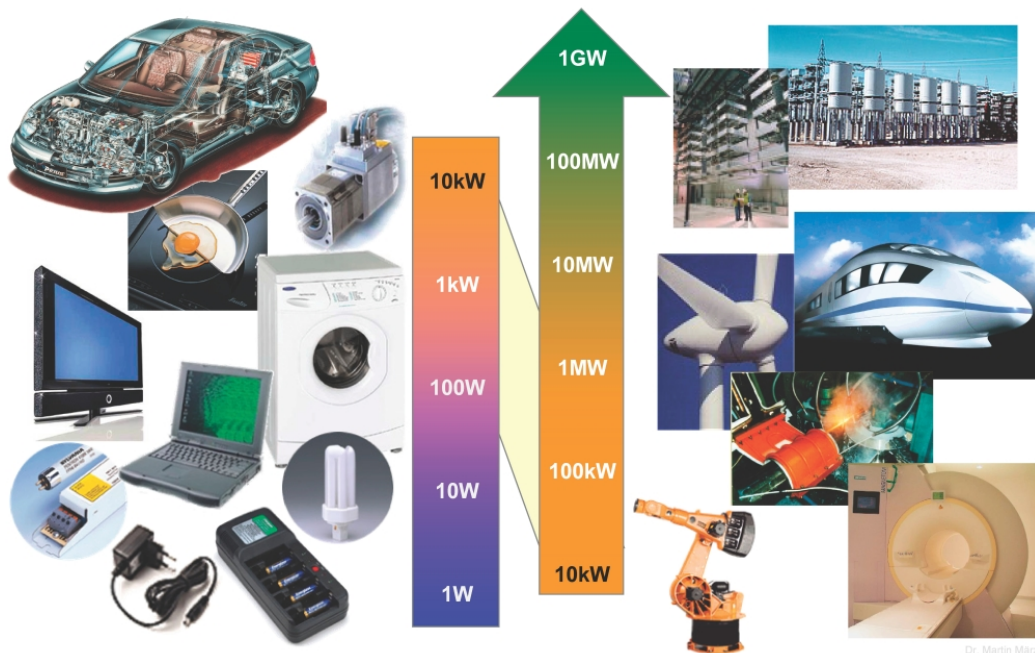


Strategic Research Agenda

on

Intelligent Power Electronics for Energy Efficiency



January 2008



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1. Introduction and Background

Energy saving, improved energy efficiency and environmental protection are ubiquitous topics in society, in Europe and globally. Despite many efforts to save energy, the demand for electricity is expected to grow and much faster in comparison with other energy sources over the next three decades. Today 40% of all energy consumption is in electrical energy, but this will grow to 60% by 2040. On the other side, 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.

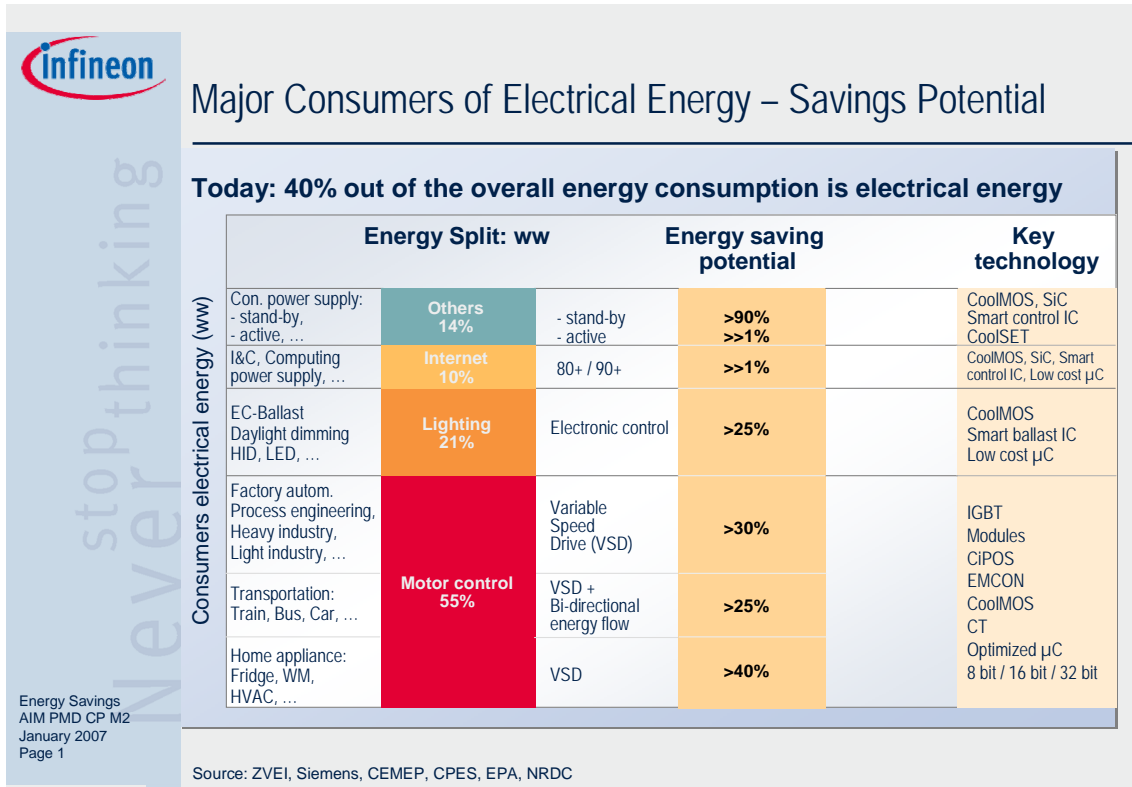
Power electronics is the key technology to control the flow of electrical energy from the source to the load precisely according the requirements of the load. It is responsible for the reliability and stability of the whole power supply infrastructure in Europe from the sources, the energy transmission and distribution up to the huge variety of applications in industry, transportation systems and the home & office appliances. Power Electronics is not restricted to the high power range but, as a cross functional technology, it is covering the extreme high Giga Watt (GW) power e.g. in energy transmission lines down to the very low milli Watt (mW) power needed to operate a mobile phone. Therefore, **power electronics is not defined by the power range but by the basic functionality to convert, control and condition electric power according to the needs of the different loads.**

Power electronics is “the” enabling technology to efficiently use, distribute and generate electrical energy. 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.

Some examples which highlight potential savings:

- Motor drives use 50-60% of all electrical energy consumed in the developed world. By using power electronics controlled motor drives a potential reduction in energy consumption of 20-30% is achievable.
- 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%.
- New concepts for power supplies can improve overall efficiency of 2-4% 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 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 compressor motors (with 3-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%.

All the above examples show how power electronics is the key for using electrical energy efficiently and reducing overall energy consumption.



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, Si technologies, new materials (e.g. SiC; GaN) and system reliability will dominate the power electronics development. Efficiency improvements with power management and energy recovery are important topics for the future, as well as reconfigurable power supplies applying digital power conversion. With the top experts in industry and universities in Europe, the excellent education of students and the outstanding research infrastructure there is a good basis to compete in the future. Furthermore, there is a real opportunity to keep electronics production in Europe, and even get back production to Europe, where it has been already lost, with the highly sophisticated assembly lines for high temperature power electronics or ultra-high power density mechatronic systems e.g. in transportation, information and communication, medical and industrial applications.

2. The Role of Power Electronics for Energy Savings

Smart power electronics can make a large difference in the energy efficiency of products and systems and is a cornerstone for sustainable use of ICT, automation, and numerous other electricity powered devices: Worldwide there is a trend towards an increasing amount of electronics in homes and there is also a significant increase of electronics in homes, in particular of industrialising countries of Asia. Data centers and internet server farms consume the same power as small towns. At the same time most electricity is simply wasted and dissipated as heat due to the inefficiency of devices.

The policy agenda of the European Commission currently targets the energy efficiency of electrical and electronic appliances; product related measures are a high priority as a means to reduce CO₂ emissions and to achieve the Kyoto protocol targets. Power electronics play a key role to reduce power consumption of consumer electronics, household appliances, office equipment and all kinds of motor driven systems. For example, for television sets alone in a study by Fraunhofer IZM¹ a power savings potential of 45 TWh per year for 2020 is identified, if energy saving technologies – among them improved power electronics components and designs – will be introduced to televisions. The saving potential for motor systems in home and industrial applications is even larger, and variable speed motor controls are one of the major technical methods to realize these potentials². The ZVEI shows that a saving of 22,3 TWh per year is possible by applying variable speed motor control in the German industry. The design challenge is to provide control in a simple way and to do it cost effectively. In most cases the smart use of power electronics even can lead to significant cost savings with return on investment in a few months. In many cases even the cost of investing in power saving systems can even be lower than for the less efficient alternatives. The ongoing trend to replace analog with digital in power electronic applications is motivated not only by lower energy consumption but also better functionality of control, and reduced wear out of the complete e.g. driving system.

The replacement of bulky linear transformers with switch-mode devices does not only increase power efficiency, but also the consumption of scarce resources and materials. Switch-mode power supplies are more compact and light-weight. The improvement of switch-mode designs and advanced topologies even have the potential to realize power savings with additional material savings by reducing the number of components.

However, the electricity consumption of homes will increase in the future due to the growing number of devices in households, including charging requirements for mobile devices and increased functionality, e.g. the trend towards larger TV screen sizes and networking of devices, if no measures are taken to actively foster power saving solutions.

Standby power consumption and off-mode losses of electrical and electronic appliances used in households and offices are estimated to be close to 100 TWh in the European Union³ currently. Power electronics can play a major role to reduce especially the electricity consumption during standby operation.

The European Commission will address the topic of power electronics specifically in the near future under the ecodesign framework directive: Power electronics components have been identified as a priority for such legislative measures to increase energy efficiency in general. A recent study showed that the total primary energy consumption of power electronics products (inverters, static converters, inductors, soft starters) manufactured and used in Europe within one year is 1644 PJ⁴. A standby regulation is already under development, targeting at 1 and even 0,5 W in off-mode and standby (reactivation function only) within the near future⁵. Energy consuming products such as household appliances, ICT equipment, lighting ballasts, motors and consumer electronics are currently under consideration for energy efficiency standards as well. The success of the EU Energy Efficiency Label for household appliances in recent years, with more and more highly efficient products entering the market, demonstrated the willingness of European consumers to choose more efficient products.

¹ Fraunhofer IZM: EuP Preparatory Study on Consumer Electronics (TVs), Berlin, October 2007

² ZVEI: Energiesparen mit elektrischen Antrieben, Frankfurt, April 2006

³ Fraunhofer IZM: EuP Preparatory Study on Stand-by and Off-mode-losses, Berlin, October 2007

⁴ EPTA Ltd.: Study for preparing the first Working Plan of the EcoDesign Directive, November 2007

⁵ European Commission: Working document on possible ecodesign requirements for standby and off-mode electric power consumption of electrical and electronic household and office equipment, Brussels, September 2007

Higher reliability of energy efficient power modules is essential and should be introduced on a large scale on the market in order to improve the overall lifetime of the products. Smaller size, higher level of integration and lower costs are likewise challenges for the power semiconductor industry. Increasing electricity prices are likely to create a positive market environment for highly power efficient solutions.

3. Activities of European Power Electronics Industry

ECPE Joint Research Programme funded by the ECPE companies

In the ECPE Network of about 30 industrial members and more than 40 Competence Centres in Europe, a programme has been set up to jointly fund precompetitive research at the ECPE Competence Centres. Besides the advanced integration technologies for power electronic systems, power electronics for improved energy efficiency is a key topic in ECPE research.

Highlights of ECPE Joint Research Programme:

- Demonstrator Project on '**Power Supplies with Ultra-High Power Density**'
The integration of the power electronic inverter with an electrical machine in the automotive powertrain is in the focus of the automotive Demonstrator Programme where the existing cooling circuit from the internal combustion engine is used also for the direct liquid cooling of the power electronics. The mechatronic integration of motor and power electronics leads to an ultra-high power density of 75 kVA/l for the inverter. The high temperature of the cooling medium of up to 115°C in combination with this high power density poses a unique challenge.
- Research Project on '**Photovoltaic Inverter**'
The project aims at the study, development, and testing of grid-connected inverters for PV plants ranging from 1 to 20 kW. Three aspects of PV inverters will be considered: topologies, digital control and reliability. Different topologies of PV inverters will be considered aiming to efficiency maximisation and passive components reduction.
- Research Programme on '**eLighting**'
The research programme aims at the integration of control ICs and power switches (SOC or SIP) and the reduction of the size of passives. Target is that power electronics fits in the standardised lamp socket. The smart control combining power electronics, sensors, supervisor control and remote control has to include occupancy and light sensors, a user interface or communication via remote control. Furthermore, efficient and comfortable light source have to be developed e.g. hybrid lamps, nanotube lamps or electrodeless lamps.

Furthermore, ECPE is driving the topic of **Digital Power Conversion** in Europe initiating a technology study and organising an expert seminar in this field which will take place in February 2008 in Munich.

ECPE Programme on Research Roadmap Development

ECPE European Centre for Power Electronics will accompany and support the targeted research focus on 'Intelligent Power Electronics for Energy efficiency' by a European initiative of academia and industry to jointly develop power electronics research and technology roadmaps. 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.

ECPE Roadmap Teams:

1. Power grid infrastructure (power generation & distribution) and renewable energy sources
2. Large drives (large industry and traction drives)
3. High performance motor drives
4. Small drives for home appliances
5. High frequency power conversion > 1 kW
6. High frequency power supplies < 1 kW
7. Automotive power electronics

The ECPE Roadmap development methodology is starting from the **Vision 2020** defining the role of power electronics in 2020 and especially the role of Europe (industry, R & D) in power electronics. In the next step **trends, forces and drivers** are identified (relate megatrends to power electronics, end user and technology trends/drives). After discussing **limiting challenges and technology gaps** the **strategic goals** are defined: where do we want to stand in 2020 and what are the intermediate steps (2010, 2015).

Megatrends in society with impact on power electronics:

Megatrends:	Consequences for Power Electronics
Mobility	E-car, hybrid car, fuel cell car urban transport, trains, more electric aircraft/ship
Information & communication society	PC, internet, server farm, digital control and system communication body area network (mobile human, mobile miniaturized system)
Energy saving; security, availability and reliability of energy supply; clean environment	Energy efficiency, power quality, electrification, system reliability, intelligent power management, digital control
Comfort; elder society	Electrification, self-learning systems
Urbanisation; basic infrastructure; transport	Electrification
Globalisation	Standardisation

4. Research Agenda

Basically, there are three ways power electronics can contribute to energy efficiency improvement:

- Increase of **efficiency of power electronic components, modules and systems** by optimised component technology or circuit topology e.g. for a photovoltaic inverter or a power supply; use of new semiconductor materials and improved semiconductor technologies for realisation of high efficient power electronic components.
- Increase energy efficiency on system level **applying power electronics** e.g. by introducing variable speed drives. Power electronics enables **energy recovery** (recuperation) of electric drives e.g. in trains, cars or lifts. During regenerative braking the motor acts as generator.
- Energy efficiency improvements on system level using **intelligent power electronics**. The key for customer/market penetration is costs requiring a (mechatronic) integration of power electronics in the application system, together with sensors and information and communication technologies.

Apart from efficiency improvement of power electronic devices and subsystems in ICT applications, e.g. computer or telecom power supplies, the major impact lies in the **integration of power electronics, ICT and sensors** to save electrical energy with more intelligent systems in various power electronics applications.

Some examples for smart (remote) controlled power electronic systems are

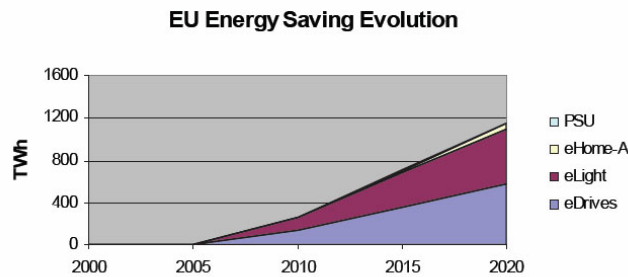
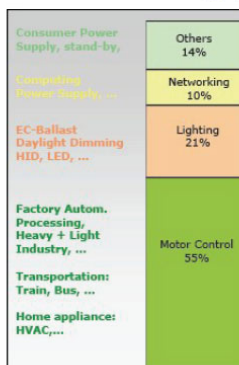
- smart battery (charging) management systems,
- smart home (lighting, heating, cooling),
- adapt energy consumption to power generation: smart (remote) control of electric loads,
- use decentralised energy storage systems for power quality function and grid stabilisation (e.g. in EVs or plug-in Hybrid EVs),
- smart remote control of decentralised PV converters for active power factor correction.

Discrete solutions are possible today, but significant cost reduction and performance improvement is necessary for a market penetration. This can be achieved by **smart integrated power electronic modules**. These advanced integrated modules applying high temperature power electronics and ultra-high power density mechatronics will facilitate to keep power electronics production in Europe. In analogy to the microelectronics world, the smart integrated power electronic modules are the “integrated circuits” in power electronics.

Major application areas for intelligent power electronics for energy efficiency:

- **Power supplies and power management solutions**
 - Reconfigurable power would help in the standardisation, light load and standby power reduction of off-line power supplies and Voltage Regulation Modules to supply digital circuits.
 - Power device technology, ranging from CMOS to wide bandgap devices (SiC, GaN) would enable on-chip power processing and faster and higher temperature conversion.
 - Power supply systems, ranging from autonomous (self-powered) or mobile applications to large data servers, would benefit from power management techniques to reduce load consumption by an appropriate supply strategy.
- **Electronic Lighting (eLighting)**
 - integration of control ICs and power switches (SOC or SIP) and reduction of size of passives
 - smart control combining power electronics, sensors, supervisor control and remote control
 - development of efficient and comfortable light source
- **Automotive power electronics**
 - conventional electric systems (low voltage) driving mechanical actuators
 - emerging technologies e.g. x-by-wire, power steering
 - hybrid and electric traction (high voltage)
- **Industrial applications**
 - smart drives
 - energy recovery
 - energy efficient industrial processes (e.g. thermal, chemical)
- **Renewable energy**
 - photo voltaic inverters
 - converters and generators for wind turbines and biogas turbines

Energy Saving – Energy Efficiency



Source: ZVEI Workshop on Energy Efficiency

Facts:

- EU 25 energy consumption FC 2020: 4000 TWh
- Increase of energy efficiency FC p.a. in 2020
 - eDrives: 575 TWh
 - eLighting: 525 TWh
 - eHome-Appliance: 40 TWh
 - ePSU: 10 TWh
- Total Energy-Saving FC 1150 TWh in 2020 (= 30%)
- 1150 TWh is equivalent to 115 nuclear power plants

European Power Electronics

How to improve efficiency with power electronics:

1. Efficiency improvement of power electronic interfaces

- Since power electronics interfaces, e.g. power supplies, are present between the grid and most electrical loads a 1% improvement will lead to a substantially more than 1% lower energy consumption and CO₂ emissions. The improvement is more than doubled if the efficiency of electricity generation and transport is considered.
- Problem: In many applications of power electronic interfaces a substantial efficiency improvement is possible but not used because is more expensive or there is no market demand for it.

R&D opportunity: New power electronic solutions with higher efficiency and the potential of market acceptance.

2. Leveraged efficiency improvement in renewable energy systems

- A multiplication factor on the system performance that is larger than one. An efficiency improvement of 1% will result in a system benefit of more than 1%.
- Example leverage factors:
 - o (Energy cost for manufacturing system) ÷ (yearly energy yield)
 - o System cost per kW/hour energy delivered
- Efficient power electronics and system integration methods for alternative solar cell technologies (e.g. large area organic PV) will play a crucial role the development of this renewable energy source.

R&D opportunity: Sophisticated and complex solutions that may cost more but which give a substantial efficiency improvement.

3. System efficiency improvement by energy recovery

- Energy that would be wasted as heat is recovered by converting it to electricity.
- Examples: electronic resistors, electronic brakes and electronic heat exchangers to be used in elevator systems, fitness studios, industrial manufacturing plants etc.

R&D opportunity: Numerous potential applications exist that have not been investigated.

4. More efficient combustion with power electronics

- Energy storage and power electronics combined with a combustion engine allows the combustion engine to be operated at its point of maximum efficiency.
- Example: The fuel efficiency of a diesel engine with a variable load can be doubled.

R&D opportunity: Develop this technology further to improve fuel consumption and reduce CO₂

5. Improved sustainability with miniaturization

- Smaller power converters and higher power density is the Moore's law of power electronics. Smaller systems, lower recycling cost and a reduced impact on the environment.
- Examples: Less material is used and systems like PDA's and computers can become smaller with more computing power. Trains, trams and battery vehicles can be made lighter.

R&D opportunity: Higher energy density passive components, low loss switching devices and integration technologies.

6. Efficiency improvement with power management

- Integration of power electronics and ICT in systems makes it possible to apply energy where and when it is needed in space and time.
- Example: A lighting system that use power electronic energy saving lamps and ICT to turn the light on and of and control its intensity.

R&D opportunity: System level research, exploiting the potential of the synergy of ICT and power electronics in energy saving.

7. Reconfigurable power supplies with digital power

- Modify the internal structure of the power conversion stage, by means of intelligent interconnection of small power cells or devices, so that the performance of the power supply is adapted dynamically to the changing requirements of the energy source and load.
- Examples: Reduce power loss when the product operates in standby or light load, by activating lower number of cells; facilitate standardization of AC adapters and converters with wide variation of the input voltage. Flexible use of standard power converters in a variety of applications.

R&D opportunity: Combine the use of digital techniques and intelligence with advantageous power technologies which are available for low power processing, to obtain versatile and efficient power converters in their whole operation range and for a variety of application.

- [1] 'Action Plan for Energy Efficiency: Realising the Potential', European Commission, Brussels, 19.10.2006
- [2] ECPE Study 'Power Electronics Potentials and Political Framework to Improve Energy Efficiency', Nuremberg, March 2007
- [3] ECPE Position Paper 'Energy efficiency – the Role of Power Electronics', March 2007