# Hot Topic Energy Efficiency

Energy saving, improved energy efficiency and environmental protection are ubiquitous topics in society, in Europe and globally. Despite many efforts to save energy, demand for electricity is expected to grow, and much faster in comparison with other energy sources over the next three decades. Power electronics is the key technology to controlling the flow of electrical energy from the source to the load precisely, according to the requirements of the load.

**Power Electronics covers the Gigawatt power e.g. in energy transmission lines down to the very low milliwatt power Source: ECPE**


According to a position paper on 'Energy Efficiency – the Role of Power Electronics' (based on the results of a European workshop held on 7 February 2007 in Brussels, organised by ECPE European Center for Power Electronics in cooperation with EPE Association), today 40% of all energy consumption is in electrical energy, but this will grow to 60% by 2040. On the other hand, the share of electrical energy which will be controlled by power electronics e.g. in variable speed drives, will increase from 40% in 2000 to 80% in 2015. Power Electronics is responsible for the reliability and stability of the whole power supply infrastructure from the sources, the energy transmission and distribution up to the huge variety of applications in industry, transportation systems, office appliances and the home. Power Electronics is a cross-functional technology covering the extreme high Gigawatt (GW) power e.g. in energy transmission lines down to the very low milliwatt (mW) power needed to operate a mobile phone (Figure 1).

## High energy saving potentials

Many market segments such as domestic and office appliances, heating, ventilation and air conditioning, digital consumer, communication, factory automation and drives, traction, automotive and renewable energy, can potentially benefit from the application of power electronics technology. Advanced power electronics could, for example, realise savings of more than 50% in energy losses in converting from mains or battery voltages to that used in electronic equipment (Figure 2).

Motor drives use 50 to 60% of all electrical energy consumed in the developed world. By using power electronics controlled motor drives a potential reduction in energy consumption of 20 to 30% is achievable. In home appliances, electronic thermostats for refrigerators and freezers can yield 23% energy saving, and an additional 20% can be saved by using power electronics to control

**Major consumers of electrical energy and savings potential Source: ECPE/Infineon)**

| | Energy Split: ww | | Energy saving potential |
|---|---|---|---|
| Con. power supply, - stand-by, - active, ... | Others 14% | - stand-by - active | >90% >>1% |
| I&C, Computing power supply, ... | Internet 10% | 80+ / 90+ | >>1% |
| EC-Ballast Daylight dimming HID, LED, ... | Lighting 21% | Electronic control | >25% |
| Factory autom. Process engineering, Heavy industry, Light industry, ... | Motor control 55% | Variable Speed Drive (VSD) | >30% |
| Transportation: Train, Bus, Car, ... | | VSD + Bi-directional energy flow | >25% |
| Home appliance: Fridge, WM, HVAC, ... | | VSD | >40% |

compressor motors (with three-phase PMDC motors). The connection of renewable energy sources to power grids is not possible without power electronics: photovoltaic power electronic converters optimise the efficiency of PV solar panels, inverters are necessary for wind generators etc.

In automotive applications electric and hybrid drive trains are only possible with efficient and intelligent power electronics. X-by-wire concepts operated by power electronics will generate saving potential of more than 20%.

New concepts for power supplies can improve overall efficiency of 2 to 4% by reducing low power and standby consumption or a reduction in losses of 14 to 30%. Digital control techniques can further reduce energy consumption. In general lighting power electronics can improve the efficiency of fluorescent and HID ballasts by minimum 20%. Advanced power electronics for dimming together with light and occupancy sensing can save on average an additional 30%.

### Actions required

Power electronics has more that 40 years history in Europe and has set many milestones in industry. Power semiconductor devices and smart control ICs have been the key technology driver for the last two decades. In the next two decades, however, packaging and interconnection technologies, high power density system integration together with advancements in Si devices and system reliability will dominate the power electronics development.

Therefore, Europe has to invest in various areas with focussed R&D effort e.g. in a next generation of semiconductors, advanced device concepts and high temperature (wide band gap) power semiconductor materials (SiC, GaN, diamond); new concepts for pure Si and/or SiC system design; semiconductor elements allowing higher voltage and power; and advanced materials (isolation, thermal conductivity, passives, sensors) for system integration and harsh environment, incl. nanostructure materials and filled polymers.

In packaging new interconnection technologies for ultra-high power density systems and high temperature electronics; advanced thermal management; high temperature magnetics, capacitors, sensors, control ICs; advanced EMI filtering and high level of passive integration; system cost reduction by standardisation of mass producible power electronics building blocks; and functional system integration (reduce losses, costs, weight and size, optimise cooling) or integrated mechatronics e.g. for fridge compressors, air conditioners and pumps should be developed.

New topologies for further standby power reduction and digital power conversion and smart power management are required, as well as smart and simple dimming concepts in lighting; smart control of street lighting; high efficient light sources (LED/OLED) and their power electronic drivers; and higher level of integration e.g. for more compact energy saving lamps.

In the 'Action Plan for Energy Efficiency: Realising the Potential' from October 2006, the European Commission has underlined the importance of this topic for Europe. In the next step, the potential must be realised by establishing a European R&D Platform for power electronics supported by the European Commission. ECPE will support this process by a European initiative of academia and industry to jointly develop power electronics research and technology roadmaps. Eight working groups for key applications and systems using power electronics have been formed with experts from industry' as well as from university and research institutes. The vision is that these medium to long term research roadmaps (up to 2020) will become a guideline for power electronics research in Europe and help industry to prepare for upcoming technology challenges.

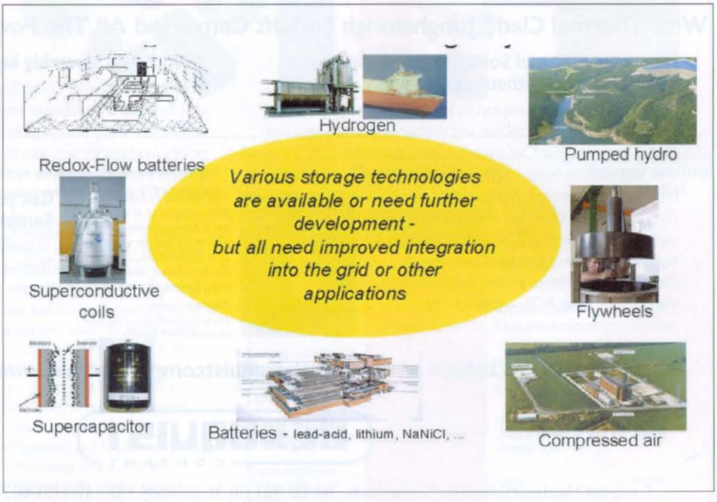
### Areas of interest

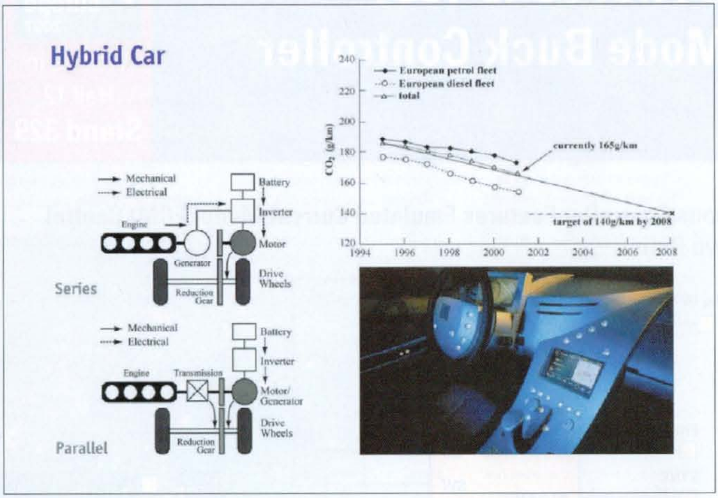
Power Generation & Distribution and Energy Storage, Transport and Mobility, Industrial Drives, Information and Communication Technologies, Home Appliances, and Lighting are the application areas of interest, chaired by leading European scientists.

High voltage (High Voltage Direct Current - HVDC) transmission, static VAR compensators, dynamic voltage restorers (DVRs) and medium voltage static transfer switches (MVSTS) are existing applications of power electronics in distribution and transmission systems to improve power quality and reduce transmission losses. "More power electronics are being used on the generation side to convert electrical power, often from DC to 50Hz fixed frequency AC. Power electronics is also indispensable to link future storage systems to the power grid. It is anticipated that in the future all electrical energy will flow at least once through silicon", says Prof. Dr. R. De Doncker (RWTH Aachen/ Germany).

Power electronics not only makes the power systems more flexible and stable, but allows significant energy savings in partial loads (maximum power point tracking) and major investment cost savings as new and lighter power sources can be realised. "To break through in the field of power generation, distribution and storage systems, power electronics research should focus on increased reliability with simpler control, better packaging, power electronic building blocks; lower cost through optimised cooling, improved packaging, lower

**Storage technologies for electrical energy**
**Source: ECPE/RWTH Aachen**






Example for energy efficiency in transportation, the hybrid car Source: ECPE/ETH Zurich

losses, smaller weight and size; more integration at higher temperatures with integrated cooling; and finally interfacing with utility communication systems", Doncker added.

Analysis of the potential evolutionary development of silicon-based power electronics in HVDC and and Flexible AC Transmission Systems (FACTS) indicates performance and cost limitations that will prevent effective implementation of the 'New Unified European Electricity Grid'. Similarly, the cost of silicon-based power electronic systems will limit the penetration of small distributed generators (DG) in Europe's Electricity Supply Grid. "In comparison, high-voltage silicon carbide (SiC) based technology, with SiC device ratings between 10 and 15kV have the potential of offering the performance advances and system cost reductions required to allow effective implementation of a European Grid and to enable deep penetration of DG", comments Roger Basset from UK-based Areva T&D. These SiC devices would be exploited as part of a new class of Voltage Source Converters (VSC) that would be dramatically more reliable and energy efficient than those currently in silicon. Such devices will provide substantial reductions in the size of the entire HVDC and FACT systems allowing, for example affordable increase in capacity of transmission lines into cities.

"Europe's strength in HVDC and FACTS positions it to rapidly achieve global leadership in SiC-based technology thus allowing it to timely provide the technology required to implement the future electricity grid. As a consequence, funding of a European programme needs to be made a high priority. This programme would pull together Europe's distributed expertise and manufacturing base to effectively compete against US and Japan based competitors. Such a project would protect existing jobs in the European power electronics and power industries, whilst providing affordable and reliable electricity and societal to European Citizens.

The required European-level programme of work would have synergies to that required for SiC electronics for the automotive industry. However, there are unique requirements, e.g. low-cost, thick epitaxial growth techniques, new high-voltage insulation and new circuit designs. Overall, the application of SiC in VSC HVDC will power electronics to 'come of age' and become the new standard for power transmission", Basset adds.

Chairman for the sector Industrial drives is Dr.P. Barbosa from ABB. "The Kyoto protocol establishes that by 2012 Europe must reduce 8% (340Mton) $CO_2$ emission compared to the levels of 1990. In 2000, the total EU-15 electricity consumption was 2,570TWh. Out of this, industry use accounted for 950TWh. Industrial motors and drive systems alone consumed the bulk electricity, that is, 610TWh or 64% of the total industrial consumption. 180TWh is the potential to save energy using variable speed drives (VSDs), which accounts for 80Mtons of $CO_2$ reduction. As a result, industrial VSDs can accomplish alone 24% of the required $CO_2$ reduction per the Kyoto protocol. If we consider the EU-25 member states, the potential to save energy increases to 200TWh or 100Mtons of $CO_2$ reduction. It is amazing to notice that in terms of power plant requirements, the energy that can be saved is equivalent to 45GW of installed generation capability, that is, 130 fossil fuel 350MW power plants or enough energy to supply a whole country the size of Spain. The conclusion is that savings justify by themselves a massive investment on industrial VSDs", Barbosa stated.

The matter of fact is that today's VSD technologies are fully capable to provide the savings. above. So, what is motivating us to doing more research in this area? "Indeed, to improve the performance and widen the acceptance of VSDs we have to make them more reliable, lower cost, more efficient, more compact, and easier to manufacture and easier to use. To accomplish results in the issues listed above, we will need to develop technology in the multidisciplinary areas mentioned such as power semiconductors, passive componets or packaging", Barbosa added.

Passive components have not shown a fast development track record in the last 30 years. For this reason, size, operating temperature and frequency are barriers which are easily reached by state-of-the-art components. There is a great need to develop new/better materials for capacitors, inductors, transformers and filters. As a result, higher energy density materials, such as nano-magnetics and nano-dielectrics are required to achieve compactness, higher operating temperature, and higher frequencies. Power semiconductors have developed much faster than passive components in the last 30 years. The invention of the insulated gate bipolar transistor (IGBT) and the integrated gate commutated thyristor (IGCT) have been responsible for major breakthrough in industrial VSDs. Clearly, further loss reduction is needed for high voltage IGBTs (>1700V). In addition, operating at higher temperatures is extremely beneficial to slashing cost related to thermal management. To make it possible to improve the performance of power semiconductor devices further development of Si IGBTs, super-junction devices and new wide-band gap components based on silicon carbide (SiC) or gallium nitride (GaN) are necessary.

"Home appliances is a special application field where cost is the main driver. They use 30% of all electricity generated, produce 12% of all energy-related $CO_2$ emissions, are the second largest consumer of electricity, and are the third largest emitter of greenhouse gas emissions. From a manufacturer's view washing machines and dishwashers are close to the technological limit of efficiency, refrigerators and freezers are close to the least life cycle cost, industry investments were in average €1 billion per year over the last decade and +30% in the last five years, and 70 to 90% of products are in class A or better", says Home Appliances Chairman Prof. Dr. A. Consoli from University of Catania/Italy. "But there is a large market of small appliances where motor efficiency is still in the order of 5 to 10%. Efficiency of the larger appliances ranges within 50 to 60%. New solutions such as Permanent Magnet motor drives must be adopted".

Power electronics can also help to improve efficiency at the converter stage by introducing new solutions for power components and sensing (Intelligent Power Modules, hybrid integration, IGBT drivers, PFC, current sensing), as well as at the control stage enhancing efficiency and reliability of the home appliances (sensorless control, field weakening operation, reliability of torque and power estimation, dynamic maximisation of torque/current ratio, load identification algorithms).

"To make lighting significantly more efficient than it is today, several high-risk scientific research projects should be initiated", states Chairman Prof. ir. M. Hendrix from Philips Lighting. "Fast, high voltage (400 to 800V) and high temperature (120 to 250°C) switch technologies e.g. SiC or ESBT including their drive and protection mechanisms should be very inexpensive. A cost-breakthrough for lighting is possible when both high voltage (diodes and switches) and low voltage IC processes (controllers) can be combined on the same die. Cost can be saved with an order of magnitude faster microcontrollers with on-chip very high resolution (nanosecond) timers. High speed can be used to circumvent costly hardware - fast ADC and DACs with off-chip components. Higher processing speed and faster timers allow direct driven switches and adaptive on-line dimming algorithms for very efficient high-intensity, and thus energy-saving, discharge lamps. High-temperature electrolytic capacitor replacements, e.g. high-temperature polymers should also be researched".

In transportation, power electronics is a key enabler for realising energy efficient vehicles with hybrid powertrains (Figure 4). "Due to recuperation of kinetic energy, operation of the internal combustion engine with maximum efficiency, and combustion engine shut down at idle, hybrid cars show a significantly improved fuel economy for standard city based drive cycles. However, the automotive environment challenges the power electronics controllers with extreme temperatures and requirements for low weight/low volume and zero defect over 15 years lifetime. Furthermore, cost reduction by factor of 4 until 2020 is a prerequisite for allowing wide spread of hybrid technology", states Prof. Dr. J.W. Kolar from ETH Zurich/Switzerland.

"To meet these challenges research in power electronics has to focus on functional integration/ modularisation of various converters systems; advanced thermal management; homogeneous (space/time) power conversion/ multi-cell converters; advanced EMI filtering; high temperature magnetics/ apacitors/sensors/control ICs; application of wide band gap power semiconductors; fault tolerant converter/motor systems; stress analysis/reliability prediction; and multi-domain/scale/level modelling and simulation", Kolar points out. Similar research requirements exist for more electric aircraft where hydraulic actuators are supported or replaced by power electronics controlled electromechanical actuation. Reduction of aircraft weight, fuel economy, easier maintainability and aircraft design flexibility are main drivers in this area.

PEE's panel discussion on hybrid car technology (PCIM 2007, May 23, 16.00-17.00) with heavy industrial participation will focus on the role of power electronics and already existing solutions for hybrid electric vehicles (HEVs).

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