2nd Generation LLC Current Resonant Control IC, "FA6A00N Series"

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ABSTRACT

LLC current resonant power supply, which is characterized by soft switching, resonance control with a duty ratio of 50% and leakage transformer structure, is suitable for efficiency improvement, noise reduction and profile lowering in switching power supply. Fuji Electric has developed the 2nd generation "FA6A00N Series," which inherits the characteristics of the 1st generation LLC current resonant control IC, "FA5760N," and is enhanced with lower standby power and improved protective functions. It integrates the world's first high-precision secondary side over-load protection function while further reducing the standby power by approximately 20%. For the over-current protection function, the delay time can be externally adjusted.

1. Introduction

Switching power supply products, which are used in various types of electronic equipment, are rapidly being improved in terms of efficiency, noise reduction and low profile to meet the demands for energy efficiency and space saving. An LLC current resonant power supply is characterized by its use of high-efficiency, low-noise soft switching technology and low-profile leakage transformer structure. These characteristics facilitate efficiency improvement, noise reduction and profile lowering and make it suitable for use as a power supply of 100 to 500 W, which is a medium capacity range for a switching power supply. The LLC current resonant power supply, however, is prone to a switching shoot-through phenomenon*1 during a start-up, heavy load conditions or low input voltage conditions. The power supply has problems including a breakdown of a power metal-oxide-semiconductor field-effect transistor (MOSFET) due to this phenomenon and efficiency degradation with a light load due to an excitation current, and these factors limited its scope of application.

In order to solve these problems, Fuji Electric commercialized "FA5760N," an LLC current resonant control IC that uses its unique new control system. FA5760N is an LLC resonant converter that eliminates the need for a PFC converter and dedicated standby converter and allows a power management system configuration that offers high efficiency, low standby power and compactness. This has expanded the scope of its application such that it is adopted to a power supply of about 50 W without a PFC converter.

Fuji Electric has recently developed the "FA6A00N Series," the 2nd-generation LLC current resonant control IC. With the characteristics of the 1st-generation LLC current resonant control IC "FA5760N" inherited, it is enhanced with a lower standby power, improved protective functions, higher quality and lower system cost and offers a higher degree of design freedom.

2. Overview of Product

Figure 1 shows the external appearance of the FA6A00N Series and Fig 2 the block diagram. Table 1 lists the major ratings, Table 2 the major functions and Table 3 shows the product lineup. The following outlines the LLC current resonant control IC of the FA6A00N Series.

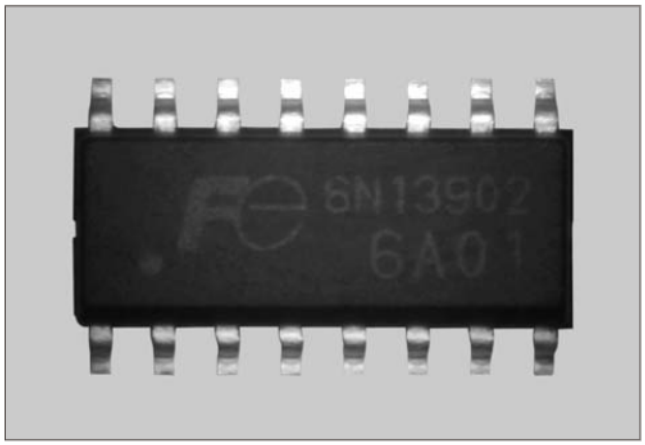


Fig.1 "FA6A00N Series"

*1: Switching shoot-through phenomenon: a phenomenon in which, when a current flows through the body diode of one power MOSFET in a bridge switching circuit, the opposing power MOSFET turns on to instantaneously generate a large current.

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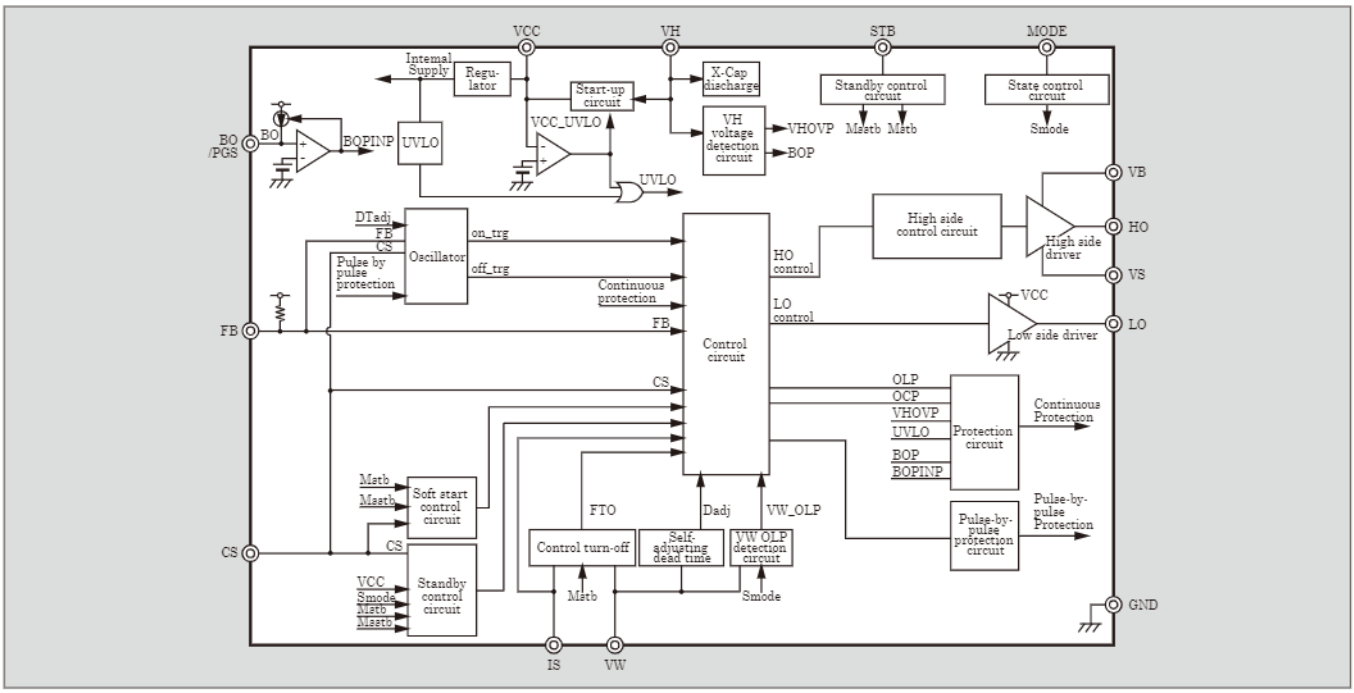


Fig.2 “FA6A00N Series” block diagram

Table 1 Major ratings

Item	Rated value
High side power supply voltage to ground	−0.3 to +630 V
High side power supply voltage (V_{BS})	−0.3 to +30 V
Low side power supply voltage (V_{CC})	−0.3 to +30 V
VH terminal input voltage	−0.3 to +600 V
Maximum allowable offset power supply voltage dv/dt	±50 kV/μs (max.)
Total loss	0.83 W
Operating junction temperature	−40 to +150 °C

Table 2 Major functions and terminals

Function	Terminal (No.)
Start-up circuit	VH (1), VCC (10)
Low voltage malfunction prevention circuit	VCC (10), VB (16)
State setting function	MODE (7)
X-Cap discharge function	VH (1)
Fixed brown-in/brown-out	VH (1)
Variable brown-in/brown-out	BO (3)
Overvoltage protection	VH (1), VCC (10)
Over-current protection with variable delay time	IS (8), MODE (7)
Overload protection	VW (9), FB (4)
Overheat protection	Integrated
External latch signal input	MODE (7)
Forced turn-off function	VW (9), IS (8)
Automatic dead time adjustment function	VW (9)
High-precision overload protection function	VW (9)
Soft start function	CS (5)
Low standby power operation mode	VCC (10), CS (5), VH (1)
Power Good signal	PGS (3)

Table 3 Product lineup

Product name	Terminal 3	Overload protection	Over-current protection
FA6A00N	PGS terminal	Auto-restart	Latch stop
FA6A01N	PGS terminal	Auto-restart	Auto-restart
FA6A10N	BO terminal	Auto-restart	Auto-restart
FA6A11N	BO terminal	Latch stop	Latch stop

(a) Control circuit with 3.3 V, 5 V and 30 V breakdown voltage for controlling the LLC current resonant circuit
(b) Driver circuit with 630 V breakdown voltage capable of directly driving the high side and low side switching devices in the half bridge circuit
(c) Built-in 600 V breakdown voltage start-up device realizing IC start-up with low power consumption
(d) JEDEC-compliant 16-pin small outline package

The high side and low side outputs alternately operate with a high-precision duty cycle of 50% and the operating frequency range is 38 to 350 kHz.

3. Features

3.1 Low power dissipation burst control

FA5760N, the 1st-generation product, used the VCC and CS terminals for hysteresis burst control and achieved a world-class low standby power without the standby converter. The FA6A00N Series, which is the 2nd generation, is additionally provided with burst control optimization to further reduce the standby power by approximately 20% from FA5760N.

The LLC current resonant control has a high side

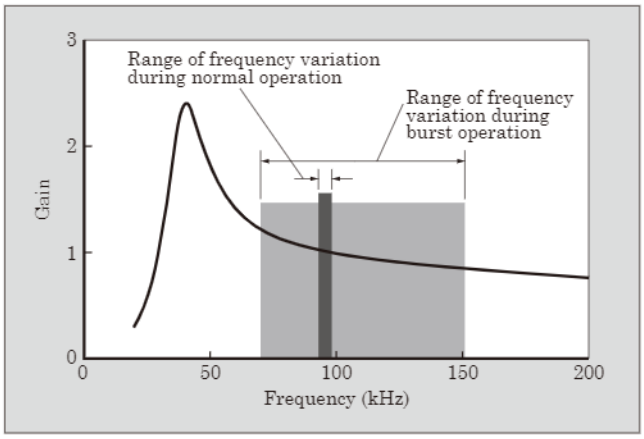


Fig.3 Current resonant gain diagram

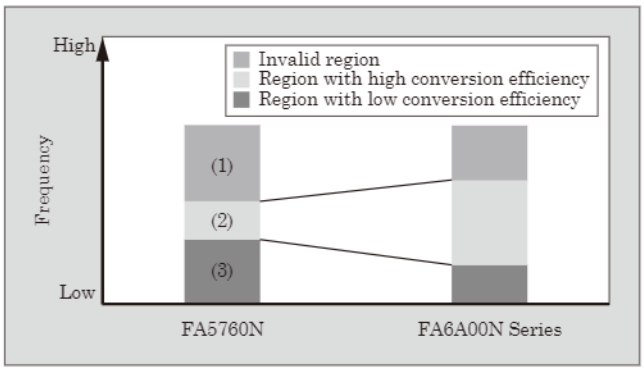


Fig.4 Frequency during burst operation

and low side duty cycle of 50% and controls the gain by the switching frequency. Figure 3 shows the current resonant gain diagram. The frequency variation range is narrow in principle during normal operation and widened during burst operation.

Figure 4 shows the frequency during burst operation. The high frequency region (1) is an invalid region in which the gain is low and switching cannot transfer energy. In the low frequency region (3), the gain is high and excitation current is large, which makes energy transfer inefficient; hence there is a low conversion efficiency. With the FA6A00N Series, the invalid region and the region with low conversion efficiency have been reduced to widen the region with high conversion efficiency (2), resulting in successful reduction of standby power. Audible noise has also been suppressed.

3.2 High-precision overload protection function

The 1st-generation product FA5760N used the primary side auxiliary winding P2 (see Fig. 5) to supply power to the VCC terminal and realized hard switching protection and shoot-through current prevention. The FA6A00N Series, which is the 2nd generation, uses this auxiliary winding to integrate the high-precision overload protection function for the first time in the world while inheriting the functions of FA5760N.

The overload protection, which is intended for

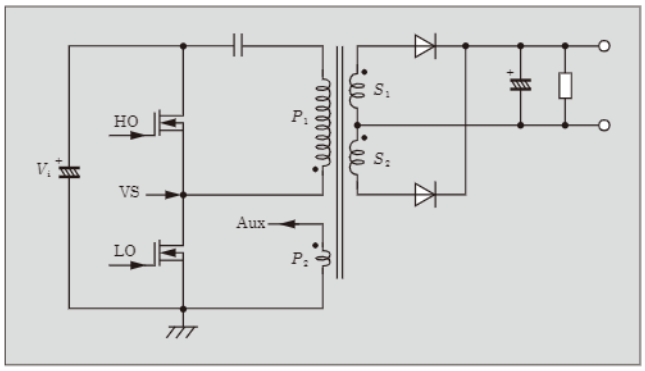


Fig.5 Schematic circuit diagram of current resonance

protecting the power management system, is a function that stops switching when a certain delay time has elapsed after a load increases to approximately 1.5 times the rated load. Degradation of the precision of this function causes insufficient output power or failure to limit the output power, thus the overload protection cannot perform adequately. In addition, the overload protection level must be maintained within a certain range (about ±20%) even if an input voltage varies in a wide range.

Figure 6 shows the circuit configuration of the high-precision overload protection function of the FA6A00N Series. The auxiliary winding voltage is detected by the resistor-divided voltage, V_W voltage. The recommended precision of this voltage-dividing resistor is ±1%. The V_W voltage exceeding the threshold voltage V_{olpvw} is recognized as an overload state, and when the overload state continues for 76.8 ms, switching is stopped. In order to improve the detection precision, variation of V_{olpvw} has been specified to be within ±3%, which is highly precise. The commercialized versions are the auto-restart version, which restarts when the switching stop time has reached 550 ms, and the latch stop version that does not restart.

Figure 7 shows a waveform during overload protection operation. In overload protection operation, switching is suspended and the output voltage drops along with an energy transfer stop.

Figure 8 shows how the overload protection operating power depends on the input voltage. FA5760N provides overload protection with general resonant current detection. With this method, the overload

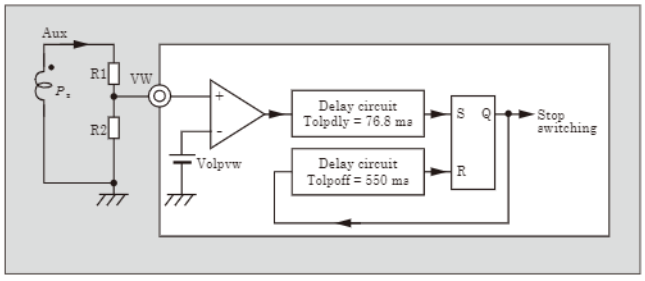


Fig.6 Circuit configuration of high-precision overload protection function

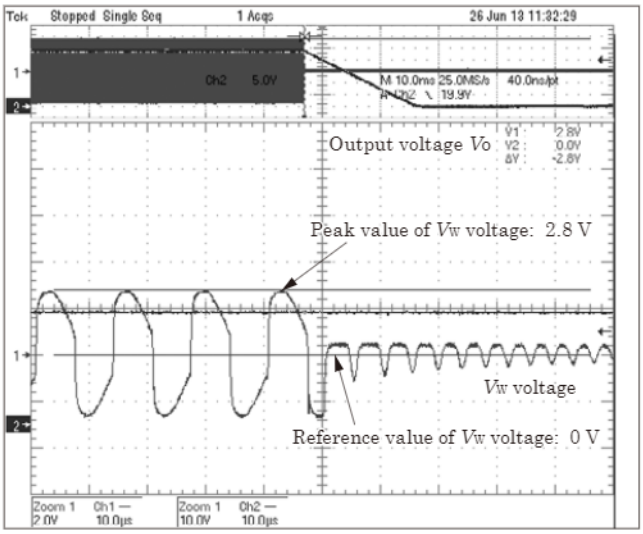


Fig.7 Operation waveform during overload protection

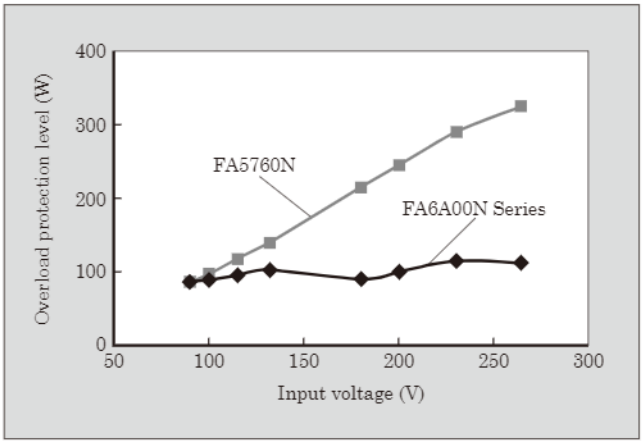


Fig.8 Input voltage and overload protection operating power

protection level is highly dependent on the input voltage when the input voltage range is wide, and this has necessitated the addition of a dedicated overload protection circuit. With the FA6A00N Series, variation of the overload protection level is small even if the input voltage varies, allowing for a high-accuracy overload protection function without a dedicated overload protection circuit. As a result, the number of power supply system components can be reduced, allowing for a cost reduction of a power supply system.

3.3 Over-current protection function with variable delay time

When a load short circuit occurs and an over-current state has continued for the specified time T_{ocp}, switching stops. This is called the over-current protection function. The power device has a possibility of being damaged if the Tocp setting is too long. If the T_{ocp} setting is too short, it causes an over-current state at start-up, and this may be detected as a load short circuit state and might hinder the start-up. The optimum T_{ocp} depends on a power supply and capability to adjust Tocp with an external component offers a higher degree of flexibility in power supply design.

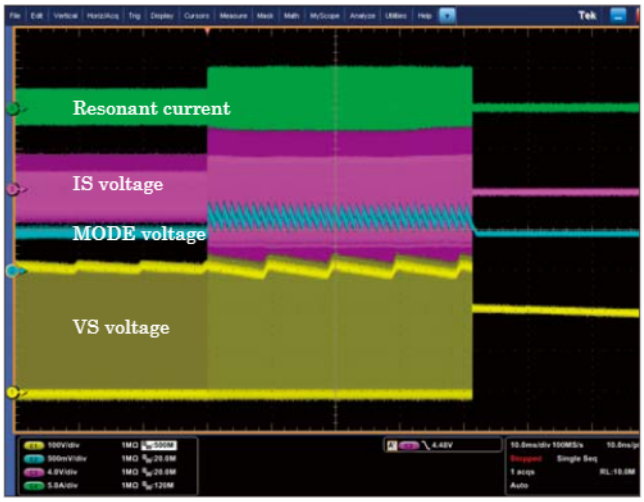


Fig.9 Waveform during over-current protection operation

With the FA6A00N Series, adjustment of T_{ocp} is shared by the MODE terminal for state setting, which has led to the realization of the over-current protection function with a variable delay time without increasing the number of terminals. Figure 9 shows a measured waveform. When a resonant current rapidly increases, an over-current state is detected on the IS terminal. The MODE terminal voltage is clamped to 0.5 V after state setting and, when an overload state is detected, oscillates between 0.6 and 0.8 V. When the number of oscillations reaches 36, switching stops and provides over-current protection. The duration of one oscillation can be adjusted by the capacitor connected to the MODE terminal.

4. Effect on Application to Power Circuit

4.1 Standby power reduction effect

Figure 10 shows a sample application circuit and Tables 4 and 5 the specification of the sample application circuit and major semiconductor components in the circuit. Figure 11 shows the measured standby power with a 35 mW load. The FA6A00N Series can reduce the standby power by approximately 20% from FA5760N, which allows elimination of the standby converter even if requirements for standby power are severe.

4.2 Number of circuit components reduction effect

Figure 12 shows the configuration of a general LLC current resonant power supply. A general LLC current resonant power supply is composed of a filter for EMI (electromagnetic interference) noise elimination, PFC converter for power factor correction, standby converter and LLC converter. Use of the FA6A00N Series allows significant reduction in the number of components, making it possible to build a low-cost LLC current resonant power supply (see Table 6).

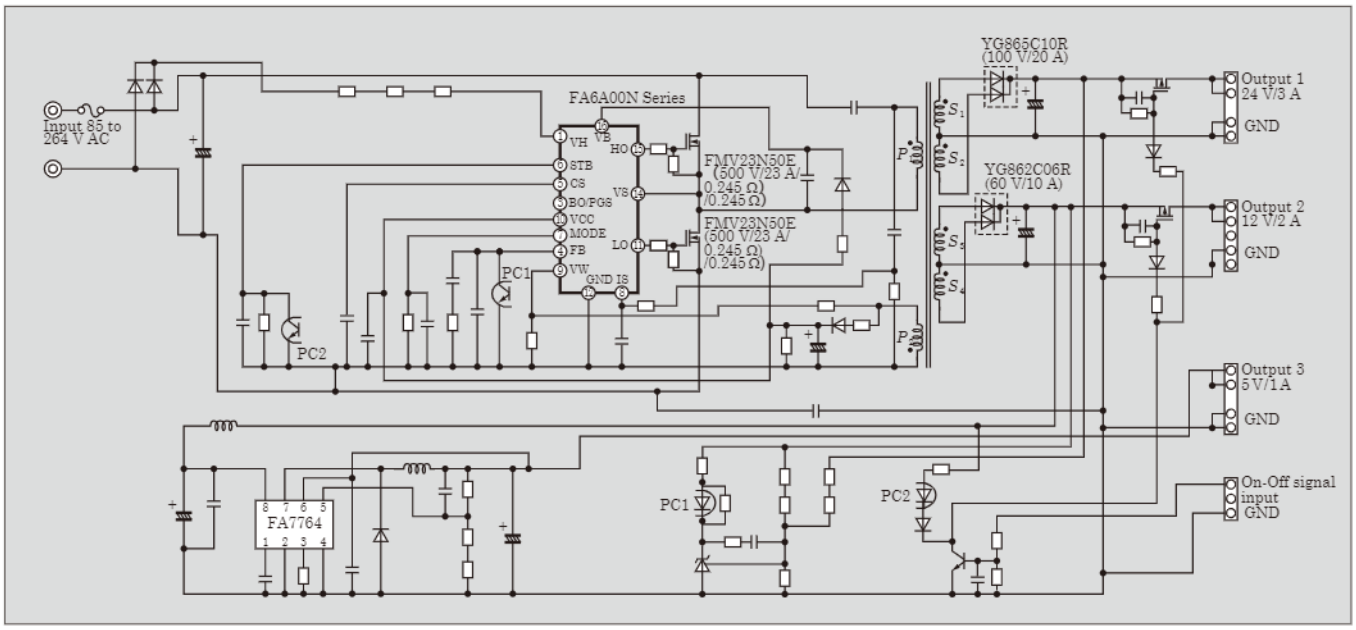


Fig.10 Sample application circuit

Table 4 Specifications of sample application circuit

Item	Characteristic, etc.
Input voltage	85 to 264 V AC
Output voltage/current	24 V/3 A, 12 V/2 A, 5 V/1 A
Output power	100 W (max.)

Table 5 Major semiconductor components in sample application circuit

Component	Model
Control IC	FA6A00N Series
Bridge MOSFET	FMV23N50E (500 V/23 A/0.245 Ω)
Diode (24 V)	YG865C10R (100 V/20 A)
Diode (12 V)	YG862C06R (60 V/10 A)
5 V AC/DC converter	FA7764AN

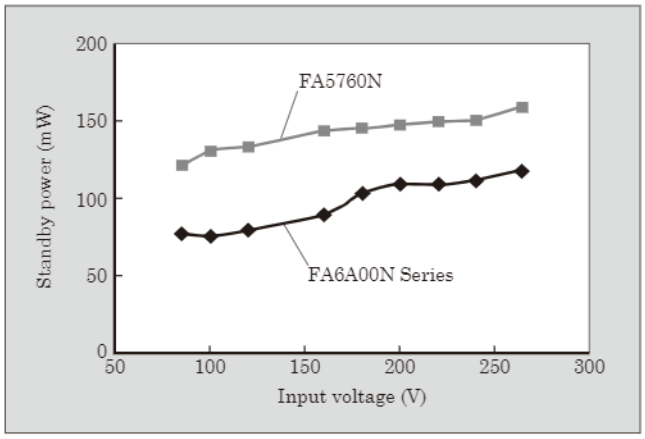


Fig.11 Standby power with 35 mW load

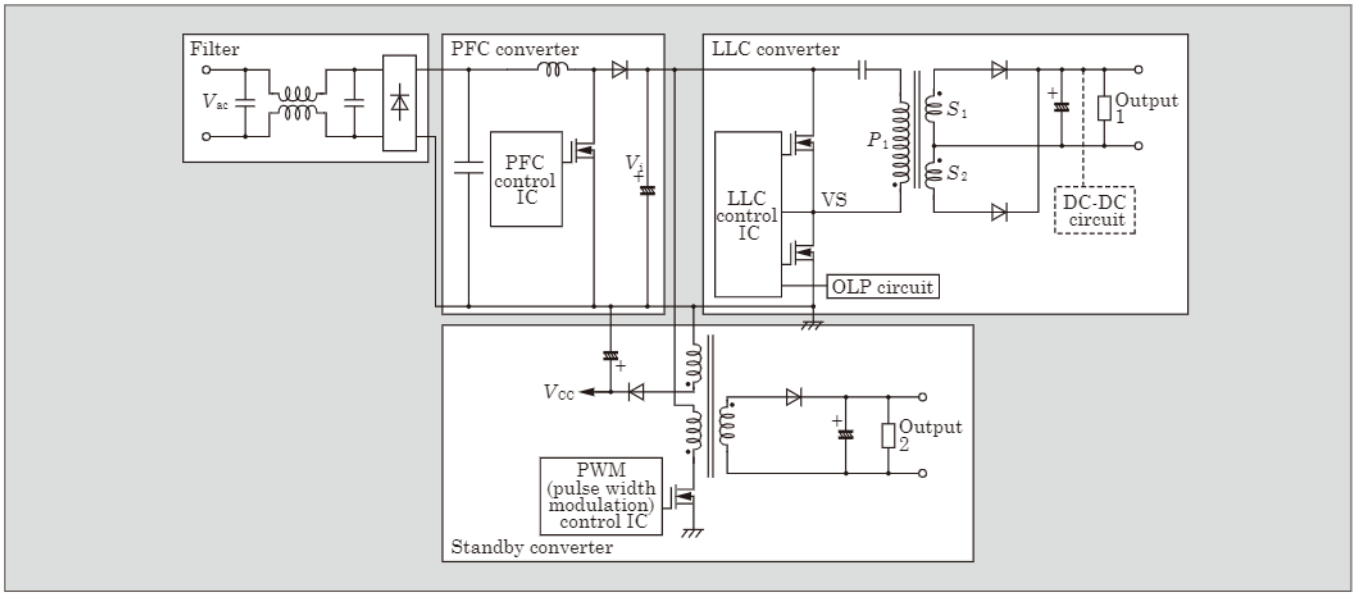


Fig.12 Configuration of general LLC current resonant power supply

Table 6 Comparison on number (approximate number) of components

		Filter	PFC converter	Standby converter	LLC converter			Total number of components
					Main	DC-DC	High-precision OLP	
FA5760N		10	30	40	60	Not required	10	150
FA6A00N Series	75 W or more	10	30	Not required	60	20	Not required	120
	less than 75 W	10	Not required	Not required	60	20	Not required	90

5. Postscript

This paper has described the 2nd-generation LLC current resonant control IC "FA6A00N Series." This IC, which inherits the characteristics of the 1st-generation product "FA5760N," has achieved further evolution of current resonant control with features including the high-precision overload protection function.

We intend to continue working on establishing new technologies that realize even higher efficiency and further noise reduction, and developing power supply control ICs that contribute to the miniaturization and profile lowering of power supply.

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