Research on Suppression Method of Power Noise in the Stability Test Device

Junhao Huang¹, Fang Fang², Zhihua Wang³, Mingxuan Hang⁴*, Yibo Wang³ and Yong Chen³

¹E. Energy Technology Co., Ltd, Hangzhou, Zhejiang, 310014, China
²State Grid Zhejiang Electric Power Co., Ltd Research Institute, Hangzhou, Zhejiang, 310014, China
³Wuhan Kemov Electric Co., Ltd, Hubei, Wuhan, 430223, China
⁴E-mail: huangmingxuan@kemov.com

Abstract. The static tester has simultaneous output of multiple voltage and current sources, and supports multiple communication interfaces such as GPS (Global Positioning System), the functional characteristics of the stability test device determine its high demands for power supply noise and radiation. Aiming at the specific requirements for power supply system in the main functional modules of stability test device, the operating principle of switching power supply is analyzed, the generation and transmission mode of power supply noise are studied. Under the condition of ensuring the analog output accuracy and communication stability of the test device, the noise of the switch and the rectifier circuit is reduced, and the influence of the distributed capacitance is minimized to achieve the purpose of suppressing the noise of the switching power supply.

1. Introduction

With the continuous construction and development of the power grid, the safety and stability control system as the second and third lines of defense is playing an increasingly important role in the safe and stable operation of the power grid. The regional stability control system refers to a system composed of security and stability control devices installed in two or more plant stations to solve the stability problem of a regional power grid, which are connected through information channels and communication interface equipment. With the large-capacity, long-distance interconnected power transmission requirements and the gradual improvement of the power market, the structure of the power grid has become more and more complicated. The safety and stability control system must ensure the reliability and real-time communication between devices in order to make the grid system respond in time after a failure, and must accurately collect and reflect the frequency and amplitude changes of the grid system voltage. The communication debugging and strategy detection of the safety and stability control system has become an important content of the stability test [1]. At the same time, higher requirements are put forward on the accuracy of voltage output, phase error, frequency control, and communication stability of the stability test device [2].

The hardware of the stability test device can be divided into five modules, as is shown in Figure 1, including the central processing unit, switch and analog units, external communication unit, man-machine interface and power supply system. Among them, there are higher requirements for the
accuracy of the voltage and current output of the analog quantity and the stability of the E1 asynchronous high-speed serial communication [3].

The power supply is a device that provides electrical energy to the stability test device. The switching power supply is widely used in the stability test device due to its small size, light weight and high efficiency. However, due to its own power conversion mechanism, it will produce strong noise [4].

Noise may directly affect the normal operation or communication quality of electronic equipment, especially the weak signal detection circuit. At the same time, for the constant current source reference voltage, noise directly affects the stability of the subsequent circuit. In order to suppress switching power supply noise, it is necessary to analyze the generation mechanism and transmission mode of switching power supply noise, so as to find an appropriate suppression method.

This article describes the typical functional modules of the stability test device, studies and analyzes the working principle of the switching power supply that provides energy, the generation and transmission of power noise, and reduces the switching power supply by reducing the noise of the switching circuit, the rectifier circuit and the distributed capacitance. The purpose of the noise suppression is to ensure the accuracy and phase error of the voltage source and current source output and the stability of communication of the stability test device.

![Functional block diagram of stability test device](image)

2. Noise analysis of switching power supply

2.1. Generating mechanism of switching power supply noise

Noise refers to non-designed electromagnetic signals generated in electronic equipment. When noise affects the normal operation of electronic equipment, it will cause interference. According to the source of noise, it can be divided into man-made noise and natural noise. Man-made noise is the noise that appears after the electronic equipment is used, and natural noise exists in the real environment, electronic equipment requires anti-interference to it.

Therefore, switching power supply noise can be divided into two categories: one is the noise formed by the internal components of the switching power supply; the other is the noise caused by external factors [5].

2.2. Internal noise interference of switching power supply

The switching power supply is mainly composed of a full-wave rectifier circuit and a power conversion circuit, as is shown in Figure 2, and its internal noise includes high-order harmonic noise and peak voltage noise.

The full-wave rectifier circuit uses four rectifier diodes to form a rectifier bridge. After the power frequency sine wave current passes through the rectifier bridge, it becomes a unidirectional pulse
current. This current can be decomposed into a DC component and a series of different frequencies. The sum of AC components, these harmonics, especially high-order harmonic noise, will arrive at the input along the transmission line, not only distorting the front-end power waveform, but also reaching the power line, causing conduction interference and radiation interference to the outside world.

The power conversion circuit is shown in Figure 2, mainly composed of a power switch tube, a high frequency transformer and a square wave rectifier diode.

![Figure 2. Basic circuit diagram of switching power supply](image)

The power switch tube works in a fast-changing switching state, and its switching frequency itself has strong higher harmonics. When the large DC current flows through the fast switching switch tube after rectification and filtering, both \( \frac{dI}{dt} \) and \( \frac{dv}{dt} \) are changing sharply, and the switching action is chopped into a square wave, which contains many higher harmonics.

The primary coil of the high frequency transformer is an inductive load of the power switch tube. When the switch tube is turned on, a large pulse spike voltage noise \( v = L \frac{dI}{dt} \) will be generated in the transformer coil. When the switch tube is turned off, due to the leakage flux of the primary coil, a part of the energy is not transmitted from the primary coil to the secondary coil, and an induced motive force \( e = -L_{ep} \frac{dI}{dt} \) is generated in the primary coil. This part of the capacity is related to the collector, the capacitance and resistance in the circuit form an attenuated oscillation with a spike, which is superimposed on the turn-off voltage to form a turn-off spike voltage noise.

The square wave rectifier diode is on the side of the secondary coil of the high-frequency transformer. During the reverse recovery process of the diode from forward conduction to reverse cut off, a large reverse current is generated in a short time, when it flows through the secondary side coil, a large spike voltage noise is generated.

2.3. The transmission mode of switching power supply noise

The mode of switching power supply noise transmission is conduction and radiation.

Conduction is the transmission of electromagnetic noise along a certain path, which is divided into direct coupling and capacitive coupling.

Direct coupling, noise is transmitted to other circuits along the wire, causing interference to other circuits.

Capacitive coupling, due to the distributed capacitance between the switching power supply circuit and the protective ground (heat sink, casing), there is a distributed capacitance between the primary and secondary of the high-frequency transformer, so that high-frequency noise is coupled to the other end through the distributed capacitance to form an interference loop.

Radiation is the transmission of electromagnetic noise through space, which is divided into antenna coupling, closed loop coupling and inductive coupling.

Antenna coupling, the external power line of the switching power supply, and the long signal line in the circuit all have an antenna effect and can receive or emit electromagnetic noise.

Closed loop coupling, the closed loop in the switching power supply circuit forms a loop antenna. When there is a large current or a sharply changing current in the closed loop, a changing magnetic field is generated in the closed loop, and electromagnetic radiation noise is emitted. When a large-area
closed loop receives electromagnetic radiation noise in the space, it will also produce corresponding electromagnetic noise interference in the closed loop.

Inductive coupling, a rapidly changing high-current wire generates a changing magnetic field, which is coupled to adjacent circuit signals through magnetic field mutual inductance to form electromagnetic noise interference.

3. Suppress the internal noise of switching power supply

Since the external noise interference of the switching power supply is mainly implemented through the EMS test, and the magnitude of the external noise applied by it relates to the test level of the EMS, the internal noise of the switching power supply is mainly tested and suppressed.

3.1. Measurement of internal noise in switching circuits

The internal noise of a switching power supply generally has three measurement indicators:

1) The ripple of the power supply noise, the accuracy of the voltage source and the current source are measured by an oscilloscope;

2) The conduction noise of the switching power supply is tested by the conduction emission of the power supply. A line impedance stabilization network (LISN) is added between the power supply and the switching power supply, and the high-pass filter of LISN is used to couple the conducted noise of the switching power supply to the EMI test receiver for analysis, as is shown in Figure 3.

3) The radiated noise of the switching power supply is tested by radiation emission test shown in Figure 4.

L1\rightarrow L2=50\mu H, C1=C2=0.1\mu F, R1=R2=50\Omega

Figure 3. Conducting emission test LISN model

L1=50\mu H, C1=0.1\mu F, R1=R2=50\Omega

Figure 4. Schematic diagram of radiation emission test

3.2. Reduce the noise of switching circuit

A typical switching power supply circuit is shown in Figure 5, where:

Parasitic resistance \( R_s \) and parasitic capacitance \( C_{ds} \) of switch \( Q1 \);
The primary leakage inductance $L_{ep}$ and the secondary leakage inductance $L_{es}$ of the transformer TX1, the distributed capacitance $C_{tx}$ between the primary and the secondary; 
The junction capacitance $C_j$ of the diode $D1$.

\[ f_{mos} = \frac{1}{2\pi\sqrt{L_{ep}C_{ds}}} \]  

The peak attenuated oscillation voltage $V_{Lep}$ on $L_{ep}$ is superimposed on the turn-off voltage $2VC_1$, and the turn-off peak voltage noise $V_{ds}=2VC_1+V_{Lep}$ at this time.

It can be seen that, in order to reduce the peak voltage noise, the parasitic capacitance $C_{ds}$ of the switch tube and the leakage inductance $L_{ep}$ of the transformer can be reduced.

3.3. Reduce the noise of rectifier circuit
Because the diode $D1$ is not an ideal diode, there is a junction capacitance $C_j$. When the diode $D1$ turns from forward conduction to reverse cut-off, due to the existence of the junction capacitance $C_j$, the diode cannot be cut off immediately, which will cause a large reverse current $I_R$ during the reverse recovery time. When $I_R$ flow through the secondary side coil, a large spike voltage noise is generated.

It can be seen that in order to reduce the peak voltage noise, the diode junction capacitance $C_j$ and the reverse current $I_R$ can be reduced.

4. Measures to suppress noise of switching power supply and comparative tests

4.1. Noise reduction measures for switching circuits
Connect an RC circuit in parallel between the DS poles of the switching tube $Q1$, as is shown in Figure 6. The parallel capacitor $C3$ reduces the parasitic capacitance $C_{ds}$ of the switching tube and reduces the oscillation frequency. The resistor $R1$ can consume part of the capacitor energy and reduce the temperature of the switching tube. It can also reduce the noise amplitude.

As is shown in Figure 7, connect a freewheeling diode circuit in parallel between the primary of the high-frequency transformer. The parallel freewheeling diode $D2$ makes the turn-off peak voltage noise $V_{ds}$ add a bleeder circuit on the basis of loop 1 in Figure 5. Play a role in reducing noise amplitude.
4.2. A measure to reduce the noise of rectifier circuits
Connect an RC circuit in parallel at both ends of the diode, as is shown in Figure 8. The parallel capacitor C4 reduces the parasitic capacitance Cj of the diode, absorbs the reverse peak voltage VRM induced by the transformer, reduces the reverse current IR, thereby reduces the noise amplitude.

4.3. Measures to reduce distributed capacitance
High-frequency noise conducts capacitive coupling through distributed capacitors. The equivalent circuit of distributed capacitance of switching power supply is shown in Figure 9.

Distributed capacitance Cm from the primary side of the switching circuit to the protective ground;
Distributed capacitance Cd from the secondary side of the switching circuit to the protective ground;
The distributed capacitance Ctx between the primary and secondary of the high-frequency transformer.
Add a high-voltage Y capacitor between the primary side of the switch circuit and the protective ground, between the secondary side of the switch circuit and the protective ground, and between the signal ground of the primary side and the secondary side, respectively, to reduce the distributed capacitance, which provide a direct loop to high-frequency noise to reduce noise.
4.4. Comparison test of suppressing switching power supply noise

4.4.1. Analog power output accuracy test. According to the technical requirements of the safety test device: when the analog voltage output is 0.1~1V, the accuracy needs to be less than 0.5mV; when the analog current output is 0.05~0.2mA, the accuracy needs to be less than 0.2mA.

Before taking measures to suppress the noise of the switching power supply, the output accuracy of the analog voltage and the analog current exceeded the requirements, and the voltage ripple was large. After taking measures to suppress the noise of the switching power supply, the output accuracy of the analog voltage and the analog current can meet the requirements, and the test values are presented in Table 1.

Table 1. Result of analog power output accuracy test

| The Set Value | The Output Voltage | Voltage Accuracy | The Output Current | Accuracy of Current |
|---------------|--------------------|------------------|--------------------|---------------------|
| 0.1 V / 0.02 A| 99.66 mV           | 0.34 mV          | 19.85 mA           | 0.15 mA             |
| 0.2 V / 0.04 A| 199.85 mV          | 0.15 mV          | 39.97 mA           | 0.03 mA             |
| 0.4 V / 0.06 A| 399.73 mV          | 0.27 mV          | 59.89 mA           | 0.11 mA             |
| 0.6 V / 0.08 A| 599.88 mV          | 0.12 mV          | 80.03 mA           | 0.03 mA             |
| 0.8 V / 0.1 A | 800.33 mV          | 0.33 mV          | 100.06 mA          | 0.06 mA             |
| 1 V / 0.2 A   | 999.96 mV          | 0.04 mV          | 200.11 mA          | 0.11 mA             |

4.4.2. Power conduction emission test. According to GBT 14598.26-2015 Measuring Relays and Protection Devices Part 26: Electromagnetic Compatibility Requirements, the power conduction emission test should meet the following requirements in Table 2.

Table 2 Requirements of power conduction emission test

| Test Project               | Frequency Range | Limit               |
|----------------------------|-----------------|---------------------|
| Conducted emission         | 150 KHz to      | 79 dB Quasi-peak    |
|                            | 500 KHz         | 66 dB Average value |
|                            | 500 KHz to      | 73 dB Quasi-peak    |
|                            | 30 MHz          | 60 dB Average value |

Figure 10 shows the test results of the power conduction emission of the stability test device, with the quasi-peak reaching up to 85 dB and the average reaching up to 70 dB, both exceeding the limit requirements.

Figure 10. Power conduction emission of stability test device

Figure 11 shows the test results of the conducted noise of the power supply of the stability test device after taking measures to suppress the noise of the switching power supply. Both the average value and the quasi-peak value have dropped to the limit requirements.
4.4.3. Radiation emission test. According to GBT 14598.26-2015 - Measuring relays and protective devices - Part 26: Electromagnetic compatibility requirements, radiation emission tests shall meet the following requirements in Table 3.

| Test Project                      | Frequency Range       | Limit  |
|----------------------------------|-----------------------|--------|
| Radiation emission (10 meters)   | 30 MHz to 230 MHz     | 50 dB  |
|                                  | 230 MHz to 1000 MHz   | 57 dB  |

Figure 12 shows the radiation emission test results of the stabilization test device. In the vertical direction of the antenna and within the frequency range of 35~65MHz, the measured value of radiation emission reaches 57.995dB, exceeding the requirement of the limit value of 50dB.

Figure 13 shows the test results of the radiation emission noise of the stabilization test device after taking measures to suppress the noise of the switching power supply. Within the frequency range of 35~65MHz, the radiation emission test value has dropped below the requirement of the limit value of 50 dB.
Figure 13. Comparison diagram of radiation emission of stability test device

5. Conclusion
By reducing the noise of the switching circuit and the rectifier circuit, reducing the distributed capacitance, this paper can effectively reduce the noise of the switching power supply, thus ensuring the accuracy and phase error of the output of the voltage source and current source, and the stability of communication of the stability test device.

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