SEVENTH FRAMEWORK PROGRAMME

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Electronics Enabling Efficient Energy Usage

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Vision 2020

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European Commission
Information Society and Media

Vision 2020

Content

Strategic Research Agenda on Intelligent Power Electronics for Energy Efficiency and Vision 2020

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 to the requirements of the load. It is responsible for the reliability and stability of the whole power supply infrastructure in Europe from the sources, energy transmission and distribution up to the huge variety of applications in industry, transportation systems and the home and office appliances. Power Electronics is not restricted to the high power range but, as a cross functional technology, it cover from 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. 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 High Intensity Discharge (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 by 2-4% (when reducing low power and standby consumption) or a reduction in losses between 14 and 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 permanent magnet DC motors).

- The connection of renewable energy sources to power grids is not possible without power electronics: photovoltaic (PV) 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 a 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 than 40 years history in Europe and has set many milestones in industry. Power semiconductor devices and smart control ICs have been the key technology drivers for the last two decades. In the next two decades, however, packaging and interconnection technologies, high power density system integration together with advances 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 Information and Communication Technologies (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 for industrialised countries of Asia. Data centres 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 CO_2 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, a study by Fraunhofer IZM[1] identifies a power savings potential of 45 TWh per year by 2020 if energy saving technologies –among them improved power electronics components and designs– were introduced. The saving potential for motor systems in home and industrial applications is even larger. Variable speed motor controls are one of the major technical methods to realise these potentials[2]. The ZVEI shows that savings of 22.3 TWh per year are 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.

[1] Fraunhofer IZM: EuP Preparatory Study on Consumer Electronics (TVs), Berlin, October 2007
[2] ZVEI: Energiesparen mit elektrischen Antrieben, Frankfurt, April 2006

In most cases the smart use of power electronics 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 by better functionality of control, and by reduced wearout 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 have further potential to realize power savings with additional material savings by reducing the number of components.

However, electricity consumption in 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 per year in the European Union[3] currently. Power electronics can play a major role to reduce these, especially the electricity consumption during standby operation.

The European Commission will address the topic of power electronics specifically in the near future under the eco-design 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 PJ[4] (≈ 457 TWh). A standby regulation is already under development, targeting 1 and even 0.5 W in off-mode and standby (reactivation function only) within the near future[5]. 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, demonstrates the willingness of European consumers to choose more efficient products.

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 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.

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[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

3 Vision 2020

I. The ´More Electric World´: the share of green electricity on the overall energy significantly increases.

II. Three technologies information processing, power processing, and sensors&actuators converge to enable smart energy efficient systems.

III. Industry in Europe takes global leadership in smart energy efficient systems and products based on these converging technologies.

IV. Universities and research centres in Europe take global leadership in research and innovation in electronics enabling efficient energy usage.

V. Smart Grids in 2020 are able to handle 20% plus share of fluctuating renewable energy in an economic and efficient way.

VI. Zero-emission e-mobility in megacities

VII. Halving life-cycle costs of buildings including lighting and climate conditioning

VIII. Energy on demand for ICT and wireless energy supply for mobile applications

3.1 The ´More Electric World´: the share of green electricity on the overall energy significantly increases

The finiteness of fossil energy sources and the necessity to reduce our CO_2 emissions are pushing forward the electrification of our society. Today, we are considering electric vehicles but also more-electric aircrafts and more-electric ships. In the next decades, we will see a transition from the burning of fossil fuels towards green electricity, step by step. For example, Japan is aiming for a fully electrified society in 2050 to be independent from fossil materials. Power electronics will be a dominant technology in the `More or All Electric World´.

In the previous decades, people were aiming at the vision of a hydrogen society describing a scenario where hydrogen was generated in the deserts of North Africa by solar energy. This energy carrier H_2 was to be shipped from Africa to Europe where the energy was converted to electricity in fuel cells. In the meantime, it has become obvious that the Hydrogen society is the wrong way for safety and cost reasons. But the main issue are the losses, considering the full chain of energy conversion from the source to the use of energy: Hydrogen technology is inefficient. In a future more electric scenario, the physical efficiency of Hydrogen technology is a factor of three worse compared to transmission and storage of electricity (20% efficiency vs. 60%).

In our vision of a ´More or All Electric World´, electricity is produced in southern Europe and North Africa as well. However in this case the electrical energy is directly transported to the areas where it is consumed. This long distance energy transmission is performed by a transcontinental super grid using low loss HVDC (High Voltage Direct Current) technology. The peripheries in the South (for solar energy) and in the North (for wind energy) are connected to the European power transmission grid.

A solar thermal power plant covering the area of the Assuan reservoir would be sufficient to generate the amount of energy equivalent to the oil production of the whole Middle East region. Alternatively, 3% of the area of the Sahara desert would supply all the energy needed in Europe.

Trends & Drivers

- Finiteness of fossil energy sources
- World climate protection: reduction of CO_2 emissions
- Wider energy basis: reducing the dependency from oil and gas (geopolitical dependencies)
- Use of renewable energy sources (e.g. wind power, solar energy, water power)

Limiting Challenges and Technology Gaps

- Energy storage capacity in the power grids
- Wide distance energy transmission infrastructure
- Connecting solar plants in southern Europe and especially in North Africa (transcontinental Super Grid)

What Power Electronics Can Do

- Increase efficiency, reducing the losses in power conversion and transmission (HVDC)
- Feed renewable energy to the power grids (PV inverter, wind turbine generator)
- Enable energy recovery (recuperation)

3.2 Three technologies – information processing, power processing and sensors&actuators – converge to enable smart energy efficient systems

People have realised that power electronics can contribute to energy saving and improved efficiency in several aspects:

- Increasing efficiency of power electronic components, modules and systems by optimising component technology or circuit topology (e.g. for photovoltaic inverters or power supplies).
- Improving energy efficiency on system level applying power electronics (e.g. by introducing variable speed drives or enabling energy recovery or recuperation of electric drives e.g. in trains, cars or lifts).
- Energy savings with intelligent power electronics. The key for customer acceptance and market penetration is cost, requiring a (mechatronic) integration of power electronics in the application system, together with sensors and information and communication technologies.

A 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 of smart (remote) controlled power electronic systems are smart battery management systems or smart homes including lighting, heating and cooling. Further examples are load management, the use of decentralised energy storage systems for power quality function and grid stabilisation or 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 considerable market penetration. This can be achieved by smart integrated power electronic modules. Furthermore, these advanced integrated modules utilising high temperature power electronics and ultra-high power density mechatronics will help to keep power electronics production in Europe.

<u>Trends & Drivers</u>

- Reduction of volume and weight, leading to higher power density
- Mechatronic system integration

<u>Limiting Challenges and Technology Gaps</u>

- Cost effective integration technology
- Technology compatibility between Power and CMOS (low cost)

<u>What Power Electronics Can Do</u>

- Improve system level efficiency

3.3 Industry in Europe takes global leadership in smart energy efficient systems and products based on these converging technologies

- European industry has an excellent starting position to take global leadership in smart energy systems as Europe has, on the one side, a strong component and module industry (power semiconductors, driver and control ICs, integrated smart power, modules and IPEMs). On the other side, Europe has a very strong system industry covering many 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 -System on Chip (SoC) or System in Package (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

- <u>Trends & Drivers</u>

- Reduce of volume and weight increasing the power density
- Further integration e.g. mechatronic system integration
- Reduce costs

3.4 Universities and research centres in Europe take global leadership in research and innovation in electronics enabling efficient energy usage

In the near future, new opportunities for research and innovation will be opened due to the trend towards the more electric world: the penetration of renewable energy sources, more electric vehicles, more networked world, energy harvesting, etc. These trends look forward to reducing the global warming at a competitive cost so that the benefits can be extended to the whole society. These trends are also supported and encouraged by the European Commission and European governments' willingness to support energy efficiency initiatives.

Europe has a strong tradition in research on power electronics and related areas that has helped to keep a strong industry in power semiconductors and devices, power conversion, industrial process, motor drives, consumer appliances, lighting, portable devices, space applications, renewable generation and connection to the grid. However, the fast development in research and innovation in emerging countries like China, India, Brazil, Russia, as well as the strong centres in USA, Canada and Australia can limit the capacity of our existing knowledge to keep the innovation and research pace needed to maintain the EU industry and Universities in top position.

Skill shortage is a major concern for engineering industry and academia, as they rely on highly skilled staff in research and innovation. Proactive policies should be introduced to improve the uptake of science and engineering subjects in secondary schools and therefore increase the number of students doing engineering in university.

Strong research centres and universities will attract high achiever students to an exciting and motivating field, well supported by both government and industry, to generate new technologies and to face the challenges of the more electric world. The benefits for Europe of these strong research centres and universities are clear:

- Keep leadership position in research and innovation
- Provide skilled workforce and researchers to support the industry
- Foster the research and knowledge needed by industry to keep and even improve their positions
- Attract top level students and talent from both inside and outside EU to carry out research at doctoral and postdoctoral level.
- Develop new, more ecological and more efficient devices and systems.
- Achieve EC policies regarding energy efficiency.

3.5 Smart Grids in 2020 are able to handle 20% plus share of fluctuating renewable energy in an economic and efficient way

The fast evolution and implementation of clean renewable energy sources and the ever increasing high quality demand of customers will place significant changes and challenges for the power grid that must be tackled. These changes are also aligned and fostered by the European Commission policies, expressed in the EC 2006 green paper. According to this discussion document, the main objectives of the European energy policy are: sustainability, competitiveness and security of supply. Also, according to the 2020 initiative, 20% of the energy consumption in Europe and 33% of the electrical energy will be provided by renewable energy sources.

In parallel with the development and penetration of renewable energy sources, the improvement in the efficiency of hybrid electric vehicles and electric vehicles, promoted by the advances in energy storage, electrical drives and power electronic technologies, will lead to a significant increase in the fleet of low emissions electrical vehicles.

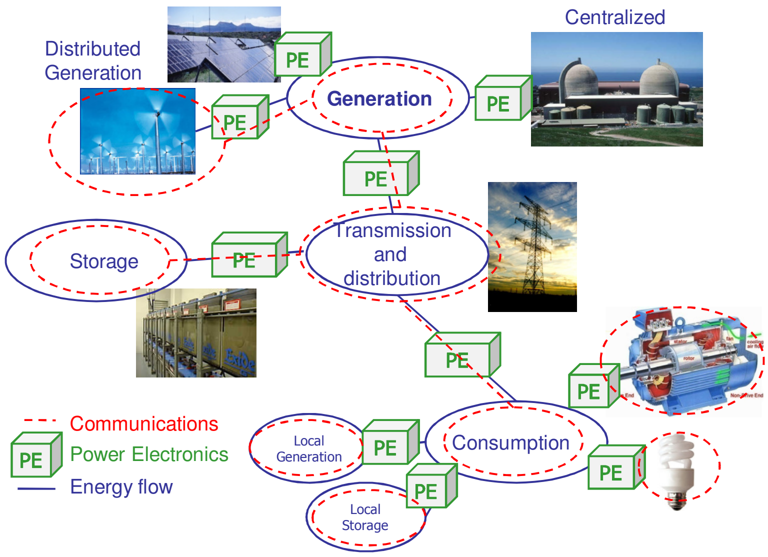

Figure 1: Schematic of future smart grid and impact of power electronics.

The massive force of these small electric generators and storage systems, the electric vehicles, can help to support the large-scale renewable energy sources and to stabilise the grid. This situation will make possible the vehicle-to-grid (V2G) implementation, allowing a more efficient use of the energy.

The change in the conception of the traditional grid to a situation in which more actors come to play will pose significant technological challenges that have to be faced. The smart grids have to fulfil customers' necessities providing power where it is needed and when it is needed, trying to provide most of the energy from renewable sources at high efficiency with low carbon emissions. The quality and the security of supply must also be assured, and all this has to be provided in an economical and sustainable way.

The high complexity of future smart-grid and plug-in electric vehicles to support the grid will have to be handled by the integration of three main technologies: new smart and efficient power electronics systems, seamless monitoring systems and communication and information processing technologies. A significant effort in research in all these technologies will enable the high penetration of renewable energy sources, the massive introduction of more efficient electric vehicles and the interaction of both concepts to optimise the energy processing chain.

3.6 Zero-emission e-mobility in megacities

Plug-in hybrid electric vehicles (PHEVs) which combine today's hybrid automotive technology with larger battery systems that can be recharged from the electrical grid are expected to enter the market in 2010. At the same time, full electric city cars (EVs) using lithium-ion energy storage technology enabling a driving range of 100–250 km will soon be widely available. Fleet tests are running in several European cities e.g. in London and Berlin. Recently, four German Federal Ministries have launched a "National Development Plan on Electric Mobility" announcing a plan to put a million plug-in cars on the roads by 2020.

This move to a more electric mobility will challenge the existing electric grids. An infrastructure is needed to charge the electric vehicles from the grid which has to supply the energy for this additional load. On the other side, it is possible to make the distributed energy storage capacity of these EVs available to the grid while increasing the share of fluctuating renewable energy sources.

Power electronics together with information and communication technologies is the key to meet these challenges, providing the bidirectional flow of energy and information between the electric car and the grid.

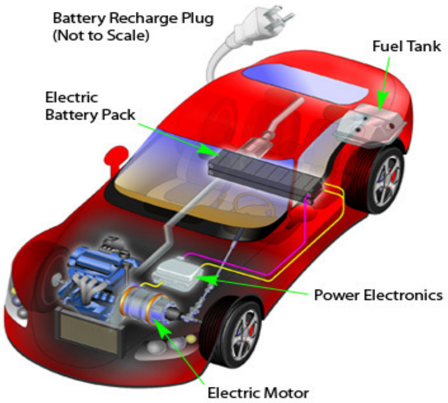

Figure 2: Schematic of a plug-in hybrid electric car

<u>Trends & Drivers</u>

- Finiteness of fossil energy sources
- World climate protection: reduction of CO_2 emissions
- Wider energy basis: reducing the dependency from oil and gas (reducing political dependencies)
- Use of renewable energy sources for individual mobility
- Reducing local emissions: pollutants, fine dust and noise
- Vehicle-to-Grid: improve the efficiency and stability of the power grid, enabling the further use of renewables

<u>Limiting Challenges and Technology Gaps</u>

- High costs and limited energy density of energy storage devices
- Integrated charging infrastructure required

<u>What Power Electronics Can Do</u>

- Efficient on-board power conversion enabling energy recovery
- Fast and efficient battery charging
- Intelligent energy management for the battery
- Providing bidirectional vehicle-to-grid power and information/communication interface

3.7 Halving life-cycle costs of buildings including lighting and climate conditioning

While it is generally perceived that the main life-cycle cost of a building occurs during construction, it has been shown that the running energy costs including Climate Control (HVAC: heating, ventilation and air conditioning) and Lighting can account for half the total life-cycle cost of a building. The introduction of more energy efficient technologies during construction can and will contribute to increase the initial cost of the building. However, energy savings achieved during the total life of the building will halve the life-cycle costs. According to the Electra Report[6], energy consumption in residential and commercial (tertiary) buildings in Europe in 2005 accounted for 280 and 157 Mtoe respectively. At the current level of consumption growth, these figures will keep increasing to reach 338 and 211 Mtoe by 2020 if nothing is done. There is, however, an energy saving potential of 30% if energy efficiency is implemented.

The two main power consumers in tertiary buildings (and also large consumers in private dwellings) are lighting and HVAC. Therefore, energy efficiency measures to reduce energy consumption in these areas are essential. Furthermore, buildings generating their own energy (PV, solar, micro-wind) will become energy neutral or even energy generators. This will reduce the life-cycle cost of a building to just the construction and physical maintenance costs, with no energy cost or even energy revenue.

This vision can only achieved if additional costs of including energy efficiency measures and systems during construction are small compared with the overall construction costs. Therefore, the power electronics must achieve the required efficiency, but within limited costs.

Building developers and owners/occupiers are generally different entities with different interests. The first ones are responsible of (and will try to reduce) initial costs, the second are more interested on energy running costs. Therefore, this vision can only be achieved if both work in partnership. Furthermore, building regulations and energy rating of buildings will be necessary to encourage developers to include energy efficiency measures during construction.

[6] Electra Report, EC http://ec.europa.eu/enterprise/electr_equipment/electra.htm

The following table summarises the areas where energy efficiency is required and the corresponding power electronics solutions.

Energy Efficiency Requirements	Power Electronics Solutions
Stable and reliable local generation (PV, micro-wind, …), transmission and distribution	▪ Voltage/current stabilisers ▪ Load monitoring and control ▪ Active/reactive power control (power factor compensation) ▪ High efficiency converters, inverters
Low consumption (high efficiency) loads	HVAC ▪ Efficient motor drives (fans, pumps, compressors, …) ▪ Variable speed drives ▪ Partial load operation ▪ Dynamic torque/current optimisation Lighting ▪ High efficiency sources: e.g. LEDs
Use optimisation – Intelligent automation and control	Intelligent climate control ▪ Continuous control of temperature, humidity, air flow, insolation, … Intelligent lighting control ▪ Constant luminous intensity ▪ Occupancy sensing Wireless and wired sensors

According to the Electra Report [4], energy management systems are a fundamental part of the overall solution by allowing optimised use of energy, general reliability, and sustainability of performance.

3.8 Energy on demand for ICT and wireless energy supply for mobile applications

The high penetration and growth of information and communication technologies is placing significant challenges from the point of view of energy consumption, energy management, cooling and costs. According to some studies, the use of Internet is growing 10% per year worldwide. This growth is supported by the increase of applications and uses of the net: information access, music and video on demand, online gaming, e-commerce, social networking interfaces and voice-over-Internet. This increase in the use of internet is also driving the increase of communications, personal digital devices, and processors and digital components.

Additionally, the penetration of micro-sensor networks, with hundreds and thousands of small distributed sensors gathering and sending information will pose significant challenges from the point of view of their autonomy. The use of the surrounding energy will clearly make the difference between autonomous and non autonomous networks.

The importance of energy efficiency of ICT equipment nowadays is highlighted by current data centres, in which the Energy Cost to Acquisition Cost ratio (EAC) is close to three, meaning that the cost of the equipment is exceeded by the electricity bill of the three firsts years of operation. In the case of communications, the efficiency of conventional radio base stations is around 1.2% (to transmit 120 W it is necessary to waste 10 kW). It is clear that this situation is no longer acceptable and new solutions must be provided to sustain the growth of ICT due to the tremendous social benefits of their evolution.

To keep the growing pace of ICT, new developments and research in smart power electronics systems and devices are necessary. These should not only improve the efficiency of equipment but also overcome the thermal limitations that will limit its growth.

The use of intelligent load management, variation of the supply voltage according to the work load, and the integration of power electronics with the digital processors and devices can yield a tremendous improvement in the energy efficiency of all ICT systems. For example, the use of multi-core technologies to improve the performance per watt of current microprocessor can be improved even further if locally supplied cores can adapt their voltage according to their work load or even dynamically turn on and off their supply to follow the user demand.

To make this happen, a significant effort in research has to be made on enabling technologies that will bring into being this supply-on-demand concept.