Innovative Power Electronics Technology

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1. Introduction

Modern society is demanding solutions to the environmental problems such as global warming by reducing CO_2 emissions and protecting the environment. These and other problems must be solved, however, while securing a source of energy. The society is based on an infrastructure that uses electric energy and therefore, the appropriate and waste-free use of this electric energy must be realized and highly efficient and reliable electric power sources must be secured.

Power electronics technology has already been fulfilling that role, and is widely used in applications ranging from social infrastructures such as generators and traction control equipment to industrial, automotive, and home electronic equipment, and cellular phones.

This paper presents Fuji Electric's recent activities concerning power electronics.

2. Missions of Power Electronics

Figure 1 shows the representative product families of Fuji Electric's power electronic products and power devices. Fuji Electric has pioneered efforts to increase the efficiency and performance, bringing IGBT (insulated gate bipolar transistor) technology into the inverters and UPSs (uninterruptible power systems), and replacing switching devices for static var compensators and static flicker compensators from thyristors or GTOs (gate turn off thyristors) to high power IGBTs, and has commercialized low loss, high performance devices. Recently in the field of the medium-power products such as high-voltage inverters, there is a trend to increase the operating voltage.

Figure 2 shows the changes in volume of inverters over time. The size of the inverter has reached almost the same level as that of the motor, due to the remarkable reduction in loss achieved by power devices. Moreover, improvements in high-speed MOSFET switches contributed in size reduction and performance enhancement in the areas of information processing and mobile equipment.

In the 1990's, one of the major tasks of power electronics has been to replace the function of the engine, the machine system, the generator or the battery with an equivalent electronics system to achieve higher performance. Progress in downsizing, cost reduction, performance enhancement, and network system connectivity has expanded the range of power electronics applications to various fields.

The new challenge of power electronics in the 21st century is to achieve harmony between the desire for more sophisticated information technology and the need to conserve resources and protect the environ-

Fig.1 Power devices and power electronics products

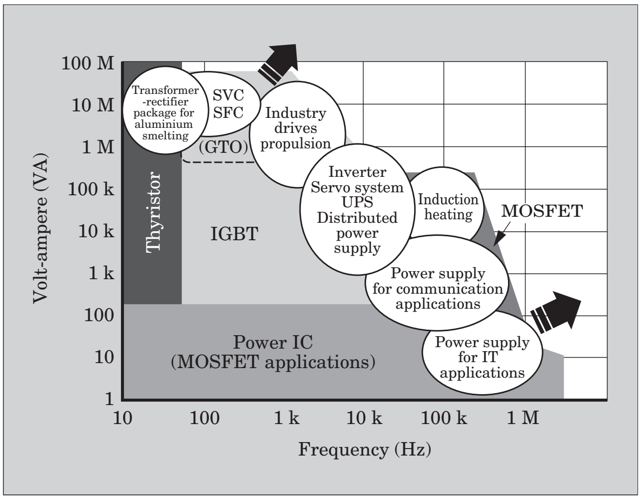
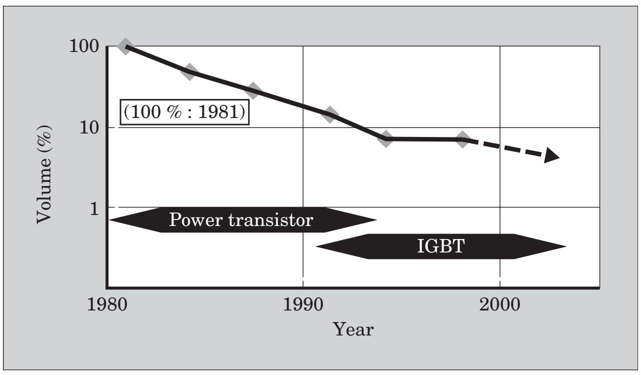


Fig.2 Changes in volume of general-purpose inverter



ment. To accomplish this, Fuji Electric is working toward the following technological goals.

(1) Technical innovation enabled by new key components

(2) Downsizing and loss reduction enabled by new technology

(3) Improvement of intelligent functions

3. New Technological Trends

Fuji Electric is developing new technologies to achieve maximum performance while reducing power loss. Several examples of these new technologies are introduced below.

3.1 Technical innovation enabled by new key components

New power devices have brought about breakthroughs in power electronics. The latest one of these innovative devices from Fuji Electric is a unique key device, the RB-IGBT (reverse blocking IGBT) [1].

Table 1 compares the functions and circuitry comparison of the RB-IGBT and conventional power devices.

Most conventional power devices have no reverse blocking capability, and therefore require a flywheel diode (indicated as Di in the table) connected in parallel as shown in Table 1. Circuit topologies that required reverse-blocking devices have long been ignored because conventional high-speed power devices such as most GTOs, bipolar power transistors, MOS FETs, and IGBTs, can not block a reverse voltage. Moreover, conventional power conversion circuits have a limitation in that a desired function must be realized by a multiple stage combination of AC-DC and/or DC-DC converters. The RB-IGBT has no such limitation, which greatly increases its capability to realize various new circuit topologies and achieve significant loss reduction.

The matrix converter, which is a typical AC-AC direct converter, requires bi-directional switches. The conventional bi-directional switch was composed of two pairs of an IGBT and diode as shown in Table 2.

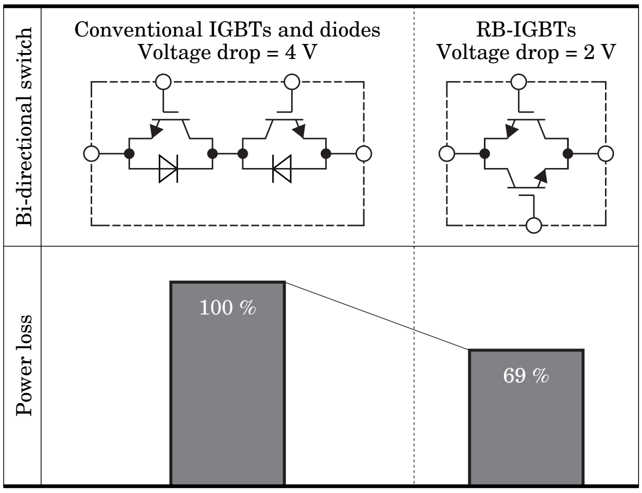
Table 1 Controllability of power devices

Power devices & circuits		Current controllability	
		Forward	Reverse
Conventional power devices	GTO, Power transistor, IGBT	Available	Prohibited
	GTO (Di), Power transistor (Di), IGBT (Di), MOSFET	Available	Conduction
RB-IGBT		Available	Block

However, a new bi-directional switch can be realized with only two RB-IGBTs in an anti-parallel connection.

Figure 3 shows the three-phase matrix converter, composed of nine bi-directional switches, and its input and output waveforms. The matrix converter directly converts the input voltage into an AC output voltage with arbitrary frequency and amplitude, and the input current becomes sinusoidal. The voltage drop across the new switch is reduced to 1/2 and the loss is reduced to 2/3 that of the conventional switch. The control method of this matrix converter is usually complex and much different from that of the inverter. To solve this

Table 2 Bi-directional switches



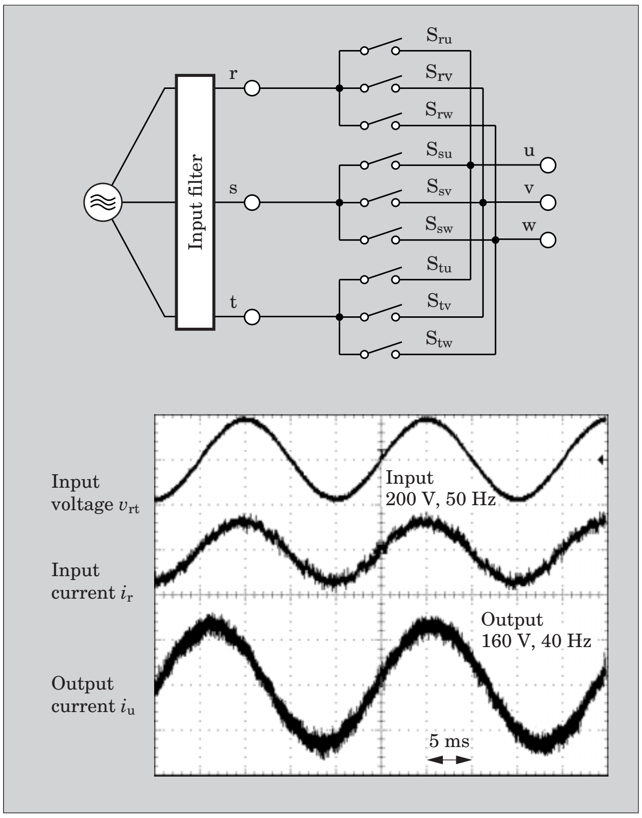
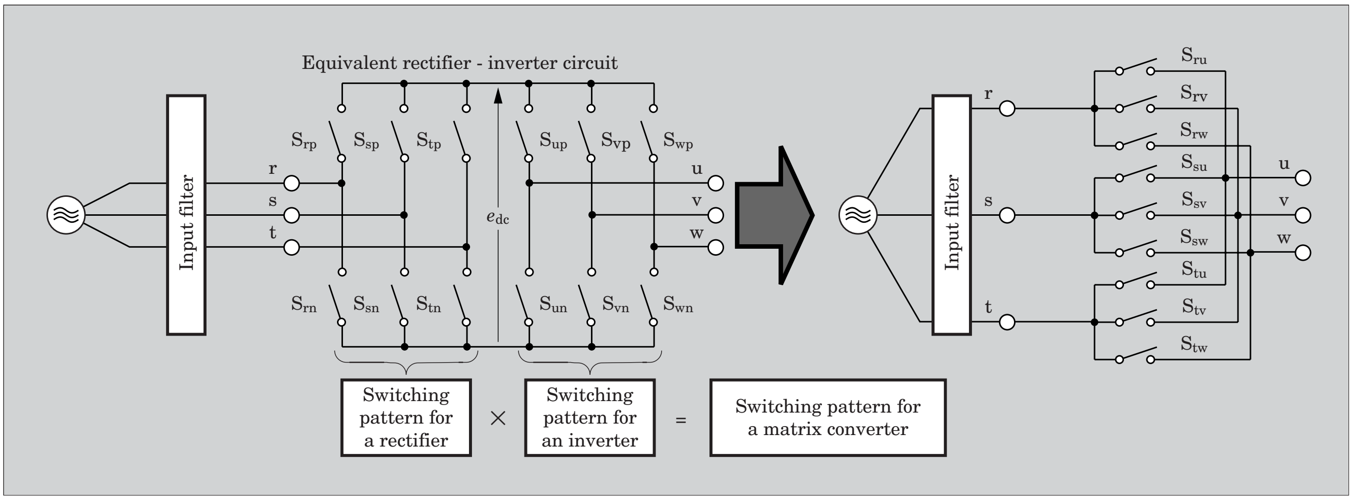


Fig.3 Matrix converter circuit and its waveforms

Fig.4 Virtual indirect control method



problem, a virtual indirect control method has been developed and employed.

The switching patterns for the matrix converter are synthesized mathematically from the switching patterns for a PWM rectifier and an inverter. This method enables the latest inverter control technologies to be applied to the matrix converter. (Refer to Fig. 4.)

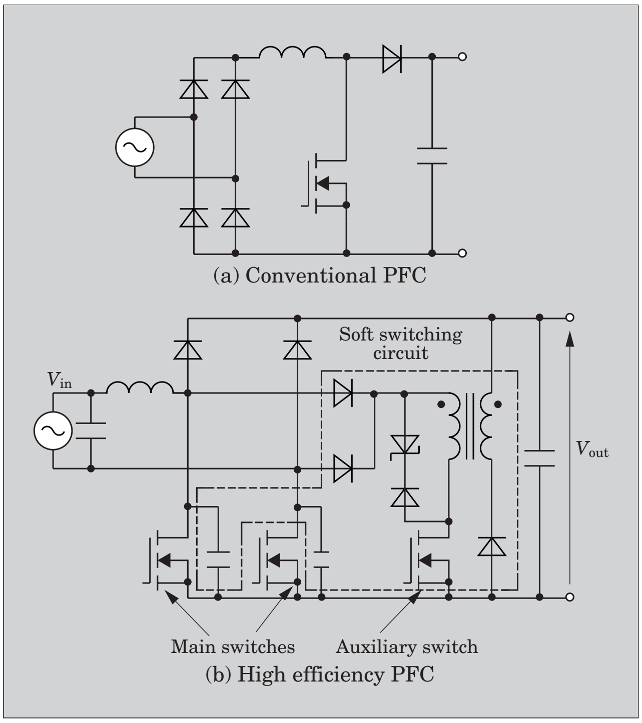
3.2 Downsizing and loss reduction enabled by new technology

Equipment for converting and controlling electric energy is required to have high controllability and low loss. Fuji Electric has control technology capable of providing high-speed response and high accuracy. In order to achieve high performance and high efficiency to conquer old theoretical limits, Fuji concentrated on the development of conversion technologies. Several new achievements in the field of power supplies are presented here.

As the AC-DC conversion circuit for power supplies, the diode rectifier has been recognized as the most efficient and advantageous device in terms of noise emission. The diode rectifier, however, has a major drawback of generating high levels of current harmonics, which prevents its use for regulating power supply harmonics. Because of this problem, PFCs (power factor compensators) are becoming popular, but they too have problems as loss and noise emissions due to the switching action.

Figure 5 shows examples of single-phase PFCs. Figure 5(a) is the most common circuit. The efficiency of this circuit is at most 95 %. The majority of the loss is due to the conduction loss of the diodes and the switching loss of the MOSFETs. Figure 5(b) shows a new PFC circuit in which the loss is much lower than in the circuit of Fig. 5(a). The total loss decreases remarkably to 1/2 that of Fig. 5(a), and the noise is suppressed at the same time by employing the forward gate bias during the reverse-conduction period of the main MOSFET switch and combining a soft-switching

Fig.5 Single phase PFC circuits



technology using auxiliary switches. Technology to reduce channel resistance is being developed rapidly in the field of the power MOSFETs, and in the near future, a remarkable reduction of resistance can be expected to achieve higher efficiency than that of the diode rectifier.

Next, an example of the three-phase PFC[(2)] is shown in Fig. 6. The proposed method reduces the IGBT's rated voltage to half that of the general three-phase PWM converter by skillfully applying a bi-directional switch circuit. As a result, compatibility with power-supply voltages of 200 V and 400 V can be achieved by using low-cost IGBTs with low voltage ratings. In addition, due to the low switching loss of the IGBT having a low voltage rating, the efficiency of

Fig.6 Worldwide three phase PFC circuit

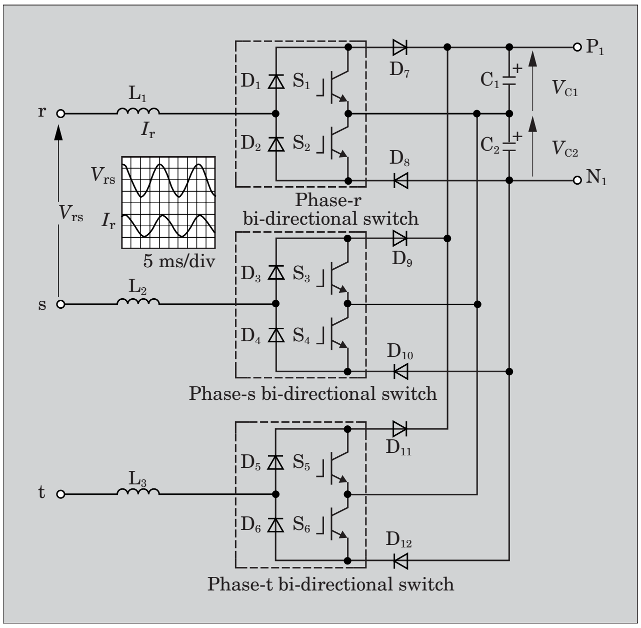


Fig.7 Plant identification result of the singular value decomposition method

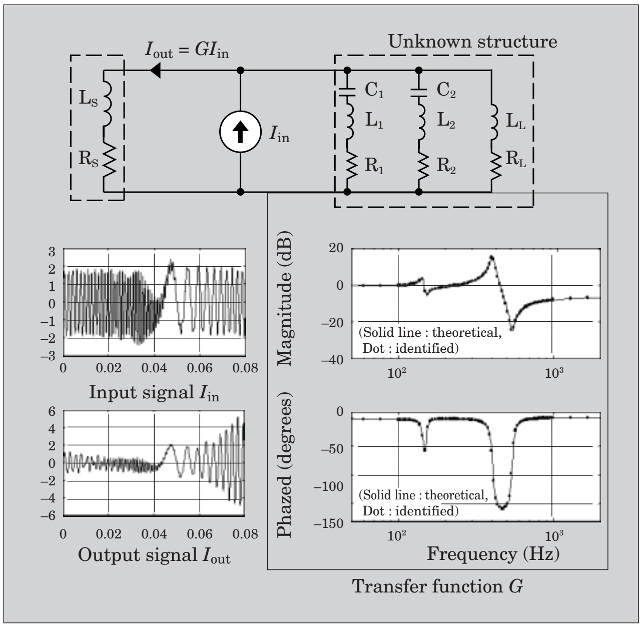
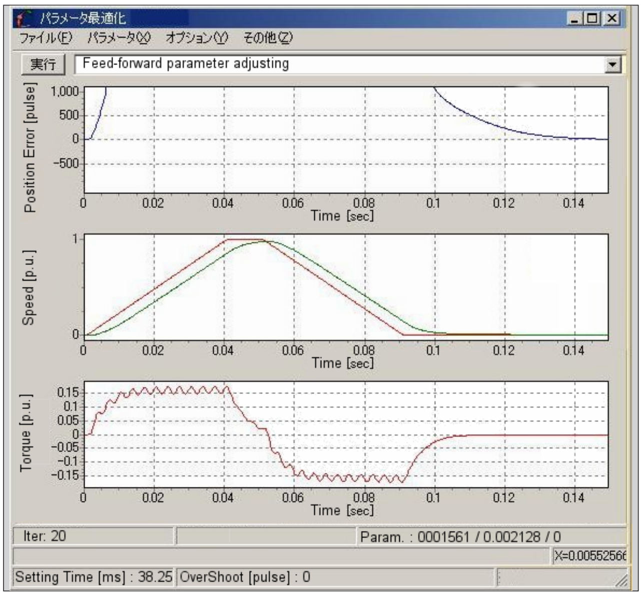


Fig.8 Control parameter adjustment using a meta-heuristic technique



the converter is 97.4 % at 400 V operation and the size is reduced to half that of Fuji Electric's past product.

3.3 Improvement of intelligent functions

Recent power electronic equipment has functions for connecting to standard networks and meeting the requirements of IT systems. One aim for future technical innovation is to achieve a built-in intelligent function. The theory of optimization based on specific rules has been defined and an algorithm has been established. However, the optimization of the process for making judgments has not been systematized and its algorithm is complex.

In some areas, auto-tuning techniques have been widely used to adjust the control parameters. However, manual-tuning by skilled experts is still needed in most areas where higher performance is required, thereby presenting an obstacle to easy optimization of the control system.

Therefore, application technologies of a mathematical method and a meta-heuristic technique are developed as parts of the research for a solution. One example of automation technology relating to adjustment is discussed below.

The identification of an unknown structure at a plant, which is the intended target for control, is one of the tasks to require an expert's judgment ability. One result of a trial to automate the identification is shown in Fig. 7. This is an example in which the structure identification utilizes the singular value decomposition method. The structure can be specified by adding the order determination into the identification process of the structure's transfer function.

After the identification of the system structure has been finished, an appropriate control system can be selected and its parameters adjusted.In actual plants, however, there are many adjustable elements having complicated interdependencies, and the adjustment of these elements is extremely difficult. Therefore, one approach is to apply a meta-heuristic technique for parameter adjustment instead of a human operator who can adjust only 1 or 2 parameters at a time.

Figure 8 shows an example of the results of the adjustment.

Because the meta-heuristic technique can manipulate many parameters simultaneously, the adjustment result can be obtained without repeating many trials.

While the above-described technique has not yet reached the level of human experts, translating the "experiences" of those experts into the algorithms is expected to lead to new intelligent systems to aid or substitute for humans in the adjustment of complicated control systems.

4. Conclusion

As a leading company in the field of power electronics and power devices, Fuji Electric will continue to develop new frontiers, especially in Fuji Electric's strong fields such as inverters, UPSs, and distributed power sources using fuel cells or solar cells. Through those efforts, Fuji Electric would like to contribute to the realization of an advanced and comfortable society that lives in harmony with the environment.

References

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(2) K. Mino, et al. A Three-Phase AC-DC Converter using Universal Input Voltage Type PFC Circuit and Phase-Shift Controlled DC-DC Converters, Conference Record of the 2002 IEEE Industry Applications Conference, 37th IAS Annual Meeting, Vol.3, pp.2117-pp.2124 (2002)