

INRUSH CURRENT SUPPRESSION SCHEME OF HOT SWAP POWER MODULES

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Abstract

The corrected magnet power supplies apply modular designed for Taiwan Photon Source synchrotron project (TPS). If the module is damaged in the chassis, it must be replaced without interrupting the power. However, the modular is a shared DC bus. If there is no good design and planning, it will cause the protection circuit into action.

In this article the theoretical derivation and implementation are used to prove the feasibility and necessity of the soft-start circuit. In the actual signal measurements it could be clearly seen the inrush currents is refrained and improved. Finally, the soft-start circuit is implemented applications in correction magnet power supply modular of Taiwan Photon Source synchrotron project (TPS).

INTRODUCTION

TPS corrected magnet power supplies apply modular designed, the architecture shown in Figure 1. A chassis can be installed eight corrected magnet power supplies module. These three busses in main power and operating voltage and control signals were shared by eight corrected magnet power supply modules. Shared these busses can effectively reduce the volume of the machine itself, and complexity of the hardware circuit, that also equivalent to achieved higher economic returns [1-2].

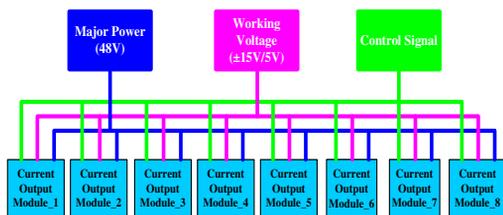


Figure 1: The architecture of TPS corrected magnet power supplies modular.

The modular power supply systems in practical applications, usually uninterrupted power supply of equipment systems. When the modules in the chassis were damaged, must replace the modules of the systems in uninterrupted power supplies.

The prototype of TPS corrected magnet power supply systems as an example. The waveform of the modules was plugged into the main systems, shown in Figure 2. The main power supply voltage 48V had plunged, which plunged about 9.2V (19%), the lowest voltage was 38.8V. When the main power supplies voltage was below 45V, corrected magnet power supply modules itself sent the mains input voltage failure signal and stopped working, it

can be seen from the chart the voltage below the 45V duration approximately 2mS. The all of Corrected magnet power supply modules inside the chassis were stopped working, which was with the original modular designed concept different. It's worth noting that when the corrected magnet power supply modules plugged into main power bus, which main power supply output current swelled to 230A, shown in Figure 2. This current phenomenon was called Inrush current, Inrush current can cause to fuse was burned and damaged to other electronic components with the system can't operated normally.

In order to maintain the normal operation of the power supplies, so added the soft start design to the power supplies. The soft-start design can be ranged into active and passive two types, the active design must need a controller and a current sensor to control switches, so in this paper used passive design.

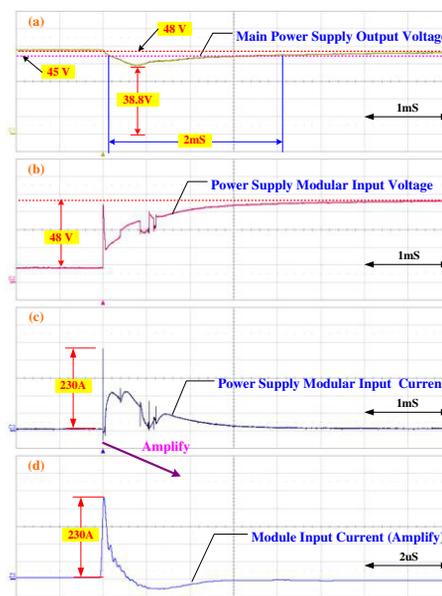


Figure 2: Corrected magnet power supplies modular plugged into the main system's waveform.

PRINCIPLE OF PASSIVE INRUSH CURRENT LIMITING

Understand the impact caused by the inrush current, then in this section was proposed ways to improve the inrush current. Due to the charging of capacitors, so that were produced the inrush current when the corrected magnet power supply modules plugged into the chassis. Using the resistor and capacitor (RC) charge circuit for the architecture is shown in Figure 3, the capacitor charging current formula such as the equation (1).

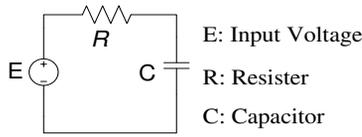


Figure 3: RC Charging Circuit.

$$i = \frac{E}{R} e^{-t/RC} \quad (1)$$

When the resistance R is small, the charging time will be reduced, but in the charging current will be increased, as shown in equation 1, the waveforms of output voltage and current shown in Figure 4. The main power supply output voltage is 48V, the rated output power of 1KW the rated output current is 21A, the starting current is set at below the rated current 2%, so the starting current within 0.4A. Due to the control circuit have power early, therefore capacitor have the initial voltage of 8V. The voltage difference between the capacitor and the main power supplies is 40V, in order to limit starting current within 0.4A, so the resistance value is set to 100Ω.

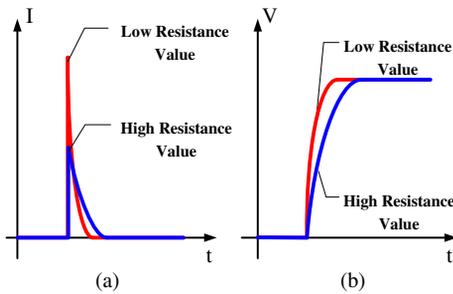


Figure 4: The waveform of charging circuit (a) charge current (b) charge voltage.

The passive soft-start circuits used the RC charging circuit as the basic structure, as shown in Figure 5. Use switching control to control the charging current magnitude, switch turn-on to force current must flow through the resistor in the start moment, that limit the start-current, that to prove the equation as shown below.

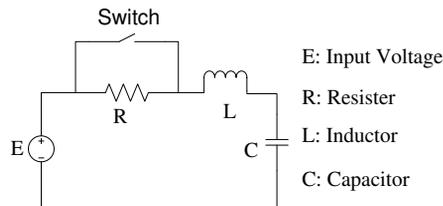


Figure 5: Passive soft-start circuit.

$$L \frac{di}{dt} + Ri + v_c = E \quad (2)$$

$$i = C \frac{dv_c}{dt} \quad (3)$$

$$v_L = L \frac{di}{dt} \quad (4)$$

$$\frac{di}{dt} = C \frac{d^2 v_c}{dt^2} \quad (5)$$

Substitute of equation (5) into equation (2), get new equation.

$$LC \frac{d^2 v_c}{dt^2} + RC \frac{dv_c}{dt} + v_c = E \quad (6)$$

Solutions can be obtained as shown below.

$$v_c(t) \approx 40(1 - e^{-5.32t}) + 8 \quad (7)$$

$$i(t) \approx 0.4e^{-5.32t} \quad (8)$$

From equations (7) and (8) can be drawn the waveforms of the capacitor input voltage and current in the soft-start moment. Set the soft-start circuit to start work in 0.4 seconds. Due to the control circuit have power early before the switching start work of soft start circuit, therefore capacitor have the initial voltage of 8V, so have the initial value condition in the equation, such as shown in equation (7), which waveforms of the capacitor voltage and output current as shown in Figure 6.

The switching is turn-on in the soft start circuit complete work, the switching impedance is 50mΩ, the capacitance value is 1880uF (equivalent series resistance: 5mΩ), the inductance value is 10uH (equivalent series resistance: 10mΩ), so the total resistance of the circuit is 65 mΩ. If you want to limited start current less than 0.4 A in soft-start circuit start work, that can use the Ohm's law $V = I * R$, so get the equation as shown below.

$$V = 0.065 * 0.4 = 0.026 \quad (9)$$

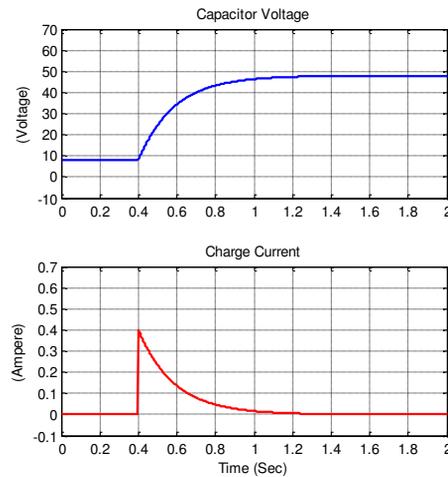


Figure 6: The capacitor voltage and input current waveform of soft-start circuit start up.

By the equation (9) can known, that the voltage difference control below in 26 mV was safest, so by equation (7) can be obtained t must be greater than 1.38 (Sec), due to the specifications of electronic components, so the t set at 1.45 (Sec), when the time t = 1.45 (Sec),

that the voltage difference of the capacitor voltage and the input voltage is 17.9 mV. From equation (2) to (5) can get the equation of input current, such as equation (10), from equation (10) can be seen that the oscillation frequency is about 1040Hz, that the input current waveform as shown in Figure 7.

$$i(t) \approx 0.274e^{-3250t} \sin(6530t) \quad (10)$$

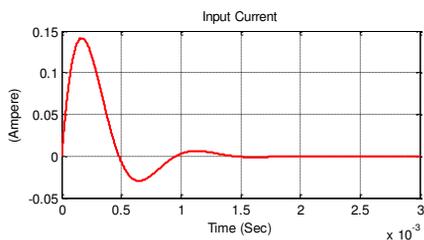


Figure 7: The input current waveform of soft-start end.

SIMULATION AND EXPERIMENTAL ANALYSIS

The proven equations and design circuits simulate by circuit simulation software, the waveforms of circuit simulation as shown in Figure 9.

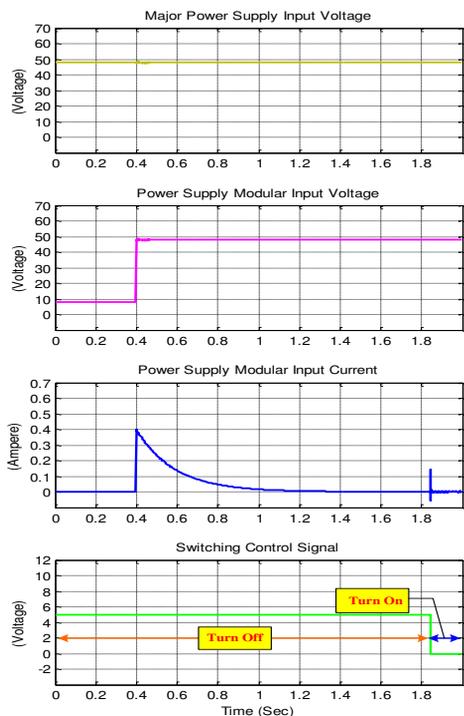


Figure 8: The simulation results.

The passive soft-start circuit of circuit simulation changed to physical circuit, used oscilloscope to measure the power supply modular response waveforms at the power supply modules plugged into main power bus, the measurement results as shown in Figure 9. By figure 9 can see that, the main power supply output voltage is not lower than the trigger voltage (45V) of operate voltage

protection, and the main power supply output voltage waveform is not have significant change, and maintain the instantaneous input current is below the 0.4A.

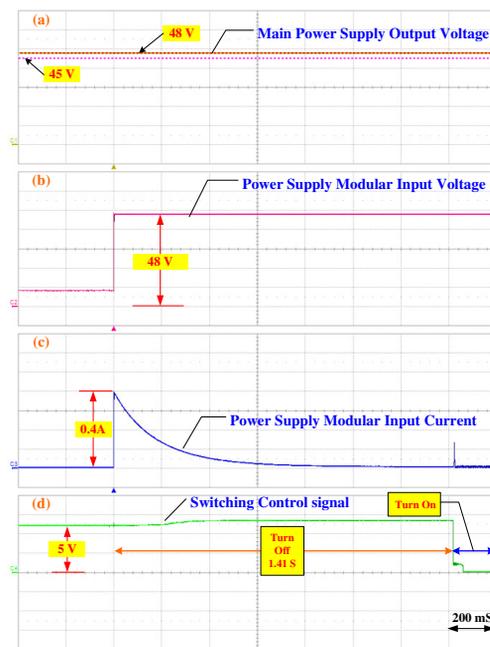


Figure 9: The actual waveform change of module connection main system.

CONCLUSION AND RECOMMENDATIONS

By way of the theoretical derivation and simulation are used to prove the feasibility of the soft-start circuit, and then by the actual measurement signal waveforms of circuit can prove the actual signal waveforms consistent with the theoretical waveforms.

The soft-start circuit can effectively suppress Inrush current of generated by the hot-swap case, and prevent transient voltage sag caused by Inrush current, and thus improve power system protection malfunction caused by voltage sag, proved that the power supplies has soft-start circuit is necessity. In this paper, the soft-start circuit is the use of passive components in this control mode, in the start time will be longer than the active type, if turned into the active type digital constant-current soft-start that can effectively shorten the soft-start time. However in terms of price and design will be more expensive and cumbersome, but can provide the better features for the power supplies.

REFERENCE

- [1] TPS corrector magnet power converter: Kuo-Bin Liu, Yi-Da Li, Kuo-Tung Hsu Bao-sheng Wang (NSRRC, Hsinchu, Taiwan), Jimmy Chun-ming Hsu (CMS/ITRI, Hsinchu, Taiwan) IPAC10.
- [2] TPS fast corrector magnet power converter: Yi-Da Li, Kuo-Bin Liu (NSRRC, Hsinchu, Taiwan) IPAC11.

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