Development of 1200A AC/DC Linear Standard Power Supply

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Keywords: Linear Power, AC, High Current, Ripple Wave

Abstract. With the development of science, technology and production, there is an increasing demand for high-current power supply, which is widely applied in research of high-speed railways, subways, electric cars, DC transmission and electromagnetic measurement science. The commercial high-current power supply basically uses the form of switching power supply and its ripple wave is generally greater than 1%, with the peak-peak value up to the pulse ripple shortcomings of a few volts (with a constant amplitude), and the ripple wave basically has nothing to do with the amplitude of the output current. Therefore, it is very difficult for switching power to be applied in high-current AC power supply. In this paper, we have researched and designed a kind of AC/DC linear high-current power supply based on the linear theory. In this paper, we have researched and designed a kind of AC/DC high-current power supply based on the linear theory, with the AC current frequency kept from 50Hz to 1 kHz. Moreover, a plan has been designed to test the AC/DC high-current performance and assess the accuracy, ripple wave (harmonic wave) and short-term drift performance of the power supply.

System Principle and design

The linear current supply means that the power supply has no break variable or pulse superposition in the process of current output. DC current supply has better stability and a small ripple coefficient, while AC current supply has smaller distortion and better stability.

Commonly, a high-current DC power supply above 1kA usually adopts direct mains supply rectification and the low output voltage will result in a larger ripple wave (above 2%) and poor stability (about 0.2% / 3 minutes), because the output current will change with the circuit resistance of the power grid and power supply. Therefore, the solution of the above-mentioned problems requires an adjustable and stable AC supply featuring a higher frequency (above 1 kHz) and free of power frequency modulation by means of rectification and filtration. AC current supply is even more demanding.

To sum up, the high power amplifier (HPA) should be the core component for research and design of AC/DC linear high-current supply, requiring that the power amplifier amplitude can be adjusted (in an intelligent manner) and have a higher common mode rejection ratio. Moreover, DC current supply is provided with an efficient rectification and filtration assembly. The short-term stability of AC/DC current supply depends on the simulative closed-loop system while the long-term stability depends on the SCM (single chip microcomputer) digital closed-loop system subject to automatic tracking.

See Fig.1 for the schematic block diagram of the power supply for research and design: After filtration, the grid 220V (50Hz) current goes through the isolation transformer, the rectification and filtration circuits as well as a power amplification circuit. Then, an AC or DC high-power current will be output through current boosting, filtration and current sampling feedback control.

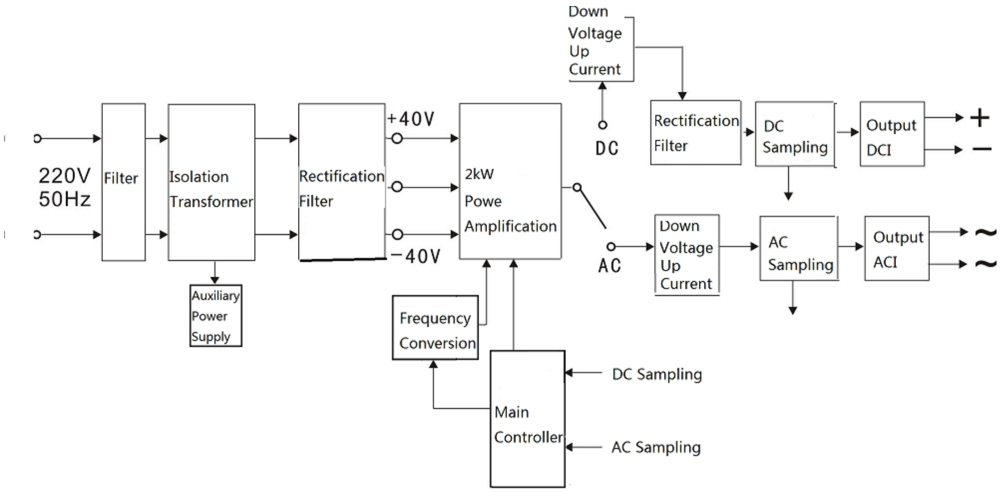

Fig. 1 Schematic block diagram

From the design principle, it can be seen that the development of AC/DC high-current supply includes such key and difficult points as follows: isolation transformer matching, power frequency rectification and filtration, power amplifier, DC step-down current-boosting devices, DC rectification assembly, DC filtration assembly, AC/DC sampling and AC step-down and current-boosting, etc.

Design essentials for key components

1. Development of 2 kW power amplifiers

Fig.2 and Fig.3 show the matching isolation transformer and the rectifier bridge respectively. According to the theoretical calculation, the power amplifier for a 1kA AC/DC power supply should have its maximum working current about 80A; in order to improve the reliability, 8 power modules (The maximum current and withstand voltage should be above 200A and 500V respectively for each power module) are adopted.

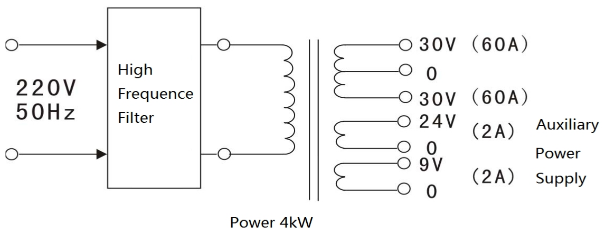

Fig.2 Principle of isolation transformer

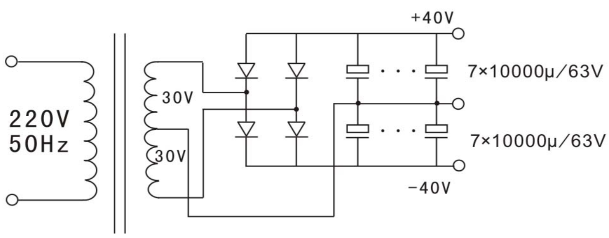

Fig.3 Rectifier Bridge

The whole power amplifier has a fairly excellent common mode rejection ratio (CMRR) to ensure that 50Hz (100Hz) will not activate modulation of the current output.

Hint: The power frequency (and its frequency doubling) modulation signal will produce beat frequency interference in the AC current supply. For a DC current supply, its ripple coefficient will be increased and the ripple wave is difficult to remove in a conventional manner.

2. DC step-down current boosting

Each transformer coil has inherent inductance, so a higher frequency is no doubt good for filtering, but the output efficiency of the power amplifier will consequently be lower, which is a disadvantage in the linear power supply, as shown in Fig.4. We choose the frequency of 1 kHz as a compromise.

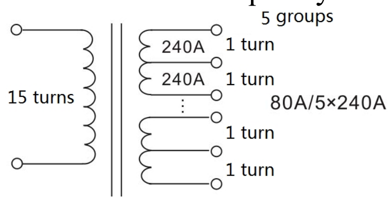

Fig.4 Principle of current boosters

3. DC rectifier

The output voltage of the AC current supply is only 1.5V, so it requires that finally there should be a 0.5 V / 1200A output after rectification and filtration. This is indeed a very difficult task, the tube voltage drop of a Schottky rectifier tube (if used in design) is 0.4V ~ 0.7V; if a full-wave rectifier (not a bridge rectifier) is used and we use a Schottky module (300A/30V) characterized by a high current and a low voltage drop, the rectifier tube loss will be below 0.5V and two filter inductance coils will suffer from the loss of 0.15V. The sampling DC resistance diverter will suffer from the loss of 0.1V and the step-down on the whole lead will be about 0.2V. A 1.5V AC voltage will provide a 1.3V DC voltage theoretically after rectification. Therefore, connect the lead and adopt 2.5A/mm2 as the current density of the transformer coil lead. Reduce the resistance value of the sampling resistor and the loss will be reduced, but, at the same time, the noise will increase while the accuracy will drop. Select a 300A/30V rectifier tube and let it working only at around 50A; a Schottky module uses a total of twenty 300A/30V rectifier tubes and then the voltage drop at its both ends will drop to 0.4V.

4. DC filter

It adopts a 5-way double filtering network as shown in Fig.5:

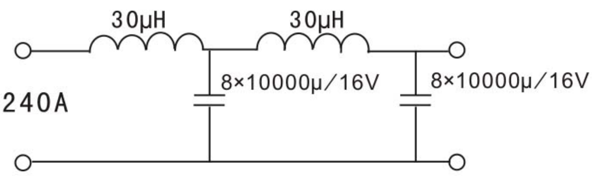

Fig. 5 type filtering network

The single-stage AC attenuation ratio is 1:40 while the two-stage 1:1600, which can ensure that the ultimate current ripple coefficient is less than 0.1% (about 0.05%). For such a filter circuit, if the frequency is reduced by 20 times (namely, power frequency), the AC attenuation ratio is 1:1.25 and then the power frequency ripple wave almost cannot be filtered, so that it is extremely difficult to filter the high-current power frequency ripple wave.

5. DC current sampling

The most classic and reliable way is to use sampling resistors (diverters) for DC current sampling, as long as the thermal stability of resistors can be ensured, then the resistor accuracy can be enhanced (The temperature control standard resistors have their resistance values of 80μΩ and 800μΩ respectively). In case of a 1200A current, the voltage drop is 96mV, the current below 100A is set as 800μΩand this resistor still can guarantee the accuracy of 0.01% if the ambient temperature is kept at 10℃ ~ 35℃. The working principle of this resistor is as follows: The internal preheating device first heats the resistor to the temperature of 32℃. When the internal sensor detects the temperature beyond 32℃, the fan will start to cool the resistor radiator, so that the resistor could always be controlled at the temperature of 32℃～38℃, within which the resistor can have its resistance change less than 0.005%.

6. AC step-down current boosting

The power amplifier is working at the state of AC output, and when the external load is approximately short-circuited, the power amplifier tube will bear great power consumption, so that the heat dissipation could be ensured by joint function of the fan rotational speed and temperature, as shown in Fig.6.

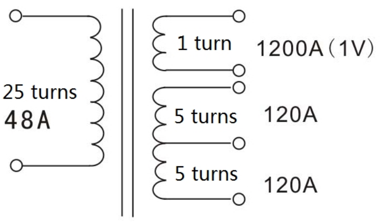

Fig. 6 AC step-down current boosting

7. AC sampling

The AC sampling adopts heart-through combined instrument transformers, as shown in Fig.7.

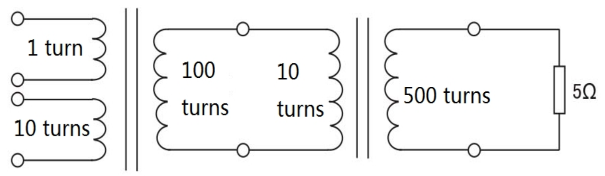

Fig. 7 AC sampling

The above instrument transformer combination structure can not only greatly reduce the power consumption of the sampling resistor, but also significantly reduce the 1 kHz errors.

8. Main controller

The main controller is the brain of the power supply, mainly undertaking to:
(1) Change the output frequency, 50Hz, 60Hz, 400Hz and 1 kHz.
(2) Complete closed-loop control and tracking the scale of the output current and ensure the stability and accuracy of the current output.
(3) Display: Display the real-time scale of the output current.
(4) Safety protection: Automatically disconnect the signal source in time of no load, overload and overheat, so that the power amplifier could have no output.
In the main controller, the advanced digital and analog closed-loop technology is simultaneously used to ensure a stable, reliable and accurate output.

Heat dissipation

This power supply has two large heat generators. The Schottky rectifier will dissipate the power greater than 500W. The power amplifier tube has its maximum calorific value higher than 1400W. The air cooling method is adopted and we can control the highest temperature of the radiator under 75℃ according to the experience and theoretical calculation, but the loud noise is disturbing. Except that a powerful and quiet high-quality fan is used, we also add a control circuit to the fan, so that the fan speed could increase while the radiator temperature is rising. In case of a medium and small current output or a short-time high-current output, the fan noise can be ignored.

Performance test

There are two difficulties in the performance test, namely, measurement of the DC high-current ripple coefficient and short-term drift and measurement of the AC high-current distortion and short-term drift.

1．DC ripple test

For small current ripple test, we often uses a non-inductive resistor and measure the ratio of the AC and DC voltage at both ends, but for an extremely high current, we cannot use an ordinary diverter for sampling as shown in Fig.8. At this moment, the sampling DC voltage is relatively small and the AC and noise voltage could not be identified, so there is no any practical value. For DC switching power supply, this method doesn't work anymore, because the AC frequency of the switching power supply is more than 20 kHz (there is no such high-current non-inductive resistor at all).
(AC voltage millivolts/100) / (DC amperes) is known as the ripple coefficient. Two methods can be used to measure the large current ripple. Firstly, use a Roche coil to directly measure the AC current component. Secondly, use a cored transformer not apt to saturate and an appropriate sampling resistor at the secondary side to measure the AC voltage at both ends of the resistor. Alternatively, an oscilloscope can be used to directly analyze and measure the waveform at both ends.

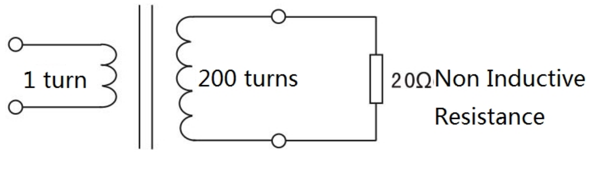

Fig. 8 DC ripple test

2. Measurement of AC distortion

Sample the voltage on the resistor to measure the distortion as shown in Fig.9 and Fig.10.

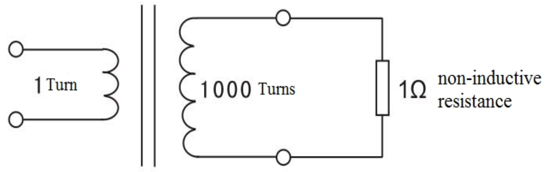

Fig. 9 cored transformer

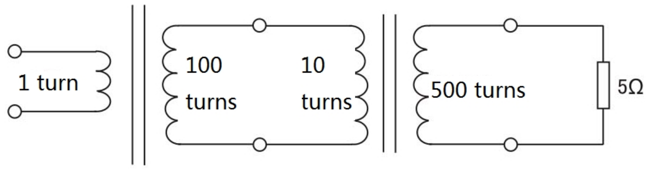

Fig.10 combined instrument transformers

3. Verification of the DC current accuracy

Use a comparison current meter to measure the ground output accuracy of the DC high current supply, as shown in Fig.11. The measurement results are as shown Table 1:

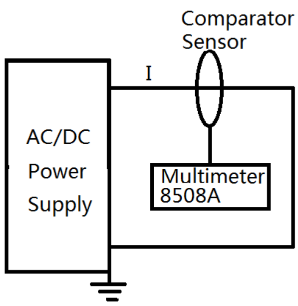

Fig. 11 Principle of the current test

Table 1 Result of the DC accuracy test

Output (A)	Actual (A)	Related Error (%)
100.00	100.00	0.00
500.00	500.01	0.002
1000.0	1000.1	0.01
1200.0	1200.2	0.02

4. Verification of the AC current accuracy

Use comparison current sensor, non-inductive resistor and digital multi-meter together to measure the current.

For 400 Hz and 1 kHz, the existing power frequency transformer could not be used any more, and the high-precision power frequency transformer features smaller no-load voltage ratio errors and smaller angle differences, but they are all limited within the range of the power frequency. While the frequency is increasing, the core nature and coil distribution parameters will directly affect the final errors as shown in Table 2.

Table 2. Floating-point operations necessary to classify a sample.

Output (A)	50 Hz Actual Value(A)	400 Hz Actual Value(A)	1000 Hz Actual Value(A)
100.00	100.01	100.02	100.03
500.00	500.02	500.03	500.04
1000.0	1000.2	1000.3	1000.5
1200.0	1200.3	1200.4	1200.5

5 Stability test

As the short-term stability of the reference standard device is superior to 0.001%, the comparison of current sensors, standard resistance and DMMS measuring are used to assess the power short-term stability is a very convenient way. The testing result is illustrated in Table 3.

Table 3. Stability test result

Status	Actual Value(A)	50 Hz Actual(A)	400 Hz Actual Value (A)	1000 Hz Actual Value (A)
Initiation	100.003	100.005	100.016	100.026
10 minutes later	100.003	100.003	100.014	100.024
Initiation	1200.08	1200.28	1200.36	1200.46
10 minutes later	1200.03	1200.24	1200.30	1200.36

Conclusion

The commercial high-current power supply basically uses the form of switching power supply and its ripple wave is generally greater than 1%, with the peak-peak value up to the pulse ripple shortcomings of a few volts (with a constant amplitude), and the ripple wave basically has nothing to do with the amplitude of the output current. Therefore, it is very difficult for switching power to be applied in high-current AC power supply. In this paper, we have researched and designed a kind of AC/DC high-current power supply based on the linear theory, with the AC current frequency kept from 50Hz to 1 kHz. Moreover, a plan has been designed to test the AC/DC high-current performance and assess the accuracy, ripple wave (harmonic wave) and short-term drift performance of the power supply.

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