POWER ELECTRONICS
A CRUCIAL AND STRATEGIC TECHNOLOGY FOR THE ENERGY TRANSITION AND ELECTRIFICATION

think
SMARTGRIDS

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EXECUTIVE SUMMARY

While the climate crisis and its consequences grow even stronger, emphasizing the urgent need for decarbonizing certain industrial uses and processes, Power Electronics (PE), albeit overlooked, is playing an increasingly important role, to the point that the energy transition **relies on PE in every corner as it impacts supply chains' resilience for "net-zero" technologies in Europe.**

Power electronics-based conversion systems play an essential role in applications using electric energy, from its production to its use, via transmission and distribution.

Today, PE is a key technology for :

- **Sustainable energy sources development,**
- **EV integration to the grid,**
- **European power systems interconnection,**
- **Energy storage,**
- **Power grid operation.**

This manifesto aims to highlight how crucial PE is to power grids, which **requires France and Europe to monitor and gauge their autonomy regarding this technology.**
It also sheds light on the changes needed for the grid that would stem from PE massive deployments as well as the challenges and opportunities in terms of sustainability and environmental footprint that need to be anticipated prior this deployment.

Last but not least, **it envisions a medium-term transformation of power distribution, particularly in the medium-voltage sector, and calls for more attention to be given to training, skilling, upskilling and research in the PE field.**

This document expresses the Think Smartgrids association's opinion. It was drafted under the guidance of its Scientific Advisory Board.
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MAIN RECOMMENDATIONS

Develop an open strategic autonomy to strengthen European resilience and competitiveness

Driven by growing demand linked to the energy transition, PE are at the nexus of major strategic challenges in terms of open strategic autonomy, competitiveness and European resilience. **This sector benefits from a very dynamic research field in French laboratories in particular, offering a wide range of technological solutions.** These include new large-gap semiconductor materials competing with silicon (SiC, GaN), as well as work on packaging, cooling, etc. **This "new deal" represents an opportunity to develop a strong industrial sector for power electronics in France and Europe.**

Standardize connection conditions and increase PE participation in power system operation

Massive electrification is increasing the number of devices connected to the power grid via PE. Yet, this dynamic impact on equipment and on the network still remains overlooked. Standards to ensure adequate operation of both the electrical network and connected equipment need to be adapted and supplemented.

In addition, **PE enable participation to the power system operation, thanks to the electrical power controllability as it is being exchanged to the grid.**

Assess environmental impact and develop a circularity chain

PE's benefits for **energy decarbonization cannot be outweighted by its environmental footprint** throughout its life cycle - from raw materials extraction to end-of-life waste. Inverter manufacturers therefore need to implement eco-design at the design stage, addressing **very early in the process circularity issues and documenting databases to quantify the electrical equipment's environmental footprint.**

Make PE as reliable as any power grid equipment

PE's massive rollout means bringing this technology up to the same level of reliability as other network equipment. **However, the electrical and thermal stresses induced on converter components are far more severe than in other kinds of electronics.** Moreover, given this greater fragility, it is essential to get proper information on the estimated converters' lifetime. A major research effort is needed to understand failure mechanisms, propose more robust designs, identify relevant indicators and elaborate a prognosis.

Support innovative PE developments and services on medium-voltage networks

Medium voltage is a key element in the development of **future electrical infrastructures, essential for the massive integration of new renewable energy sources**, as well as for electrification to replace carbon-heavy energies. Power electronics is a key technology for these future networks, enabling new functionalities (electrical constraints reduction, network capacity increase, use of FACTS systems, MVDC networks or lines, etc.).

Strengthening EP's expertise through substantial support for training, skilling and research

Electrification and the ensuing PE-based conversion will increase demand for training at all levels of study tenfold. This will require a strategic plan to increase its related technological fields' attractiveness and bolstering partnerhsips with the European industrial ecosystem.

“Electrification and the ensuing PE-based conversion will increase demand for training at all levels of study tenfold.”

1. POWER ELECTRONICS : AN ESSENTIAL AND STRATEGIC TECHNOLOGY FOR A LOW-CARBON ELECTRIC SYSTEM

1.1 PE FOR RE-BASED ELECTRICITY GENERATION

Many renewable energy (RE) generation sources deliver electrical energy in continuous (DC) or variable-frequency alternating (AC) form. **To enable them to be connected to power grids, the electricity generated must be conditioned – thanks to Power Electronics (PE) converters** – o be compatible with the 50 Hz alternating frequency operation of distribution or transmission power grids.

Combined with dynamic control laws, PE maximizes the energy injected into the grid by intermittent generation. **RE's increasing contribution to the energy mix automatically leads to more PE converters connected to electricity grids.**

1.2 PE FOR EFFICIENT ELECTRICITY CONSUMPTION

PE is used massively on a daily basis for our energy consumption needs. 70% of electricity consumed is converted by PE[1].

Without PE, DC charging for electric vehicles from an AC grid is impossible, just like countless "wireless" applications. In addition to converting electrical energy, PE can power most electrical equipment (computers, TVs, etc.).

The control functions intrinsic to the operation of electronic converters are also leveraged for a more efficient electricity consumption: for example, LED lighting with variable light intensity, soft start-up of heat pumps to avoid power peaks, thermal control of air conditioners, etc.

1.3 PE FOR ENERGY STORAGE

Power grids are facing highly variable demands, both from new electrical loads (electric vehicles, heat pumps, etc.) and from RES deployment.

Storage devices can improve power system performance in terms of energy management for overall balancing between electricity production and consumption, power quality and behavior in the case of failure from the grid. Their role is set to become much more important to reach the energy transition's goals.

PE provides essential interfaces for bidirectional, fast-response (on-load and off-load) energy transfers between storage units and the grid, and enable additional control functions such as reactive power generation/consumption, AC voltage RMS value maintenance, fast (primary) frequency control, contribution to system stability, active harmonic filtering and inertial response synthesis (virtual inertia).

1.4 PE FOR ELECTRICITY TRANSMISSION AND DISTRIBUTION

Power lines' physical characteristics are not suited to very high AC power transmission (>1GW) over long overhead lines (>500 km). It is especially true for underground (or submarine) connections over 50 km.

Thus, interconnected continental AC transmission grids' reinforcement often involves **underground connections in DC technology** (France-Spain, France-England or France-Italy interconnections, but also in German North-South interconnection projects). This means that conversion systems are needed to switch from AC to DC (and vice versa). All of which is PE-enabled.

These developments also affect medium- and low-voltage distribution networks: using converters on generation units to reduce constraints and increase reception capacities, and at a very local level offering complementary medium- or low-voltage DC connection solutions to connect PV producers or electric vehicle charging stations.

What all these applications have in common is their reliance on a single technology: PE, which plays an essential role in achieving the energy transition's goals. Although this technology has reached a certain level of maturity, it still requires major efforts from many stakeholders, both in terms of integration into electrical systems (the control capabilities that can be provided by PE, and the interactions between these devices to guarantee overall reliability), and in terms of improving the performance of electronic components to reduce costs and enable new applications to emerge.

1. https://www.hitachienergy.com/news/perspectives/2021/08/power-electronics-revolutionizing-the-world-s-future-energy-systems

PE's role in Photovoltaics and Wind Turbines

Driven by the need to reduce the ecological and economic cost of the electricity produced, wind and PV systems have undergone substantial technological evolution over the last few decades, thanks to advances in the power semiconductors' field.

The peak power produced by a photovoltaic panel is now approaching 200W/m² under DC conditions. **PE is essential not only for generating an AC wave suitable for the electrical grid, but also for adapting the panel's operating point in real time to maximize power generation.** To create a high-power PV plant, many panels need to be combined (in series and/or parallel). In such settings, a PE-based inverter connected to an array of solar panels maximizes power generation. This way, a PV power plant can use several inverters, each one being dedicated to one set of solar panels. Alternatively, all the panels can be connected to a single (centralized) high-power inverter, in this case a central inverter. Both inverter installation techniques are widely adopted in practice.

Wind power systems have gone from a nominal unit power of 50 kW in the 80s to up to 15 MW in recent years, with the same trend towards more powerful on-board PE for energy conversion, controlled management of power transfer to the grid and internal protection.

PE's control on power enables participation to electric system's operation

A common function of the electronic conversion stages of an RES-based system is to transfer energy to the grid according to the RE's dynamic (the power delivered depends on ambient conditions, e.g. wind speed, or irradiance level). This means optimizing electricity production based on primary energy variability, a function known as MPPT (Maximum Power Point Tracker).

The ability to control the power exchanged with the grid has led to the development of software functions to improve the performance and integration of a wide range of electrical equipment into the existing grid. When controlling the converter connected to the grid, the aim is to ensure that high-quality currents are generated or consumed (e.g. low THD). Therefore, in many cases, currents exchanged with the network are controlled by PE.

Finally, today's PE can offer a wide range of control functions, enabling them to play an active role in power system operation, such as frequency control, dynamic consumption of reactive power or injection...

Major material improvements in PE for RE, but some challenges need to be addressed

Whether it is for large wind or PV farms, or for domestic power generation, energy conversion must be as efficient as possible to reduce energy costs.

By increasing the components' power density, it is possible to reduce mass, volume and costs.. For offshore wind turbines, for example, higher power density of semiconductors leads to lower installation costs, which in turn helps reduce wind power generation's costs. As was the case in the early days of AC networks, higher converter operating voltages will lead to a technical and economic optimum. High-voltage operation represents an additional challenge in terms of power converter topologies, passive filter design and integration, and control, particularly with the increasing use of Wide Band Gap (WBG) semiconductors to improve efficiency.

PE and HVDC

Historically, HVDC transmission networks have used an LCC (Line Commutated Converter) configuration based on low-cost semiconductor technologies organized in simple structures and driven by time-shifted pulses to reduce harmonics. However, their controllability is poor. These constraints have led to the development of transistor-based electronic converters, which are also more compact. This is an advantage for offshore platforms, where space is limited and the cost of one m² is a major factor in the overall project's expenses.

Numerous PE devices are used to raise and lower the DC voltage level. In this respect, the investment in HVDC substations makes the HVDC system more expensive than the HVAC system. However, at the same power level, the cables of an HVDC system require fewer electrical conductors and are less expensive than those of an HVAC transmission system. What's more, HVDC technology delivers greater dynamic range (1GW / 100ms) and accuracy of power flow control, and eliminates the need for intermediate substations to compensate for reactive power. Additionally it keeps line voltage relatively constant. Finally, HVDC technology is economically viable for long-distance power transmission and is being increasingly used.

However, challenges associated with direct-current circuit breakers, but also with meshed HVDC networks (directly via other EP converters) called multi-terminal, still need to be addressed, because of the need for interoperability of solutions for instance.

2. DEVELOP AN OPEN STRATEGIC AUTONOMY TO STRENGTHEN EUROPEAN RESILIENCE AND COMPETITIVENESS

2.1 NEW MATERIALS WITH NEW PROPERTIES FOR SEMI-CONDUCTORS' MANUFACTURE

Semiconductors are materials with controllable electrical conductivity. They are used in the manufacture of power converters to modify and control energy flows at their point of connection to the electrical grid, and indirectly across the entire network.

Today, new materials are leading to significant and rapid technological improvements. This represents an opportunity to develop a strong PE sector in Europe and France.

2.2 EUROPE'S STRENGTHS: R&D, INDUSTRIES AND GROWING MARKETS

The PE sector is supported by France's world-renowned PE research ecosystem with areas of expertise ranging from cutting-edge semiconductor materials to the development of full-scale equipment and applications for power grids. **However, major industrial stakeholders' presence in the semiconductor field is very limited** (STMictroelectronics). At European level, semiconductor component foundries are active in SiC technologies (Germany, Infineon), (Switzerland, HITACHI), (Italy, STMicroelectronics), GaN (France, STM), (Belgium, BelGaN), (Germany, Infineon) and emerging large-gap substrates: France (SiC & GaN, Diamant), Germany (SiC, AlN), Sweden (SiC, GaN), Poland (GaN Substrate).

Mastering the encapsulation of these components in appropriate packages and modules is also very important for their use. This market is dominated by German (Infineon, Semikron) and Japanese (Mitsubishi, Fuji) stakeholders. France lacks industrial stakeholders in these activities. Electronic converters manufacturers for industrial, transport and automotive sectors are much more numerous and spread out all across Europe. Connectors, printed circuit boards, embedded software and software tools for the design of controlled electronic systems are also well covered by a network of SMEs. **This sector is set to expand as new markets open up in line with the growing trend towards low-carbon electrification as part of the energy transition.** For electrical systems, the major growth markets with strong demand for PE are those linked to EN charging, industrial transitions towards the decarbonized electricity vector, intermittent renewable energy power generation, and energy savings through the electronically variable speed systems deployment. For high-voltage DC applications, skills in France remain scarce.

At the same time, there is a growing demand for communication and intelligence functionalities development on electronic converters, or in connection with their processes, to meet new uses based on energy use monitoring and management.

2.3 ELECTRONICS IS AT THE HEART OF MAJOR STRATEGIC CHALLENGES FOR EUROPEAN RESILIENCE AND COMPETITIVENESS

However, the vast majority of basic electronic components are produced in Asia. **Semi-conductors' shortage that hit during the COVID crisis and continued afterwards showed the limits to their highly globalized production chain, and France and Europe's heavy reliance in terms of supply.** With global growth in energy technologies, there is still a high risk of shortages in the face of exponential demand.

Furthermore, the PE industry is struggling with **over-dependence on non-EU countries with a high concentration of supplies.** Strategic and competitive autonomy losses are numerous, as many examples have showed - PV panels, lithium-ion batteries, critical raw minerals refining.

Given those proven vulnerabilities, it is essential for France and Europe to ensure their own economic, technological and industrial control of the sectors that are essential to their energy transition.

2.4 FOR A EUROPEAN INDUSTRIALIZATION OF SEMICONDUCTORS, POWER CONVERTER AND POWER GRID MANUFACTURING

To overcome supply disruptions and excessive dependence on imports, we need to relocate a competitive PE manufacturing industry in Europe. This involves identifying market gaps and critical raw materials (Galium, etc.) for the electronics industry, in order to prioritize the most promising, high-performance semiconductor components' manufacture.

The risk also includes "ancillary" components' supply – those are needed to build conversion equipment, as well as the materials they are made of. It is therefore equally important to support industrial players 'emergence and strengthen their activity in this field. This will facilitate technologies' enhancement and transfer – for example, for those developed in research laboratories with worldwide expertise, as in the field of GaN technology.

This industry is facing challenges not only in terms of competitiveness, but also in terms of responsiveness and flexibility to meet demand, which is constantly evolving in line with emerging technologies and the variability of volumes demanded by markets. Optimizing supply chains means improving design, production and distribution processes, right through the power converter delivery.

Lastly, most European and French stakeholders are small and therefore have lower investment capacities compared to their American and Asian competitors. Investment support is essential to meet the challenges ahead.

Like battery gigafactories, these industrial development projects require public co-financing and support in terms of territorial location, without which they could not see the light of day.

HVDC applications in transport networks are an exception, with the three main suppliers in Europe and a clear lag in development in North America.

"Optimizing supply chains means improving design, production and distribution processes, right through the power converter delivery."

New industrial forces outside of Europe are rapidly emerging

Europe and the United States currently produce the majority of wide-gap power components. However, large-scale investment in recent years has led to the emergence of Chinese manufacturers in the market for third-generation substrates and components, whose competitiveness continues to steadily grow.

According to forecasts, the market share of these new competitors is likely to rise sharply t **rom less than 5% to 50% in the next few years.**

New semi-conductors technologies

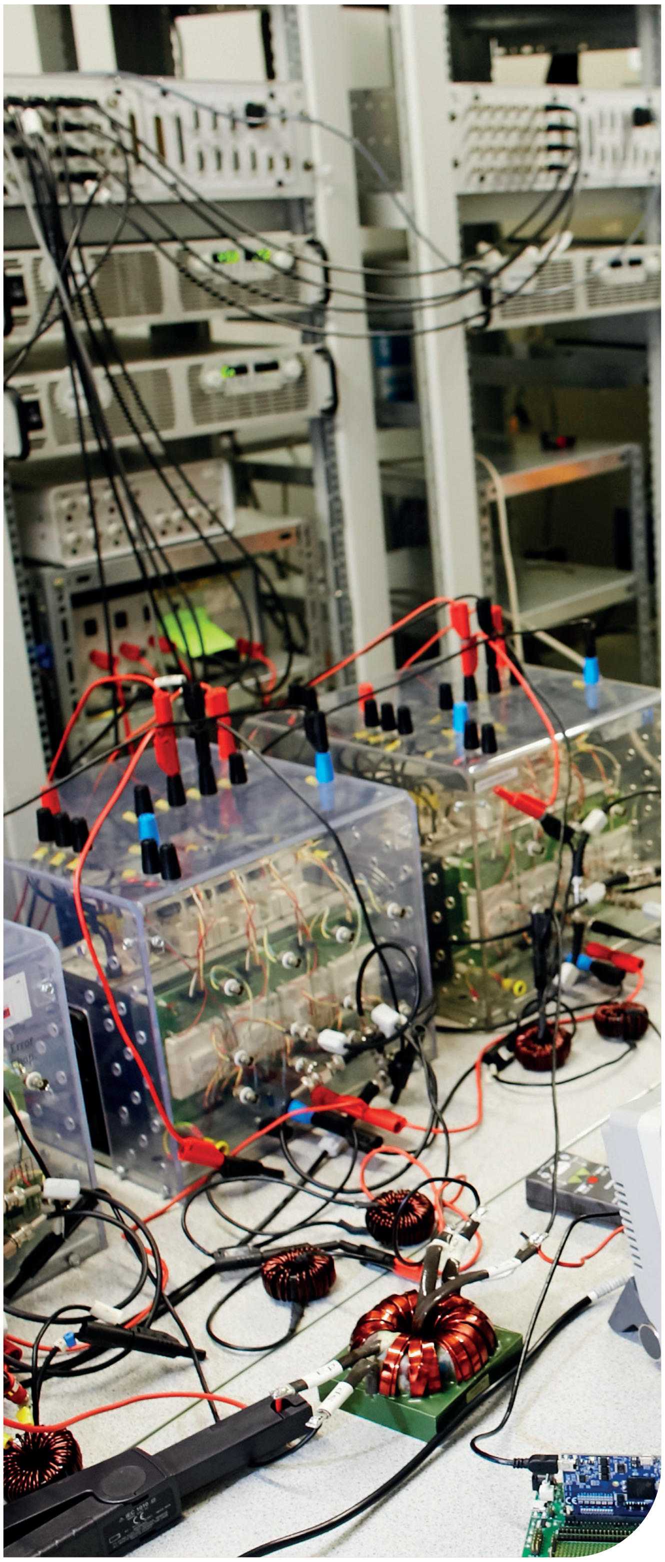
Historically, silicon has been used to manufacture current electronic components: IGBTs and MOSFETs. However, the use of wide bandgap semiconductor materials allows to produce electronic components with very low internal electrical resistance and extremely fast switching times (transitioning from conducting to blocking state and vice versa).These two properties lead to better efficiencies (in conduction and switching) and better miniaturization of the associated passive components – therefore the converter produced as well.

Ultimately, the resulting increase in the converters' power density enables a reduction in size and weight, along with a higher conversion efficiency.

Gallium nitride (GaN) is particularly interesting due to its performance at very high frequencies (beyond 100 kHz) and is fit for low voltage applications (650V). However, R&D efforts are extending this voltage limit up to 1200V. As for silicon carbide (SiC), which is rapidly growing due to the hybrid and electric vehicle charging market, it could also become prominent for high-voltage converters and high-power applications.

In terms of R&D, transitioning to larger substrates (8 inches for SiC and 12 inches for GaN) and exploring new materials with ultra wide band gap properties leads to continuous evolution. For example, materials like gallium oxide (Ga2O3), aluminum nitride (AlN), and diamond show interesting wide bandgap semiconductor properties, enabling manufacture of components that are even more efficient in terms of switching speed and reduced losses.

Miniaturization and increased yields are accompanied by the implementation innovative passive components, such as new winding techniques, new types of transformers like planar transformers, and new magnetic materials from ferrite manufacturers.



3. STANDARDIZE CONNECTION CONDITIONS AND INCREASE PE PARTICIPATION IN POWER SYSTEM OPERATION

3.1 POSSIBLE CONTRIBUTIONS TO POWER GRID OPERATIONS

Power electronic converters are controllable and can set or modify energy flows at their connection point based on the grid's needs for proper operation. PE's ability to offer necessary services to the electrical system's effective functioning is still uncertain. Existing solutions have been identified (such as reactive power control from photovoltaic inverters), but the main issues focus on power generation units' connection to the grid via PE. Understanding, modeling, measuring and managing impacts, as well as identifying optimal locations and adjustment capacities remain key issues.

Currently connected electronic converters (mostly PV inverters) are controlled to behave as power injectors ("grid feeding / following") through the current they inject. Their participation in regulating the electrical system (frequency/voltage) is limited **since they require a voltage that meets standards at their terminals to enable synchronization. Therefore, "conventional" alternators are necessary to provide inertia to the system.**

Research has been developed over the past decade to control them as voltage sources, and thus frequency sources (an operation mode known as "grid forming"). This mode can enhance the system by increasing its stability ranges while providing inertia through converter control. This approach thus requires software adaptations to the control law and overcurrent converter protection

3.2 POORLY UNDERSTOOD DYNAMIC IMPACTS LINKED TO MASSIVE PE CONNECTIONS

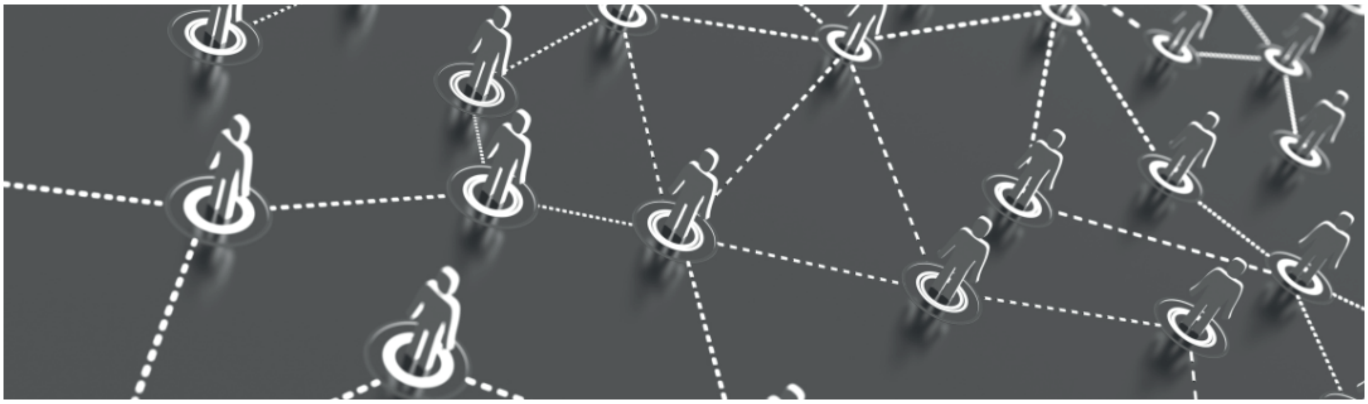
Electronic converters' performance and characteristics differ from today's conventional equipment. A high rate of connection via PE means that we need to be able to ensure impacts on near-real-time frequency, voltage, stability regulation as well as on the protection systems that ensure human and equipment safety.

In terms of R&D, this will require precise dynamic modeling tools that are representative of these impacts, in order to preserve power system reliability under steady-state, transient and restoration conditions.

3.3 STANDARDIZATION NEEDS

A massive spate of electrical equipment connection via PE can lead to significant disturbances to electrical system operation, distorting the 50Hz AC voltage wave.

In order to comply with acceptable quality levels for electrical quantities, it is essential to ensure that EMC (Electro-Magnetic Compatibility) standards for equipment (emission / immunity / compatibility / measurements) and voltage quality are all consistent with real-life power system situations, without leading to over-quality and unjustified costs. Attention must be paid to new developments around Smart Grids (e.g. use of PLC (Power Line Communication) on the 2 - 150 kHz frequency band for information transmission, while ensuring secure data transfer). For the grid operator, dealing with a non-quality situation on the grid is complex and costly. **Standards ensuring the correct operation of both the grid and connected equipment** need to be adapted and supplemented.



Towards desired demand behavior virtualization with control laws

As more and more electromechanical synchronous generators are taken off and replaced by systems connected by PE, the equivalent electromechanical inertia of the network and short-circuit powers decrease. This makes the electric power system less stable and more sensitive to incidents.

Additional control functions can nevertheless be implemented, such as synthesizing a dynamic inertial response (so as to behave like a conventional alternator), maintaining the connection under temporary faults originating from the grid (e.g. voltage drops) and even contributing to grid voltage restoration.

However, these new functions have an impact on conversion electronics' sizing, heat dissipation and cost.

Advanced grid control strategies

An increasing number of grid operators require large-scale wind and photovoltaic power plants to be able to dampen power oscillations and participate in grid reconstruction (black start) in the event of a blackout. This enhances the power system's transient stability and, at the same time, renewable energy generation systems' availability.

Intrinsic operating causes

Both the non-linear characteristics of PE components and converter control laws are responsible for undesirable higher-frequency voltage and current elements (**harmonics**, i.e. distortions of the AC voltage wave). Even if each piece of connected equipment complies with current standards, the increase in their number leads to interactions between the various devices, resulting in parallel or series resonances, depending on the power system's impedances.

The absence of suitable standardization in this situation leads to complex connection procedures for the various stakeholders involved (customers, manufacturers and DSO).

The challenge is to simplify and accelerate these procedures, while protecting networks from uncontrolled disturbances.

“The absence of suitable standardization in this situation leads to complex connection procedures for the various stakeholders involved (customers, manufacturers and DSO).”

4. ASSESS ENVIRONMENTAL IMPACTS AND DEVELOP A CIRCULARITY CHAIN

Used to reduce energy losses, integrate renewable energy sources into the electrical system and optimize power quality, PE thus play an essential role in the energy transition and optimize some resource use involved in the infrastructures involved.

However, PE systems have their own environmental footprint throughout their life cycle, from greenhouse gas emissions and high energy consumption during manufacture, to performance during use, and environmental and social impact from raw material extraction to waste management.

4.1 RECYCLABILITY MUST BE MASSIVELY DEVELOPED

Given the high demand for raw materials, recycling materials at the end of a converter's life cycle is necessary to reduce the pressure on demand for materials and thus limit the impacts associated with their extraction, although this is also a source of impacts to be anticipated.

Right from the design stage, it is worthwhile optimizing the functional life of systems, increasing circularity by facilitating their disassembly, repairability, total or partial reuse (reconditioning), disassembly for remanufacturing. However, after collection, this recycling chain still needs to be built and organized on the scale of the massive development of EP.

4.2 ENHANCING PE SUSTAINABILITY THROUGH ECO-DESIGN

Introducing environmental requirements would encourage eco-design for PE-based products, as well as a circular economy. Integrating eco-design methods at the very early stages of system design process can help integrate all requirements.

Developing methods based on system's functional analysis can help designers integrate those issues through technical choices they make while defining system topologies. This can help **mitigate environmental and negative social impacts.**

Last but not least, power systems development is subject to a series of European regulations (e.g. Critical Raw Material Act, Ecodesign for Sustainable Products Regulation) translated into **European and international standards which require PE devices characteristics and systems to be ecodesigned** before they can be put on the market. All these requirements are evolving relatively rapidly due to ecological transition and international market tension.

> **“Integrating eco-design methods at the very early stages of system design process can help integrate all requirements.”**

4.3 A STRONG NEED FOR RELIABLE DATA FOR LIFE CYCLE ASSESSMENTS (LCA)

Accounting for environmental impacts, including the carbon footprint integrating greenhouse gas emissions over the entire life cycle of systems, i.e. from the extraction of the resources required for their manufacture to end-of-life, is essential to eco-design.

In fact, LCAs use several categories of environmental impact **indicators** and several stages in the life cycle of the systems designed. Calculation is based on inputs (material and energy resources), emissions and waste at each stage of each industrial process involved.

To date, few LCAs are provided by manufacturers, due to a lack of data or traceability.
Yet they are essential to answer key issues - how many kW.h converted, is the CO2 initially emitted for the design of the conversion system offset by emissions reduction during use, and **is this "justified" regarding the potentially countless and irremediable other environmental impacts generated?**

Future power grids will be systemically dependent on PE systems. **As a result, tools and methods for analyzing such ecosystems' sustainability are to be developed and harmonized.**

4.4 NON-CARBON IMPACTS ARE YET TO BE PRECISELY ASSESSED

PE generates other environmental impacts, such as resource depletion due to increased pressure on critical materials. These constraints are further compounded by the technological challenges and responses outlined above.

Strong growth in demand for PE could lead to market imbalances, supply risks and, more generally, dependence on third countries (non EU Member States).

It is therefore necessary to assess the criticality of the materials used, in order to prioritize the least impacting converter technologies.

Extracting and refining critical materials also has numerous social and environmental impacts, in terms of working conditions in mines, water resources and local pollution, all of which need to be taken into account in CSR policies..

5. MAKE PE AS RELIABLE AS ANY POWER GRID EQUIPMENT

Electrical transmission and distribution network equipment has a lifespan of several decades.

But before static converters can achieve such a long service life, there are still many technical challenges to overcome. Several studies have shown that the most fragile components are capacitors and semiconductors.

For the same size, large-gap semiconductors have smaller surface areas than silicon components, which generates greater thermal and thermo-mechanical stresses. **It is important to understand the physical phenomena associated with these degradation modes. Research needs to be done on mechanical stress analysis and fracture physics.**

To avoid having to take a system out of service for too long, and to be able to plan for this, we need implement damage monitoring tools to enable predictive maintenance. To achieve this, some obstacles need to be overcome.

First of all, reliable damage indicators need to be identified: these are generally electrical or thermal quantities that are strongly intertwined, making it difficult to set up "health" monitoring tools. Under high voltage and with higher dynamics, the electrical quantities found in semiconductor components have a strong tendency to vary over time or depending on operating conditions.

There are two solutions: either identifying other physical methods for damage monitoring (ultrasound use, optical methods, etc.), or understanding the phenomena behind variations in electrical indicators for wide-gap components.

Next, algorithms for prognostics need to be developed in order to gauge the components' remaining lifetime. Artificial Intelligence could be a useful tool in this respect.

Integration of large-gap semiconductors is still to be improved

Semiconductor components' reducing in size drastically reduces available space for connecting bonding wires (current leads), which then are characterized by a higher power density.

Technological efforts must therefore be made to find more robust solutions at a reasonable cost, by using devices with different shapes (clips instead of bondings, for example) or materials with lower expansion coefficient.

6. SUPPORT INNOVATIVE PE DEVELOPMENT AND SERVICES ON MEDIUM-VOLTAGE NETWORKS

6.1 INNOVATIVE APPLICATION DEVELOPMENTS AND TECHNO-ECONOMIC BENEFITS

In the energy generation sector, wind or PV power plants' increasing size and power, potentially combined with massive storage systems, require conversion systems that must also increase in power for efficiency and competitiveness purposes..

When it comes to applications, the same trend is driving the need for higher-power conversion systems to support electrification, which must be reliable, flexible and efficient.

The increasing intensification and more widespread use of electricity will require local distribution infrastructures capable of supporting higher power densities. MVDC (Medium Voltage Direct Current) is currently being closely examined as a solution to meet this requirement, enabling an overall reduction in costs for internal electrical infrastructure, commonly referred to as the "Balance of Plant" for those installations.

MVDC is also being considered to reinforce networks in areas where traditional solutions are encountering difficulties. One example is the Angle-DC project in Scotland, where the replacement of a MVAC link by an MVDC link increases the power transited and improves grid stability, with the same or even a smaller footprint. In addition, some costly and time-consuming network reinforcements could be avoided by installing PE solutions at strategic points on the network, such as FACTS (Flexible Alternating Current Transmission) systems.

6.2 OPTIMIZING CONVERTER RANGES FOR MEDIUM-VOLTAGE APPLICATIONS (AC OR DC)

To facilitate the massive, sustainable and acceptable deployment of these electrical infrastructures, it will be necessary to have power conversion systems that are reliable, high-performance, flexible and competitive.

Substantial research and development efforts are essential for these little-explored power and voltage ranges. Indeed, much remains to be done to define the most efficient global solutions, optimally integrating PE components, converter architectures and their control.

A concrete example of these development priorities pertains to DC/DC converters, which will be at the heart of technological building blocks essential to many applications.

These include the development of modular, optimized power conversion structures to meet future industrial needs - massive storage, hydrogen production and other facilities.

6.3 FINANCE DEMONSTRATOR PROJECTS

Current research and development aimed at developing these future technological building blocks is mainly carried out in the laboratory, involving converter mock-ups or sub-components. **Given the powers and voltages involved, full-scale tests are hardly implemented and are very much limited by budget constraints.**

However, given the complexity of these systems, which combine several sub-components subject at the nexus of electrical, thermal and environmental constraints, it is of utmost importance to test them on a real scale. It is therefore crucial to have adequate budgets and resources to successfully reach the next stage of development and TRL (Technology Readiness Level).

These systems interact closely with the environments they are integrated in. It is therefore of paramount importance to move on from individual tests to testing in representative, even real-life situations, using demonstrators.

This transition makes it possible to assess one system's performance under real-life conditions and to better understand their behavior in complex contexts, thus contributing to more robust and efficient implementation of the technologies developed.

7. STRENGTHEN PE EXPERTISE THROUGH SUBSTANTIAL SUPPORT FOR TRAINING AND RESEARCH

7.1 A MASSIVE NEED FOR SKILLED WORKERS TO TACKLE THOSE CHALLENGES

PE systems' massive deployment, combined with re-industrialization and in-house technological expertise, will generate very substantial needs for highly-skilled personnel.

Indeed, semi-conductor components' evolution **land digital control development, as well as various constraints in terms of compactness and reliability, among others, have radically transformed PE engineering and associated job titles.**

In addition, every stage in the product's lifecycle is to be scrutinized, from design and manufacture of systems in a reindustrialization approach, to maintenance to ensure that these systems function properly. Last but not least, those skills are also needed for recycling.

When it comes to HVDC power transmission networks, a strong link between European PE manufacturers and their training programs would create a strong base of "field" expertise that would benefit the entire industry.

For example, some sectors, such as electric vehicles, are consequently drastically changing their business model - from $4,000 million to $10,000 million in market value between 2022 and 2028, confirming the massive need for upskilling/re-skilling in a very short timeframe[2].

7.2 NEEDS AT ALL STUDY LEVELS

All levels from 2 year- bachelor degree to engineer and PhD will be concerned, which will require a significant improvement in the sector's attractiveness and in the technological field to the general public, but more specifically to young high school students.

Should industry players be able to tackle these technological challenges, achieving "net zero" objectives as quickly as possible and ensuring Europe's competitiveness, the EU needs to have a significant number of engineers and researchers trained in cutting-edge techniques..

This can only be achieved with strong support from the various stakeholders for Master/Engineer level training and research organizations. There is a major need for skills in drafting technical specifications for electronic converters based on expressed requirements (voltage/current levels, temperature, dimensions, analog and digital interfaces, losses, etc.), in parameterization and digital interfacing of converters, in mastering methods and tools linked to design (choice of power conversion architectures and sizing), and in drafting specifications based on knowledge of electrical network standards as well as suppliers' technologies and products.

Furthermore, these new systems' operation and maintenance will require maintenance workers familiar with PE techniques. This calls for strong support for 2 year technical degrees-type training courses, in order to develop or adapt courses in these fields.

7.3 THESE TECHNOLOGICAL FIELDS' ATTRACTIVENESS HAS TO BE IMPROVED

It will be necessary to improve the sector's visibility and attractiveness to attract young people and young women. Science and technology's study field has been suffering for several years. This will be all the more critical as these needs will be added to those linked to low-carbon power generation systems deployment.

Indeed, in the PV sector alone, projections linked to the relocation of the industry lead to estimates of several thousand jobs at technician/engineer level by 2030. **Well-identified technology clusters in France are forecasting a need for almost 3,000 new hires by 2027, in the Grand-Est and PACA regions' clusters alone.**

The transport sector will also boost demand following on the combustion-powered vehicles ban by 2035.

One could also mention the housing sector (with heat pumps) and the digital sector (powering servers): it's clear that the electrification movement and the accompanying PE-based conversion are exploding demand for training at all levels.

Certain technologies, such as converters, will see their market value rise sharply between 2023 and 2028 thanks to electric vehicles in Europe (DC chargers are expected to see a 22.3% jump in value) and renewable energies[2].

7.4 SUPPORTING THE ONGOING TRAINING OF CURRENTLY WORKING PERSONNEL IN THESE NEW TECHNIQUES

Workers who currently carry out maintenance on power grids shall not be overlooked. The transition from essentially electromechanical systems to highly electronic and controlled systems requires new knowledge and methodologies – therefore re and upskilling.

In the field of photovoltaics alone, which is a corollary of the growth in PE's development needs, the more than 5,000 new hires required by 2027 in metropolitan France require an average budget of 1,900 euros per person[3].

More generally, CHIPS of Europe believes that the EU Chips Act will also increase demand for skilled workers in the semiconductor industry - if no action is taken, **he sector will face a shortage of 350,000 workers by 2030[4].**

2. *Status of the Power Electronics Industry 2023 report, Yole Intelligence, 2023*
3. *Projet CAP PV, Data collected from a multiregional consortium (Energy Transition institutes, industrial sites, equipment manufacturers, networks of initial and continuing education stakeholders, vocational training campuses)*
4. *Press release CHIPS of Europe, project co-founded by the EU (Digital Europe), ECPE European Center for Power Electronics,* June 2024

THINK SMARTGRIDS FEDERATES AN ENTIRE ECOSYSTEM

The Think Smartgrids association unites a diverse range of stakeholders, including grid operators RTE and Enedis, leading French energy manufacturers and suppliers, major digital service providers, numerous French SMEs, ETIs, and cutting-edge startups in energy and digital technologies. Additionally, the association engages with academic and research institutions to foster innovation and collaboration.

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