MOSFET Inverter Type High-Frequency Power Supply

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1. Introduction

Induction heating is a typical application field for high-frequency power supplies whose operating frequencies range from one to several hundred kilohertz. Induction heating applies an alternating magnetic field generated from the current flow in a coil to the conductive matter to be heated. This induces eddy currents on the conductive matter, those currents generate joule loss due to the matter's resistance and thus cause the matter to be heated. Steel sheet heating, hardening, and seam welding are some examples of the industrial applications of induction heating, and still now, there is much demand for the high-frequency power supplies used in these examples.

In the past, vacuum tube oscillators were used for the high-frequency power supplies from one to several hundreds of kilohertz. In recent years, with the emergence of inverters using MOSFET (metal-oxide-semiconductor field effect transistor) devices suitable for high-speed switching, the volume of power supplies has been reduced to about 1/4, resulting in space savings. Also, efficiency has significantly increased to 96 % (during rated operation) from about 75 % previously, resulting in enhanced energy savings and productivity.

Fuji Electric has previously commercialized flat-packaged 500 V, 240 A MOSFETs and high-frequency power supplies using 20 to 100 kW stacks which incorporated those MOSFETs.

This paper will report the newly developed and commercialized flat-packaged large-power 500 V, 500 A MOSFET and the 125 kW stack containing those MOSFETs, both of which were applied to a 1,000 kW, 150 kHz high-frequency power supply for steel sheet heating in a steel production process.

In addition, recent seam welding power supplies, application of high-frequency power supply for plasma heating, and surface treatment for metalizing film using high-frequency discharge, will also be introduced.

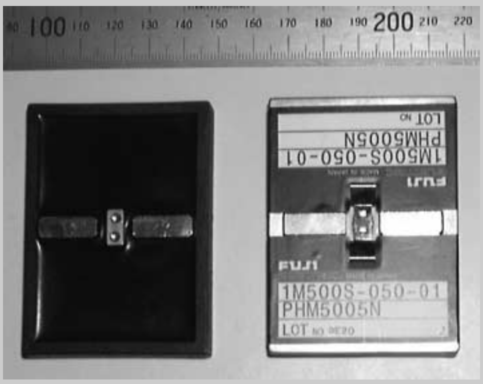
2. 1,000 kW, 150 kHz High-Frequency Power Supply

2.1 Large-power flat-packaged 500 V, 500 A MOSFET [1]

Figure 1 shows external views of an existent 500 V, 240 A MOSFET and large-power 500 V, 500 A MOSFET, and Table 1 lists their specifications. As with the existent MOSFET, the large-power MOSFET has Fuji Electric's unique low-inductance-type slim shape suitable for high-frequency use. Both of the MOSFETs have the same external dimensions. But, compared with the existent MOSFET, the large-power MOSFET's performance is extensively improved.

Advantages of the large-power flat-packaged MOSFET are as described below.

Fig.1 External views of existent and large-power MOSFETs



Existent MOSFET (500 V, 240 A) Large-power MOSFET (500 V, 500 A)

Table 1 Specifications of existent and large-power MOSFETs

Classification / Item	Existent MOSFET	Large-power MOSFET
Rated current	240 A	500 A
Rated voltage	500 V	
On-resistance ratio	1	1/2
Thermal resistance ratio (between channel and case)	1	1/3
External dimensions	13 thick × 71 long × 52 wide (mm)	

(1) Double the rated current

The MOSFET chip has been redesigned to reduce its on-resistance to 1/2 and the thermal resistance between the chip channel and the case to 1/3 of prior values. This allows the on-state loss to be reduced and the cooling performance to be improved. As a result, the rated current is increased by more than twice, from 240 A to 500 A, despite having the same dimensions.

(2) Low inductance

The structure of the MOSFET device is changed to realize reduced wiring inductance, an important factor in high-frequency use. This change is implemented in consideration of applications up to 500 kHz, the same as the existent MOSFET.

(3) Backward compatibility with conventional components

Because of the external dimensions are maintained the same as the existent MOSFET, conventional stack components can be used for the 125 kW stacks. This makes it possible to cut the lead-time and reduce the cost for all 125 kW stacks.

2.2 125 kW stack

Figure 2 shows an external view of the stack with a unit capacity of 125 kW, and Table 2 lists specifications of an existent 100 kW stack and of the 125 kW stack. The 125 kW stack inherits its shape from the existent 100 kW stack, but its cooling structure, gate drive unit (GDU), intermediate DC capacitor, hose connectors for cooling water, and the like are substantially changed.

Advantages of the stack are as described below:

(1) 25 % increase in output power

The design to reduce thermal resistance at cooling parts of the MOSFET devices is implemented in the stack, as well as within the device itself. As a result, the thermal resistance per MOSFET device between the channel and the cooling water is decreased to 1/3, compared with the existent 100 kW stack. This increases the output current and increases the output power by 25 % despite a reduction in the number of parallel devices per arm.

(2) Reduction in size and weight

Changing the GDU mounting locations, the hose connectors, and redesigning the stack interior such as high-density mounting of the intermediate DC capacitor, has achieved the following reduction in size and weight. Compared with the existent 100 kW stack, dimensions have been reduced by 10 mm in width and by 100 mm in depth, and thus to 80 % in volume. Mass has been decreased to 60 %, from 56 kg to 34 kg.

(3) Improved reliability

The stack structure is designed to reduce its inductance, resulting in less switching oscillation of the stack together with the MOSFET device. This allows the noise and surge levels to be decreased and the device characteristics to be improved.

2.3 1,000 kW, 150 kHz inverter

Figure 3 shows an external view of a 1,000 kW, 150 kHz inverter panel. The panel contains eight of the newly developed 125 kW stacks connected in parallel and has an output capacity of 1,000 kW. This is used for a steel sheet heating power supply.

Figure 4 illustrates a schematic diagram of the 1,000 kW, 150 kHz high-frequency power supply main circuit. The rectifier uses a diode bridge; each 125 kW stack in the high-frequency output section has a voltage source type full-bridge connection with a single phase output, and the body diode of the MOSFET device is used as a free wheeling diode of the voltage source inverter.Each stack output is connected to a high-frequency current transformer (HFCT) that serves both as a current sensor and a current balancer for each stack.

To reduce the load impedance and to improve the load power factor, a series or parallel resonance circuit

Fig.2 External view of 125 kW stack

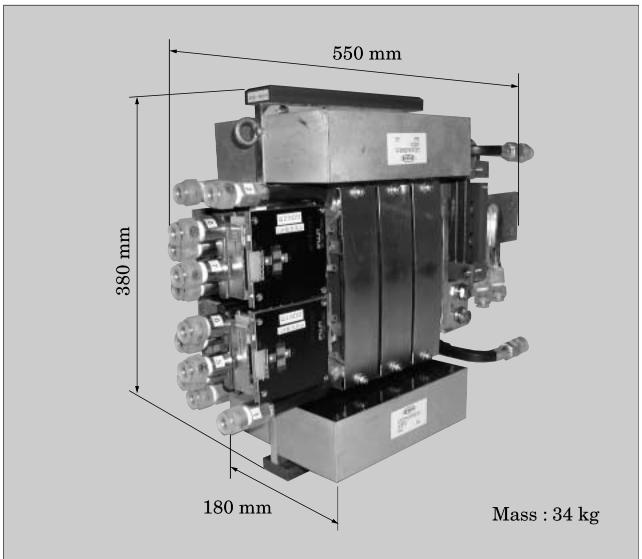
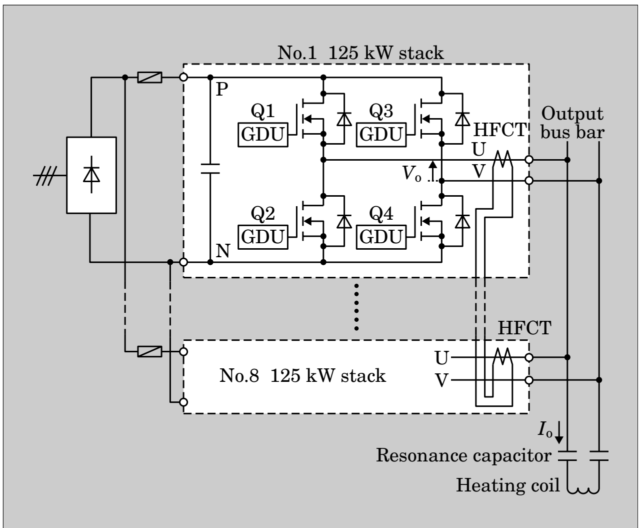


Table 2 Specifications of existent 100 kW stack and 125 kW stack

Item \ Classification		Existent 100 kW stack	125 kW stack
Input (three phase)		220 V, 50/60 Hz	
Rated output (single phase)	Power	100 kW	125 kW
	Voltage	300 V_{p-p} (square wave)	
	Frequency	up to 500 kHz	up to 150 kHz
Cooling	Method	Water cooling (ionized water circulating system)	
	Thermal resistance ratio per device (between channel and cooling water)	1	1/3
Dimensions [width × height × depth] (mm) (Volume ratio)		190 × 380 × 650 (100 %)	180 × 380 × 550 (80 %)
Mass (Ratio)		56 kg (100 %)	34 kg (60 %)

Fig.3 External view of 1,000 kW, 150 kHz inverter panel

Fig.4 Schematic diagram of 1,000 kW, 150 kHz high-frequency power supply main circuit



is used in load circuits where a high-frequency large current flows. For MOSFET inverter type high-frequency power supplies, Fuji Electric generally uses series resonance circuits in which a resonance capacitor of the load circuit is connect in series to a heating coil.

Figure 5 shows examples of each stack's current waveform, both in and out of operation. The stack currents are each superimposed over one another to appear as a single waveform. It can be verified that each stack current is balanced with the current balancing function of the HFCT.

Figure 6 shows waveform examples of a 1,000 kW, 150 kHz inverter's output voltage and current. The voltage waveform with low surge voltages and rapid oscillation attenuation and the current waveform with little distortion are both favorable and are obtained due to the reduced inductance of the MOSFET devices

Fig.5 Example of each stack's current waveform, both in and out of operation

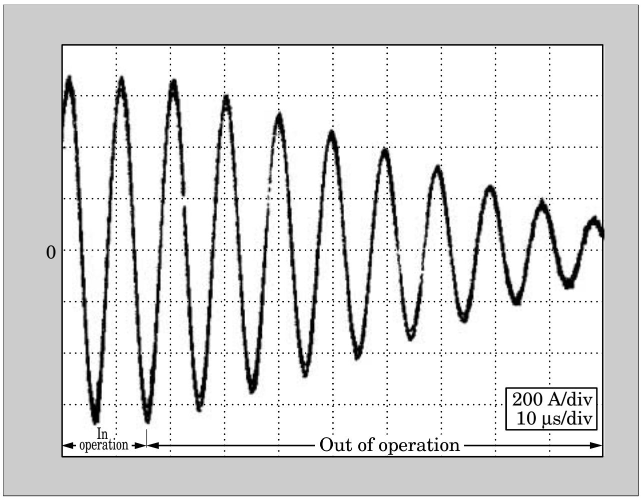
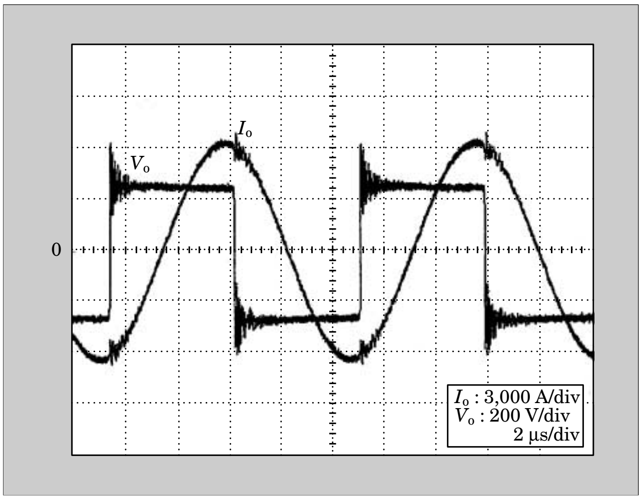


Fig.6 Waveform examples of 1,000 kW, 150 kHz inverter's output voltage and current



and the stacks.

Fuji Electric is further studying how to enhance the output capacity, and has capability to build inverters up to 2,000 kW and 200 kHz by combining multiple configurations of the above-mentioned circuits.

3. A Recent MOSFET Inverter Type High-Frequency Power Supply and Examples of its Application

Table 3 shows the standard lineup and specifications of existing MOSFET inverters.

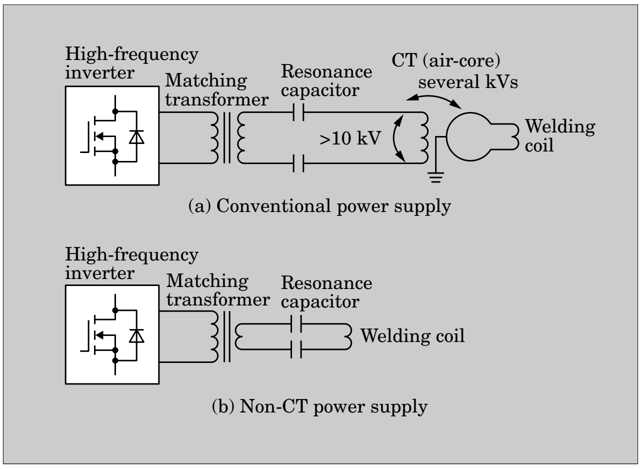
3.1 Non-CT power supply for seam welding

Because a welding coil requires a large current, as shown in Fig. 7 (a), a current transformer (CT) is connected behind the resonance capacitors in the conventional power supply for seam welding. Recently, the non-CT power supply, in which the CT has been

Table 3 Standard lineup and specifications of MOSFET inverter

Item		Specification		
Input (three phase)		220 V±5 % (insulated source)		
Output (single phase)	Inverter system	Voltage source inverter		
	Load circuit	Series resonance circuit		
	Power	20 kW	100 kW	500 kW
		30 kW	200 kW	600 kW
		50 kW	300 kW	800 kW
		75 kW	400 kW	1,000 kW
	Voltage	±150 V_{p-p} (square wave)	±300 V_{p-p} (square wave)	
	Frequency	10 to 500 kHz		
	Control system	Power control		
	Adjusting range	10 to 100 %		
Cooling	System	Water cooling (ionized water circulating system)		
	Cooling water temperature	5 to 35°C		

Fig.7 Conventional and non-CT power supplies for seam welding



omitted as shown in Fig. 7 (b), has become typical. Figure 8 shows an external view of this compact power supply.

Advantages of the non-CT power supply are as described below:

(1) Low withstand voltage design and easy maintenance

Insulation having a high withstand voltage rating is unnecessary since no section in the primary side of the CT has a high voltage of more than 10 kV. Moreover, the power supply seldom causes a dielectric breakdown and is easy to maintain. Surge voltages during a dielectric breakdown do not adversely effect other equipment.

(2) Improved efficiency and reduced size

Because there is no use of a lossy air-core CT (having a large power loss of about 30 %), it is possible to improve the efficiency by about 20 % and to reduce the size.

Fig.8 External view of non-CT power supply for seam welding

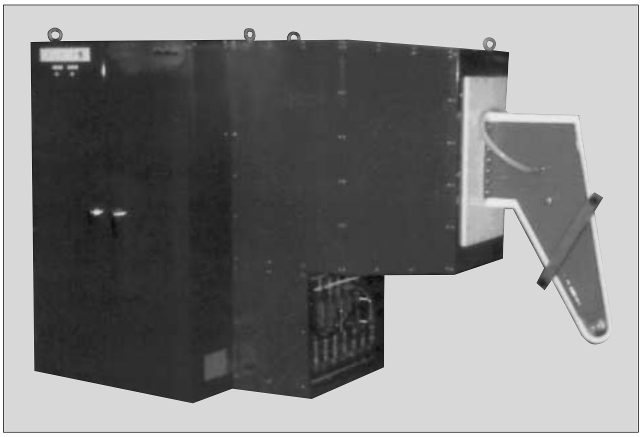
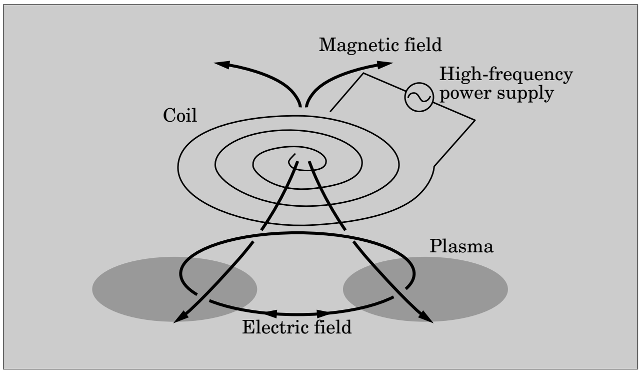


Fig.9 Principle of plasma generation in ICP spent resin volume reduction system



3.2 ICP spent resin volume reduction system

Figure 9 illustrates the principle of plasma generation in the ICP (Inductively Coupled Plasma) spent resin volume reduction system. An inverter with an output frequency of 450 kHz is used for the power supply. The current flow in a coil gives rise to a magnetic field and an interlinked electric field, which generates plasma. Figure 10 shows an external view of the plasma generating section (during plasma generation).

This system decomposes radioactive ion-exchange resin, which has been used in water-based cleaning systems at atomic power-plants, through oxidation using oxygen heated and activated by plasma, and thus reduces its volume. A large volume reduction ratio of 20:1 is possible in this system. The decomposed matter is treated as waste and then buried underground. (This system is currently undergoing verifying tests.)

3.3 Surface treatment for metalizing films

The surface of a metalizing film must be roughened by silent discharge treatment to enhance metalizing. Figure 11 is a diagram showing the principle of surface treatment for a metalizing film. Fuji Electric's high-frequency power supply is also used in this

Fig.10 External view of plasma generating section (during plasma generation)

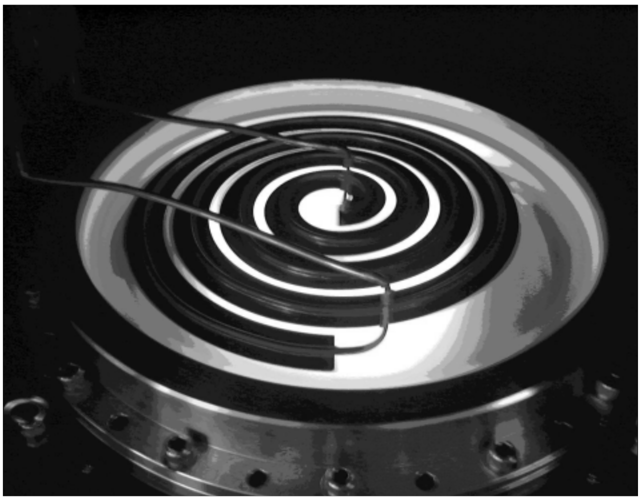
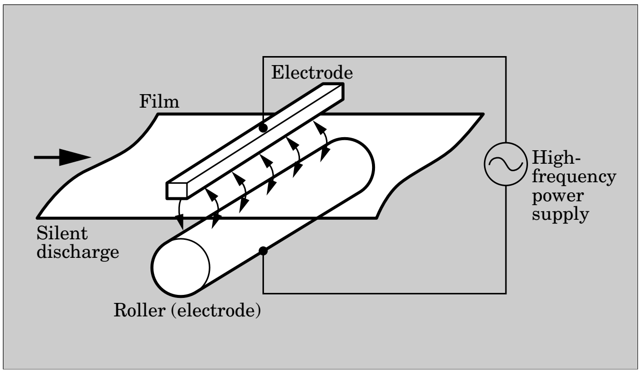


Fig.11 Principle of surface treatment for metalizing film



system, wherein electrodes are placed at both sides of a film that is moved by a roller, and the power supply generates silent discharges between the electrodes.

The surface-treated plastic film with metalized zinc or aluminum is used in capacitor electrodes and food packaging materials such as for snacks, as a high-performance film providing both the air-tightness of aluminum foil and strength of plastic.

This surface treatment is also utilized to enhance the ease of ink printing on films.

4. Conclusion

Fuji Electric has previously developed high-frequency power supplies with MOSFET devices from several tens of kilohertz to five hundred kilohertz and has commercialized them for various application fields. Fuji Electric is now promoting the development and production of large-power flat-packaged 500 V, 500 A MOSFETs, the 125 kW stacks containing them, the applicability of new type high-frequency power supply systems, and expansion of the high-frequency power supply application range including environmental use.

In the future, Fuji Electric will make every effort to supply products with advanced performance and higher reliability by improving the 125 kW stacks to achieve higher output frequencies and to support a wider range of loads. In addition, Fuji Electric hopes to contribute to the progress of high frequency circuits and their application fields through further development of power supplies with larger power and higher output frequency.

Reference

(1) Miura, T. et al. Prototype of 500 kHz, 250 kW MOSFET Stack for High Frequency Power Supply. IPEC-Tokyo 2000, vol. 2, 2000, p. 899-904.