

Design of Active Power Filter for Low Voltage and High Current Switching Power Supply

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Abstract—Switching power supply of low voltage and high current based on power electronic technology is widely applied in some industry fields, especially in electroplating, welding and heating. Harmonics in high-power switching supply pollute power system heavily, which must be suppressed effectively. On basis of analyzing harmonic current of switching supply that the output technical specification is 60V/500A, this paper designs active power filter for switching power supply with high power and frequency, which adopts i_p-i_q current detecting method and hysteresis current control method. Based on simulation platform of Matlab/Simulink, the filtering effect is simulated and analyzed. Simulation results demonstrate the active power filter has expected performance, which can not inhibit harmonic current instantaneously, but also compensate reactive power. The designed active power filter can effectively improve the power quality.

Keywords-low voltage and high current; switching power supply; active power filter; harmonic current; hysteresis current control.

I. INTRODUCTION

With the development of power electronic technology, low voltage and high current switching power supply has been applied widely in production and life. But harmonic pollution becomes severe increasingly in switching power supply. Generally, there are two methods to eliminate harmonics, which are mainly passive power filter and active power filter. The former is relatively low cost, but filtering effect is far from desirability^[1, 2]. By contrast, the latter can suppress the harmonics instantly and compensate reactive power, and it becomes an effective approach to inhibit harmonics^[3, 4]. Thus, this paper employs active power filter to suppress harmonic current of low voltage and high current switching power supply.

This paper proposes the design and performance analysis of active power filter for 60V/500A switching power supply.

II. HARMONICS ANALYSIS OF SWITCHING POWER SUPPLY

A. Basic structure and Technical specification of the low voltage and high current power supply

The low voltage and high current power supply mainly consists of three components: “input rectifier filter circuit”, “high frequency inverter circuit” and “output rectifier filter circuit”. Through the conversion of AC~DC~AC~DC, the needed DC voltage can be obtained. Structure diagram of the low voltage and high current power supply is shown in Figure1.

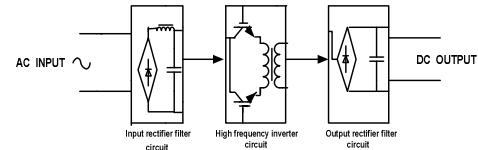


Figure 1. Structure diagram of the low voltage and high current power supply

Technical specification of the low voltage and high current power supply:

- 1) Input Voltage: AC $380 \pm 10\%$ V;
- 2) Power grid Frequency: 50Hz;
- 3) Output Standard Voltage: 60VDC;
- 4) Output Standard Current: 500A;
- 5) Output Voltage Range: 55~65VDC;
- 6) Output Maximum Current: 540A;
- 7) IGBT Operating Frequency: 20kHz;

B. Harmonics in the low voltage and high current power supply

In the presence of full-load, the voltage and current of the low voltage and high current power supply can be detected by using the HIOKI 3196 Power Quality Analyzer, and is concretely shown in Figure2.

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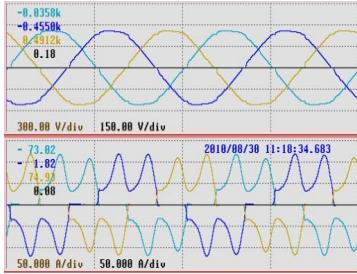


Figure 2. Waveform of three-phase voltage and current

As can be seen from Figure 2, the distortion of three-phase voltage waveform is not obvious, THD_U=2.62%<5%, confirming to GB's limits, while the distortion of three-phase current waveform is quite serious. The histogram of A-phase harmonic current is the middle section in Figure 3, which shows that 5th harmonics is nearly 25A, 7th harmonics can reach to 12.5A. Individual harmonic current value is detailedly shown in TABLE I .

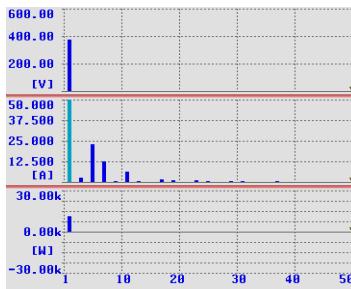


Figure 3. A- phase harmonic voltage, current and power histogram

MEASUREMENT VALUE, SIMULATION VALUE AND GB'S LIMITS OF A-PHASE HARMONIC CURRENT

Harmonic order	conversion value of GB's limits /A	Harmonic current measurement value /A	Harmonic current simulation value /A
1	/	53.53	56.57
3	3.72	2.35	4.24
5	3.72	23.02	23.16
7	2.64	12.65	15.55
11	1.68	6.57	7.1
13	1.44	0.43	4.8
THD _I /%	/	51.12	52.13

Table footnote: standard voltage is 0.38kV, and standard short circuit capacity is 600kVA; GB's limits converted value is calculated according to GB/T1459-1993 "harmonic power quality utility grid"^[5].

Total Harmonic Distortion of A-phase harmonic current is shown in TABLE I , THD_I=51.12%. 5th, 7th and 11th harmonic current all have exceed GB's limits, and must be restrained.

III. DESIGN OF ACTIVE POWER FILTER

A. System configuration of Active Power Filter

System configuration of Active Power Filter is shown in Figure4, and its operating principle is as follow: firstly, detect the voltage and current of compensated object; secondly, calculate the instruction signal of the needed compensated current via the operation circuit of instruction current; thirdly, amplify the instruction signal via generation circuit of compensating current, and get the needed compensating current; finally, the obtained compensating current eliminates the harmonic component in load current to attain the expected grid-side current^[5].

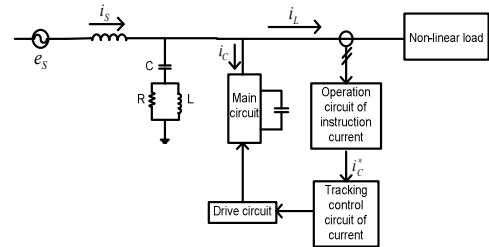


Figure 4. System configuration of Active Power Filter

B. Design of Instruction Current's Generation Circuit

On the basis of instantaneous reactive power theory, there are two methods to detect the harmonic current. They are p-q and i_p-i_q detecting methods respectively^[6, 7]. When power grid voltage appears distortion, i_p-i_q detecting method will be more precise. So it is used extensively. The principle diagram of i_p-i_q detecting method is shown in Figure5^[8].

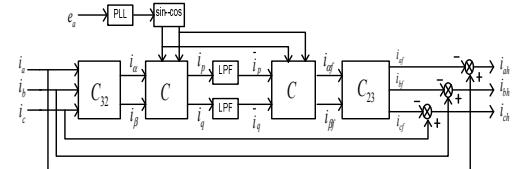


Figure 5. Principle diagram of i_p-i_q detecting method

The expressions of C32 and in the fig2-2 are following.

$$C_{32} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -0.5 & 0.5 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix};$$

$$C = \begin{bmatrix} \sin \omega t & -\cos \omega t \\ -\cos \omega t & -\sin \omega t \end{bmatrix}.$$

i_p-i_q detecting method mainly applies Phase Locked Loop(PLL), sine and cosine signal generator to obtain the sine and cosine signal with the same phase as grid-side A-phase voltage. Calculate the value of i_p and i_q according to definition, attain the DC components of i_p and i_q via the Low-Pass Filter(LPF), get i_{af} , i_{bf} and i_{cf} through reversed transformation of the DC components, and then ultimately calculate the instruction current signal i_{ab} , i_{bh} and i_{ch} .

C. Design of Current Tracking-control Circuit

Due to that the compensating current obtained in Active Power Filter should timely follow the changing trend of instruction current signal, compensating current generator should have excellent real-time. So current-control should adopt comparative method of instantaneous value of hysteresis comparator. The principle diagram of comparative method of hysteresis comparator's instantaneous value is shown in Figure6.

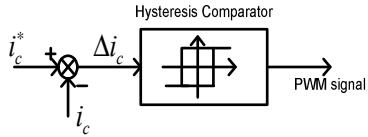


Figure 6. Principle diagram of comparative method of hysteresis comparator's instantaneous value

Hysteresis band H has a great effect on tracking performance of compensating current in this control method. The broader H is, the lower switching frequency and performance of power semiconductors can be, but it means there are more tracking error and high-order harmonics at the same time. While H is little wider, the contrary is the case.

D. Control of DC-side capacitor Voltage of Active Power Filter

Traditionally, the method to get voltage of DC-side capacitor is that voltage regulator and rectifier provide DC power for the capacitor, but this method increases the complexity and the cost of the system. Moreover, the control of DC-side capacitor voltage is achieved only by regulating main circuit appropriately, as is shown the control principle diagram of DC-side capacitor voltage in Figure7.

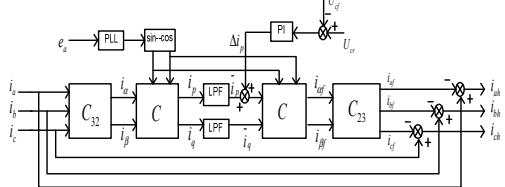


Figure 7. Operation circuit of instruction current including DC-side capacitor voltage's control

U_{cr} is the given value of U_c , U_{cf} is the feedback value of U_c in Figure7. The deviation between the given value and the feedback value convert to the signal Δi_p through PID regulation. The signal Δi_p is added to active component of instantaneous active current. Make the instruction signal contain the certain fundamental active current by calculation and the compensating current include the certain fundamental active current component, so as to make the DC-side and AC-side of active power filter exchange energy, and then U_c reach to the given value.

E. Parameter Design of Active Power Filter's Main Circuit

Primary parameters of main circuit are DC-side capacity voltage U_c and AC-side inductance L . Parameter design depends on the two equations below:

$$U_c \geq 3E_m \quad (1)$$

$$9L\eta = 4U_c \quad (2)$$

Where E_m is peak value of Phase voltage; and η is a defining variable influencing the compensating effect.

Pay attention to the following two points:

1) The minimum U_c should be three times bigger than peak value of Phase voltage, otherwise, $|\Delta i_c|$ may not reduce as required. Under this condition, the more U_c is, the faster i_c changes, but power electronic device must endure higher voltage.

2) The smaller L is, the faster i_c changes; otherwise, the contrary is the case.

IV. SIMULATION ANALYSIS OF ACTIVE POWER FILTER

A. Simulation Module

As is shown that Figure8 is simulation module on basis of i_p-i_q detecting method, Figure9 is simulation module of active power filter.

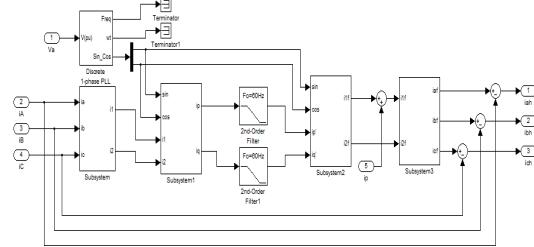


Figure 8. Simulation module on basis of i_p-i_q detecting method

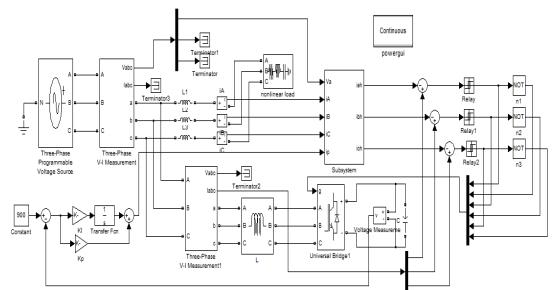


Figure 9. Simulation module of active power filter

B. Analysis of Simulation Result

It can be seen waveform of instruction and compensating current are the same almost as well, by the comparison of Figure10 and Figure11, which shows that tracking performance of active power filter is much excellent.

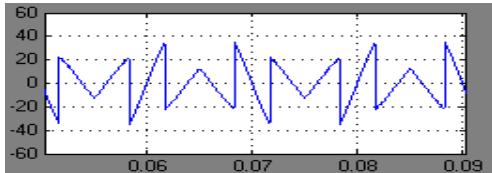


Figure 10. Waveform of A-phase instruction current

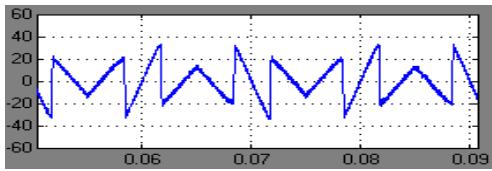


Figure 11. Waveform of A-phase compensating current

As is shown that A-phase current waveform after filtering have been much better and almost come near to sinusoidal, by comparing Figure12 and Figure13. Individual harmonic current value is shown in TABLE II .

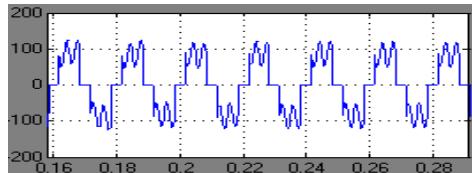


Figure 12. A-phase current waveform before filtering

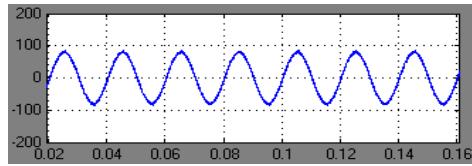


Figure 13. A-phase current waveform after filtering

TABLE I. COMPARATIVE TABLE OF A-PHASE HARMONIC CURRENT VALUE BEFORE AND AFTER FILTERING

Harmonic order	GB's limits conversion value /A	Harmonic current value before filtering/A	Harmonic current value after filtering/A
1	/	56.57	57.12
3	3.72	4.24	0.04
5	3.72	23.16	0.78
7	2.64	15.55	0.81
11	1.68	7.1	0.93
13	1.44	4.8	0.88
THD/%	/	52.13	1.55

Table footnote: standard voltage is 0.38kV, and standard short circuit capacity is 600KVA; GB's limits converted value is calculated according to GB/T1459-1993 "harmonic power quality utility grid"^[5].

As can be seen from TABLE II , 5th, 7th and 11th harmonic current value are substantially reduced (not more than 1A), far

less than GB's limits; Total Harmonic Distortion of A-phase harmonic current is that, THD_f=1.55%.

V. CONCLUSION

This paper analyzes harmonics in switching power supply of low voltage and high current and designs active power filter to suppress the harmonic current. Not only introduce operating principle and parameter design comprehensively, but also verify the filtering effect via constructing the simulation module on the platform of Matlab/Simulink. The simulation results show harmonic current of low voltage and high current switching power supply can be inhibited instantaneously, and the active power filter has the nice performance of compensating harmonics.

If design the active power filter to suppress harmonic current of the switching power supply with higher power, it requires bigger capacity of the filter, so the active power filter is difficult to achieve in engineering application and easy to make mistakes at run time. Thus, it attempts to consider the Hybrid Active Power Filter combining the advantages of PPF and APF^[9, 10]. Active power filter can not perfect the results of passive power filter, but also have a lower capacity, improve the cost performance of the power system.

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