Power electronic devices have achieved higher performance by using new technologies such as power transistors, insulated gate bipolar transistors (IGBT) and microprocessors.

In recent years, in response to the trend of information technology, factory automation, and home automation (HA), facilities management is becoming integrated in factories, transportation systems, power systems, offices, and stores, which are the traditional application areas of power electronic devices.

At home, the number of electrical appliances that include induction heating and “inverter” are increasing.

The basic functions of power electronics include the use of electronics to control and transform electric energy in terms of voltage, current, frequency and waveform. The basic functions also include the use of electronic control for conversion to other forms of energy such as electromagnetic energy, actuators, and high-frequency induction heating (Fig. 1). We can therefore expect power electronics to play an increasingly important role in the accurate management and control of electric energy at high speed in the age of information. This paper reports on the trends in power electronics and the current state of research and development.

Current state and issues of power electronics

Power electronic devices normally feature low losses because the switching operations that they perform are controlled by the on/off state of semiconductors. However, because they can also cause electromagnetic interference due to switching, it is necessary to maximise the advantages of the devices while eliminating or minimising their disadvantages. Since the control technology is flexible and wide in applications from high-speed control in the generation of power with a high peak demand to operations that save energy, appropriate operations can be adjusted to the required conditions. It is therefore useful to have a clear idea of the trend of technology for the improvement of performance, functions and of the necessary benchmarks while maintaining harmony with our surroundings, including the environment, as seen from various points of view.

Reduction of resource consumption and stress to the environment

Roughly speaking, the size of current power electronics equipment is about one-tenth that of 20 years ago and its weight about one-fifth. In efforts to reduce the amount of energy consumed and to reduce carbon dioxide levels, attempts to save energy by reducing loss related to elements and circuits and to use regenerative energy recovery have been made. To continually maximise the effects of these efforts, new technologies are needed to optimise system operation beyond the partial optimisation techniques, such as the low-loss circuit systems and new power devices, and the size and weight reduction provided by such techniques.

Limiting noise and harmonics distortion

Circuits that suppress noise and harmonics distortion caused by the switching of power devices and structures that block the radiation of noise are important as means of preventing failures and errors in other electronic equipment. In recent years, steady progress has been made in the standardisation of electromagnetic compatibility (EMC). In the IEC standard of the International Electrotechnical Commission, a directive was issued to limit the terminal voltage noise (conductive noise) in 150 kHz – 30 MHz to no more than the preset value. In Japan, Guidelines for High-Voltage Users” and “Guidelines for Protective Measures against Harmonics in Household Appliances and General-Purpose Products” along with the IEC directive were established in 1994 to impose self-regulation. For domestic information processing devices, self-regulation was imposed by the Voluntary Control Council for Information Processing Equipment and Electronic Office Machines to eliminate radio interference caused by electromagnetic radiation.

The development of equipment that conform to the above requirements and that are electromagnetically clean, requires advanced circuits and structure technologies that suppress power supply harmonics and terminal voltage noise.

Seeking new values

As information continues to gain greater importance, we can expect more contributions from the creation of new cutting-edge technologies, in which the control of electric energy, motion and IT are closely integrated, by improving the level of device performance.

Even today, practical equipment with surprising levels of performance, such as fast response IGBT type static var compensator that controls reactive power of several tens of MVA, high-speed power supplies which provide lowvoltage and large currents to high-speed CPUs, and servos

Fig. 1: Power device timeline.
Applied power electronic technologies

The key elements required in power electronic equipment are the power devices. As shown in Fig. 2, controllable power devices started with the thyristor. They have since progressed to the bipolar transistor, gate turn-off thyristor (GTO) and lately to the IGBT.

Because it is relatively easy to make a high-voltage, large-capacity IGBT, the IGBT is expected to replace the thyristor and GTO. It is also important to develop IGFBs which have superior characteristics to other power devices.

The following describes applied technologies for power devices.

Applied technologies for new power devices

Fuji Electric is currently working to develop two new devices, the field stop IGBT (FS-IGBT) and reverse-blocking IGBT. As the work on device development continues, applied technologies are being developed, too.

FS-IGBT

The FS-IGBT is a faster device compared with conventional ones, as well as having a substantially reduced forward voltage drop. A slim-line package with a footprint one-half that of conventional devices has been implemented by optimally laying out IGBT chips that can take higher current densities and input/output terminals. When we evaluated a prototype inverter stack that includes a high-performance cooling fan, the result we obtained showed a reduction in loss of about 20%. This result leads to a substantial miniaturisation of inverters and power supply equipment.

Reverse-blocking IGBT

The reverse-blocking IGFB is a new device with reverse withstand voltage. Conventional IGFBs have no reverse withstand voltage and are limited to opening and closing in the forward direction only. The conventional IGBT is therefore not suitable for circuits to which reverse voltage is applied, even if simple ones, such as a thyristor rectifier. The newly-developed reverse-blocking IGBT, with its proprietary withstand voltage structure, succeeds in having reverse withstand voltage without increasing the forward voltage drop. When two reverse-blocking IGFBs are connected in an antiparallel connection, a bidirectional switch that is almost ideally fast and low in loss can be realised.

A new power device is a source for new applications. With the advent of the reverse-blocking IGBT, we can expect new developments in circuit systems, including AC-AC direct conversion.

Sensing technology within the package

In a large-capacity power device in which multiple chips are mounted, ensuring reliability is a major problem. Multiple IGBT chips mounted in a package are designed so that the load among them is balanced. The balancing is accomplished by reducing changes in operating conditions resulting from the structure and layout to a minimum. However, when we attempted to check the load balancing under more stringent conditions, it was not easy to measure the current of each chip within a narrow package with high electromagnetic fields, and a small, high-speed sensor with the required precision was difficult to obtain. We therefore developed a microsensor that could be incorporated into pressure welding elements (see Fig. 3) and succeeded in observing minute differences in chip current without affecting the elements. This procedure also verified that the load is balanced normally in all areas. We think it is possible to use this measuring technology to improve the performance and reliability of large-capacity power devices.

Technological trends and challenges

Fig. 4 summarises the relationships among the power supply, drive fields and the essential technology for circuits, control, and information. Because low noise, high power factor, low harmonics, and high efficiency are the measures of devices in the power supply field, the emphasis is on circuit technology.
In particular, if the capacity is small, implementation with the minimum number of parts becomes important.

In the drive field, on the other hand, the emphasis is on operation and control - for example, energy-saving operation, reduction of labour by tuning, and better performance through state estimation and identification.

The series-parallel connection technology of the IGBT poses a challenge in both the drive field and power supply field for increasing capacity. The following explains how these essential technologies and applications are being addressed.

Challenges in the power supply field

Noise, harmonics, and loss reduction

Soft switching is a technology that attacks the given problems by using the resonance of circuits. This technology is particularly suitable for a small power supply with high switching frequencies. One of the problems entering public awareness recently is the reduction of power consumption in the standby state. As a solution to this problem, a top class technology for low power consumption in the standby state that uses intermittent operation by burst oscillation has been developed.

A high level of integration is effective for implementing a small-capacity circuit with good reproducibility while satisfying the complex requirements described above. Fuji Electric has already brought to market ICs for power supply switching. Fig. 5 shows the IC.

A power supply with a rating of the several hundreds W to several kW is in many cases used for server and communications equipment. Such a power supply should therefore feature high levels of precision and efficiency, a high power factor, and low harmonics so that the system will operate efficiently and stably. See conversion circuit in principle that can capture all of these features in a single system (Fig. 6 shows the circuit configuration and the device).

New applications

Some devices used in recent production facilities and information processing require a very stable power supply environment. If an instantaneous voltage drop occurs, the damages, such as various problems and reduction in yield, are serious. Also, a problem with the conventional uninterruptible power supply (UPS) is the rapid deterioration of batteries caused by repeated charging and discharging of the batteries if instantaneous voltage drops are frequent. Fuji Electric has made commercially available equipment that takes special measures for instantaneous voltage drops. Fig. 7 (b) shows the principle of operation.

Because a large capacitor is used as an energy storing element instead of the batteries used in a UPS in Fig. 7 (a), the device has excellent reliability and does not require maintenance for a long time. We think that the device will contribute much to improve the quality of supplied power.

Drive system challenges

Presented here are the technologies for the inverter and servo, the main applications in the motor drive field.

Inverter control technology

Inverters suitable for induction machines or permanent magnet synchronous machines have been developed. With regard to induction machines, vector control, speed sensorless vector control, V/f control, and an enhanced type of V/f control (that is, torque vector control) are already being used in a wide range of motors, from specialized motors and general-purpose motors to high-voltage motors.
A V/f control that can be easily handled is appropriate for energy-saving drives because high-efficiency control is implemented. The V/f control achieves a control performance that is comparable to the speed sensorless vector control.

New servo functions

Work on servo systems used for high-speed and high-precision applications is focused on two areas. One area is the performance improvement of the servo amplifier. High-speed positioning and damping control are essential in obtaining the best performance from machines in which a servo is installed. The other area is a support tool used for tuning when the working machines are incorporated. The machine analysis function incorporated in the tool can analyse the complex machine oscillation modes that are to be used to tune the system. Fig. 8 shows an example of combining the servo system and the support tool. Hitherto a long time was needed for tuning if there were complex machine vibrations. When the support tool is used, tuning of the vibration suppression control are both quick and accurate. If the identification accuracy of the machine transfer function is improved in the future, automatic tuning of the servo may be expected.

High power technology

In a large-capacity converter used for flicker compensation, reactive power compensation, or driving of a large motor in a power system, the required equipment capacity must be implemented using series-parallel connections of power devices. In the conventional series technology, a function that balances the voltage among the thyristor, GTO, and IGBT is implemented using a resistor or snubber circuit. When this method is used, loss due to the resistor is large and the balance can be maintained at a low carrier frequency and switching speed. These restrictions prevent miniaturisation of the converter and hinder performance. Fuji Electric has developed a new series technology that could overcome these problems. The configuration is a simple one in which balance cores are inserted for the gate drive. Since the balance is maintained automatically by the amplification of the IGBT, the technology has potential for higher performance at high carrier frequencies. Fig. 9 shows a basic configuration when a multiseries circuit is applied to the inverter.

Conclusion

In this article we presented an overview of the current research and development in power electronics. In the future, we also intend to consolidate and improve our technical expertise in response to various types of needs and to quickly develop new technologies that will play a part in solving environmental and energy problems.

References


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