

A fast amplifier applied to secondary system test

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Abstract. Present, the secondary equipment test of substation mainly adopts the separation test and the overall flow method. The main reason for the failure to achieve the overall test is limited to high power current amplifier technology. On the one hand, it is because the amplifier is bulky, heavy, the power supply is high, and the installation of the substation is difficult to move. On the other hand, large current output amplitude, load, current accuracy and current response speed cannot meet the requirements. Based on the high power MOSFET fast amplifier technology can achieve 2000A current amplifier output current, output current response speed is less than 500 us at the same time, small volume, light weight, mobile convenience, make the secondary equipment at the scene of the whole test to become a reality, the substation debugging maintenance is of great significance.

1. Introduction

With the improvement of people's living standard, the demand for electricity is increasing. Electricity has become an indispensable source of energy for people's life and social development. At present, the number of substations is increasing, the equipment is increasing year by year, and people are paying more and more attention to the maintenance and maintenance of substations [1]. However, the low efficiency and low pertinence of the secondary equipment overhaul method in all substations in China directly affect the safety of power equipment and the reliability of power supply. Especially in recent years with the development of intelligent substation, Using the virtual terminal connection between the secondary equipments [2], enables debugging of the secondary equipments to improved greatly; At the same time, the strength and content of the commissioning and maintenance work have also increased at least one times. It is difficult to control the service of the maintenance. The unsuccessful maintenance of the secondary equipments will directly threaten the safety and reliability of the power grid. Therefore, it is very necessary to develop an overall test technology of secondary equipments [3].

To realize the overall test of the secondary equipments, the current is directly emerged from the primary side of the current transformer. BY means of simulating short circuit fault [4], this ia the method to realize the overall test of MU, relay protection device, intelligent terminal and circuit breaker. High power amplifier is one of the key technologies. In this paper, a high power fast amplifier technology based on MOSFET is introduced. By way of the research of influence of current response speed on protection device, we analysis the feasibility of the high power fast amplifier technology to realize the overall test of the secondary equipments.



2. Influence of current response speed on relay device

Most of the relay protection devices use the transient component as the protection logic criterion. It is necessary to simulate and determine the current abrupt variable, the voltage abrupt variable, the frequency abrupt variable and the impedance variable, and so on [5]. Therefore, the rising rate of the sudden change of the output of the relay protection device (the response speed), that is, the transient characteristics of the testing instrument, should meet the relevant specification requirements of the relay protection testing instrument. In the relevant standards of relay protection testing instruments, it is clearly stipulated that the transient response time of output current and output voltage of relay protection testing instrument should not be greater than 100 μ s.

Now the substation's protection debugging is that the current and voltage, and the input and output signal is directly connected to the corresponding terminal row of the protection device. According to the commissioning outline or instruction manual, the protection functions are debugged in detail [6]. The current rise and fall time of relay protection tester is less than 100 μ s, but when the actual electrical fault occurs, the fault current to the relay device is less than 10 μ s, which is basically instantaneous. When the transient failure occurs, though the CPU processing and the action delay of the relay, the actual export time is also greater than 10ms, so the 100 μ s (the current response time of the tester) does not affect the test of the relay device.

The output of relay test instrument is small current signal, but realization of the secondary system overall test, needs the large current power amplifier to create current from the transformer primary side. Limited by the hardware product performance and other technical conditions, at present, the current rise and fall time of large current amplifier can be less than 500 μ s, his output time of relay device is basically above 10ms, therefore, in theory, the current response time of the large current amplifier is 500 μ s, which can meet the requirements of the field use.

To verify whether the current response speed of the power amplifier which is 500 μ s has an impact on the protection logic judgment, in this paper, the PN4661 relay protection tester is used to simulate and test the line protection device of the domestic mainstream relay protection manufacturers. The current precision of PN4661 is 0.1%, the current rising time is 100 μ s, 500 μ s, 1000 μ s and 2000 μ s by replacing the internal resistance and other components. Under different current response time, we test the outlet time of RCS931 [7]. The results of the detailed test verification are shown in Table 1.

From the test data of Table 1, we can find: With the increase of the output response time of the relay testing instrument, the output time of the protection device will increase gradually. The current response time of the testing instrument is within 1000 μ s, and it has no effect on the operation logic and the output time of the protection device. Therefore, the current response time of large current amplifier is set for 500 μ s, it can achieve the overall test of the secondary equipments.

Table 1. The output time under different current response time

Test project	Protection setting value	the outlet time of protection, Under different current response time			
		100us	500us	1000us	2000us
Ground Distance Zone-I (A Phase)	2.0Ω 0s	0.0350s	0.0360s	0.0370s	0.0400s
	0.4Ω 0s	0.0360s	0.0360s	0.0370s	0.0390s
Ground Distance Zone-II (B Phase)	4.0Ω 0.5s	0.5300s	0.5320s	0.5340s	non
	0.8Ω 0.5s	0.5320s	0.5320s	0.5320s	0.5360s
Ground Distance Zone-III (C Phase)	6.0Ω 1s	1.0260s	1.0280s	1.0280s	non
	1.2Ω 1s	1.0270s	1.0280s	1.0280s	1.0320s
Phase-phase distance Zone-I (AB Phase)	2.0Ω 0s	0.0340s	0.0370s	0.0390s	non
	0.4Ω 0s	0.0360s	0.0370s	0.0380s	non
Phase-phase distance Zone-I (ABC Phase)	2.0Ω 0s	0.0350s	0.0350s	0.0350s	0.0370s
	0.4Ω 0s	0.0370s	0.0380s	0.0390s	non
Phase-phase distance Zone-II (BC Phase)	4.0Ω 0.5s	0.5300s	0.5320s	0.5340s	non
	0.8Ω 0.5s	0.5310s	0.5330s	0.5350s	non
Phase-phase distance Zone-II (ABC Phase)	4.0Ω 0.5s	0.5300s	0.5310s	0.5310s	0.5370s
	0.8Ω 0.5s	0.5320s	0.5320s	0.5320s	non
Phase-phase distance Zone-III (CA Phase)	6.0Ω 1s	1.0250s	1.0270s	1.0290s	non
	1.2Ω 1s	1.0270s	1.0280s	1.0280s	1.0550s
Phase-phase distance Zone-III (ABC Phase)	6.0Ω 1s	1.0260s	1.0260s	1.0260s	1.0320s
	1.2Ω 1s	1.0260s	1.0270s	1.0270s	1.0280s
Differential protection	2.0A 0s	0.0360s	0.0360s	0.0360s	0.0380s
	0.5A 0s	0.0370s	0.0370s	0.0370s	0.0400s
Zero-Sequence Over-Current Zone-II	5.0A 0.5s	0.5370s	0.5380s	0.5380s	0.5390s
	1.0A 0.5s	0.5360s	0.5380s	0.5380s	non
Zero-Sequence Over-Current Zone-III	3.0A 1.0s	1.0380s	1.0380s	1.0380s	1.0390s
	0.6A 1.0s	1.0380s	1.0380s	1.0380s	non
single-phase reclosing	2.0s	2.0100s	2.0110s	2.0110s	2.0160s
	0.5s	0.5180s	0.5180s	0.5190s	0.5220s
Three-phase Reclosing	2.0s	2.0120s	2.0130s	2.0130s	2.0160s
	0.5s	0.5180s	0.5180s	0.5190s	0.5210s

3. THE high-power amplifier scheme based on MOSFET

The high-power amplifier based on MOSFET mainly consists of the inverter power module and the amplifier module composed of MOSFET devices. Its working principle is shown in Figure 2. The whole structure adopts a modularized and distributed design, Amplifier module and power module is separated. It is connected via a cable connection, it is easy to disassembly move. Power supply module provides 100kW power supply for single-phase amplification module. The MOSFET tube is used as the power switch driving circuit. The amplifier part will be output in parallel with two power amplifier modules, One of the power modules provides the output fundamental wave current and harmonic current, and uses the principle of switching amplifier to reduce the volume and weight of the device. The module is set as module 1. The other module provides transient current, which will be designed with the principle of linear amplifier. The module is set to module 2. The synchronous output of module 1 and module 2 is controlled by the main control module, and the high current of no less than 2000A is output.

The whole work flow of high power fast amplifier based on MOSFET: The main power module of 100kW turns the 380V AC power into the DC power used by the amplifier module, which is transmitted to the amplifier module through the cable, thus driving the whole amplifying circuit to work normally. The main control module transmits synchronous control signals on one hand through the optical fiber to realize the synchronous output of all phase power amplifiers. On the other hand, the digital output signal is transmitted to control the amplitude, phase angle and frequency of the output current of each phase of the power amplifier. High speed DA module of power amplifier transfer the digital signal of the main control module to the analog signal that the amplifier module can use, that signal through the power module 1 and the power module 2 and the corresponding high-speed current sensor, and the steady-state output and transient control of the high current is realized. Two power modules are connected in parallel at the output end through the cable to achieve the high current synchronous output.

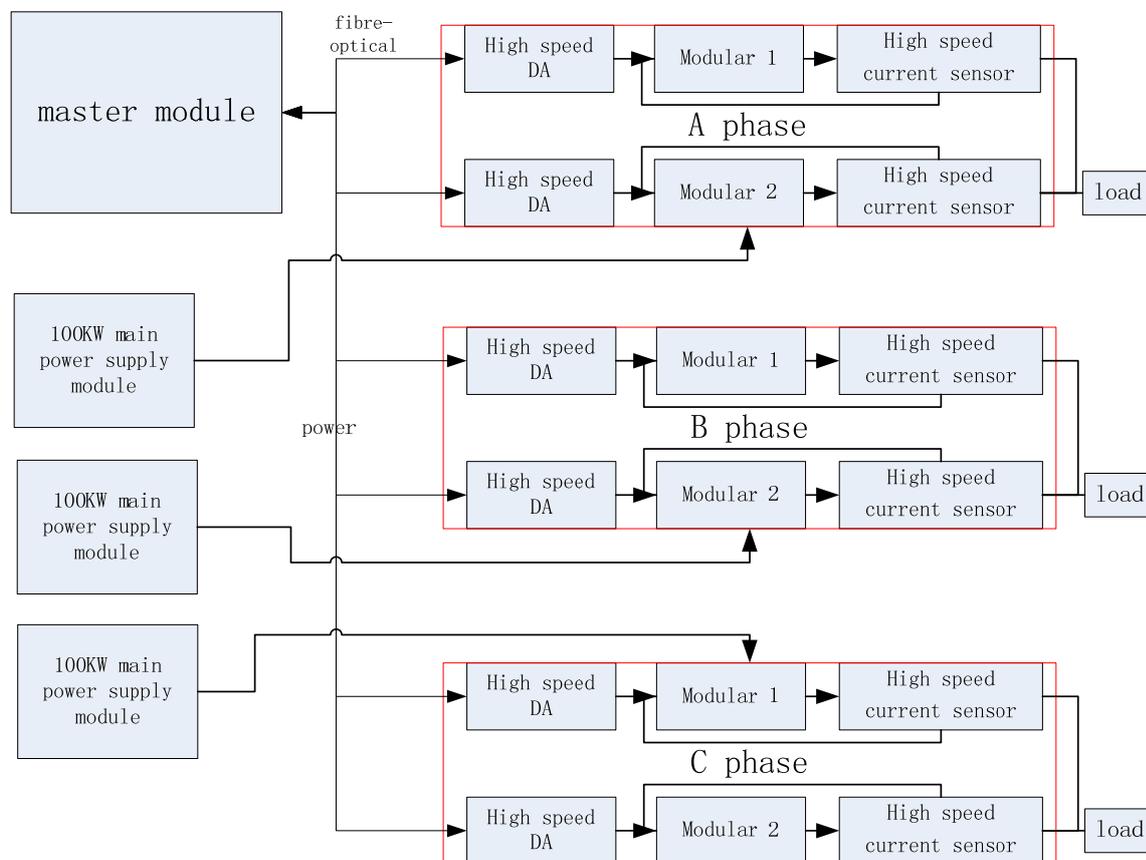


Figure 1. The schematic diagram of fast high-power amplifier based on MOSFET

4. the structure of high-power amplifier based on MOSFET

4.1. Power supply module

Present, the power module of power amplifier usually adopts inverter circuit which use bipolar switch tube, and the base drive current is basically $1/\beta$ of switching current. Therefore, to achieve large current switching circuit, we must use multistage amplification. In this way, the circuit is not only complicated, but also the reliability is also bad. Moreover, with the increase of output power, the driving current of switch tube is larger than the $1/\beta$ of collector current, which makes the general driving IC unable to drive directly [8]. Although multistage amplification can achieve the purpose, the waveform distortion is obviously increased, which leads to the cut-off loss of switch tubes. Meanwhile, the use of MOSFET tube as switching device can solve this problem well. The leakage - source resistance of MOSFET tube has the current-sharing feature of the resistance, and the parallel application does not have to add the current-sharing resistance, and the drain-source voltage is directly connected with the parallel application. At the same time, the MOSFET tube is controlled by voltage. The control mode is convenient, and has the advantages of high input resistance, low noise, good thermal stability, strong anti-interference ability, low power consumption and small volume.

the processing technology of the power seriously affects the whole weight of equipment, the average weight of power transformer of 100KW is in 300-500Kg, If we use power frequency transformer [9] to reduce voltage isolation, then the power supply part is very heavy, and the power factor is also low, so this way is not suitable for on-site handling and testing. Therefore, we develop the power module of 5-10KW, and many power modules are used in parallel. Considering that the equipment does not work in a long and continuous state, the distribution design can disperse the heat of the power. At the same time, it is not necessary to use a large power device that will reduce the weight of the power supply and improve the stability of the power supply. In addition, the frequency of power switch which has lower power can be done relatively high, the greater the power level, the lower the frequency of the power switch. So the use of multiple modules in parallel will greatly reduce the weight of the power supply.

4.2. Amplifier module

Set the carrying capacity of the device which is 50V, the peak voltage of the load should be:

70.7V, the maximum current is 2000A, therefore the maximum peak current is 2828A, the maximum time of the rise of the current is 500uS, and we can calculate the maximum inductance of the output load:

$$L = \frac{70.7 \times 500 \times 10^{-6}}{2828} = 12.5 \mu H \quad (1)$$

So the inductive load of the equipment output must be $<12.5\mu H$. The DC impedance of output load is determined by the length and section area of the output line. In order to reduce the weight, the output line is preset to 1m, and the return line is 2m. The resistivity of pure copper wire is $1.75 \times 10^{-8} \Omega/m$, the output line is 200mm^2 , and the DC impedance of the output line is:

$$R = 1.75 \times 10^{-8} \times 5000 \times 2 = 1.75 \times 10^{-4} \Omega \quad (2)$$

The voltage of 2000A current on DC impedance is:

$$U_1 = 2000 \times 1.75 \times 10^{-4} = 0.35V \quad (3)$$

The AC voltage of 50Hz, the voltage of 2000A base wave current on the maximum inductive load is:

$$U_2 = 2000 \times 2 \times 3.14 \times 50 \times 12.5 \times 10^{-6} = 7.85V \quad (4)$$

So the maximum load voltage $V = (0.352 + 7.852) / 2$ and $U = 7.85V$ when the fundamental wave 2000A output is needed, the 2000A base wave band carrying capacity should be 10V, in order to ensure duty switch of module 1 working at duty greater than 80%, the output filter inductor of module 1 is about 4 times the output load inductance. $L = 50\mu H$. Assuming that the fundamental wave is 0A, the maximum harmonic current is $I < 100A$ when the 1KHz harmonic frequency is outputting, and the minimum continuous current 6A of module 1, duty cycle is 50%, and the switching frequency is temporarily set to 100kHz.

Therefore, the main power topology parameters of the amplifier module 1 can be determined. The full bridge switching amplifier [10] is used, the switching frequency is 100 kHz, the power supply voltage is 80V, and the output filter inductance is 50uH. The rise time of the module from 0A to the output peak is:

$$t = \frac{2828 \times 62.5 \times 10^{-6}}{80 \times 0.9} = 2.45ms \quad (5)$$

The main power topology parameters of amplifier module 2 can also be basically determined [9]: the full bridge linear amplifier, the power supply voltage 80V, 0A to the output peak current is 450uS, and the output time of module 2 is $t = 2.45ms$. Module 1 and module 2 work in parallel. The input signal is the same analog signal. Module 2 provides the transient signal in the initial stage. When the transient signal is completed, module 2 stop, and module's output is continuously.

5. Conclusion

Technology of high-power amplifier based on MOSFET can achieve the large current's output, we can control the change of the transient current. Fast response time and high precision can complete the whole substation current test, also it simulate different short-circuit faults in primary side of CT, to achieve the overall test of substation's secondary system. At the same time, the distributed design is applied to separate the power supply module and the amplifier module, so as to reduce the overall volume and weight, facilitate the disassembly and movement, and the on-site commissioning and maintenance of the substation.

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