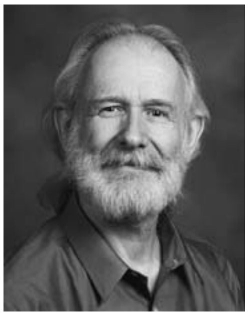
Power Semiconductors Enabling Energy Management



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Over the past 50 years, power electronics has played an increasing part in energy management for humanity. It is estimated that more than 30% of energy consumed by humanity today is processed by electronic power converters. With the current trends of full industry automation, and increased electrification and automation of transportation and agriculture, as well as anticipated dominance of distributed generation from sustainable energy sources, it is predicted that in several decades 80% of the global energy consumption will be in the form of electricity processed by power electronics.

Power semiconductors have been the main technology drivers of power electronics ever since the discovery of silicon controlled rectifier (SCR) in 1957, which is recognized now as an IEEE Milestone and celebrated every June 20th as the Power Electronics Day. SCRs, and derivative p-n-p-n silicon devices, are still used in the highest-power applications for energy management in electrical grids, like high-voltage direct current (HVDC) and flexible AC transmission system (FACTS), although they are being supplanted by high-voltage and high-current insulated gate bipolar transistor (IGBT) modules. Over the last 35 years, silicon IGBTs and p-i-n diodes have been the “workhorse” devices for the medium-voltage (600 V to 10 kV), medium-power (kilowatts to megawatts) applications, like motor drives and grid-connected converters for industry automation, commercial buildings, data processing centers, and transportation. At the low-voltage end (<300 V), silicon power metal-oxide-semiconductor field-effect transistors (MOSFETs) and Schottky diodes have dominated the power supply applications, with wide variety of circuit configurations and packaging structures. It is important to emphasize that silicon devices, as well as the diverse application-optimized packaging technologies, are being continuously perfected through numerous engineering innovations, both in academia and industry. This is enabling ongoing enhancements of energy management systems by increasing efficiency, switching frequency and power density, while improving manufacturability, reliability and life cycle costs.

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After two decades of anticipation, both vertical silicon carbide (SiC) and lateral gallium nitride (GaN) devices are becoming widely commercially available in the continuously increasing spectrum of voltage and current ratings. They are offering major reductions in losses and increases in switching frequencies and operating temperatures. However, the impact of these improvements at the system level is severely limited by the existing technologies for packaging and passive components (capacitors, inductors, transformers, conductors and insulators); requiring significantly increased investments in research and development. Additionally, the implementations of ancillary active electronic circuits, such as gate drives, sensors, controls, protection, and auxiliary power supplies, need radical re-thinking in order to assure dependable operation in the very high dv/dt, di/dt, and temperature environments. Hence, direct replacement of silicon with wide-bandgap devices in (otherwise unmodified) power converters would rarely result in appreciable benefits. For the highest impact, innovative circuits and energy management architectures, which are custom tailored to fully utilize the new wide-bandgap device potentials, will need to be developed. On the other hand, these new semiconductor materials are opening the opportunities of using high-frequency-switching power conversion in applications where it was not possible ever before.

In the low-voltage range, lateral GaN devices are already enabling operation at unprecedented switching frequencies, in the megahertz range. This trend will allow substantial improvements in power density and efficiency, as long as the corresponding improvements in passive components and packaging are materialized. Increased monolithic integration of ancillary active electronic circuits with power devices into Power ICs – both Si and GaN – will continue to provide huge benefits in high volume markets. In 300 V to 1 kV (off-line) applications, SiC Schottky diodes will completely replace Si p-i-n diodes very soon. However, high-voltage GaN high electron mobility transistors (HEMTs) and SiC MOSFETs will have very hard time competing with Si super-junction MOSFETs and IGBTs based on converter cost, efficiency, size and performance! Only in applications that would benefit by an order of magnitude higher switching frequencies, the wide-bandgap devices could be a winner, provided better module and converter packaging, as well as magnetics technologies will be developed.

It could be expected that SiC could be overtaking Si within 3-5 years for 1-6 kV applications. Again, improved packaging for higher switching frequencies, higher voltages, higher temperatures, and longer lifetime will provide competitive advantage for SiC. Much improved energy management systems based on new designs for electrical machines, passives, and converters will be a "game changer." For medium and high voltage (>6 kV) applications, SiC could be the future! Ability to operate at switching frequencies exceeding 20 kHz will define completely new approaches to electrical energy management in the megawatt power range. Very innovative packaging and passive component technologies, as well as new energy processing architectures will enable development of completely new power systems and applications. This will become huge when a new "electronic grid" will start to be built.

Papers in this issue provide some excellent examples of the described trends.

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