Indonesian Journal of Electrical Engineering and Computer Science
Vol. 44, No. 1, October 2026, pp. 1~8
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v44.i1.pp1-8

Editorial

Power electronics as the intelligent energy interface of future electrical systems

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Article Info

Keywords:

Electrification
Energy conversion
Grid-forming converters
Intelligent energy interface
Power electronics
Wide-bandgap semiconductors

ABSTRACT

The accelerating electrification of transportation, industry, buildings, and energy infrastructure is fundamentally reshaping modern electrical systems. As renewable energy sources, distributed energy resources, energy storage systems, and intelligent loads continue to proliferate, electrical networks are becoming increasingly decentralized, bidirectional, and digitally interconnected. Within this evolving landscape, power electronics has emerged as an indispensable enabling technology that extends far beyond its traditional role in energy conversion. Modern power electronic converters are evolving into intelligent energy interfaces capable of regulating power flow, supporting grid stability, coordinating distributed energy resources, and facilitating real-time interaction between physical power infrastructures and digital control systems. This editorial argues that the future of electrical engineering will be increasingly defined by the integration of advanced power semiconductor devices, digital control, artificial intelligence, grid-forming technologies, and cyber-physical intelligence within power electronic systems. Together, these technologies enable adaptive, autonomous, and resilient operation across diverse applications, ranging from renewable energy integration and electric transportation to microgrids, industrial electrification, and future smart energy systems. Looking ahead, power electronics will become a strategic foundation for next-generation electrification by serving not merely as an energy conversion technology but as the intelligent interface that seamlessly connects energy sources, storage systems, electrical networks, and end-use applications in increasingly sustainable and interconnected energy ecosystems.

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Introduction

The global transition toward electrification is reshaping the technological landscape of modern society. Electricity is becoming the dominant energy carrier across transportation, industrial production, residential buildings, and digital infrastructure as nations pursue decarbonization, energy security, and sustainable economic development. The rapid deployment of renewable energy sources, battery energy storage systems, electric vehicles, hydrogen-based energy technologies, and smart manufacturing is accelerating the transformation of conventional electrical systems into highly interconnected, intelligent, and decentralized energy ecosystems. Consequently, electrical engineering is undergoing one of the most significant paradigm shifts since the establishment of modern power systems.

Unlike traditional electricity networks, future electrical systems are characterized by bidirectional power flows, distributed generation, extensive digitalization, and increasingly dynamic operating conditions. Renewable energy resources introduce variability and uncertainty into power generation, while distributed energy resources actively participate in energy management at both local and system-wide levels. Simultaneously, the proliferation of intelligent loads, fast electric vehicle charging infrastructure, data centers,

and industrial automation requires electrical systems to respond rapidly to continuously changing demand profiles. These developments demand unprecedented levels of flexibility, controllability, and interoperability throughout the entire energy ecosystem.

Power electronics has emerged as the technological foundation enabling this transformation. For decades, power electronic converters have primarily been viewed as efficient energy conversion devices responsible for converting electrical energy between different voltage levels, frequencies, and power sources. Their success has traditionally been measured by conversion efficiency, switching performance, power density, and reliability. Although these characteristics remain essential, they are no longer sufficient to satisfy the increasingly sophisticated operational requirements of future electrical systems.

Today, power electronic systems perform functions that extend far beyond conventional energy conversion. Modern converters continuously monitor electrical conditions, communicate with supervisory control systems, coordinate distributed energy resources, regulate bidirectional power flows, support grid voltage and frequency, and execute advanced control strategies in real time. Supported by digital control platforms, high-performance processors, advanced sensing technologies, artificial intelligence, and high-speed communication networks, power electronics is evolving into an active participant in system operation rather than a passive interface between electrical components.

This evolution is particularly evident across a wide range of emerging applications. Grid-forming converters enable stable operation in converter-dominated power systems with high shares of renewable generation. Bidirectional converters facilitate vehicle-to-grid services and flexible battery energy storage operation. Solid-state transformers provide intelligent power routing and enhanced grid controllability. Smart inverters improve renewable energy integration through adaptive voltage regulation and ancillary services, while intelligent motor drives optimize industrial energy efficiency and operational performance. Collectively, these developments demonstrate that power electronics is becoming the technological backbone connecting energy generation, storage, transmission, distribution, and utilization.

This editorial argues that the future role of power electronics should be understood from a broader systems perspective. Rather than serving solely as an energy conversion technology, power electronics is evolving into the intelligent energy interface that seamlessly integrates physical power infrastructure with digital intelligence. By combining advanced semiconductor devices, digital control, artificial intelligence, communication technologies, and grid-support functionalities, intelligent power electronic systems enable adaptive, autonomous, and resilient operation across increasingly electrified environments. This transformation fundamentally redefines the contribution of power electronics to modern electrical engineering and positions it as one of the key enabling technologies for future sustainable energy systems.

The remainder of this editorial explores this technological evolution in greater detail. Section 2 examines the progression of power electronics from conventional power conversion to intelligent energy interfaces. Subsequent sections discuss the enabling technologies, emerging applications, future challenges, and research directions that will shape the next generation of power electronic systems supporting increasingly electrified and interconnected societies.

Evolution of Power Electronics

Power electronics has undergone a remarkable transformation over the past several decades, evolving from a specialized technology for electrical energy conversion into a fundamental enabler of modern electrical systems. Initially developed to improve the efficiency and controllability of electrical energy conversion, conventional power electronic converters were primarily designed to perform well-defined functions, including AC–DC rectification, DC–AC inversion, DC–DC voltage regulation, and AC–AC frequency conversion. Their performance was largely evaluated using technical metrics such as conversion efficiency, switching frequency, power density, thermal performance, and reliability. These objectives remain important today; however, the role of power electronics has expanded considerably as electrical systems become increasingly decentralized, digitalized, and intelligent.

The widespread deployment of renewable energy sources, battery energy storage systems, electric vehicles, and distributed energy resources has fundamentally changed the operating environment of power electronic systems. Instead of functioning as isolated energy conversion units, modern converters now operate as interconnected components within highly dynamic electrical networks characterized by bidirectional power flows, variable generation, and distributed control. Consequently, converters are increasingly expected to contribute not only to efficient energy conversion but also to system stability, operational flexibility, power quality, and grid resilience.

This evolution has been enabled by significant advances in semiconductor technologies, digital signal processing, sensing, and communication. The emergence of wide-bandgap semiconductor devices, particularly silicon carbide (SiC) and gallium nitride (GaN), has substantially improved converter efficiency, switching speed, power density, and thermal performance. At the same time, increasingly powerful digital

controllers and embedded processors have enabled the implementation of sophisticated control algorithms capable of real-time optimization, adaptive regulation, predictive diagnostics, and coordinated operation across distributed energy systems. These technological advances have transformed power electronic converters into intelligent devices capable of perceiving operating conditions, processing information, and responding dynamically to changing system requirements.

An equally important milestone in this evolution is the transition from grid-following to grid-forming converter technologies. Conventional grid-following converters synchronize with existing grid voltage and frequency and therefore depend on a stable electrical network for proper operation. In contrast, grid-forming converters actively establish voltage and frequency references, emulate the dynamic characteristics of synchronous generators, and support stable operation in power systems with high penetrations of inverter-based resources. This capability is becoming increasingly important as conventional rotating machines are gradually replaced by converter-interfaced renewable generation and energy storage systems. Power electronics is therefore evolving from a passive interface that follows grid conditions into an active technology capable of shaping grid behavior.

Beyond advances in hardware and control, digitalization has further expanded the functional role of power electronics. Modern converters continuously exchange information with energy management systems, microgrid controllers, supervisory platforms, and cloud-based monitoring services. They generate operational data that support predictive maintenance, condition monitoring, fault diagnosis, and asset optimization throughout their operational lifecycle. Increasing integration with artificial intelligence, edge computing, digital twins, and industrial communication networks further enhances their capability to support autonomous decision-making and adaptive system operation. Consequently, the value of power electronics increasingly derives not only from efficient energy conversion but also from its ability to process information and coordinate intelligent system behavior.

These technological developments collectively redefine the identity of power electronics within future electrical systems. Rather than being viewed solely as energy conversion equipment, modern power electronic systems should be regarded as intelligent energy interfaces that seamlessly connect energy sources, storage systems, electrical networks, and end-use applications. They simultaneously manage the flow of electrical energy and operational information, enabling coordination across increasingly distributed and interconnected infrastructures. In this broader perspective, power electronics serves as the interface between the physical and digital domains of future energy systems, integrating advanced hardware, intelligent control, communication capabilities, and system-level decision support within a unified technological platform.

This functional evolution also reflects a broader shift in engineering philosophy. Historically, the primary objective of converter design was to maximize electrical performance through improved efficiency, reduced losses, and enhanced reliability. Today, these objectives are complemented by requirements for adaptability, interoperability, cybersecurity, and intelligence. Future power electronic systems are expected not only to convert energy efficiently but also to collaborate with other intelligent devices, respond autonomously to changing operating conditions, and contribute actively to the stability and resilience of increasingly complex electrical infrastructures. As a result, power electronics is emerging as one of the defining technologies that will shape the architecture and operation of next-generation electrical systems.

Figure 1 summarizes the evolution of power electronics from conventional energy conversion technology to an intelligent energy interface for future electrical systems. It illustrates the convergence of advanced semiconductor devices, digital control, artificial intelligence, communication networks, and grid-forming capabilities that collectively redefine the role of power electronics beyond efficient energy conversion. Rather than functioning solely as power converters, modern power electronic systems are emerging as intelligent platforms that seamlessly integrate energy processing, system control, and digital intelligence across increasingly interconnected electrical infrastructures. The following section explores these enabling technologies and their contributions to the development of intelligent, adaptive, and grid-interactive power electronic systems.

Intelligent Energy Interface

The transformation of power electronics from conventional energy conversion technology into an intelligent energy interface is driven by the convergence of advanced hardware, digital intelligence, communication technologies, and autonomous control. Modern power electronic systems are no longer designed solely to regulate voltage, current, or power flow. Instead, they are increasingly expected to perceive operating conditions, process information, coordinate distributed energy resources, and respond adaptively to rapidly changing system dynamics. As illustrated in Figure 1, this evolution is enabled by multiple complementary technologies that collectively integrate energy conversion with intelligent decision-making, thereby establishing power electronics as an active component of future electrical systems rather than a passive energy conversion device.

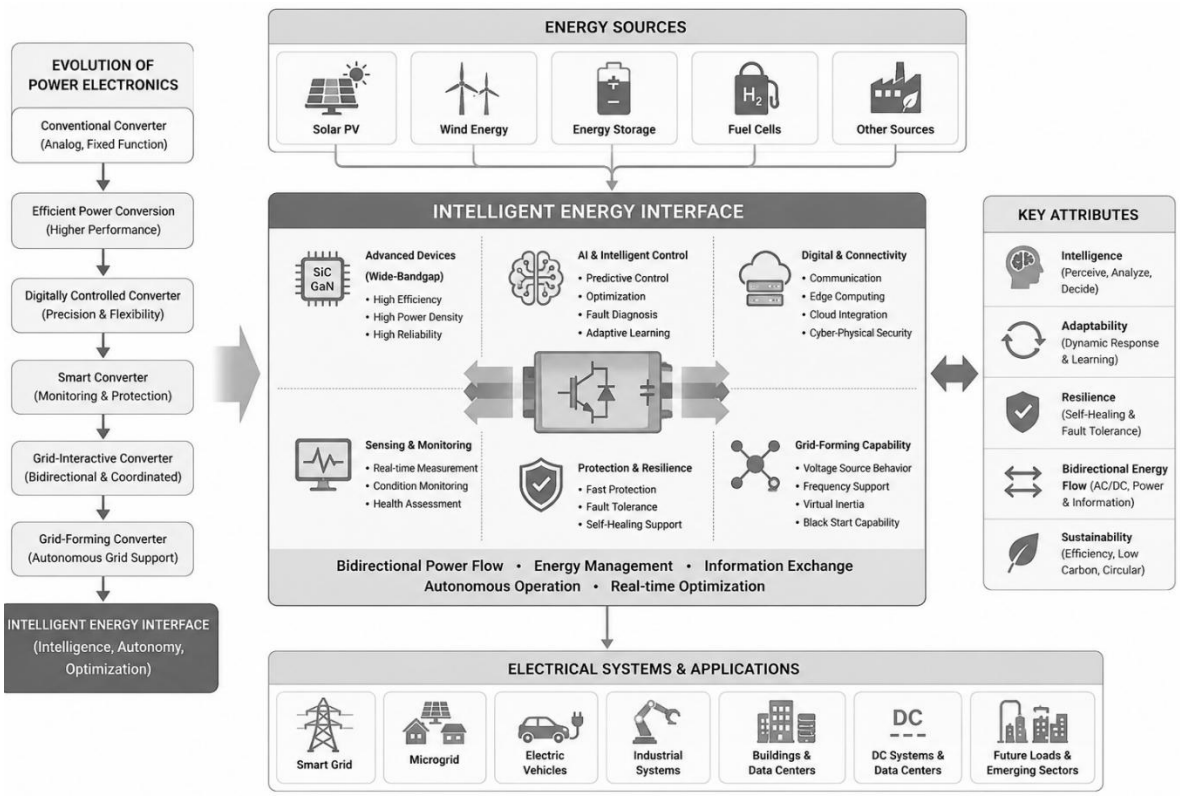

Figure 1. Evolution of power electronics from energy conversion to intelligent energy interface

Conventional power converters were primarily designed to maximize conversion efficiency, improve power quality, and ensure reliable operation under predefined operating conditions. While these objectives remain fundamental, future electrical systems require converters capable of adapting continuously to changing network conditions, fluctuating renewable generation, dynamic load demands, and distributed energy resources. Modern converters must also respond intelligently to increasingly complex operating environments by balancing multiple performance objectives, including efficiency, stability, power quality, and operational flexibility, in real time. Consequently, intelligent power conversion emphasizes adaptive operation rather than fixed control strategies. Instead of relying solely on predetermined control parameters, intelligent power electronic systems continuously adjust operating behavior according to evolving system conditions, enabling more responsive, coordinated, and resilient energy management across increasingly decentralized electrical networks.

Modern converters continuously monitor electrical variables such as voltage, current, frequency, harmonic distortion, temperature, and power quality. These measurements enable real-time optimization of switching strategies, converter efficiency, thermal management, and power sharing among interconnected devices. Intelligent control algorithms further allow converters to regulate bidirectional energy flows while maintaining system stability under highly variable operating conditions. As a result, power converters are evolving into autonomous energy management units capable of balancing efficiency, reliability, and operational flexibility simultaneously.

Artificial intelligence is becoming an increasingly important enabler of next-generation power electronic systems. Unlike conventional rule-based control methods, AI techniques enable converters to learn from operational data, recognize complex system behaviors, predict equipment degradation, and optimize control strategies under uncertain conditions. Machine learning, deep learning, and reinforcement learning are increasingly being investigated for applications including parameter estimation, predictive maintenance, fault diagnosis, adaptive control, and energy management.

AI also enhances the capability of converters to operate autonomously within increasingly decentralized electrical systems. By combining historical operational data with real-time measurements, intelligent converters can anticipate disturbances, optimize switching actions, and coordinate their operation with neighboring converters or distributed energy resources. Furthermore, AI-assisted diagnostics improve asset management by identifying abnormal operating conditions before equipment failures occur, thereby

increasing system availability and reducing maintenance costs. Rather than replacing conventional control techniques, artificial intelligence complements established control methodologies by providing higher-level decision support and adaptive optimization capabilities.

One of the most significant developments in modern power electronics is the emergence of grid-forming converter technology. As renewable generation and inverter-based resources continue to replace conventional synchronous generators, future electrical systems require converters capable of actively supporting voltage stability, frequency regulation, and system inertia. Grid-forming converters address these challenges by establishing stable voltage and frequency references rather than merely synchronizing with existing grid conditions. This capability becomes increasingly important in converter-dominated power systems, where maintaining stable system dynamics can no longer rely solely on the electromechanical characteristics of conventional rotating machines.

This capability fundamentally changes the role of power electronics within electrical networks. Instead of behaving as passive interfaces between renewable generation and the grid, grid-forming converters become active contributors to overall system stability. Grid-forming operation facilitates autonomous microgrid control, improves resilience during grid disturbances, enables seamless islanded operation, and supports black-start capability following large-scale outages. Advanced grid-forming control strategies further enhance system flexibility by enabling coordinated operation among multiple inverter-based resources, thereby strengthening voltage and frequency stability under increasingly dynamic operating conditions. Consequently, grid-forming technologies represent a major step toward converter-dominated power systems in which intelligent power electronics assumes many operational functions traditionally performed by rotating synchronous machines.

The digitalization of power electronics extends intelligence beyond converter hardware by integrating communication, computation, and data analytics into converter operation. Modern power electronic systems increasingly communicate with supervisory controllers, energy management systems, distributed energy resources, cloud platforms, and edge computing devices through standardized communication protocols. This connectivity enables coordinated control across multiple converters while providing continuous operational visibility throughout electrical infrastructures. Such digital connectivity also supports distributed decision-making, allowing geographically dispersed power electronic assets to cooperate in maintaining system stability and operational efficiency.

Digital twins, edge intelligence, and cloud-based analytics further enhance converter capabilities by supporting condition monitoring, predictive maintenance, performance optimization, and lifecycle management. Combined with advanced sensing technologies, these digital platforms enable converters to continuously evaluate operational status, detect anomalies, and recommend corrective actions before failures occur. Continuous data acquisition and intelligent analytics further support asset health assessment, remaining useful life estimation, and performance benchmarking, enabling more proactive maintenance strategies throughout the converter lifecycle. Such capabilities improve both converter reliability and overall system resilience while reducing operational costs.

The integration of digital intelligence also enables increasingly autonomous operation across diverse applications, including renewable energy systems, battery energy storage, electric vehicle charging infrastructure, microgrids, and industrial automation. Rather than functioning as isolated hardware components, digital power electronic systems become interconnected cyber-physical assets capable of exchanging information, coordinating operational decisions, and supporting system-wide optimization in real time. As digitalization continues to advance, intelligent power electronic systems are expected to evolve into collaborative energy nodes that seamlessly integrate power conversion, communication, distributed intelligence, and autonomous control within increasingly interconnected electrical ecosystems.

The convergence of intelligent power conversion, artificial intelligence, grid-forming control, and digitalization establishes the technological foundation of the intelligent energy interface envisioned throughout this editorial. Collectively, these enabling technologies allow power electronic systems not only to process electrical energy efficiently but also to perceive system conditions, communicate with surrounding infrastructures, adapt autonomously to changing operating environments, and actively contribute to the stability, flexibility, and resilience of future electrical systems. The next section demonstrates how these capabilities are transforming a wide range of applications, from renewable energy integration and energy storage to electric transportation, smart grids, and industrial electrification.

Emerging Applications

The evolution of power electronics into intelligent energy interfaces is fundamentally transforming the operation of future electrical systems. As illustrated in Figure 1, modern power electronic systems integrate advanced energy conversion, intelligent control, communication, and grid-support capabilities within a unified technological platform. These capabilities extend the role of power electronics beyond conventional converter functions, enabling increasingly autonomous, flexible, and interconnected operation across a wide range of

emerging applications. From renewable energy integration to industrial electrification, intelligent power electronics is becoming an essential enabling technology for the next generation of sustainable electrical infrastructures.

The rapid expansion of renewable energy generation has significantly increased the importance of power electronics in modern electricity networks. Solar photovoltaic systems, wind turbines, and hybrid renewable energy plants all rely on power electronic converters to regulate power conversion, synchronize with electrical networks, and maintain power quality under continuously changing environmental conditions. As renewable penetration continues to increase, converters are expected not only to maximize energy harvesting but also to provide ancillary services such as voltage regulation, frequency support, reactive power compensation, and fault ride-through capability.

Intelligent power electronic systems further enhance renewable integration by continuously adapting converter operation according to grid conditions, generation variability, and operational constraints. Combined with advanced forecasting algorithms and real-time monitoring, intelligent converters enable renewable energy resources to participate more actively in maintaining overall system stability and operational reliability. Adaptive converter control also improves the capability of renewable energy systems to provide ancillary services, including dynamic voltage regulation, frequency support, reactive power compensation, and fault ride-through operation, thereby strengthening the reliability and flexibility of increasingly renewable-dominated power systems.

Energy storage has become an indispensable component of increasingly flexible and resilient electrical systems. Battery energy storage systems, supercapacitors, and emerging storage technologies require bidirectional power converters capable of managing charging and discharging processes with high efficiency and precise control. Beyond energy conversion, intelligent converter systems optimize battery utilization, improve energy management, extend asset lifetime, and support multiple grid services simultaneously. These capabilities enable energy storage systems to respond rapidly to fluctuations in renewable generation and electricity demand while facilitating peak shaving, load balancing, and frequency regulation across diverse operating conditions.

The integration of artificial intelligence and predictive analytics further enhances storage operation by forecasting energy demand, estimating battery health, optimizing charging strategies, and coordinating distributed storage resources. Consequently, power electronics enables energy storage systems to evolve from passive backup resources into intelligent assets that actively contribute to grid flexibility, renewable integration, and system resilience. Continuous monitoring and data-driven optimization further improve operational efficiency by supporting predictive maintenance, extending battery service life, and enabling more effective utilization of distributed storage assets throughout their operational lifecycle.

The global transition toward electric mobility has substantially expanded the application of power electronics across transportation infrastructures. Electric vehicles, fast-charging stations, railway electrification, electric ships, and electric aircraft all depend on highly efficient and intelligent converter technologies. Modern charging systems increasingly require bidirectional operation to support vehicle-to-grid (V2G) and vehicle-to-building (V2B) services, allowing electric vehicles to function as distributed energy resources within future power systems. Intelligent charging converters further facilitate coordinated charging schedules, adaptive demand response, and real-time interaction with energy management systems, enabling transportation electrification to contribute not only to sustainable mobility but also to improved flexibility and resilience of future electrical networks.

Intelligent charging infrastructure also enables adaptive load management, coordinated charging scheduling, demand response participation, and real-time interaction with energy management systems. These capabilities reduce peak demand, improve grid utilization, and facilitate the integration of large electric vehicle fleets without compromising system stability. Advanced charging management further enables dynamic power allocation, renewable-aware charging strategies, and coordinated interaction with distributed energy resources, thereby enhancing both operational efficiency and grid flexibility. Accordingly, power electronics serves as the critical interface connecting transportation electrification with future smart grids, supporting the seamless coordination of energy flows between electric vehicles, charging infrastructure, and increasingly intelligent electrical networks.

Power electronics is equally fundamental to the modernization of electrical infrastructure and industrial energy systems. Within smart grids, intelligent converters support microgrids, virtual power plants, distributed generation, flexible AC and DC distribution networks, and solid-state transformers. These technologies enable increasingly decentralized energy architectures in which distributed resources operate cooperatively while maintaining overall system stability and power quality. The ability of intelligent converters to regulate bidirectional power flow and communicate with distributed control platforms enables increasingly decentralized and autonomous grid operation. Furthermore, coordinated converter control improves system

observability, operational flexibility, and resilience by facilitating real-time power balancing, distributed optimization, and adaptive network reconfiguration under changing operating conditions.

Industrial electrification presents another rapidly growing application domain. High-performance motor drives, industrial automation systems, robotics, and data centers increasingly require intelligent power electronic systems capable of maximizing energy efficiency while maintaining operational reliability under dynamic operating conditions. Advanced converter technologies also facilitate process electrification, improve energy management, and reduce industrial carbon emissions, supporting broader sustainability objectives across manufacturing sectors.

Looking ahead, intelligent power electronics will continue expanding into emerging application areas such as hydrogen production, all-electric ships and aircraft, resilient critical infrastructures, and multi-energy systems that integrate electricity with heating, cooling, and hydrogen networks. These developments demonstrate that the future impact of power electronics extends far beyond individual devices or converter topologies. Instead, intelligent power electronic systems are becoming the technological foundation that enables seamless interaction among diverse energy resources, electrical networks, industrial processes, and end users.

Collectively, these emerging applications demonstrate that power electronics has become a strategic enabling technology across the entire electrification ecosystem. Rather than serving as isolated conversion hardware, intelligent power electronic systems increasingly coordinate energy flows, support grid stability, optimize system performance, and facilitate real-time interaction among distributed energy assets. As electrification continues to accelerate worldwide, their role will expand from enabling individual applications to orchestrating increasingly interconnected, autonomous, and sustainable electrical systems. The following section discusses the major technological and engineering challenges that must be addressed to fully realize this vision.

Challenges and Future Directions

Despite the remarkable progress achieved in power electronics over recent decades, significant scientific and engineering challenges remain before intelligent energy interfaces can be fully realized across future electrical systems. Increasing electrification, higher penetrations of inverter-based resources, expanding digitalization, and growing system complexity require power electronic technologies to evolve beyond incremental improvements in efficiency and power density. Future developments must simultaneously address intelligence, resilience, interoperability, sustainability, and cybersecurity while maintaining the high reliability expected of critical electrical infrastructures. Meeting these multidimensional requirements will require continued innovation across semiconductor technologies, control systems, digital intelligence, system integration, and engineering practice.

The continued advancement of power electronics depends heavily on next-generation semiconductor devices. Wide-bandgap technologies, particularly silicon carbide (SiC) and gallium nitride (GaN), have significantly improved switching performance, efficiency, thermal capability, and power density. Nevertheless, further progress is required to enhance device reliability, reduce manufacturing costs, improve packaging technologies, and ensure long-term operation under increasingly demanding electrical and environmental conditions. Future research should also explore novel semiconductor materials and advanced integration techniques that support higher operating voltages, faster switching frequencies, and more compact converter architectures.

Artificial intelligence is expected to become an intrinsic component of future power electronic systems rather than an auxiliary analytical tool. AI-native converters should be capable of continuously learning from operational data, adapting control strategies to changing system conditions, predicting component degradation, and optimizing performance throughout their operational lifetime. Achieving this vision requires the development of trustworthy AI algorithms, explainable decision-making mechanisms, high-quality operational datasets, and computationally efficient machine learning models suitable for real-time embedded implementation. Ensuring that AI-based control remains reliable, transparent, and verifiable under safety-critical operating conditions represents an important research priority.

As power electronic systems become increasingly interconnected, ensuring dependable operation extends beyond hardware reliability alone. Intelligent converters now exchange operational data with energy management systems, cloud platforms, distributed controllers, and other cyber-physical assets, creating new challenges related to cybersecurity, data integrity, and communication reliability. At the same time, the growing diversity of manufacturers, communication protocols, and control architectures highlights the need for greater interoperability among heterogeneous converter platforms. Future engineering efforts should therefore integrate reliability engineering, secure communication, standardized interfaces, and resilient control strategies into unified converter design methodologies.

The rapid expansion of power electronic installations also raises important sustainability considerations. Future converter technologies should not only maximize operational efficiency but also

minimize environmental impacts throughout their entire life cycle. Eco-design principles, recyclable materials, modular architectures, and circular economy strategies will become increasingly important as power electronic equipment is deployed on a massive scale across renewable energy systems, electric transportation, and industrial applications.

Equally important is the continued evolution of grid-support functionalities. Future converters are expected to provide not only efficient power conversion but also voltage regulation, frequency stabilization, virtual inertia, black-start capability, and coordinated operation within converter-dominated electrical systems. The expanding provision of ancillary services will further position intelligent converters as active grid assets capable of supporting secure, flexible, and resilient system operation under increasingly dynamic conditions. Consequently, power electronics will increasingly contribute to maintaining overall system stability rather than merely interfacing individual energy resources with the grid.

Looking ahead, the future of power electronics will be shaped by the convergence of advanced semiconductor devices, intelligent control, digital technologies, and system-level integration. Rather than evolving independently, these technological domains will increasingly reinforce one another, giving rise to power electronic systems that are adaptive, collaborative, and capable of autonomous operation within highly interconnected energy ecosystems. Achieving this vision will require closer collaboration among researchers, equipment manufacturers, utilities, software developers, standards organizations, and policymakers to accelerate the translation of emerging technologies into reliable engineering solutions. Such multidisciplinary collaboration will also play a critical role in developing interoperable technologies, harmonized standards, and scalable deployment strategies that support widespread electrification.

Ultimately, the next generation of power electronics will be defined not only by improvements in switching performance or conversion efficiency, but also by the ability to integrate energy conversion with intelligence, communication, resilience, and sustainability. These capabilities will establish intelligent power electronics as a cornerstone of future electrical engineering and a key enabler of increasingly electrified, digitalized, and carbon-neutral societies. As electrical infrastructures continue to evolve, intelligent energy interfaces will become indispensable for enabling seamless coordination among diverse energy resources, supporting autonomous system operation, and accelerating the transition toward sustainable and resilient energy ecosystems.

Conclusion

The accelerating transition toward electrification is fundamentally redefining the role of power electronics within modern electrical engineering. As renewable energy sources, distributed energy resources, energy storage systems, electric transportation, and intelligent industrial infrastructures continue to expand, the demand for flexible, adaptive, and intelligent energy management continues to grow. In this evolving landscape, power electronics has progressed far beyond its traditional function of efficient energy conversion to become a strategic technology that enables the seamless integration and coordinated operation of increasingly complex electrical systems.

This editorial has highlighted that this transformation is driven by the convergence of advanced semiconductor devices, digital control, artificial intelligence, communication technologies, and grid-forming capabilities. Collectively, these advances are redefining power electronic systems as intelligent energy interfaces capable of managing electrical energy, processing operational information, supporting grid stability, and coordinating distributed energy resources. This evolution positions power electronics at the intersection of the physical and digital domains, where energy conversion and intelligent system operation become inseparable.

Looking ahead, intelligent power electronic systems will increasingly serve as the technological backbone of renewable energy integration, battery energy storage, electric mobility, smart grids, industrial electrification, and emerging multi-energy systems. Realizing this vision requires continued advances in semiconductor technologies, intelligent control, interoperability, cybersecurity, sustainability, and system integration, supported by close collaboration among researchers, industry, utilities, standards organizations, and policymakers. Such collaborative efforts will be essential for accelerating innovation while ensuring reliable and scalable deployment across increasingly complex electrical infrastructures.

Ultimately, the future of power electronics will be defined not only by how efficiently electrical energy is converted, but also by how intelligently energy can be monitored, coordinated, and managed across increasingly interconnected and electrified societies. By evolving into intelligent energy interfaces, power electronic systems will become one of the fundamental technological pillars supporting sustainable, autonomous, resilient, and carbon-neutral electrical systems. As the pace of global electrification continues to accelerate, intelligent power electronics will play an increasingly central role in shaping the architecture, operation, and long-term sustainability of future electrical systems.