An improved simulated load test system

Liang Hua\textsuperscript{1*}, Jiaen Qi\textsuperscript{1}, Wei Huang\textsuperscript{2}, Sijiang Zhang\textsuperscript{2}, Feng Gao\textsuperscript{1}, Shengjiang Peng\textsuperscript{2}

\textsuperscript{1} State Grid Gansu Power Transmission and Transformation Engineering Co. LTD, Lanzhou 730000, China
\textsuperscript{2} State Grid Gansu Electric Power Company Construction Branch, Lanzhou 730000, China

\textsuperscript{1*} 2360097341@qq.com

Abstract—A miniaturized analog load-checking relay protection test device is developed in this paper, in which a high-precision wireless phase volt-ampere test device is configured. This device, characterized by intelligence and ease of operation, realizes the detection of the transformation ratio, polarity, phase, etc. of the secondary wiring of the transformer in the smart substation merging unit and the conventional substation. It meets the testing requirements of smart substations, and can test bus differential protection, line protection, and various protections such as main transformer differential.

1. Introduction

At present, in the actual application process of the electrical compartment in our country's substations, the connection of the AC current secondary circuit is judged by methods such as the source flow of the secondary circuit of the terminal box and the verification of the secondary line. Objectively, these methods are difficult to effectively simulate the situation with a load. In this case, the interval is difficult to fully ensure the normal operation of the power system as a whole before power is transmitted [1-3]. Normally, when calculating the secondary circuit of the interval bus voltage, the verification work is carried out by adopting the inspection method of the correctness of the voltage switching circuit. In the secondary circuit of the bay current transformer, it is difficult to realize the effective simulation of the actual operating state, which makes it impossible to proceed smoothly in the application process [4-5]. In the process of conventional power transmission, a certain amount of bus space should be reserved, and the phasor of the current should be tested under load by charging the bus and the interval.

A set of vector inspection test system was developed in Hebei. The system uses the principle of voltage regulator and step-up transformer to generate high voltage and large current. The system consists of a set of test power supplies and a set of simulated loads. The power supply of the test system is taken from the station transformer. The output is connected to the primary side of the current and voltage transformer, and it is connected to the relay protection device through the transformer and the complete secondary circuit as the electrical quantity for vector inspection [6]. Furthermore, the correctness of the relay protection vector is confirmed before the substation is put into operation. However, the system has the following problems:

1. The vector check simulation system is a three-phase high-power high-voltage source. The current output is affected by the size and form of the load. It must be equipped with an analog load and a compensation capacitor, and the compensation capacitor is used to adjust the current output. The calculation and operation are complicated.
2. Using the principle of voltage regulator + booster, the voltage output accuracy is low.
3. The system has a large output capacity of 100kVA, while the construction power supply capacity of general substations is less than 200kVA, and its application is restricted.
4. The total weight of the system is large, which leads to inflexible testing, long test wiring, and inconvenient use on site.

To improve economic efficiency and shorten the start-up test time of the main equipment, based on the requirements of the secondary circuit calibration and verification of the protection device before the start of the substation, a set of electronic three-phase analog load test device is developed in this article, which solves the installation and commissioning test of the protection device problem.

2. Construction and Geometrical Dimensions of Specimens
The circuit uses a full-bridge forward switching power supply structure, as shown in Figure 1.

![Fig. 1 Block diagram of circuit structure](image)

In Figure 1, the three-phase 380V AC power supply is connected, and the internal rectifier module is rectified into a high-voltage DC. After high-frequency conversion by the H-bridge power tube, the main transformer will step down and increase the current and output it to become a steamed bun wave. After the rectifier circuit changes the polarity of the steamed bun wave, it becomes a sine wave and outputs it to the external terminal.

The main structure of the circuit is shown in Figure 2:

![Fig. 2 Power circuit structure](image)

The circuit principle can be summarized in Figure 2. The three-phase 380V AC power supply is rectified by B1 and filtered by C1 to 657V (380×1.73), the maximum is 756V (437×1.73), and the minimum is 592V (342×1.73); or it is 620V (220×2×1.41) by single-phase voltage rectification, the maximum is 713V (253×2×1.41), the minimum is 558V (198×2×1.41), that is, the voltage range after rectification is \(V_{c1} = 558V~756V\), the actual voltage should be a little lower, about 85%~95%.

As shown in Figure 2, the bus voltage after rectification and filtering is applied to both ends of the H-bridge. The H-bridge power tube is driven by a PWM control chip to work in high-frequency mode. The operating frequency is tentatively set to be in the range of 4k~10kHz. This frequency drives the main transformer T1, generating alternating high-frequency currents in the primary coil. The magnetic field lines of the main transformer work in the first and third quadrants of the BH curve. In each H-bridge working cycle, the on-off times of Q1, Q2 and Q3, Q4 are equal, so that the volt-seconds of T1 in two half cycles are equal to ensure magnetic reliability Reset.

The output circuit is divided into four working processes:
Among them, working processes 1 and 2 cyclically work in the first half cycle of the sine wave in a high-frequency manner. In 0~10ms time, switch to working processes 3 and 4. Working processes 3 and 4 cyclically work in the second half cycle of the sine wave in a high-frequency manner. Within 10~20ms, switch to working processes 1 and 2.

(1) The process of the first half cycle of PWM:

![Fig. 3 Positive period of sine wave, first half period of PWM](image)

In this working stage, the MOS transistors Q1 and Q2 are turned on, the current direction of the input winding of the main transformer T1 is from top to bottom, and the output winding Q5 is turned on to provide current to the load. The polarity of the voltage on C2 is positive and negative.

(2) The process of the second half cycle of PWM:

![Fig. 4 Positive period of sine wave, second half period of PWM](image)

In this working stage, the MOS transistors Q3 and Q4 are turned on, the current direction of the input winding of the main transformer T1 is from bottom to top, and the output winding Q6 is turned on to provide current to the load. The voltage on C2 is positive and negative. In addition, the output rectifier tubes Q5 and Q6 use MOS tubes in series, connected as shown in Figure 7 below, to act as a bidirectional switch. In order to reduce the extra power consumption of the rectifier tube, MOS tubes with extremely low internal resistance should be used, and multiple groups in parallel to achieve a current capacity of 500A.

3. Test Results and Discussions

The interface of the device is shown in Figure 5.
Fig. 5 Interface of the designed device

This analog load relay protection vector detection device can simulate various three-phase symmetric and asymmetric vectors of the primary loop. This device can detect the vector correctness of secondary equipment such as bus differential protection, line protection, measurement and control devices, metering devices, and wave recording devices. It can also output three-phase power frequency or low-frequency current. The functions are shown in Table 1.

Table 1. Description of the main functions of the device

| Main functions and test content | Technical Description | Function |
|--------------------------------|------------------------|----------|
| Consistency check of PT phase sequence of busbars of all voltage levels in the whole station | The variable frequency power supply is used through the impedance converter to apply the excitation voltage (up to 1500V/12.5A) to the low-voltage side of the main transformer in the station. Based on the primary voltage that can be induced on the high-voltage side and the medium-voltage side based on the transformation ratio, the bus tie switch is closed, and then the primary voltage is induced on the low-voltage side, the medium-voltage side, and the high-voltage side. | Prevent the protection action caused by the voltage phase sequence error in the single bus running state |
| Self-produced zero-sequence voltage inspection of open delta voltage and protection device | The power supply device can choose to output the three-phase voltage unbalance mode (or lack of phase), which is used to check the correctness of the voltage transformer wiring. The PT handcart cabinet of each busbar of 10kV is checked. | Avoid incorrect wiring of the 10kV busbar PT handcart cabinet transformer. |
| Check the correctness of | The output three-phase current balance mode (mutually 120°) is selected in the power supply | Improve the work efficiency of |
Busbar current differential protection unit. It is used to check the wiring correctness of the incoming switch, bus tie switch, and outgoing switch.

Check the main transformer differential protection vector. The variable frequency power supply is used through the impedance converter to apply test current to the main transformer in the station. According to the short-circuit impedance of the main transformer, select the voltage winding and the short-circuit winding to meet the primary voltage and primary current amplitudes required by the eighteen anti-accident measures.

The main transformer switch can be used to complete the transformer differential protection inspection.

### 4. Conclusion

In this article, the three-phase symmetrical current and voltage are introduced from the primary side to confirm the transformation ratio, polarity and wiring mode of the current/voltage transformer, and inspect the line protection, metering, busbar protection, main transformer differential protection and backup Polarity of protection. It effectively avoids the load check protection and the wrong polarity of the metering circuit. It solves the shortcomings that the traditional electrician type single-phase high current generator can only be used for single-phase loop current transformer transformation ratio and polarity detection. It shortens the switching operation time for checking the ratio, polarity and phase of the primary and secondary circuits.

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