Change from Differential Equation to the World of Partial Differential Equation

OGASAWARA, Satoshi*

The history of power electronics began with the development of mercury rectifiers through the utilization of discharge phenomena. Since then, it has progressed from semiconductor-based silicon-controlled rectifiers (SCRs) or thyristors, self-extinguishing power transistors, power metal-oxide-semiconductor field-effect transistors (MOSFETs), and gate turn-off (GTO) thyristors to the now widely popular insulated gate bipolar transistors (IGBTs). The field of power electronics has advanced significantly as the primary role of power devices has changed. Furthermore, in recent years, power semiconductor devices that use wide-band-gap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) are becoming widespread. This means that we are on the verge of achieving even further advancement. Power electronics technology is based on power converters that convert and control the mode of electric power (voltage, current, frequency, etc.) using the switching of power devices. It is no exaggeration to say that power electronics is now a fundamental technology of society, since it is applied not only to general industrial, electric power, and railway applications, but is also being used in every corner of society, including automobiles, home appliances, and housing.

The principle of using power devices as switches in power electronics equipment has not changed at all since the inception of the technology. However, throughout the history of power device development, there have been continuous efforts to improve the technology. This has included reducing conduction loss by decreasing on-state voltage drop and reducing switching loss by increasing the switching speed. In particular, switching speed is on the verge of greatly accelerating from the order of microseconds to that of nanoseconds, and the available switching frequency is increasing to the order of megahertz in terms of power supply frequency. Higher switching frequencies are enabling the miniaturization of passive components, such as inductors, transformers, and capacitors. This, in turn, has allowed power electronics equipment to become increasingly smaller, lighter, and more efficient. In addition to miniaturization, from the viewpoint of loss density, power electronics equipment concurrently need to achieve enhanced efficiency and cooling. In terms of cooling technology, it is necessary to examine temperature distributions using "heat conduction equations" in addition to heat resistance circuits, while some understanding of fluid dynamics is also required.

At the same time, wiring inductance and stray capacitance, which have basically been neglected up until now, are producing a significant effect on device switching characteristics and switching loss due to the increase in switching speeds. These parameters are highly dependent on the mounting technology used for the main circuit. Close mounting of components caused by miniaturization is also a factor that increases stray capacitance. Therefore, the design of power electronics equipment requires not only a good understanding of electric circuits, but also a foundation in electromagnetism, including knowledge of electric fields, magnetic fields and electromagnetic induction. Higher switching frequencies also increase the frequencies and bandwidth of electromagnetic interference, which can affect the frequency band to the order of 100 MHz. For example, the wavelength of a 300 MHz electromagnetic wave is 1 m. In this respect, power electronics equipment and wiring must be regarded as antennas, and this means that it is also necessary to have a good understanding of electromagnetic fields. Moreover, a background in mechanical and acoustic fields is required to address factors related to equipment vibration and noise.

As power electronics technology has developed, it become difficult to express phenomena using only conventional lumped-constant models, such as electric, magnetic, mechanical and thermal circuits. Instead, distributed-constant or spatial models need to be used, such as electromagnetic fields (including electrostatic fields, magnetostatic fields, and electromagnetic induction), mechanical fields, and heat and temperature fields. Learning all of these disciplines may seem overwhelming at first. However, it is important to note that conventional lumped-constant models are expressed by differential equations, while distributed-constant and spatial models are expressed by partial differential equations. In other words, if phenomena in different physical systems are expressed by the same form of differential equation or partial differential equation, they will have the same character-

* Professor, Graduate School of Information Science and Technology, Hokkaido University

istics simply by replacing the relevant physical quantity. Knowing this should make it easier to learn these other realms. It is my hope that future engineers will advance the field of power electronics technology by moving beyond the basics of electric circuits through the application of multi-physics, while also transitioning from the world of differential equations into the world of partial differential equations. I also hope that power electronics technology will continue to flourish as a fundamental technology in society that contributes to energy management through the integration of IT and AI.

Fuji Electric

Innovating Energy Technology