Power MOSFETs for Power-Factor Improvement Circuits

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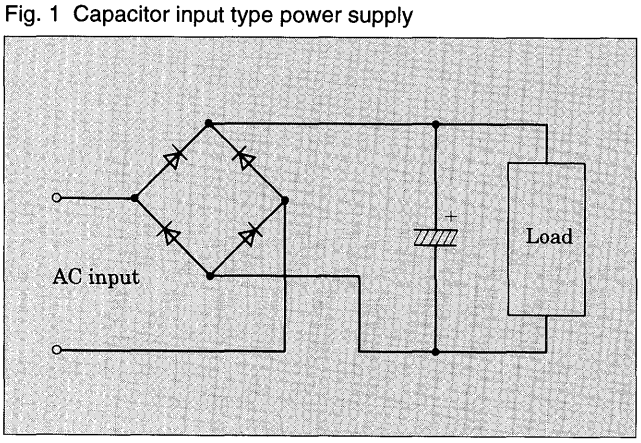
1. Introduction

Recently, the power electronics technology is widely used for the OA equipment and the home electric appliances product. A feature of these equipment are that switching power circuits are used in the power supply unit to achieve smaller size, lighter weight and higher efficiency. A switching power supply is generally used for capacitor input type shown in Fig. 1. Here, the commercial AC supply is rectified with a diode bridge and smoothed with a large capacity electrolytic capacitor to operate the equipment. When, rectification and smoothing process, a lot of higher harmonic current are generated, which affects the electric power system to which they are connected. This can lead to overheating, damage and abnormal noise in the equipment and apparatus connected to the power system and also to control unit malfunction. The high harmonics responsible for these problems are regulated under the law by IEC standard 1000-3 and similar regulations.

There is one of way to install the power-factor improvement circuit in the input part of power supply unit to control higher harmonic current. Switching power supply technology is generally used in this power-factor improvement circuit.

This paper will give an overview of Fuji Electric's new series of power MOSFETs for power-factor improvement circuits.

Fig. 1 Capacitor input type power supply



2. Power-Factor Improvement Circuits

2.1 Basic circuit

Figure 2 shows an example of a power-factor improvement circuit used in the power supply input unit of switching power supplies. This circuit consists of the boost converter composed of a full-wave rectification circuit with a diode bridge, a power MOSFET, some diodes, and a control-IC. Figure 3 shows the input voltage/current waveforms of conventional switching power supplies without power-factor improvement circuits. Figure 4 shows the input voltage / current waveforms of switching power supplies with built-in power-factor improvement circuits. Figures 5 and 6 show the

Fig. 2 Power-factor improvement circuit

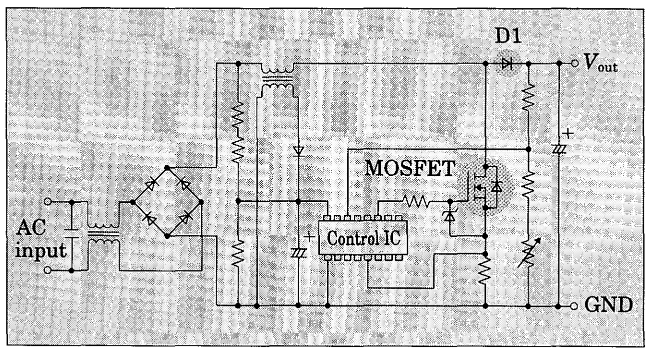


Fig. 3 Input *V*/*I* waveform (conventional type switching power supply)

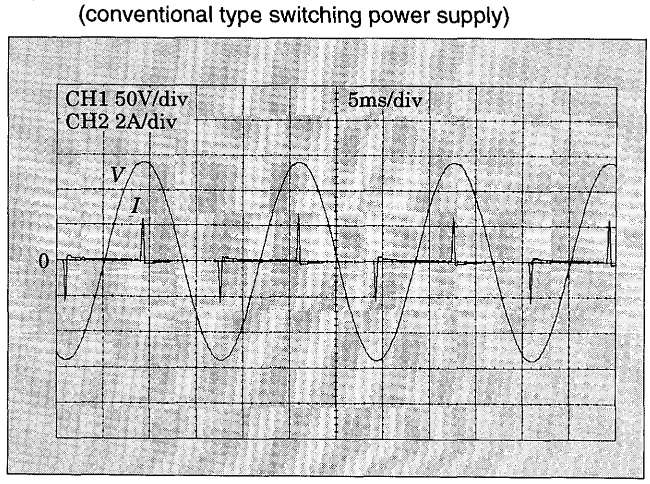


Fig. 4 Input *V/I* waveform (with power-factor improvement circuit)

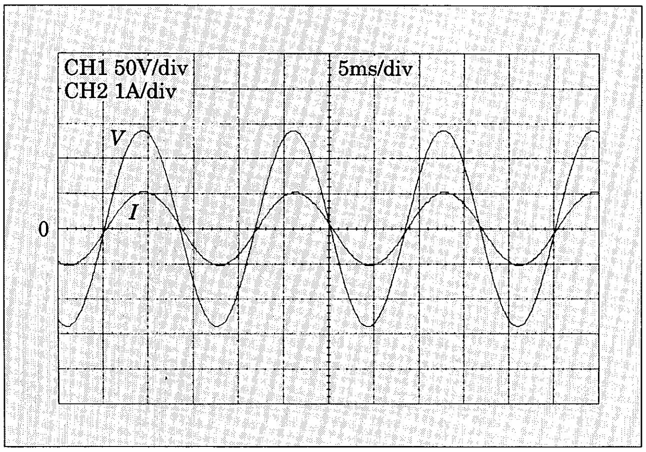
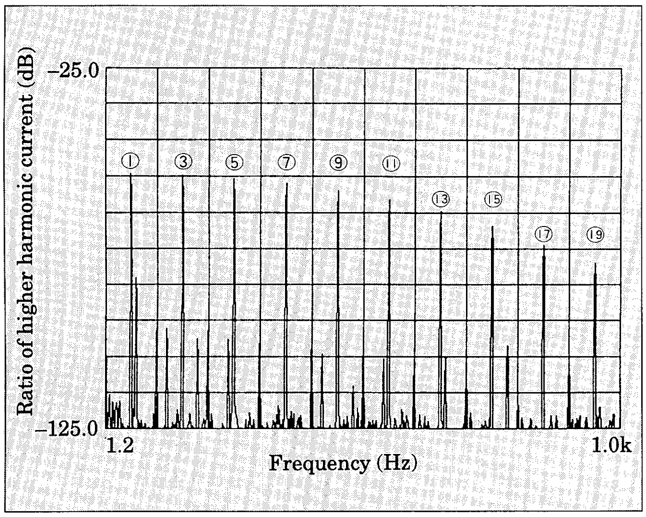


Fig. 5 Higher harmonic frequency spectrum (conventional type)



frequency spectrum of higher harmonic element in the above two cases respectively. From these waveform and frequency spectrum it can be understood that the current waveform of conventional power supplies is largely distorted compared to the voltage waveform and a lot of higher harmonics are generated. In contrast, for power supplies with built-in power-factor improvement circuit, the current waveform is in-phase with the input voltage waveform, has very little distortion and higher harmonics.

Figure 7 shows the operating waveform of power MOSFETs for power-factor improvement circuits.

2.2 Power MOSFET requirements for power-factor improvement circuits

Power dissipation and breakdown ruggedness are important problems about power MOSFET in power-factor improvement circuit as well as generally devices for switching power supplies.

A power-factor improvement circuit is a kind of filter circuit aimed at controlling higher harmonics. Its power dissipation should be much less than that of the

Fig. 6 Higher harmonic frequency spectrum (with power-factor improvement circuit)

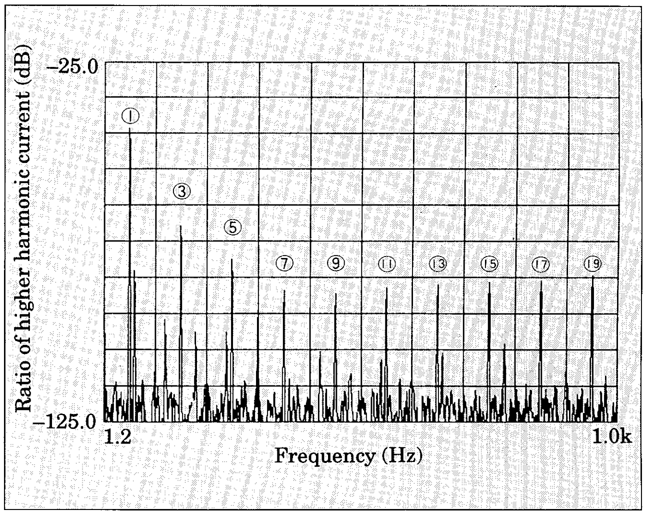


Fig. 7 Waveform of power MOSFET operation

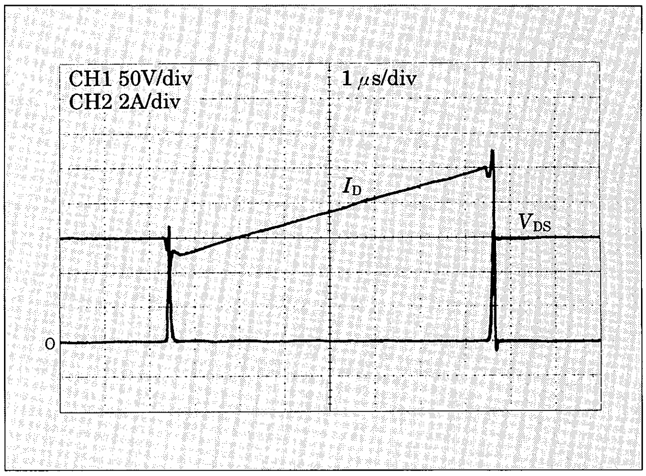


Table 1 Required characteristics of power MOSFET and diode

Control method \ Device	Power MOSFET	Diode
Average current	Low R_{DS} (on) High breakdown ruggedness High speed switching	High speed recovery
Peak current	Low R_{DS} (on) High breakdown ruggedness High speed switching	Low V_F

main circuit so as not to decrease total efficiency of the equipment. As a breakdown ruggedness, avalanche capability at unstable operation is important characteristics, for these reasons, the power MOSFETs used to power-factor improvement circuit require low dissipation and high breakdown ruggedness characteristics.

Table 1 shows required characteristics of power MOSFETs and diodes classified by the control method of power factor improvement circuits.

Table 2 Maximum ratings and characteristics

type name	2SK2469-01	2SK2470-01	2SK2471-01	2SK2473-01
package	TO-220F	TO-220F	TO-3P	TO-3P
P_D (W)	30	40	80	125
BV_{DSS} (V)	300	300	300	300
I_D (A)	5	10	10	20
$\pm V_{GS}$ (V)	20	20	20	20
$V_{GS(th)}$ (V)	4±0.5	4±0.5	4±0.5	4±0.5
$R_{DS(on)}$ (Ω)	0.6	0.4	0.4	0.13
g_{fs} (S)	3	5	5	10
V_{SD} (V)	1.1	1.3	1.3	1.3

Fig. 8 Product of on-state resistance and effective chip area ($R_{DS(on)} \cdot A$) versus blocking voltage (BV_{DSS})

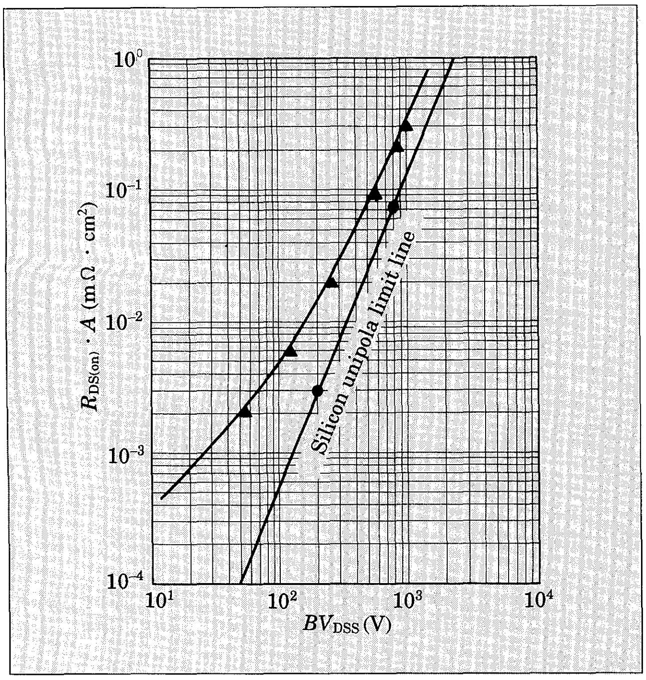
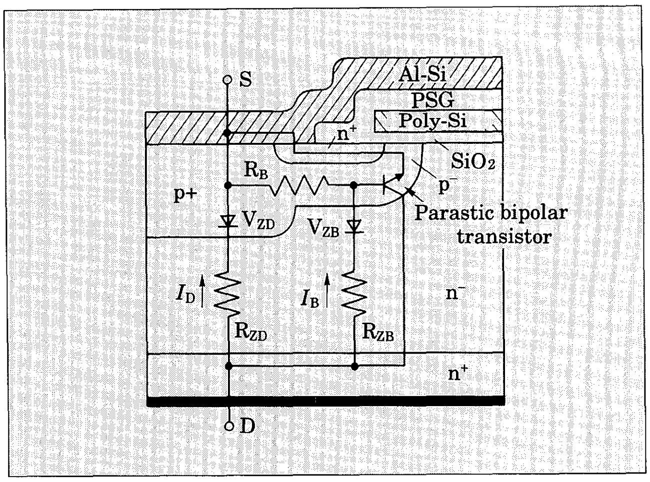


Fig. 9 Power MOSFET cross section and equivalent circuit



3. Power MOSFETs for Power-Factor Improvement Circuits

3.1 Outline

Table 2 shows characteristics of newly developed power MOSFETs for input AC 100V system power-factor improvement circuit. Rated drain-source voltage is 300V and rated drain current is 5A / 10A / 20A depending on power supply capacity.

3.2 Features

In consideration of the topics described in section 2.2, a new series of power MOSEFTs with the following features was developed for power-factor improvement circuits.

(1) Realization of low on-state resistance by special design of the drain-source blocking voltage.
(2) Realization of improved avalanche capability through optimization of the wafer process (guaranteed for individual devices)
(3) Reduction of dispersion of gate threshold voltage
(4) Speed up of turn-off

3.3 Design of blocking voltage characteristics

The special design of blocking voltage design is made on the presumption that input AC 100V system. In a power-factor improvement circuit with AC 100V input and including a boost converter, the output voltage is usually set at DC 200V. In addition, it is also necessary to consider overshoot voltage caused by the inductance of circuit wiring and the transient V_F characteristics of diodes. The applied voltage between drain and source is 200V plus the overshoot voltage. Blocking voltage should exceed the applied voltage.

Figure 8 graph represents the relation between drain-source blocking voltage and on-state resistance, for power MOSFET. The figure shows that higher blocking voltage leads to higher on-state resistance.

Therefore, both applied voltage and power dissipation should be considered in the design of the blocking voltage. With these considerations in mind, the newly developed power MOSFETs have been designed with a drain-source blocking voltage of 300V. The special design of blocking voltage made it possible to reduce on-state resistance by about 50% compared to conventional 450V series.

3.4 Realization of higher avalanche ruggedness

In a transient state such as when power is turned on, a voltage exceeding the drain-source blocking voltage could be applied between the drain and source by supply-voltage or load fluctuations, resulting in permanence destruction of the power MOSFET. This is the so-called avalanche breakdown effect. In conventional power supply circuit, the avalanche breakdown have been evaded by enlarging the margin of drain-source blocking voltage or adding the snubber circuit.

Improvement of avalanche ruggedness is required

Fig. 10 p+ well depth versus blocking voltage and avalanche ruggedness

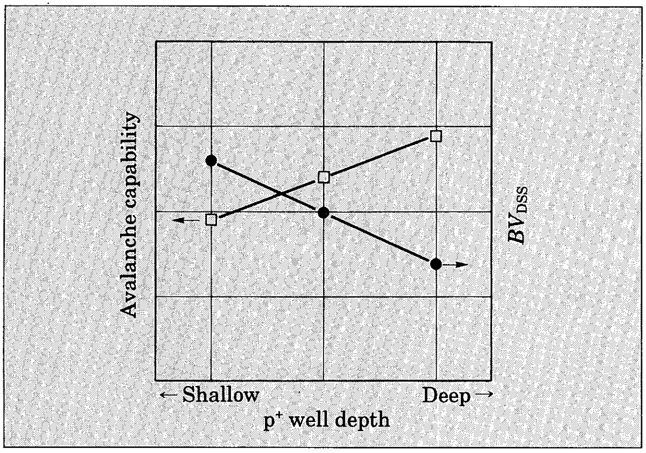
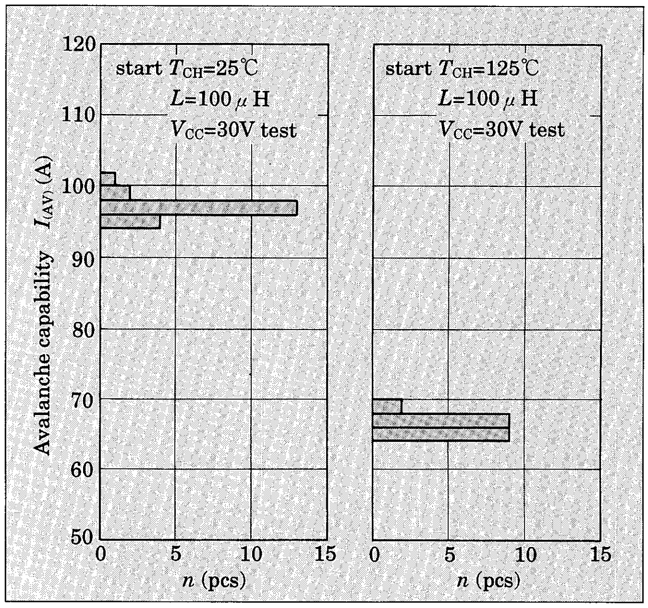


Fig. 11 Avalanche capability strength (I_D=20A)



to evaded avalanche breakdown as described above. Figure 9 shows a cross section and equivalent circuit of a power MOSFET. Avalanche ruggedness can be improved by controlling the operation of a parasitic bipolar transistor as shown in Fig. 9. There are two methods to control the operation of parasitic bipolar transistors.

(1) Control incorrect turn-on of a parasitic bipolar transistor→Decrease p-layer resistance as a base resistance
(2) Control avalanche current flowing through a parasitic bipolar transistor→Deepen the p+ well layer so that a considerable amount of avalanche current may flow through the parasitic bipolar transistor

In method (2), since there is a relationship between drain-source voltage and avalanche ruggedness as shown in Fig. 10, improvement of avalanche ruggedness decreases drain-source voltage. This new series of power MOSFETs for power factor improvement circuits utilizes method (1) to realize an improvement in avalanche ruggedness by optimizing impurity density without decreasing drain-source voltage.

Figure 11 shows avalanche ruggedness of the 20A series.

3.5 Speed up of turn-off

For average current control of power-factor improvement circuit composed of boost converter, the turn-on speed of power MOSFET switching devices is decide by the reverse recovery time (t_{rr}) of diode D1 shown in Fig. 2. That is, the switching loss of power MOSFET at turn-on is decide by the diodes themselves. For instantaneous peak current control, switching speed at turn-on and turn-off is decid by the power MOSFETs themselves; turn-off speed is less than turn-on speed and turn-off loss greater than turn-on loss.

Therefore, the switching loss of power MOSFETs in power-factor improvement circuits can be speed up of turn-off. In this new series of power MOSFETs for power factor improvement circuits, high speed turn-off has been realized by optimizing the gate threshold voltage.

4. Conclusion

This paper introduced Fuji Electric's new series of power MOSFETs for power-factor improvement circuits. This series will be expanded in the future.

The performance of these power MOSFETs is sufficient for use in secondary DC-DC converters for switching power supplies. And, CRT display capacitor switches, etc. It is our firm belief that they will contribute to improved performance of various equipment.

Power device applications are expected to expand into the new fields of household appliances and industrial equipment.

Fuji Electric is determined to develop general purpose products as well as those optimized for a specific application.