The Research on Three-phase Medium-frequency DC High-voltage Power

JIANG Yunfeng[1], ZHANG Zhiping[2], BAO Hua[1], WANG Fei[1]
YANG Xi[1], JIANG Qilong[2], WANG Aihua[2], ZHOU Chengming[2]
(1 School of Electric Engineering, Wuhan University, No.8, Dong Hu Nan RD. Wuchang, Wuhan, 430072, PR China
E-mail: Whujyf@sina.com
2 Zhejiang Jiahuan Electronic Co. No.188, Jiang Jun RD. Jinhua, Zhejiang, 321000, PR China)

Abstract: This paper analyzes the primary problems of SCR power and high-frequency and high-voltage power (SMPS), which apply to electrostatic precipitator(ESP), raises a original three-phase medium-frequency DC high-voltage power applied to ESP, and introduces the background of the research, the principle of working, the structure of the device, the output of simulation and the laboratorial trials of this original power supply.

Keywords: ESP, three-phase medium-frequency DC high-voltage power, Space Vectors PWM (SVPWM), DSP

1 THE BACKGROUND OF THE MEDIUMFREQUENCY POWER

1.1 The Single-phase SCR Power

The single-phase SCR power is usually adopted by the traditional high-voltage power; the principle Fig. 1 is as follow:

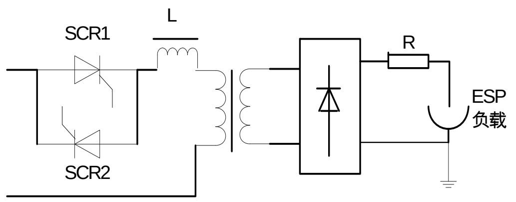

Fig. 1 The principle figure of the single-phase SCR power

Considering the limitation of control principle, the disadvantages of the SCR power are as follows:

(1) As working in frequency 50 Hz, that its transformer is very big and heavy, and it needs too much steel, iron and oil. Moreover, with the increasing price of the materials, the advantage of low cost is gradually disappearing.

(2) AC Phase Shift Control causes serious harmonics in the side of power networks. As power supply of two-phase, the SCR power is an imbalance load to power networks.

(3) AC Phase Shift Voltage Modulation makes high-voltage output wave comparatively singular, and it is inadaptable to high density dust, high-resistance dust and so on.

These reasons bring great challenge to the SCR power. Constant current source and three-phase SCR power cover its shortages in some aspects, but can not radically solve the problems.

1.2 High-frequency Power

The principle Fig. 2 is as follow:

Recently 80 kV/400 mA, 80 kV/800 mA samples have been accomplished in China, and have been produced on a small amount.

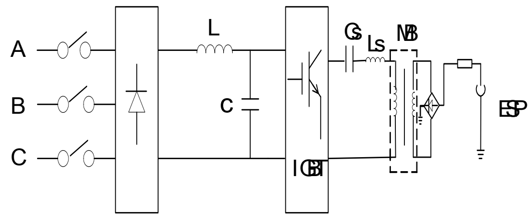

Fig. 2 The principle figure of the high-frequency power

With the great application of ESP, the capability of the high-frequency power can not reach the consumer's need, especially the 80 kV/1 A, even more, in electrical power system. Due to the high-frequency loss, high-power high-frequency power is difficult to make a breach. Now the maximal capability is 70 kV/1 A (ALSTOM: 70 kV/1.7 A), but too expensive, moreover, control cabinet is inseparable to transformer, and it runs outside the door, so its working time is a great problem. In addition, in order to adapt the outside conditions, the product cost is greatly increased, which counteracts the cost advantage brought by high-frequency.

1.3 Medium-frequency Power

Medium-frequency power not only has advantages of low switching loss, high-power of the SCR power, but also has advantages of small volume, high-performance of the high-frequency power. It has relatively maturated technology condition, which causes that high-capability medium-frequency power can be produced in a short time. So it can instead of the SCR power, especially has the advantage of cost.

Although the power tend to be high-frequency high-power, to some degree, it is difficult to exploit. Applying medium- frequency power is a compromise choice and can achieve a certain scale and capture market soon.

1.4 The Comparison of Three Power Conversion Technologies

(1) The SCR power:

Voltage-adjustment based on AC Single/three Phase Shift in frequency 50 Hz; SCR switch in low-frequency; transformer in frequency 50 Hz.

(2)High-frequency power:

Voltage-adjustment based on resonation PFM in high-frequency, IGBT switch in high-frequency (6 kHz-20 kHz), transformer in high-frequency.

(3) Medium-frequency power:

Voltage-adjustment based on SVPWM in medium-frequency, IGBT switch in high-frequency (9.6 kHz or 14.4 kHz), transformer in medium-frequency.

2 SPECIFICATIONS

(1) Input voltage: Three-phases AC- 380 V±10%.

(2) Output capability: 80 kW-160 kW.

(3) Output voltage/ current: DC80 kV/1 A-2 A.

(4) Output wave: Constant DC/ intermission wave.

(5) Power efficiency: > 92%.

(6) Power factor: > 0.9.

(7) Working mode:AC→DC→AC→DC.

(8) Working frequency:400 Hz.

(9) Switching frequency: 9.6 kHz.

(10) Current conversion mode:SVPWM (space vectors PWM).

(11) Protect function: Flashover; Open circuit, Short Circuit; Over current; Ultra-temperature and so on.

(12) Cooling mode: Air-forced cold on IGBT;Oil cold and radiator on transformer.

(13) Working condition:

Condition temperature: -10 ℃~45 ℃;

Air humidity < 90%;

Altitude < 1000 m.

3 TECHNICAL SCHEME

3.1 Principle Diagram of Main Circuit and Control Circuit(Fig. 3)

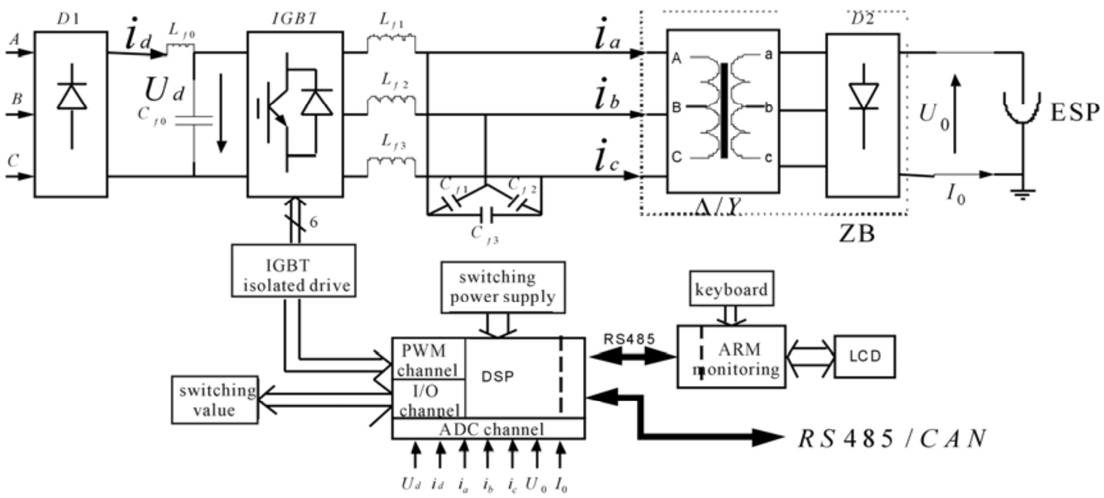

Fig. 3 The principle diagram of three-phase Medium-frequency power-supply

3.2 Working Principle of Main Circuit[1, 5]

(1) Rectification and filtering link

Three-phase AC380 V is passed through rectifier bridge D1, filtering circuit L_{f0}, L_{f1}, got about DC510 V, then sent to IGBT inverter-bridge.

(2) Three-phase high frequency inverter and filter link

DC voltage is passed through IGBT inverter-bridge , got the three-phase PWM purse, whose the Carrier ——f_s is 9.6 Kz, the modulating wave ——f_r is 400 Hz. After three-phase filtering circuit (L_{f1}, L_{f2}, L_{f3}, C_{f1}, C_{f2}, C_{f3}), the 400 Hz sinusoidal voltage is produced , then it is sent to medium-frequency transformer.

(3) Medium-frequency boost and Rectification link

After medium-frequency transformer boost and commute, the 400 Hz sinusoidal voltage is converted into DC 80 kV for ESP load.

(4) Control principle of voltage regulation link[2]

using space vector PWM can achieve output-voltage adjustment, and the specific is as follows:

By shifting magnitude of inserted zero vector working time T_0 in switching period T_s, the amplitude the 400 Hz sinusoidal wave could be adjusted, then the output-voltage is adjusted. The phase of sinusoidal wave $\theta = 2\pi * f_r * t$ depends on modulation frequency f_r.

3.3 Principle of Control Circuit

Control circuit (Fig. 4) includes links as fellows:

By comparing load current to given current, comparator gets current error ΔI, sends it to adjuster.

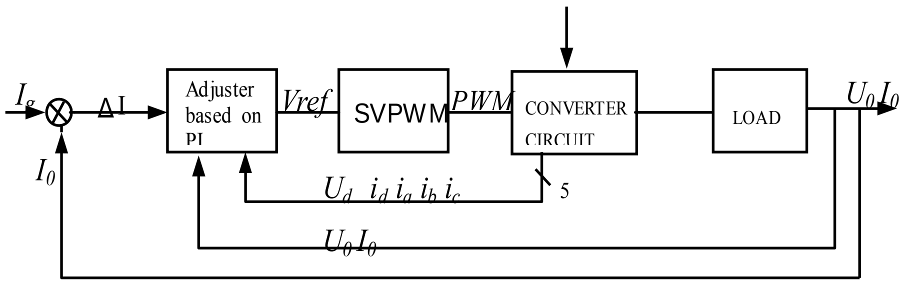

Fig. 4 The control principle diagram of three-phase medium-frequency power-supply

(1) Comparison link

(2) Adjuster based on PI link

Based on the input-current error ΔI, *PI* adjuster generates reference voltage V_{ref}, which is sent to SVPWM link. In addition, the adjuster can realize output soft-start and several protection functions(such as:flashover and faults) .

(3) SVPWM link

Based on reference voltage V_{ref}, SVPWM hardware module generates PWM signal, which is sent to IGBT converter circuit.

(4) Sampling link

Collecting the load current, load voltage and temperature signal, sampler sends them to the adjuster.

4 TECHNICAL FEATURES OF SCHEME

(1) Adopting the techniques of AC→DC→ AC→DC convert work style, Three-phase high-frequency inverter, Medium-frequency boost and Rectification, which can effectively increase the efficiency of Power-supply, reduce the volume and weight of Power-supply, minish output-ripple.

(2) Adopting IGBT Switch and double CPU control cores: DSP (TMS320F2812)[4] as run control, ARM controller as monitor control, and both communicated by RS485; If several power-supplies form a control net, the net is communicated by RS485 or CAN-bus[3].

(3) Adopting silicon-steel or Microcrystalline as material of iron-core in transformer; Adopting normal enamel wire as the coils, normal silicon-stack as rectifier bridge. Using three-phase Δ / Y winding and three-phase rectifier in transformer; The transformer is more smaller and lighter than normal SCR transformer, which reduces the cost.

(4) Fuzzy PI control algorithm is employed in steady-voltage and constant-current control, which realizes no static errors steady-voltage and constant-current control. SVPWM converting technology is employed in converting control, which reduces switching loss and increase DC utilization ratio.

(5) Perfect protection functions make the power-supply run safely and reliably.

(6) The control cabinet and the transformer can be separated (can also be integrated). The control cabinet could be placed in room.

5 SIMULATION ANALYSIS OF MEDIUM-FREQUENCY POWER-SUPPLY

All bellow are about 80 kV/1 A waveform (there is simulated flashover at 0.025 s)

Simulation Fig .5 and Fig.6 show:

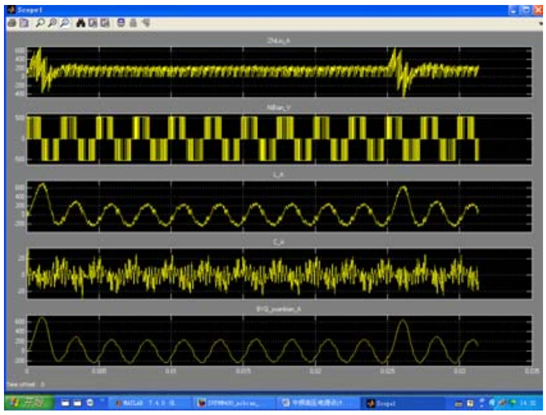

Fig. 5 The simulation waveform of power-supply

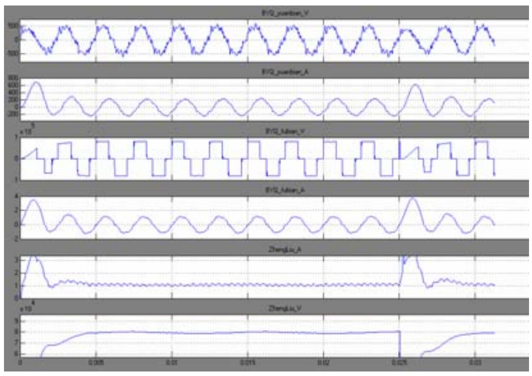

Fig. 6 The simulation waveform of voltage and current of primary side and secondary side

(1) The designed scheme could produce output voltage and current of 80 kV/1 A.

(2) Primary side over-current is about triple at flashover time.

6 EXPERIMENTAL RESULTS ANALYSIS OF MEDIUM-FREQUENCY POWER-SUPPLY

The power-supply structure is As Figs. 7, 8, 9 show (Transformer:990 kg, Control Cabinet:600 mm×600 mm ×2200 mm).

Measured voltage and current is as Figs.11, 12, 13, 14 show:

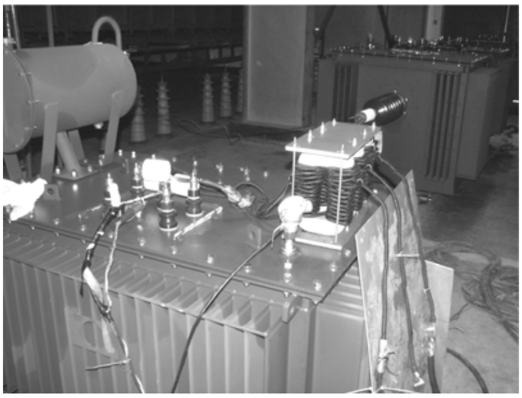

Fig. 7 The outline graph of transformer

Fig. 8 The door graph of control cabinet

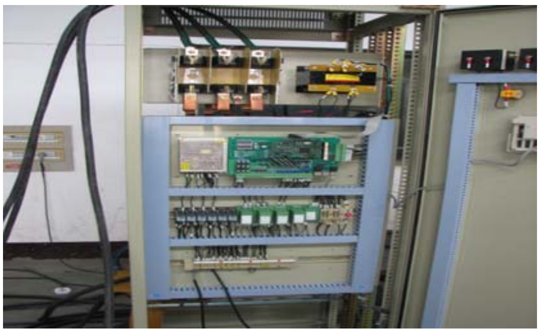

Fig. 9 The front panel graph of inside cabinet

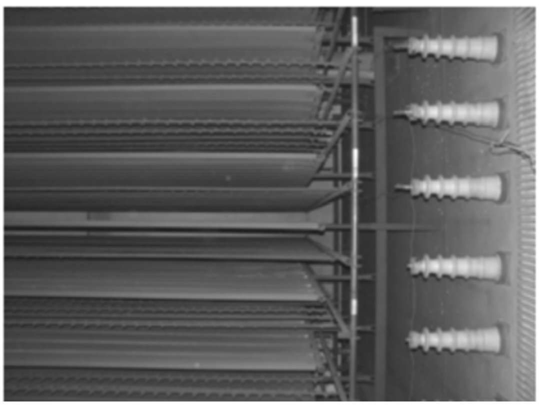

Fig. 10 The back panel graph of inside control cabinet

Fig. 11 the primary voltage diagram of transformer

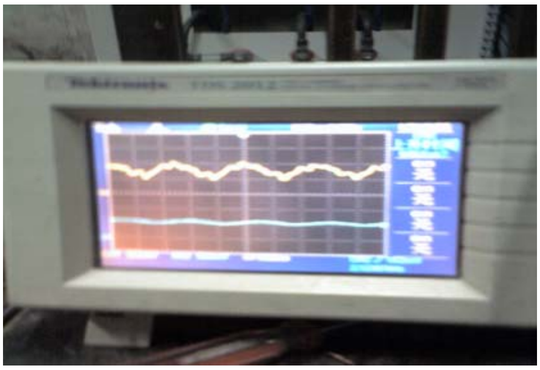

Fig. 12 The load voltage and current diagram

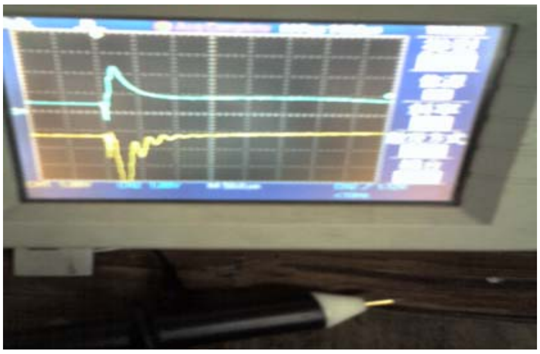

Fig. 13 The load voltage and current waveform diagram in flashover time

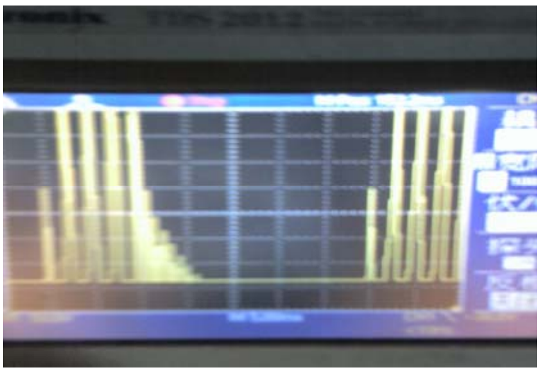

Fig. 14 The load current waveform in interval power supply

Figs. 11, 12, 13, 14 show that:

(1) Transformer original voltage waveform is approach to sinusoidal waveform.

Load voltage and current are quite smooth and approach to high-frequency situation.

(2) When load-flashover happen , current rush is quite little and can quickly ascend.

(3) Because voltage regulation, interval power-supply is easily realized and current rush is quite little.

7 CONCLUSIONS

(1) This paper analyses the merits of three kinds DC high-voltage power supply, then indicates that three-phase medium- frequency DC high-voltage power supply not only has low switching-loss and large power advantages in SCR power supply, but also has small volume and high capability merits in high-frequency power supply. So this would have the best foreground in these three DC high-voltage power supply.

(2) The paper introduces the work principle and technique features of 400Hz three-phase medium-frequency DC high-voltage power supply; Digital SVPWM and medium- frequency voltage regulation are employed in this scheme, which makes DC high-voltage power supply for ESP stride a new stage.

(3) This scheme is proved to be feasible and the design is optimized by MATLAB soft simulating.

(4) The scheme of 400 Hz three-phase medium-frequency DC high-voltage power supply has applied national patent, and own independent intellectual property.

(5) This power supply is come from Wuhan University and Zhejiang Jiahuan Electronic Co-joint development. After routine testing to model machine, all indices achieve or exceed request, and the machine can run stably.

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