3-Phase AC 400 V Input PFC Converter

Design Guide

RD044-DGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

Contents

1. Introduction

This Design Guide describes how to design various types of circuitry for the 3-Phase AC 400 V Input PFC Converter (this power supply) . Refer to the reference guide for the specifications, usage, and characteristic data of this power supply.

Even if the part number is indicated in the circuit diagram, it is not mounted on PCBs if it is indicated as "Not Mounted" in the bill of materials. A mounting location is provided on the PCB for constant value adjustment at the time of circuit design.

1.1. Power MOSFET Used

This power supply adopts a SiC MOSFET (TW070J120B with a 1200 V rating) as a switching device and directly switches each phase. This section introduces the products used in this power supply.

TW070J120B

Mounted on U, V, and W phases

V_{DSS} = 1200 V, $R_{DS(ON)}$ (typ.) = 70 mΩ@V_{GS} = 20 V, TO-3P(N) package

Built-in SiC Schottky barrier diode realizes loss reduction when reverse current is applied

2. Circuit design

This section describes the points of circuit design of this power supply.

2.1. AC line circuit design

This section describes the AC line design of this power supply. The AC line circuit of this power supply is shown in Fig. 2.1.

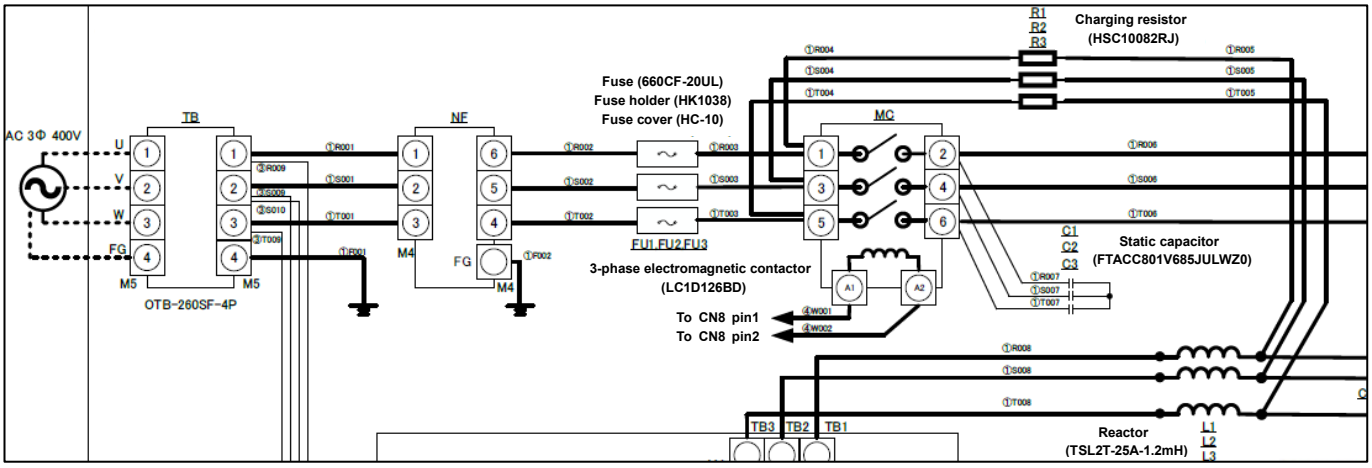

Fig. 2.1 AC Line Circuit

Fuse

Fuses (FU1, FU2, FU3) are installed to shut off the AC line when abnormal current flows through the AC line. Select a fuse from the maximum current value of the AC line. The effective value of the maximum AC line input current is calculated by the following formula.

Maximum AC line input current = maximum power/power supply efficiency/power factor/input phase voltage effective value (min)/3

This power supply has a 3-phase AC 400 V system for input and 4 kW for output. Generally, the power supply efficiency of the PFC is lower when the input voltage is low. Therefore, when calculating the AC line maximum current value, consider that the input voltage is 312 V, the lowest value in the input range of this power supply. When the line voltage is 312 V, the phase-to-phase voltage is 180 V. Therefore, assuming that the input phase voltage rms value = 180 V, the maximum power = 4 kW, the power supply efficiency = 97 %, and the power factor = 0.99, the maximum AC-line current value of this power supply is approximately 7.7A. 20A fuses are used in this power supply, taking into account the margins of fusing times. When selecting a fuse, it is necessary to consider the inrush current when the AC power is turned on, whether the product has obtained the safety standards to be complied with, etc., in addition to the above maximum current.

Inrush current countermeasures

Resistors (R1, R2, R3) are installed to suppress inrush current when the AC power is turned on. The resistance value must be set according to the maximum input current flowing through the AC line. Since the maximum input current is 10 A in this power supply, the resistance value is calculated from the following equation.

Resistance > Maximum Input Phase Voltage/Maximum Input Current

When the maximum input line voltage of this power supply is 528 V, the phase-to-phase voltage is 305 V as an effective value, and the peak voltage at that time is 431 V. Therefore, assuming that the maximum input current is 10 A, the resistance value is approximately 43 Ω from the above equation.

This power supply uses an 82 Ω resistor for margin considerations. The current value is 5.25 A when an 82 Ω resistor is used.

2.2. PFC circuit design

Inductor selection

This section explains how to select inductors (L1, L2, L3). The inductance value in this circuit can be calculated using the following items, which are power supply specifications.

- Max. output power: P_{out} (W)
- Ac-line minimum-phase effective voltage: V_{in_min} (V)
- PFC power conversion efficiency: η (%)
- PFC-output voltage: V_{out} (V)
- Switching frequency: F_c (Hz)
- Allowable ripple current width: ΔI_{ripple} (%)

Calculate the inductance value using the following formula.

$$L = \frac{\left(V_{out} - \sqrt{2} \times V_{in\_min}\right) \times \eta \times 0.01 \times {V_{in\_min}}^2}{F_c \times 0.01 \times \Delta I_{ripple} \times P_{out} \times V_{out}}$$

Here, assuming that the maximum output power (P_{out}) is 4 kW, the minimum phase-to-phase voltage (V_{in_min}) of the AC line is 180 V, the PFC output voltage (V_{out}) is 750 V, the switching frequency (F_c) is 50 kHz, the PFC power conversion efficiency (η) is 97 %, and the allowable ripple current width is 30 %, the above equation shows that the calculated inductance value (L) is 346 μH. Therefore, the setting value of this power supply is 1.2 mH considering the margin.

In the actual design, the inductance value of the inductor varies depending on the DC bias characteristics. Select a component that can secure the above calculated value with the inductance value decreased due to DC bias characteristics.

Gate drive circuit

Fig. 2.2 shows the gate drive circuit of the lower arm of the U-phase as a typical gate drive circuit. The design of the gate drive circuit affects power supply efficiency and EMI noise. Generally, power

supply efficiency and EMI noise have a trade-off relationship, so it is necessary to design both in a balanced manner. The gate drive circuit of this power supply can adjust the switching speed of MOSFET. If you need to reduce the noise at turn-on of MOSFET, changing the gate series resistor (R48) to a large value may reduce EMI noise. Note that if the gate series resistor is changed to a large value, not only the turn-on speed of MOSFET but also the turn-off speed will be reduced, which may result in a worsening of the power supply efficiency. Only MOSFET turn-off speed should be increased in order to reduce power-efficiency degradation in this situation. Changing the gate-series resistor (R46) to a small value may only increase the turn-off speed of MOSFET and reduce the power-efficiency degradation of the system. When changing the gate series resistor, it is necessary to confirm that the EMI noise, power efficiency performance, and heat dissipation performance required for the system are satisfied.

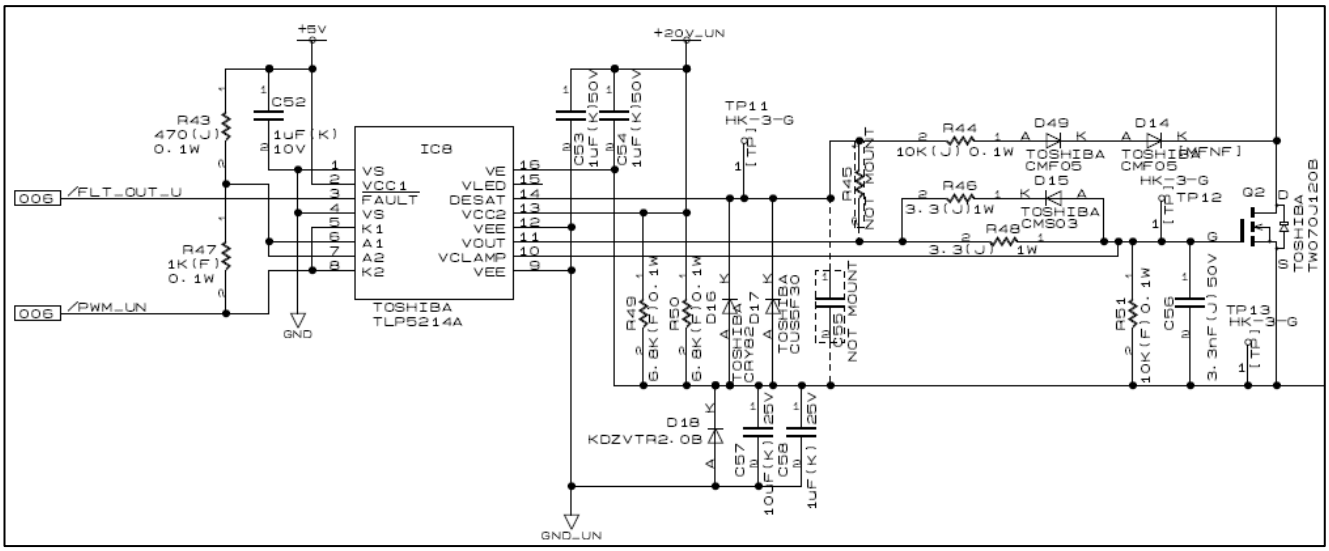

Fig. 2.2 Gate Drive Circuit (U-Phase Lower Arm)

Negative bias circuit

Use a negative-bias circuit if there is a risk of malfunction due to the parasitic mirror capacitance between the drain-gate of MOSFET. Fig. 2.2 shows the gate drive circuit that is used for the lower arm. When the lower arm is turned off and the upper arm is turned on, the intermediate potential rises steeply and displacement current is generated through the mirror capacitance between the drain-gate of the lower arm MOSSET, and flows toward VOUT terminal of the smart gate driver coupler (IC8). When this displacement current passes through the gate resistor of the circuit, a voltage drop occurs, and when the gate voltage rises, the lower arm may be faultily turned on, resulting in a short circuit of the upper and lower arms. By using a negative bias circuit using a Zener diode (D28), the gate voltage becomes negative when the lower arm is turned off, thereby preventing fault turning-on. This power supply uses a 2 V zener diode to make a 2 V negative bias circuit.

Output Capacitor

The capacitance of the output capacitor (C147 to C152) is calculated based on the hold-up time requirement. The hold-up time Thold is calculated by the following equation, assuming that the capacitance of the output capacitor is Cout, the output voltage is Vout_PFC, the lower limit voltage of the output voltage is Vmin, and the maximum output power is Pout.

$$Thold = Cout \times \frac{(Vout\_PFC^2 - Vmin^2)}{2 \times Pout}$$

The default setting is Cout = 705 μF, Vout_PFC = 750 V, Vmin = 700 V, and Pout = 4 kW. The hold-up time is 6.38 ms. Adjust the capacitance of the output capacitor to satisfy the hold-up time required for the system. In addition, when the output ripple specification is defined, the capacity required to satisfy the output ripple specification must be calculated and compared with the capacity that satisfies the hold-up time, and a large capacity value must be used. In addition, tolerances and aging degradation must be considered when selecting a capacitor.

This power supply uses Texas Instruments TMS320F28377SPTP as a PWM controller and uses a software libraries manufactured by Head Spring to create control software. For more information about the controller and the software libraries, please refer to the manufacturer's product data sheet and related documents. Please refer to "Sample Software" for the software used with this power supply and its outline.

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