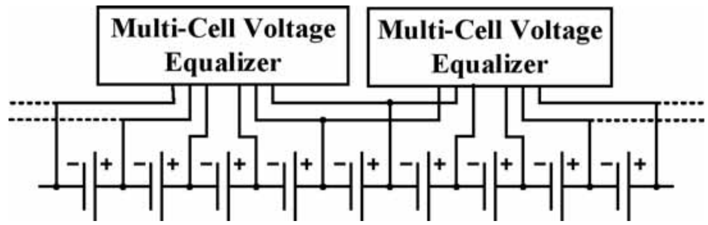


Fig. 4. Block diagram representation of a multi-cell equalizer.

From among the above described equalizers, both the inductive equalizer (with voltage control added processing power) and the transformer based equalizer, have the capability to maintain same voltage (or ideally, the same SOC) at any given time, under all load conditions or charging currents. Ideally, equalizer topologies with a low count of standard components are preferred, whereby it costs only a small fraction of the battery pack price. On the other hand, the transformer based solution has a complicated manufacturing process, and although the Cuk equalizer provides a superior outcome, it has a large component count, with unfeasible specifications, especially for use as an EV/HEV energy storage cell equalizer. Consequently, only the basic inductive configuration and the multi-cell configuration guarantee to meet the requirements of equal current distribution, high power capability, and low cost.

IV. CONCLUSIONS AND FUTURE WORK

Due the high price of EV/HEV battery packs, in the range of about $4000-$6000, the use of power electronics based cell voltage equalizers is highly imperative. This paper reviewed various popular topologies of existing as well as future cell equalizer topologies, and established the fact that an appropriately designed cell voltage equalizer is the key to improve overall on-board energy storage cycle life, which will eventually make HEVs more profitable than they already are.

It is found that the inductive cell voltage equalizers, along with complex control algorithms, fit the high current capability and equal power distribution requirements, needed to improve EV/HEV battery cycle life. Furthermore, the increased processing power can be useful to monitor other parameters related to safety, such as temperature, SOC, and internal resistance, thus reducing the overall safety risks to a minimum. In addition, meeting the overall cost targets seems fairly achievable, but a detailed economic analysis is needed before making a confident conclusion.

This paper also presented an advanced multi-cell equalizer topology, whose capabilities will be explored in depth, in the form of a novel design, as part of related future work. Additional experiments and demonstrations are essential, in order to add more mathematical precision to typical HEV battery cycle life models. Finally, supplementary improvements in battery lifetime, in conjunction with ever-increasing gas prices, will further accelerate the exploratory studies of possible solutions offered by HEVs, PHEVs, and EVs.

V. REFERENCES

[1] C. C. Chan, "An overview of electric vehicle technology," Proc. of the IEEE, vol. 81, no. 9, pp. 1202-1213, Sept. 1993.

[2] T. Markel and A. Simpson, "Energy storage systems considerations for grid-charged hybrid electric vehicles," in Proc. IEEE Vehicle Power and Propulsion Conf., Chicago, IL, Sept. 2005, pp. 344-349.

[3] R. P. Ramasamy, R. E. White, and B. N. Popov, "Calendar life performance of pouch lithium-ion cells," Journal of Power Sources, vol. 141, no. 2, pp. 298-306, Sept. 2004.
[4] M. Duvall, "Battery evaluation for plug-in hybrid electric vehicles," in Proc. IEEE Vehicle Power and Propulsion Conf., Chicago, IL, Sept. 2005, p. 338-343.
[5] M. Ehsani, A. Emadi, Y. Gao, and S. E. Gay, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design, CRC Press, Nov. 2004.
[6] Sheldon S. Williamson, "Electric drive train efficiency analysis based on varied energy storage system usage for plug-in hybrid electric vehicle applications," in Proc. IEEE Power Electronics Specialists Conf., June 2007, Orlando, FL, pp. 1515-1520.
[7] P. Ramadass, B. Haran, R. White, and B. Popov, "Performance study of commercial LiCoO2 and spinel-based Li-ion cells," Journal of Power Sources, vol. 111, no. 2, pp. 210-220, April 2002.
[8] J. W. Lee, Y. K. Anguchamy, and B. N. Popov, "Simulation of charge-discharge cycling of lithium-ion batteries under low-earth-orbit conditions," Journal of Power Sources, vol. 162, no. 2, pp. 1395-1400, July 2006.
[9] G. Ning, B. Haran, R. White, and B. Popov, "Cycle life evaluation of pouch lithium-ion battery," in Proc. 204th Meeting of the Electrochemical Society, Orlando, FL, Oct. 2003.
[10] P. Liu, K. Kirby, and E. Sherman, "Failure mechanism diagnosis of lithium-ion batteries," in Proc. 206th Meeting of the Electrochemical Society, Honolulu, Hawaii, Oct. 2004.
[11] K. A. Striebel, J. Shim, R. Kostecki, T. J. Richardson, P. N. Ross, X. Song, and G. V. Zhuang, "Characterization of high-power lithium-ion cells – performance and diagnostic analysis," Lawrence Berkeley National Laboratory, Berkeley, CA, Paper LBNL-54097, Nov. 2003.
[12] H. Croft, B. Staniewicz, M. C. Smart, and B. V. Ratnakumar, "Cycling and low temperature performance of lithium-ion cells," in Proc. IEEE 35th Intersociety Energy Conversion Engineering Conf. and Exhibit, Las Vegas, NV, July 2000, vol. 1, pp. 646-650.
[13] M. C. Smart, B. V. Ratnakumar, L. Whitcanack, S. Surampudi, J. Byers, and R. Marsh, "Performance characteristics of lithium-ion cells for NASA's Mars 2001 Lander application," IEEE Aerospace and Electronic Systems Magazine, vol. 14, no. 11, pp. 36-42, Nov. 1999.

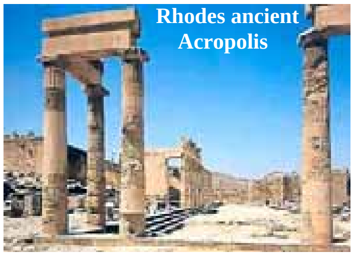

Rhodes the city of knights

PESC08

39th Power Electronics Specialists Conference
June 15-19, 2008
Island of Rhodes, Greece

PESC is an annual international conference providing a forum for research results, which advance fundamentals and principles of power electronics technologies. PESC includes: technical sessions, tutorials, and informal discussion sessions. Topics cover design, control, analysis, modeling, and simulation of power electronics systems, power converters, motor drive systems, power semiconductor devices and technologies, magnetic devices and materials, energy storage systems, emerging power electronic topologies, and all other aspects of the field. A highlight of this conference would be specially planed sessions showcasing state-of-the-art industrial applications including energy efficiency technologies.

The IEEE Power Electronics Specialist Conference for the year 2008 will take place in the island of Rhodes in Greece and will be co-sponsored by the National Technical University of Athens chaired by Dr. Stefanos Manias and Dr Vassilios Agelidis.


Rhodes ancient Acropolis

The island of Rhodes is considered to be one of the most popular summer resorts of Europe. Rhodes is gifted with unprecedented natural beauty, blessed with innumerable archaeological sites of unique value and pulsing with numerous non-identical settlements. The island of Rhodes is situated at the cross roads of two major sea routes of the Mediterranean between the Aegean Sea and the coast of the Middle East. The meeting point of three continents, it has known many civilizations.


Enjoy the Aegean sea and sky

The conference will be held at the Sofitel Capsis Hotel & Convention Center, a 5-star deluxe fully equipped resort hotel, located at the beachfront of the Ixia Bay, 5 minutes from the Medieval City of Rhodes and 15 minutes from the Rhodes International Airport.

Dr. Stefanos Manias
Tel: +30210-7723503, Fax: +30210-77503
Email: manias@central.ntua.gr

Dr. Vassilios Agelidis
Tel: +61-8-9360-7108, Fax: +61-8-9360-7104
Email: v.agelidis@ieee.org

APEC 2008 Breaks Records – Again

The 22nd Annual Conference and Exhibition continues unbroken record for growth and leadership

Greg Evans, WelComm, Inc

APEC Publicity Chairman

APEC is, without doubt, the leading conference held in North America for practicing power electronics professionals. The annual APEC program addresses a broad range of topics in the use, design, manufacture and marketing of all kinds of power electronics equipment. The combination of high quality Professional Education Seminars, a full program of refereed papers and an overflowing Exhibit Hall consistently provides an invaluable education each year. The value of APEC to working power electronics professional is shown by the ever growing number of participants that attend each year. And once again this year, APEC 2008 has broken records for attendance.

The APEC2008 Plenary Session covered diverse topics to a capacity crowd

I asked Steve Pekarek, General Chairman of APEC2008 for his thoughts on the conference. Here is what Steve had to say: "While searching for information on the city, I found the following quote describing Austin, TX, 'It's hip and trendy, yet in a vintage sort of way. It's high-tech and laid-back. It's politically charged and culturally rich. It's eclectic by nature and creative by design. Most of all, it's a place where people like to have a good time.' Upon reading, my first instinct was that someone on the APEC 2008 Conference Committee had infiltrated the Austin Visitor Center and was using a description of APEC to portray the host city. O.K – perhaps the comment on 'politically charged/culturally rich' does not provide an accurate view of APEC - but the remaining statements appear to be an accurate description of the conference.

The APEC2008 Exhibits were filled with the products and packed with visitors

"Indeed the 23rd annual IEEE Applied Power Electronics Conference and Exposition was hip and trendy," Steve continued. "Attendance was at record levels – 2698 people from 37 countries. The plenary covered current topics on the minds of many power electronics professionals – the latest in energy efficiency standards, server power demands, plug-in hybrid vehicles, new advances in electric drives, new developments in intellectual property law, and power electronics for ulta-portable applications. The Rap Sessions, 'Efficiency: Long-Term Need or the Latest Fad?' and 'Patents: Are they Worth the Trouble?' were charged and rich in substance."

Kevin Parmenter, APEC 2009 General Chairman asks a question at one of this year's Rap Sessions

"The Technical Sessions, Professional Education Seminars, and OEM Special Presentation Sessions were vintage APEC – diverse topics, strong technical content delivered by authors from all over the world presenting their latest views and findings from industry, government, and academia. Those hungry for high-tech were not disappointed. And this year's Exposition provided ample fare to satisfy the most discriminating palate. A record number (200) of exhibitor booths displayed the latest innovations from over 143 companies."

Steve Pekarek, APEC 2008 General Chairman accepts Kevin Parmenter's thanks for a job well done

Now the leadership mantle for APEC 2009 has been passed on to Kevin Parmenter. Preliminary work is already underway to sustain the energy and growth of the conference as it moves to Washington, DC, February 15-19, 2009. A "Call for Participation" will soon be posted on the website. For more information, please go to: www.apec-conf.com.

Power Electronics System Integration - A CPES Perspective

Fred C. Lee, Dushan Boroyevich, J. Daan van Wyk, Khai Ngo, Guo-Quan Lu, Elaine P. Scott, Ming Xu, and Fred Wang, Virginia Tech, Blacksburg, VA;
Thomas M. Jahns, Thomas A. Lipo, Robert D. Lorenz, University of Wisconsin-Madison, Madison, WI;
T. Paul Chow, Rensselaer Polytechnic Institute, Troy, NY;
Center for Power Electronics Systems (CPES), USA

Abstract

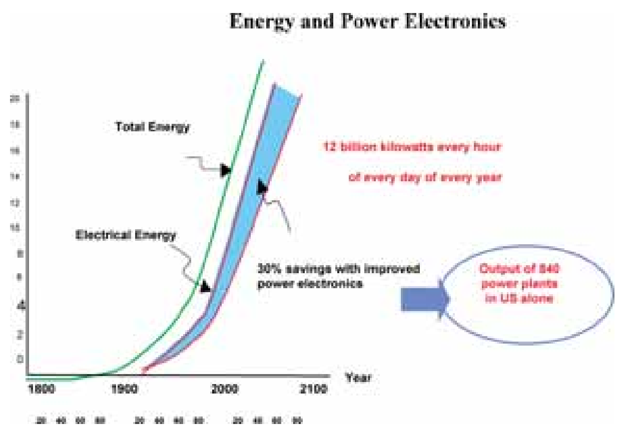
Center for Power Electronics Systems (CPES) was established in 1998 with the mission to develop advanced electronic power conversion technologies for efficient future electric energy utilization through multidisciplinary engineering research and education. The CPES vision is to enable dramatic improvements in the performance, reliability, and cost-effectiveness of electric energy processing systems by developing an integrated system approach via integrated power electronics modules (IPEMs). The IPEM-based system solutions address, concurrently, the integration of active and passive components, packaging materials, interconnect structures, electromagnetic compatibility and electromagnetic interference, thermal management, numerous application considerations. This paper provides only a highlight of some selected areas of research, excerpted from the Center's Annual Report.

Energy and Power Electronics

Throughout the world, electricity is used at an average rate of 40 billion kilowatt-hours every day of every year. With few exceptions, much of the electricity is not used in the form in which it was initially produced. Power electronics is the engineering discipline utilized to convert electrical power from one form to another. Power electronics and related power processing technologies constitute an "enabling infrastructure technology" with a significant potential impact on U.S. industrial competitiveness. This is manifested through the increased energy efficiency of equipment and processes using electrical power, and through higher industrial productivity and higher product quality, which results from the ability to precisely control the electrical power for manufacturing operations. Sales of power electronics equipment exceed $60 billion each year, and, more importantly, it supports another $2 trillion in hardware/software electronics. With the widespread use of cost-effective and energy-efficient power electronics technology, the U.S. would be able to reduce its electrical energy consumption by 33%. The amount of energy savings, by today's measure, is equivalent to the total output of 840 fossil fuel-based power plants. This will result in enormous economic, environmental, and social benefits.

The Center for Power Electronics Systems (CPES) was established as a National Science Foundation Engineering Research Center (NSF ERC) in 1998 with a consortium of 5 universities, and over 80 industry partners. The Center's mission is to develop advanced electronic power conversion technologies for efficient electric energy utilization through multidisciplinary engineering research and education in the field of power electronics. The research vision is "to

"This work was supported primarily by the Engineering Research Center Program of the US National Science Foundation under NSF Award Number EEC-9731677 and the CPES Industry Partnership Program. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation."



enable dramatic improvements in the performance, reliability, and cost-effectiveness of electric energy processing systems by developing an integrated system approach via integrated power electronics modules (IPEM)".

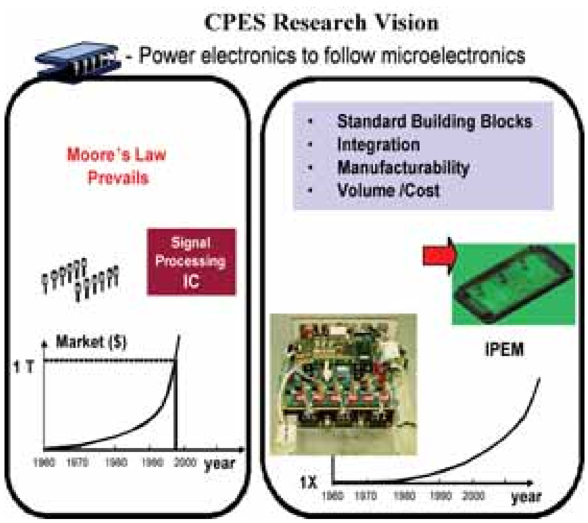
The State-of-The–Health of Power Electronics Industry

With a long design cycle, today's power electronics equipment is designed and manufactured using non-standard parts. Thus, manufacturing processes are labor-intensive, resulting in high cost and poor reliability. The current practice has significantly weakened the U.S. power electronics industry in recent years. In the 1980s, power electronics was considered as a core enabling technology for all the major corporations in the U.S. In the 1990s, the major corporations adopted an outsourcing strategy and spun off their power electronics divisions. What had been a captive market was transformed into a merchant market. Fewer resources were available to devote to technical advancement in power electronics. Consequently, innovative solutions were scarce. Products became commoditized and cost-driven. The result was the increased mass migration of manufacturing to low-labor cost countries. The problem is further compounded by the more recent trend of outsourcing engineering to India and Asian countries, especially China. Today, most of U.S. industry is bottom-line focused and spends little in R&D, mostly in development rather than in research.

CPES Systems Vision

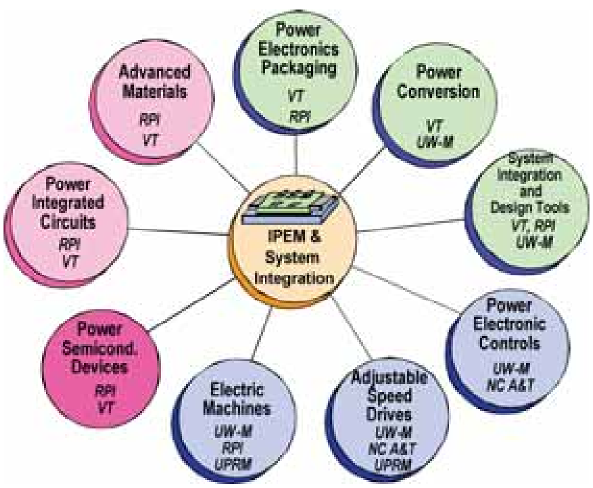
In order to bridge this gap between the increasing societal energy needs and the decreasing industrial capability to innovate, the Center for Power Electronics Systems (CPES) was established with the research vision *"to develop an integrated system approach via integrated power electronics modules (IPEMs) to enable dramatic improvements in the performance, reliability, and cost- effectiveness of electric energy processing systems."* The envisioned integrated power electronics solution is based on advanced packaging of new


EXACTING PROTECTION...
SUPERIOR PERFORMANCE
CKE
Z320EH6
Z150LA10A
Z60M911
Z60M472
MOVS
CKE manufactures a wide range of metal oxide varistors (MOVs) for your unique requirements. From low voltage radial lead styles to high energy packages, we build to OEM specs or provide direct replacements.
CKE also offers:
Selenium Surge Suppressors
Silicon Rectifiers
Custom Assemblies
Silicon Carbide Varistors
CKE
Lucernemines, PA 15754
(724) 479-3533
(724) 479-3537 FAX
e-mail: info@cke.com
www.cke.com
Diodes
1 kV to 600 kV
Fast Recovery down to 35nS
Average Forward Current up to 10 Amps
HVCA diodes are ideal for use in high voltage power supplies, medical equipment, instrumentation, satellites, control systems, voltage multipliers and military applications. Typical recovery times of 75nS or faster.
HVCA
P.O. Box 848,
Farmingdale, NJ 07727
(732) 938-4499 (732) 938-4451 FAX
e-mail: info@hvca.com
www.hvca.com
HVCA
DEAN TECHNOLOGY
CKE and HVCA are divisions of Dean Technology



generation of devices and innovative circuits and functions in the form of building blocks with integrated functionality, standardized interfaces, suitability for automated manufacturing and mass production, and application versatility, namely IPEMs, and the integration of these building blocks into application-specific systems solutions. The impact of this paradigm shift can be compared to the impact realized via the improvements in very-large-scale integrated (VLSI) circuit technology that has enabled significant advancement in computer and telecommunications equipment.

The IPEM approach will make it possible to increase levels of integration of devices, circuits, sensors, and actuators into standardized manufacturable subassemblies and modules that, in term, are customized for a particular application. Opportunities for new applications, dismissed in the past because of high cost, will for the first time, be practical due to the economy of scale and will unearth a large new market.



Center's Inter-disciplinary Research Focus

To realize the IPEM based system integration vision, CPES was created in 1998 as a broad based industry/university coalition funded under the National Science Foundation Engineering Research Center (NSF ERC) Program. The Center includes five universities with complementary expertise, and 80 major corporations. Strong interactions among the various activities at the five institutions and the Center's affiliate industries exist throughout the Center's research activities. At Virginia Tech, the research is focused on high-frequency power conversion devices and circuit technologies, high-density electronics packaging, and system integration. At Wisconsin-Madison, the research is focused on industrial and utility-grade power conversion, the integrated design for an electric machine, power electronics drives, and controls. At RPI, the research is focused on novel discrete power semiconductor devices and IC technologies, including those based on new semiconductor materials at the generic component level. North Carolina A&T State University's expertise lies in the area of non-linear control, neural network and fuzzy logic. University of Puerto Rico-Mayaguez's expertise lies in power electronics control and electric machines.

CPES's research program adopts the "integrated power electronics modules (IPEM)" approach and includes three major areas: 1) Fundamental Knowledge centers on development of advanced power semiconductors, integratable materials, high-density integration, thermal-mechanical integration, and control and sensor integration; 2) The Enabling Technology is focused on the IPEM design and synthesis techniques encompassing active IPEM, passive IPEM, filter IPEM, IPEM synthesis, and two small testbeds. One is the integrated power supply with load such as the microprocessor, the other is integrated modular motor drives; 3) The Engineered Systems is designed to demonstrate the IPEM-based system integration concept to a wide range of distributed power systems, motor drives and others applications.

These applied research projects are complemented by a substantial level of additional support from other application-oriented projects sponsored by industry and other government agencies.

Each thrust has established close collaboration with a number of industry partners serving as research champions for the technology development and testbed. The industry partners not only serve as mentors in their technology development activities, they also directly support and facilitate technology transfer.

Integrated System Approach via IPEM

Improvements in energy conservation and associated environmental impact cannot be accomplished without a significant paradigm shift in power electronics technology. The required dramatic improvements in the performance, reliability, and cost-effectiveness of electric energy processing systems could only be achieved by developing an integrated system approach based on advanced packaging of new generations of semiconductor devices and innovative circuits in the form of building blocks with integrated functionality, standardized interfaces, suitability for mass production, and application versatility.

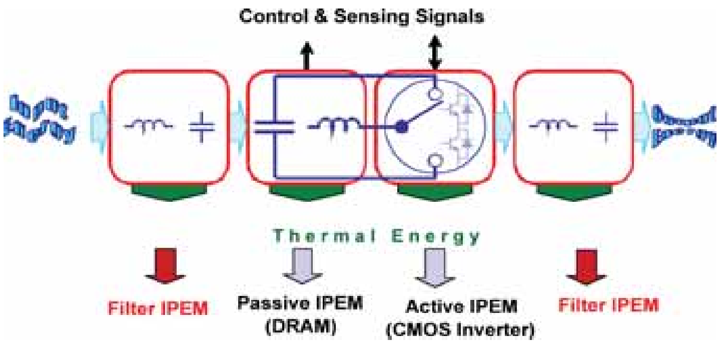
The fundamental functions needed in a power electronics system include:

1) Switching elements to regulate the flow of energy;

2) Electromagnetic energy storage and transformation to allow for proper functioning of switching, control and filtering;
3) Control to execute all operations correctly, both spatially and temporally;
4) Thermal management to assured thermal stability and operation at the correct temperatures; and
5) Mechanical/structural stability of components, modules and total assembly to ensure appropriate operation and lifetime/reliability

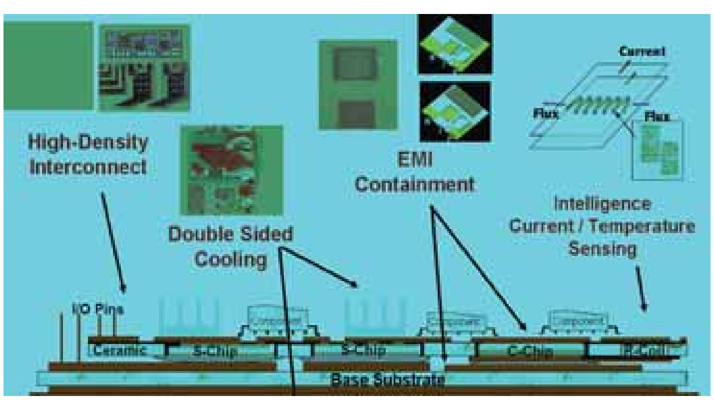
An analysis of the partitioning in terms of functionality in energy processing systems, an analogous type of partitioning leads to a standard switching cell used for the PWM waveform synthesis function referred to as active IPEM, and standard cells for integrating the electromagnetic passive functions as passive IPEM and EMI filter IPEM.

Function partitioning into cells for electronic energy processing



Active IPEM:

CPES has successfully implemented Embedded Power to succeed the previously used Flip-Chip-on-Flex technology to develop an active IPEM for motor drive and power supplies application. Several CPES technology advances are being incorporated into the active IPEM design. Embedded power technology has been adopted to eliminate all wire bonds in favor of a planar interconnection scheme that minimizes dangerous voltage transients caused by undesired parasitic inductances. In addition, the flat upper surface is valuable for mounting gate drives, sensors, and cooling components to extract extra heat from the top side of the module. Such advances contribute to reducing the module size while increasing its long-term robustness. This technology also provides valuable opportunities for combining active gate drive including adjustable dv/dt control and self-boost charge pump for the high-side gate drive power supply, and isolated GMR sensors for combined current and thermal sensing. These features will result in higher power module robustness and reliability that are key attributes desired by both the manufacturers and users of these modules.



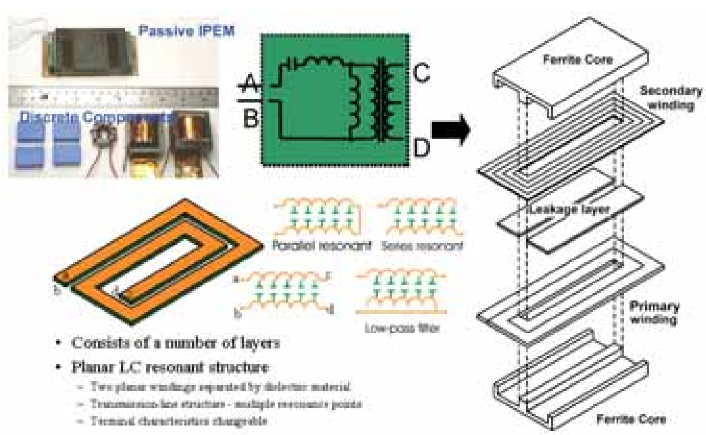
Passive IPEM:

CPES researchers have developed technology for integrating electromagnetic power passives. This passive IPEM replaces the functions of discrete capacitors, inductors, and power transformers. The passive integration is built upon multi-layer, three-dimensional structures utilizing materials with different properties such as high permeability, high dielectric constant, and high conductivity, in order to achieve integrated multi-functional properties. Functional and process integration with improved thermal management was successfully demonstrated in the lab for the first time. The original breakthrough of integrating electromagnetic power passives containing inductors, capacitors, and transformers has led to the developed CPES technology for passive IPEMs and EMI filter IPEMs. In order for this technology to be commercialized, a long-term reliability study of integrated passive IPEMs should be thoroughly conducted before final deployment in the form of a commercial product.

EMI Filter IPEM:

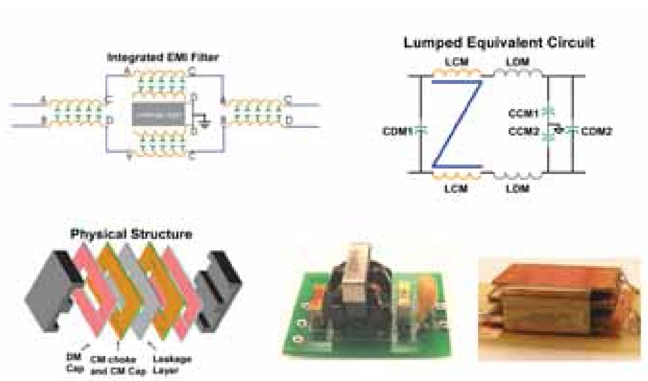
The CPES team continued with the new research program on integrated EMI filters as passive IPEMs. EMI filter design is critical for power electronics equipment to be in compliance with the EMI/EMC standard. A good filter design is to realize high frequency attenuation effectively. Such a design is often achieved empirically, with good common sense, and deemed, by and large, as an art rather than science. It is well known that the filter parasitics are detrimental to its ability to attenuate high frequency noises. While reduction of certain critical parasitics such as, parasitic inductance of filter capacitors and certain mutual couplings can be realized relatively easily in the conventional discrete filter design practice, reduction of the winding capacitors of the inductor can best be implemented in an integrated filter design. The internal electromagnetic parameters in the three-dimensional structure can be controlled to enhance the attenuation of high frequency noise.

This is done through the use of different interleaved materials and a three-dimensional geometrical configuration in order to cancel the undesired electrical field coupling to achieve near ideal behavior in the frequency band of interest. These properties cannot be achieved by construction techniques with discrete components. The integrated EMI filters have been demonstrated to be superior to their discrete counterparts in terms of filter behavior, profile and power density.



IPEM Development and Commercialization

Over the past 15 years, CPES has been leading the development of the IPEM building block concept for a wide range of system appli-



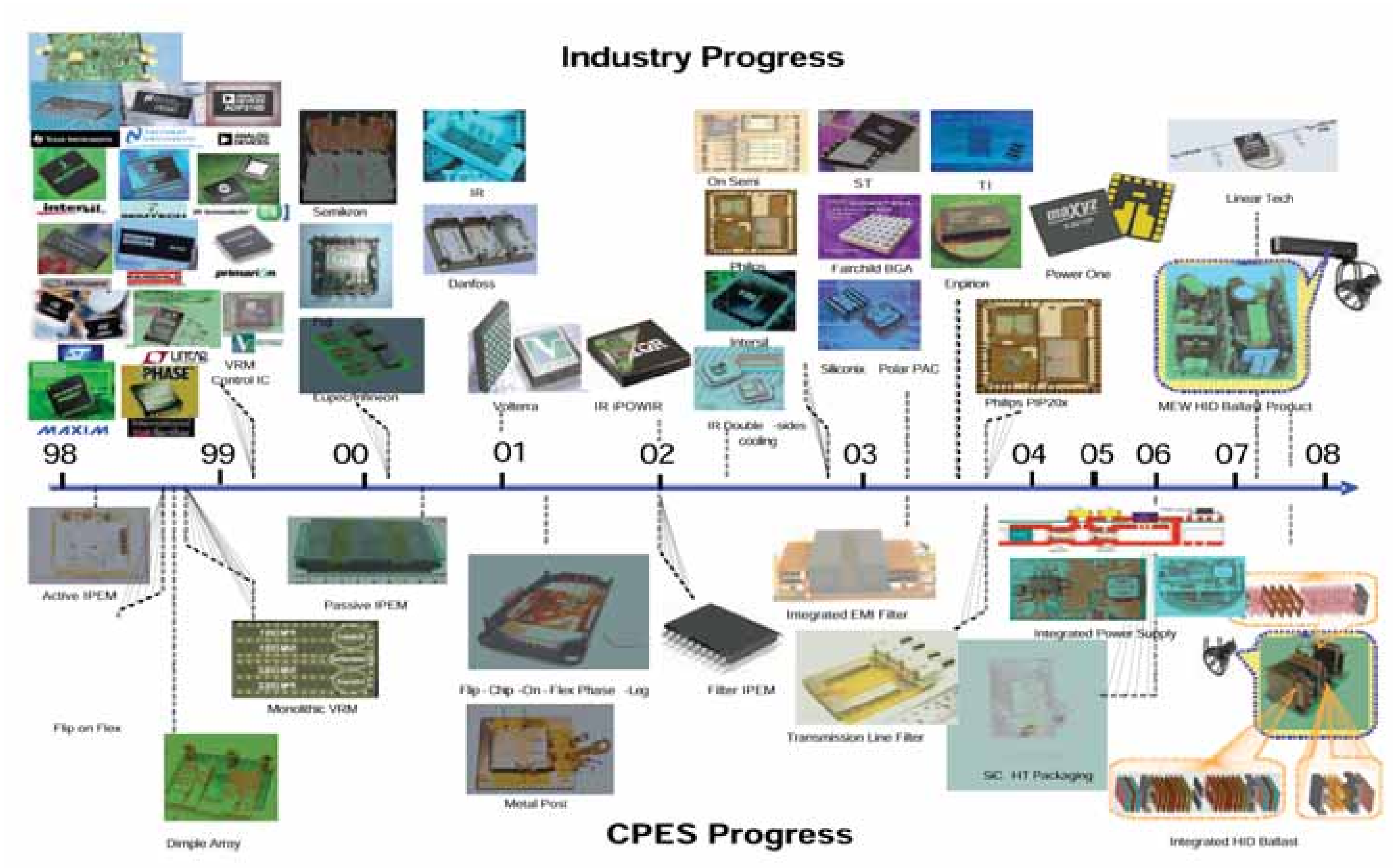
cations, from portable hand-held equipment to transportation systems. In addition to $30 million grants from NSF, a similar level of funding was secured from other federal agencies such as ONR, Army, Navy, DARPA and major industrial corporations and partners. While, the NSF ERC sponsored research focused on the 1-10 kW range, the lower power applications have been mainly supported through the industry-funded Power Management Mini-Consortium (PMC). The development of the IPEM concept for the medium and high power applications was championed by ONR and the aerospace and defense industries as the Power Electronics Building Blocks (PEBB) approach.

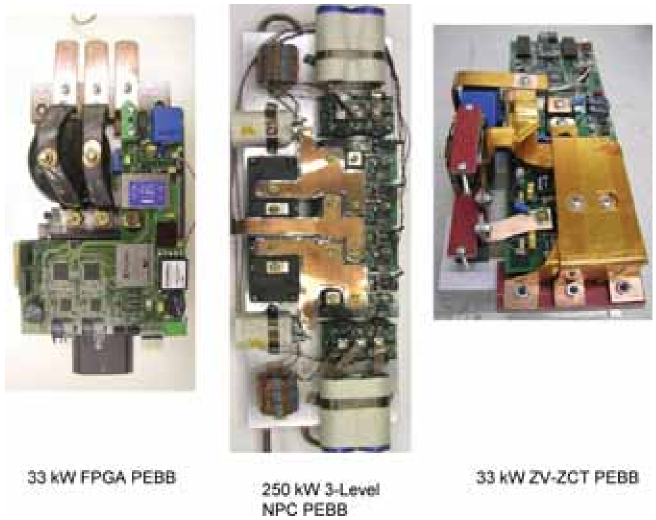
The aforementioned IPEM-based system integration vision has been demonstrated by the CPES research team with successful technology transfer in a number of areas, such as distributed power systems for computers and communication equipment, and motor drives. In the motor drives industry, although the concept of intelligent power modules (IPMs) started in parallel with PEBB and IPEM development, the widespread use of IPMs only began in recent years. Major industry leaders, including Toshiba, Mitsubishi, Siemens, ABB, Fuji, IR, Semikron and Powerex have introduced IPEM products. Today, more than 40% of appliances are using module-based inverter drives in Japan.

The power supply industry has also aggressively pursued standardization, modularization and integration. For example, the multiphase voltage regulator module proposed by CPES in early 1997, has been adopted by the industry as the standard industry solution for powering microprocessors as well as many other applications that require point-of-load power supplies. All major semiconductor companies have participated in development and commercialization of this technology and have offered new products.

CPES strongly supported from the mid 1990s the Power Electronics Building Block (PEBB) and later the Advanced Electrical Power Systems (AEPS) Office of Naval Research (ONR) programs, under which it developed numerous PEBB-based power electronics conversion systems demonstrating the advanced capabilities attainable by using a modular approach to high power electronics. Always focusing on marine applications for future NAVY more-electric ships, high power PEBB modules were developed at CPES ranging from tens to hundreds of kilowatts, exploring alternative PEBB topologies, soft and hard commutation techniques, control architectures, choice of semiconductor and passive devices, and most importantly the functional and temporal partitioning of PEBB modules. The latter work proved essential in determining the structure of PEBBs and what components should be functionally integrated into the modules, since at these higher power ratings monolithic integration was utterly unfeasible, and only a discrete approach could be used.

The validity of the modular approach embodied by the PEBB conceptæsharing CPES' own system-level vision embodied by the IPEMæhas been proven by one of the leaders of the electric power



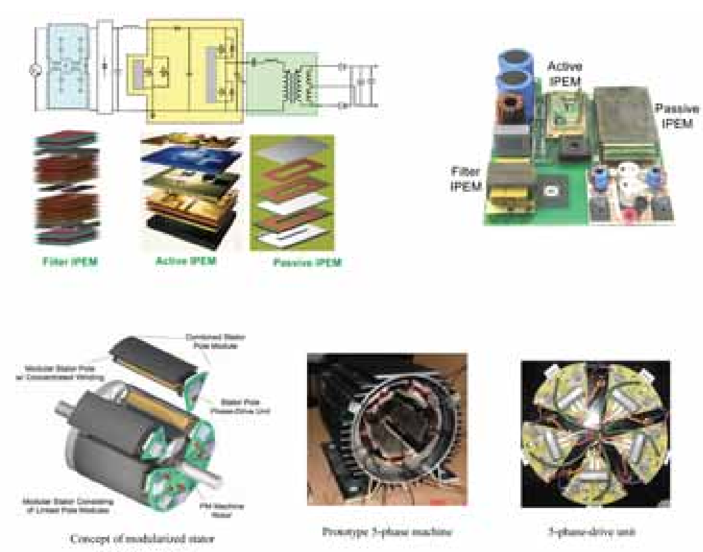


industry, ABB, who also in close cooperation with ONR has extended PEBB modules into the multi megawatt range, employing them in the most diverse range of marine and industrial applications.

Integrated Modular Power Supplies

In 2003, CPES successfully demonstrated for the first time a fully functional integrated 1 kW front-end converter for computer servers with over 75% of the energy processing functions integrated into IPEMs. The breakthrough was enabled by the CPES research that led to the development of active IPEM, where power semiconductor devices and electronic switching components are integrated using embedded power technology; passive IPEM that integrates the energy storage inductors, capacitors and power transformers; and filter IPEM for electromagnetic interference attenuation and power frequency propagation, which had been first reported to demonstrate superior characteristics and performance. All these modules could be constructed using multi-layer laminated structures suitable for automation.

The success is a result of the Center's multidisciplinary team working together to address the intertwined issues of high-frequency power conversion, semiconductor devices, advanced materials, and electro-magneto- thermo-mechanical integration. This paves the way for a complete paradigm shift in the electronic control of electrical energy to supply the needs for the very existence of our society.



Integrated Modular Motor Drive

A new motor drive architecture has been defined that offers promising long-term opportunities for reduced cost and increased reliability by emphasizing modularity and integration of the drive components. The motor is constructed from a number of modular phase-drive units that are interconnected in a ring to form the electrical core of the motor. Each of these phase-drive units includes both the iron pole piece with its winding and an electronic IPEM module that is attached to the end of the pole piece inside the motor housing. The resulting integrated motor-converter eliminates the need for a separate drive electronics box as well as the wires and connectors between the motor and the electronics.

Modular phase-drive units can be implemented as active IPEMs with integrated current and temperature sensors, offering opportunities for standardization and high-volume production to reduce future drive costs. The risk of short circuits between windings is dramatically reduced since the windings no longer overlap each other, minimizing any direct contact between the phase windings. In addition, the modularity makes it possible to design the motor drive to continue operating when one or more of the phase-drive units fails, improving overall drive reliability.

Future Expanded Vision

In preparation for the Center's continued multi-university collaboration post ERC, the Center was charged by NSF and the Center's industry partners to expand its vision by "providing leadership through global collaborative research and education for creative electronic power processing systems of the highest value to society" emphasizing both the technical focus as well as its long-term impact on society. CPES is further challenged to continue the realization of the IPEM concept for power electronics systems integration to a wide range of next-generation of energy efficient and environmentally friendly applications. To realize this grand vision, it is imperative that the Center maintain the multi-university, multidisciplinary collaboration and the integrated power electronics system curriculum across partner campuses, including the curriculum cross-listing, distance delivery, and exchange.

In order for CPES to maintain the core competence essential for its multidisciplinary research and for providing integrated power electronics solutions, the previous research structure has been consolidated into a new four-thrust structure: 1) integrated motor drive systems; 2) integrated power conversion systems; 3) semiconductor devices and power integrated circuits; and 4) material, packaging and thermal management. Technology focuses common to all four research thrusts are identified: 1) high-temperature electronics, 2) EMI and compatibility, and 3) energy efficiency and power management. The total program is structured in a manner to facilitate exploration of new research initiatives with the emphasis on green energy and green IT products. The new structure preserves the core competence established through the NSF-ERC program. With committed Center faculty and with talented and diverse students, we will strive to invent the future.

ACKNOWLEDGEMENT

This paper represents only a brief excerpt of the tenth and final year's annual report under the NSF-ERC program. This report is under preparation at the present time and is intended to capture the very essence of its ten years' progress, culminated by more than thirty faculty members and hundreds of graduate and undergraduate students. CPES was created under the NSF-ERC program with more than $30M in funding over the past ten years and with additional $30M matching funds from the institutional support and various research sponsors. Financial support and technical engagement and mentorship from the Center's industry partners throughout the years have been exceptional and the Center was cited as a model ERC for its industry collaboration and Technology Transfer program.

Redundant Power Supplies – Considerations When Paralleling Power Supply Outputs for Redundancy

Acopian Contact: Alex Karapetian
(610) 258-6149
E-mail: alex@acopian.com
Website: www.acopian.com

Easton, PA – February 28, 2008 - Although the extremely high overall reliability that can be attained with redundancy is widely recognized, implementing redundancy is not always as easy as it may first appear to be. In particular, it takes more than simply paralleling the outputs of two or more power supplies to have a redundant power system that will function as intended.

An isolation diode must be used in series with the output of each power supply, for two reasons - to avoid the possibility of the combined output being shorted by a shorted supply, and to prevent current from one supply flowing back into another and reverse biasing it (which could cause it to malfunction). However, the use of diodes introduces a significant voltage drop in the output voltage from the supply; for example, a 5 volt output might drop to only 4 volts. Using Schottky diodes can in some cases mitigate the diode drop, but it must still be considered. And keep in mind that the supply must be capable of providing a voltage equal to the sum of the voltage required across the load, the diode drop AND the drops in the wiring. A typical power supply can compensate up to a volt or so of drops in the wiring, but may not be capable of compensating BOTH the wiring and the diode drops. And if you're using remote sensing to regulate the voltage across the load, you might not be able to solve this problem by simply stepping up to a supply with a higher nominal output voltage (for example, going from a 5 volt supply to a 6 volt supply), because then the sense lines of that supply would try to maintain a nominal 6 volts across the load! In summary, be sure to use a supply that can put out a voltage high enough to compensate both the diode and wiring drops under worst-case conditions (usually, low line and maximum load current), and also has the desired load voltage within its adjustment range.

Monitoring each power supply's output is also very important. Otherwise, you might not even know that one power supply is out until the other goes, and then it's too late – you're down! Voltmeters are helpful, of course, but they don't command your attention. An audible alarm can't be easily ignored. Include an undervoltage alarm circuit for each power supply, and use them to control an audible alarm, either built-in or remotely located where it will be heard.

Power supplies don't always go low when they fail; the voltage can instead go high – by 50% or more in some cases – and fry the load. Therefore, it's vitally important that power supplies used in redundant applications should always be equipped with fast-acting overvoltage protection to assure that the output voltage can't go much higher than the nominal.

Replacing an inoperative power supply while the system remains in operation requires that each power supply have a separate AC input switch, so that the inoperative supply's wiring can be deactivated without affecting the other(s). Similarly, it must be possible to disconnect the inoperative supply and connect the replacement quickly and easily, so insulated connectors that can be easily pulled apart should be used in the wiring to each supply. And the supplies should be mounted in such a way that they can be easily and quickly removed and replaced. One way of doing this is to use thumbscrews for mounting; this also eliminates the need for tools.

Comprehensively addressing all of these considerations can be a lot of work. However, you don't need to do it yourself. Acopian's standard Redundant Systems meet all of these requirements, and are available with outputs from 5 to 125 VDC and in a choice of mechanical configurations (rack mounting, wall mounting and modular systems that can be mounted on a DIN rail).

www.acopian.com http://www.acopian.com/single-redundant.html

About Acopian Products

Acopian is a global supplier of AC-DC power supplies, DC-DC converters; & redundant & multiple-output power systems. Capabilities include shipping most models within 3 days and redundant and multiple output systems in 9 days. Standard power supplies are available in all voltages from 0v to 30 kV and up to 1200W. Standard models include single, dual, triple and wide adjust output power supplies; switching, linear, regulated & unregulated power supplies; programmable, high voltage, universal input & mini power supplies; & NEMA 4X Enclosed & UL508 listed configurations. Redundant and multiple-output power systems are available for rack, wall or DIN rail mounting and in modular configurations. Customized solutions are also available to meet special customer requirements. Our products are made in the USA.

Combined Thermal and Electrical Simulation of Power Electronic Systems with PLECS

Wolfgang Hammer, Plexim GmbH

Introduction

Power eletronic systems are today so ubiquitous that practically every industry has its own design centers to exploit it: the automobile, aeronautics, medical domestic-appliance, energy management, renewable energy industries etc., which has led to the need to develop and evaluate new circuits and concepts quickly and efficiently. An important design aspect—and becoming more critical with increasing demands for power density and efficiency—is the proper estimation of the power dissipation and junction temperatures in the semiconductors.

Estimating Semiconductor Losses

The conventional (and seemingly straightforward) method for computing the losses dissipated by a power semiconductor is to model the device in as much detail as possible and then simply multiplying device current and voltage drop. However, this approach has serious drawbacks:

1. For accurate results the simulation should use physical device models requiring not only dedicated software but also knowledge of parameters (such as the device structures and doping profiles) that the device manufacturers will not usually divulge. Behavioral device models on the other hand are more readily available but are not very reliable when used for predicting losses.
2. A detailed simulation of the switching transients requires simulation time-steps in the order of micro- or even nanoseconds. On the other hand, the thermal processes in the power electronic system have time constants as large as several minutes. This leads to prohibitively long simulation times.

Ideal Switches and Look-up Tables

PLECS therefore uses a different approach. In the electrical domain a semiconductor device is simplified as an ideal on/off switch. This reduces a switching transition to a single instantaneous event.

Before and after a switching transition, PLECS records the operating condition of the device (forward current, blocking voltage, device temperature) and uses these parameters to read the resulting dissipated energy of the considered device from three-dimensional look-up tables. During the on-state, the dissipated power is computed from the device current and temperature. The required data tables are entered via the visual editor integrated into PLECS (see Fig. 1).

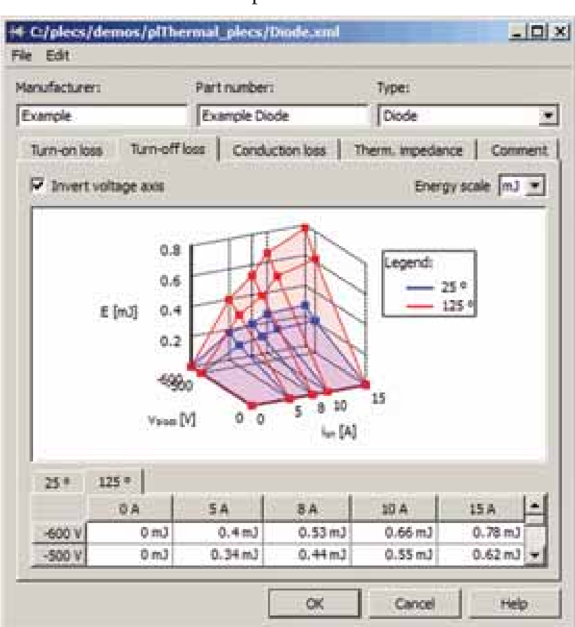


Figure 1. Screenshot of the thermal editor

This method of combining idealized waveforms with detailed device data-sheets is well known and has been shown to produce reliable results [1]. Up to now it was commonly implemented as a post-processing stage after the simulation of the electrical system with user-written tools e.g. in Excel or Matlab—an approach that is time consuming, error prone and hard to maintain.

Thermal Modeling

The computed losses are injected into a thermal model represented by an equivalent circuit of lumped thermal resistances and capacitances. In this domain a semiconductor is modeled as a heat source. Optionally, the thermal impedance of the chip can be entered in the editor as a thermal RC chain.

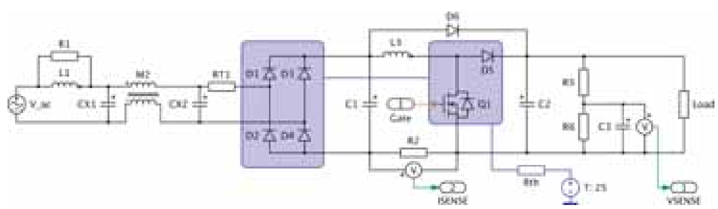


Figure 2. Schematic of a switch mode power supply

Fig. 2 shows the schematic of the power circuit of a switch mode power supply with a PFC circuit in boost topology. The controller is implemented in Simulink and is not shown here. The blue frames represent idealized heatsinks. A heatsink absorbs all losses dissipated by the components within its boundaries. It also provides an isotherm environment for these components. Heatsinks can have a thermal capacitance of their own and can be connected with other thermal elements. The two heatsinks in Fig. 2 are directly connected because they represent a single dissipator on which the input rectifier and the PFC stage are mounted. A thermal resistance connects the dissipator with the temperature of the ambient air.

The transient waveforms during start-up of the power supply under constant load are shown in Fig. 3. After the initial charging of the dc capacitor the boost converter slowly lifts the output voltage towards its rated value. At about 150 ms the controller shifts into a more dynamic mode which is directly reflected in the temperature of the PFC switches.

The small inset zooms into the MOSFET temperature during two switching cycles. At each switching event the waveform exhibits a jump due to the instantaneous dissipation of the switching losses. During the on-state the temperature gradually increases; when the MOSFET blocks it cools down again.

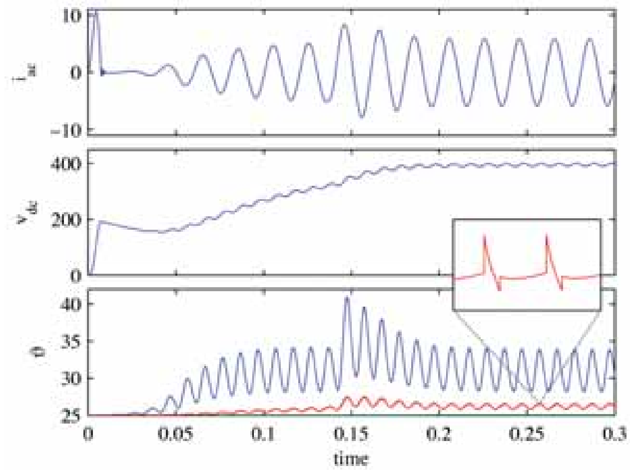


Figure 3. Transient waveforms during power-up (top: mains current; middle: load voltage; bottom: temperatures of the dissipator and the PFC switches)

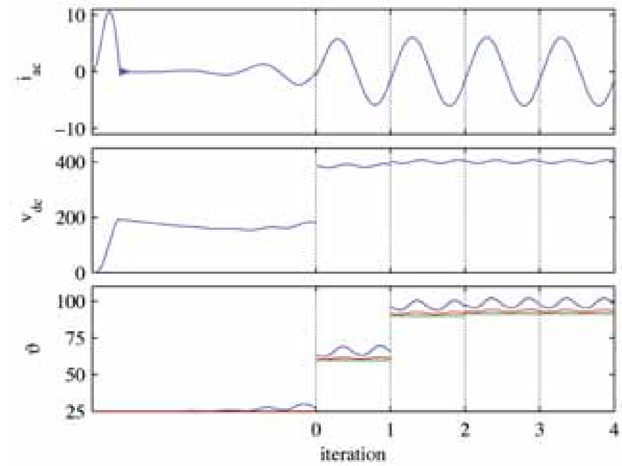


Figure 4. Trace plot of a steady-state analysis

Steady-state Analysis

Although it can not be seen in Fig. 3 the temperature levels are steadily increasing. Finding the stationary temperature levels in the power supply by simple transient simulation would take about 12 hours on a reasonably fast PC—even using ideal switch models!

PLECS therefore features an iterative shooting method to find the periodic steady-state operating point of a switching converter. Such a steady-state analysis is demonstrated in Fig. 4. After a few initial cycles the algorithm begins to predict initial state values that better match the steady-state condition: i.e. that the initial state and final state are equal. After the fourth iteration the relative error is already below 1%, and after a few more iterations the analysis finishes with a relative error of about 10-5. The whole process takes about one minute to complete.

Conclusions

PLECS is a tool for the combined thermal and electrical simulation of power electronic systems. The used method of combining ideal switch models with detailed look-up tables for the dissipated device losses provides an efficient and accurate alternative to detailed device simulations. For large systems it is the only practical technique since the small simulation time steps required for detailed simulations lead to prohibitively long simulation times.

PLECS offers a user friendly and integrated environment that can replace user-written and hard-to-maintain thermal calculation tools.

Reference

[1] S. Munk-Nielsen, L.N. Tutelea, U.Jaeger, "Simulation with Ideal Switch Models Combined with Measured Loss Data Provides a Good Estimate of Power Losses", Proc. IEEE Ind. App. Conference, Vol. 5, Oct. 2000, pp. 2915-2922.

Book Review

SWITCH-MODE POWER SUPPLIES

SPICE Simulations and Practical Designs

By CHRISTOPHE P. BASSO

McGraw-Hill, 2008, pages 889, Includes CD

The book presents a very practical and concise treatment of switch-mode power supply design and analysis. It achieves a nice balance between the theoretical basis and the real world practical knowledge in a way that will benefit both, the student and the practicing engineer. The book contains eight (8) chapters organized in a logical manner building up from the basics of power conversion and the various converter topologies to fundamentals of small signal modeling to control aspects to the basic simulation blocks and models and then on to the issues covering specific converter topologies.

Chapter 1: Introduction to Power Conversion
Chapter 2: Small-Signal Modeling
Chapter 3: Feedback and Control Loops
Chapter 4: Basic Blocks and Generic Switched Models
Chapter 5: Simulations and Practical Designs of Nonisolated Converters
Chapter 6: Simulations and Practical Designs of Off-Line Converters – The Front End
Chapter 7: Simulations and Practical Designs of Flyback Converters
Chapter 8: Simulations and Practical Designs of Forward Converters

Each chapter concisely covers the topics contained in them with the appropriate amount of mathematics to enable proper understanding on the subject matter. The language is easy to follow and flows well amongst topics providing good continuity of thought. The examples are practical, plentiful and easy to comprehend. The SPICE models will certainly provide a jump start to anyone getting involved in the business of switch-mode power supply studies. Further, each chapter comes with a clear summary of the essence of the chapter and a set of appendices and references that provide additional details and mathematical treatment of the concepts in the chapter.

The author's practical experience in doing SMPS designs comes out throughout the book in form of practical tips and recommendations.

In short, this is a book that will be of immense value to students and designers, both, as a text book and a reference.

Uday Deshpande is currently Senior Director – Power Engineering at Maxwell Technologies in San Diego, CA. In this capacity he is responsible for the electrical and systems development for their ultracapacitor products as well as developing increased understanding in the application and use of ultracapacitors in various industries. He has a Bachelor of Technology (Hons.) degree from the Indian Institute of Technology, Kharagpur and an MSEE and Ph.D. degrees from the University of Kentucky, all in Electrical Engineering.

His fields of interest are electric machines and drives, power electronics and energy storage systems.

Seeking Nominations for IEEE Medals and Recognitions

Leslie Russell
IEEE Awards Presentation Program Manager

The IEEE Awards Board is seeking nominations for IEEE Medals and Recognitions and encourages the use of its online Potential Nominee Form. This form allows a preliminary review of a nominee by the selection committee and an opportunity to obtain feedback prior to submitting an official nomination form. The Potential Nominee Form is available on the

IEEE Awards Web Page at http://www.ieee.org/portal/pages/about/awards/noms/potnomform.html

The deadline for submission of an official nomination form for any of the IEEE Medals and Recognitions is 1 July 2008. For questions concerning the Potential Nominee Form, please contact awards@ieee.org

Leslie Russell
Awards Presentation Program Mgr
IEEE Awards
445 Hoes Lane
Piscataway, NJ 08854 USA
732.562.6588 Phone
732.981.9019 Fax
l.russell@ieee.org (E-mail)

IEEE. Fostering technological innovation and excellence for the benefit of humanity.

Meetings of Interest

I&CPS 2008 the Industrial and Commercial Power Systems conference is scheduled for 4-8 May 2008 at the Sheraton Sand Key hotel in Clearwater Beach, FL. The meeting site is near Tampa, FL on the Gulf side. For more information please visit: www.ieee.org/icps2008

OPTIM-2008 venue: Biannual (in same Mountain Resort), on Power Electrical and Electronics Enginnering; May 22-24, 2008, Brasov, Romania and technical co-sponsored by IEEE – IAS, IES, and PEL's. For details please visit: http://info-optim.ro and http://optim.8m.com. Also, see the announcement in this issue.

39th IEEE Power Electronics Specialists Conference, PESC08 will take place on the island of Rhodes, Greece from 15-19 June 2008. Form more information please visit PELs website or contact PESC08 General Chair, Dr. Stefanos Manias (IEEE IAS/PELs/IES Greece Section Chair) at National Technical University of Athens, manias@central.ntua.gr

11th IEEE Workshop on Control and Modeling for Power Electronics: COMPEL2008, to be held 18-20 August 2008 at ETH Zurich, Zurich, Switzerland. Digest submission deadline is 14 April 2008. For more information visit the conference website: http://www.pes.ee.ethz.ch/compel2008

43rd Industry Applications Society annual meeting is announced for 5-9 October 2008 at the Weston, Edmonton, Alberta, Canada. Author's deadlines are abstract and digest by 15 Jan 2008 followed by notice of acceptance by 31 March 2008. For more information on the conference and technical program visit the website at: http://www.ieee.org/ias2008

5th Vehicle Power and Propulsion (VPPC2008) Conference is announced for 3-5 September 2008 in Harbin, China. Correspondence may be directed to: vppc2008@hit.edu.cn. VPP'08 general chair: Prof. C.C. Chan, Harbin Institute of Technology. Abstracts with contact details should be submitted by 1 March 2008. VPP'08 is co-sponsored by PEL's. For more information visit the website at: www.vppc2008.com

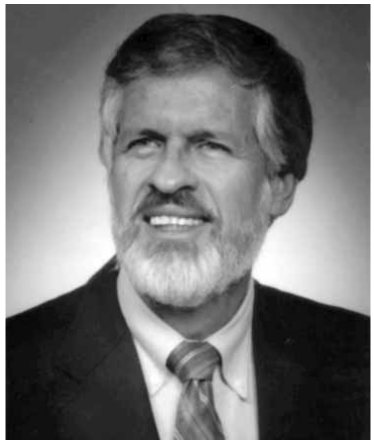
1st Annual Energy Conversion Congress and Exposition (ECCE2009) is announced for 20-24 September 2009 at the Double Tree Hotel at 2050 Gateway Place in San Jose, CA. For more information on ECCE2009 visit the conference website: www.ecce2009.org

44th Industry Applications Society annual meeting is announced for 4-9 October 2009 in Houston, Texas. This will be a new meeting format following the transition of IAS committees to ECCE2009 with more emphasis on tutorials and workshops. For more information visit the website at: www.ieee.org/ias2009

Nordic Workshop on Power and Industrial Electronics, NORPIE 2008 will be held 9-11 June 2008 in Espoo, Finland at Helsinki University of Technology Faculty of Electronics, Communications and Automation. Contact is Mrs. Anja Meuronen, Power Electronics, Helsinki University of Technology, email: anja.meuronen@tkk.fi

European Power Electronics, EPE2009, is planned for 8-10 September 2009 in Barcelona, Spain. Call for papers to be released in May 2008 with deadline for receipt of synopses Nov. 2008. For more information visit: http://www.epe2009.com

Power Electronics Community Loses a Friend



Bill Sayle, a long-time volunteer in the early years of PELS passed away recently. Many of us remember Bill from the time even before PELS was a Society. He served in many positions in PELS including chair of one of the earliest PESC conferences and program chair in 1989, PELS Secretary, and as PELS VP of Operations. Professionally, Bill's first love was engineering education. He created power electronics courses at Georgia Tech at a time when there were very few in the U.S. In addition to his work with PELS, Bill was heavily engaged in the IEEE Education Society. In 2001, he was presented with the Education Society's Meritorious Service Award, which is given for outstanding leadership and service to the IEEE Education Society ECE's over a sustained period of time. He also received the 2004 IEEE Educational Activities Board Meritorious Achievement Award in Accreditation Activities.

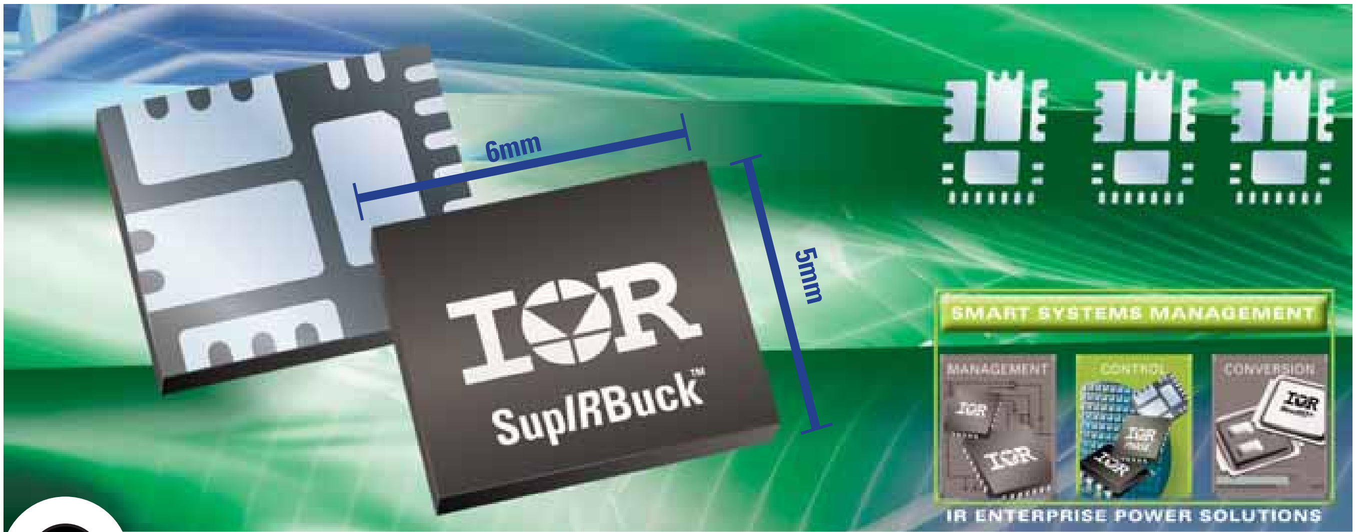
Since 1983 he has been active in engineering accreditation activities for IEEE and ABET. He served as an IEEE program evaluator for over 20 institutional visits for the Engineering Accreditation Commission (EAC) of ABET. In 1990 he was elected to an at-large position on the IEEE Committee on Engineering Accreditation Activities (CEAA), which recruits, trains, mentors, and evaluates IEEE program evaluators for the EAC of ABET. In 1995 and 1996 he chaired the IEEE CEAA and in 1996 and 1997 he chaired the IEEE Accreditation Policy Committee, which oversees IEEE accreditation activities in both engineering and engineering technology.

Bill served as the associate chair for undergraduate activities in the ECE department at Georgia Tech since 1988. In that capacity, he served tirelessly served as the primary academic advisor to the department's more than 1,600 students, supervised ECE's more than 60 graduate teaching assistants.

Bill Sayle was also heavily involved in recruiting young people to the engineering profession. For more than 14 years, he served as the Georgia Tech Engineering Faculty Consultant for the Southeastern Consortium for Minorities in Engineering (SECME). In this position, Sayle presented engineering-oriented demonstrations to students all over Georgia, and he involved local industries and made Georgia Tech resources available on a regular basis. Sayle also developed seminars and in-service training sessions so that SECME teachers are more aware and involved in aspects of the engineering profession.

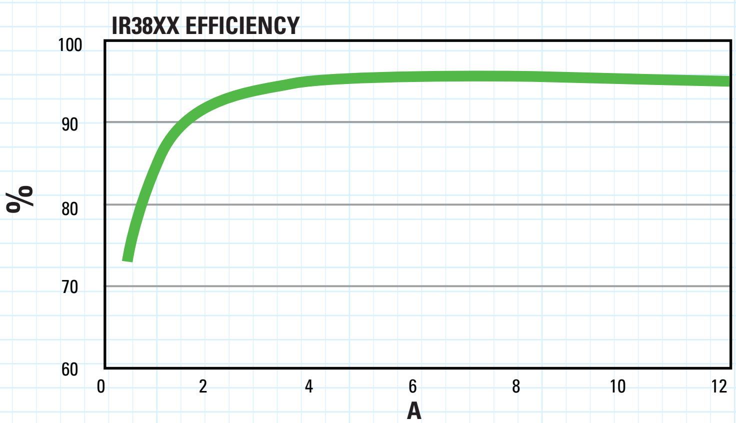
For his efforts, he earned the SECME Outstanding Service Award in 1988. Sayle also received the 1993 Engineer of the Year for Greater Atlanta from the Georgia Society of Professional Engineers.

PELS will certainly miss the enthusiasm and dedication to the profession that Bill embodied.



Sup*IR*Buck™ Integrated Regulators: Simply Smaller, Cooler

Save Energy, Accelerate POL Design, Shrink Footprint 70%



The SupIRBuck™ family of versatile point-of-load (POL) voltage regulators shrink silicon footprint 70% compared to discrete solutions and offer up to 10% higher full-load efficiency than monolithic power ICs.

Features

- 600kHz switching frequency
- 4A/7A/12A output options
- Programmable soft start with enable
- Programmable over-current protection
- 0.6V reference voltage with 1.5% accuracy
- 2.5V to 21V conversion Input
- Pre-Bias protection
- Integrates rugged control and sync FETs with control IC in one simple 5mm x 6mm power QFN package
- Optional 300kHz, DDR memory tracking, programmable PGOOD

Benefits

- Ease of implementation
- Enables single input voltage rail
- Wide input voltage range
- Common footprint for 4A, 7A and 12A power regulators
- Fewer discrete components

Part Number	V_{IN} Max/Min	V_{OUT} Max/Min	Max Current	F_{SW}	Package	Features
IR3812MPBF	21 / 2.5	12 / 0.6	4A	600KHz	5mm x 6mm QFN	OCP; OTP; Tracking
IR3822MPBF	21 / 2.5	12 / 0.6	4A	600KHz	5mm x 6mm QFN	OCP; OTP; PGood
IR3822AMPBF	21 / 2.5	12 / 0.6	6A	300KHz	5mm x 6mm QFN	OCP; OTP; PGood
IR3811MPBF	21 / 2.5	12 / 0.6	7A	600KHz	5mm x 6mm QFN	OCP; OTP; Tracking
IR3821MPBF	21 / 2.5	12 / 0.6	7A	600KHz	5mm x 6mm QFN	OCP; OTP; PGood
IR3821AMPBF	21 / 2.5	12 / 0.6	9A	300KHz	5mm x 6mm QFN	OCP; OTP; PGood
IR3810MPBF	21 / 2.5	12 / 0.6	12A	600KHz	5mm x 6mm QFN	OCP; OTP; Tracking
IR3820MPBF	21 / 2.5	12 / 0.6	12A	600KHz	5mm x 6mm QFN	OCP; OTP; PGood
IR3820AMPBF	21 / 2.5	12 / 0.6	14A	300KHz	5mm x 6mm QFN	OCP; OTP; PGood

for more information call 1.800.981.8699 or visit us at www.irf.com/dcdc

International
IOR Rectifier
THE POWER MANAGEMENT LEADER