Research on the influence and test of core components on relay protection device

Huihai Liu *, Yifan Zhang, Wei Li, Xiaoli Zhang, Huiping Wang

China Electric Power Research Institute, Beijing, China

*Corresponding author e-mail: hhliu@epri.sgcc.com.cn

Abstract. As the core equipment of power grid, relay protection device plays a key role in the safe and stable operation of power grid. It has become the development strategy of State Grid Corporation of China to research and develop high-performance and high reliability domestic chips and to carry out the localization of core components of relay protection. This paper analyzes the hardware structure of the relay protection device, studies the performance index parameters and performance of the core components of the relay protection device; combined with the operation environment of the relay protection device, analyzes the influencing factors such as temperature, humidity, electromagnetic interference, etc., puts forward a part of the test scheme of the general hardware of the relay protection device based on the domestic core, which is the centralized test of the relay protection device based on the "domestic core" Provide reference basis.

1. Introduction

As the core equipment of the power grid, the relay protection device plays an important role in the safe and stable operation of the power grid. "Digital State Grid" is an important strategy of the State Grid Corporation of China to promote the implementation of the national big data strategy, and the chip is an important support point for the digital construction of the State Grid. The development of high-performance, high-reliability domestic chips and the alteration of core components for relay protection have become the development strategy of the State Grid Corporation of China.

There is a certain gap between domestic chips and imported chips in performance. We still lack relevant research and application results whether they can meet the application requirements of relay protection and whether their reliability and anti-interference ability meet the requirements.

1.1. The Lack of analysis of how core components affects the performance of relay protection

The previous evaluation system of relay protection mainly focused on the evaluation of the reliability and maintainability of relay protection. For the core components such as CPU, DSP, FPGA, memory chip, ADC, power chip, etc., we generally take them as imported products. Without rigorous analysis and demonstration, the performance of core components may decrease after localized chip replacement, which will lead to a decrease in the reliability of relay protection, and even increase the number of incorrect actions, threatening the safety of the power system. Therefore, it is necessary to analyze the impact of relay protection core components on the entire relay protection system, so as to ensure that the replacement of domestic chips will not reduce the relay protection reliability.
1.2. The Lack of detection technology of the impact of alternative core components on the performance of relay protection

The current test of relay protection devices is an overall test relying on the integrated relay protection device products of various manufacturers. Basically, the difference in core components such as CPU, DSP, FPGA, memory chip, ADC, and power supply chip of the protection device is not considered. Therefore, the existing detection technology lacks the ability to detect the impact of alternative core components on the performance of relay protection. In order to realize the alternation of core components, it is necessary to study the detection technology that considers the difference of core components from multiple angles, so as to lay a solid theoretical foundation for the application of the replaced device.

In order to solve the above problems, this paper analyzes the structure of the relay protection device and the performance index parameters of the core components. Through the failure analysis of the core chip of the relay protection device in the installation environment, a test plan for the general hardware part of the relay protection device based on the "domestic core" is proposed.

2. Structure of microcomputer relay protection device

2.1. Structure of microcomputer relay protection device

With the development of power systems, relay protection devices have completed a rapid transformation from electromagnetic transistor to integrated circuit, microcomputer device. As of the end of 2018, the State Grid Corporation of China has 182,172 AC protection devices for 220kV and above, and the micro-computerization rate has reached 100%. The AC protection devices for 220kV and above have been fully micro-computerized [1].

The microcomputer relay protection device usually generally adopts plug-in design, mainly including power plug-in, input plug-in, output plug-in, AC plug-in, acquisition and protection plug-in, man-machine interface plug-in, CPU plug-in, etc., typical equipment structure and hardware composition shown in Figure 1 below [2, 3].

![Figure 1. Typical structure diagram of microcomputer relay protection device.](image)

2.1.1. The data acquisition system (or analog input system). mainly composed of modules such as voltage formation, analog filtering, sample and hold (S/H), multiple conversion (MPX), and analog-to-digital conversion (A/D). The main function is to accurately convert the analog input quantity into the required digital quantity.

2.1.2. The CPU main system. mainly composed of microprocessor (MPU), program memory (ROM), data memory (RAM), timer, parallel and serial interfaces and other components. Mainly through the microprocessor (MPU) to execute the prepared program, its main function is to complete various relay protection measurement, logic and control functions.

2.1.3. The input/output system. is mainly composed of parallel interface (PIA or PI0), photoelectric isolation device and intermediate relays with contacts. Its main function is to complete various protection of export tripping, signal alarm, external contact input, etc.
2.1.4. *Human-machine interface and communication system.* mainly composed of display screen, keyboard, printer, communication chip and other components. Its main function is to complete device debugging, display system status, set values and communicate with other equipment.

2.1.5. *The power supply system.* is to provide the DC regulated power supply required by the entire device.

2.2. *Analysis of Main Chips of Relay Protection Device*

CPU, DSP, FPGA, memory chip, ADC, power chip and other components are the core components of the relay protection device. The performance of each component will affect the operation of the entire power system. Taking the 110kV and above high-voltage platform device as an example, conventional relay protection devices using foreign chips involve 6 types of core components, including main control chips (DRA624 from TI, P1011 and MPC8377 from Freescale); DSP (ADSP-21469 from ADI and TMS320C6655 from TI); FPGA (XC7A100T, XC6S and XC3S series from Xilinx); ADC (AD7606 from ADI); memory chip (JS28F128, MT41K128M16 and MT29F1G08 from Micron); power chip (LDO power supply MIC47100 from Micrel). The main performance index parameters of those chips are shown in Table 1.

**Table 1. Performance index parameters of core components of 110 kV and above relay protection device**

| CHIP TYPE       | MODEL      | TYPE    | BRAND | Performance index parameters                                                                 |
|-----------------|------------|---------|-------|------------------------------------------------------------------------------------------------|
| MAIN CONTROL CHIP | DRA624     | Premium SoC | TI    | Dual-core 720 MHz ARM® Cortex™-A8 +; 4800/3600 C674x™ MIPS/MFLOPS; power consumption<3W, working temperature-40℃~+105℃ |
|                 | MPC8321    | Middle end CPU | Freescale | Single core, Main Frequency266/333MHz; Local Bus 16 bit, Frequency66MHz; 32 bit; Maximum power consumption 1.62W (@333MHz); DDR2 interface 266MHz; working temperature-40℃~+105℃ |
| DSP             | TMS320C6655 | Premium DSP | TI    | 1.25GHz, 20 GFLOP/Core for Floating Point |
| FPGA            | XC7A100T   | Premium FPGA | Xilinx | LOGIC UNIT: 101440 LAB/CLB; 7925, RAM: 4976640 IO:285 |
| ADC             | AD7606     | Premium ADC | ADI   | 16 bit SAC type ADC, 8-channel simultaneous sampling, 5V analog single power supply, ±10 V Bipolar analog input, temperature -40℃~+85℃ |
| MEMORY          | MT29F1G08  | Nand Flash | Micron | working temperature -40℃~+85℃, power supply 2.7-3.6V or 1.7-1.95V, program/erase 100,000 times, 8192 blocks 16Gb |
| BATTERY         | ADM6710    | Power Monitoring | ADI | Working temperature -40℃~+85℃, Monitoring 4 voltages |

According to the selection comparison between the foreign chips and domestic chips, we have concluded the following differences:

1) Processor: The domestically MCU chip GigaDevice GD32F450ZI has better performance than foreign chips in terms of main frequency, storage capacity, numbers of ADC external channels, and peripheral interfaces;

2) FPGA: Shanghai Anlu FPGA chip EF2L45LGI44B has great advantages in logic unit, memory, multiplier, clock management unit, user I/O, etc. Also, the supporting software debugging tools is better and easier.
3) Memory chip: SUCDT SGC25N016D has obvious advantages in reading speed, programs programming and erasing speed.

4) Power chip: the DC-DC power chip SY8003ADFC has certain advantages in input range and maximum current output capability. After actual tests, the performance of the domestic power chip is basically the same as that of foreign power chips.

5) Relay: Compared with the Japanese Panasonic relay currently used, the performance of Hongfa relay can also meet the demand of protection application.

3. Operation Analysis of the relay protection chip

The current microcomputer protection uses a large number of electronic components in the relay protection device, and the failure of the electronic components is the main reason for the incorrect action of the relay protection. Therefore, it is very important to find out the influencing factors of the reliability of electronic components and propose the corresponding test plan to improve the overall reliability of the domestic chip relay protection device [5].

The U.S. military project has conducted statistics on the failure causes of electronic components, as shown in Figure 2 below. It can be seen from the figure that the external temperature has the greatest impact on the electronic components. Combined with the substation operating environment, we analyze the impact of temperature, humidity, electromagnetic interference, etc.

![Fig. 2 Failure cause analysis diagram of electronic components](image)

### 3.1. Influence of temperature

Electronic components are composed of various materials, including metal and insulator materials such as chips, dielectric films, metal interconnects, metal lead frames, glass and plastic casings. The thermal expansion coefficients of these materials are different. Once encountered temperature changes, the interface between different materials will produce compressive and tensile stress, resulting in thermal mismatch.

The external temperature change is the external cause of thermal stress. This temperature change may come from two aspects: one is the change in the working environment temperature of the device (such as Northeast China, Xinjiang, etc., the annual temperature difference can reach more than 50℃). There is a huge disparity, which is equivalent to a slow temperature cycle test; the second is the temperature change experienced by the device during welding and assembly, resulting in residual stress, which will slowly release with time.

An increase in temperature will accelerate the appearance of failure mechanisms such as physical diffusion, chemical reactions, and material decomposition. It will cause effects such as atom diffusion, ion migration, creep, crystallization change and microstructure rearrangement, such as Si-Al contact degradation, Au-Al compound formation, and SiO2-Al reaction to make the SiO2 layer thinner. The higher the temperature and the greater the temperature difference, the faster the physical and chemical reaction of device degradation and the greater the impact on storage reliability. The relationship between...
the rate of these changes and the ambient temperature can be expressed by the Arrhenius formula shown below.

\[
d\frac{dM}{dT} = A e^{\frac{E_a}{kT}} dT
\]  

(1)

\( \frac{dM}{dT} \) is the rate of chemical reaction, A is a constant, Ea is the activation energy that causes the failure or degradation process, k is the Boltzmann constant, and T is the thermodynamic temperature.

When the ambient temperature of the device changes from T0 to T1 within t time, we can get

\[
t = \frac{\Delta M}{A} e^{\frac{E_a}{kT}}
\]

(2)

\( \Delta M \) is the degradation of the device. Then take the logarithm of (2) to get

\[
\ln t = \ln \frac{\Delta M}{A} + \frac{E_a}{kT}
\]

(3)

The above formula is the acceleration equation of temperature stress obtained by the Arrhenius model, which can be expressed as a straight line between the logarithm of t and t/T. If the temperature T0 is used as the reference stress, the time when the life test reaches a certain cumulative failure rate under this condition is taken as an example, written as the accelerated stress condition, then the time for the life to reach the same cumulative failure rate under this condition is t0 (T0), T1 is the accelerating stress condition. Under this condition, the time for the life to reach the same cumulative failure rate is t1 (T1). Then the ratio of the two is the acceleration factor

\[
A_F = \frac{t1(T1)}{t0(T0)} = e^{ \frac{E_a}{k} \left( \frac{1}{T0} - \frac{1}{T1} \right)}
\]

(4)

It can be seen from the above formula that the higher the temperature, the greater the activation energy and the faster the device degradation rate. The relationship between activation energy and degradation rate is shown in Figure 3.

![The relationship between activation energy and degradation rate](image)

Fig. 3 The relationship between activation energy and degradation rate

It can be seen from the above theoretical analysis that the higher the temperature, the higher the failure rate of electronic components.

3.2. Influence of humidity

During the storage and use of electronic devices, especially in coastal and subtropical environments, environmental conditions such as high humidity and salt spray will be encountered. Under such
conditions, the device may fail due to corrosion resulting from electrochemical reactions. On the one hand, the outer leads and the shell of the device may be directly corroded, of which the Kovar alloy lead is the most significant; on the other hand, due to the sealing defect of the shell or the hygroscopicity of the packaging material itself such as plastic packaging, water vapor will penetrate into the shell, making the aluminum metallization layer on the surface corroded and the electrical performance parameters of the chip deteriorated or even failed.

There are two moisture absorption mechanisms for plastic packaging shells: one is slow moisture absorption, where moisture migrates through the organic epoxy matrix through hydrogen bonds; the other is rapid moisture absorption, where moisture migrates through the silica filler matrix. Usually two moisture-absorbing structures will exist at the same time. This means that when the device is stored for a long enough time, it has been absorbing water vapor, and when the moisture absorption reaches a certain level, it will reach saturation. Generally speaking, the change of moisture absorption over time can be expressed by the following formula:

$$ C(t) = C_s(1 - e^{-V m t}) $$

(5)

$C(t)$ is the concentration of water molecules absorbed in the resin at time $t$, $C_s$ is the saturation value of $C$, $V m$ is the moisture absorption rate constant. The temperature and relative humidity of the environment have an accelerating effect on moisture absorption. Hallberg and Peck calculated the humidity acceleration factor

$$ A_F = \left( \frac{R H_1}{R H_0} \right)^n $$

(6)

$R H_0$ and $R H_1$ are the relative humidity during use and acceleration stress, $n$ is a constant between 2-3.

3.3. Influence of Electromagnetic interference

The electromagnetic interference of the substation is very strong. Especially in the switch yard which has a large number of primary power equipment, the electromagnetic interference is more intense and complex. With the increase of the transmission voltage, when the switch is operated or fails, a stronger electromagnetic field will be generated in the space. Moreover, the use of SF6 switches and GIS (Gas-Insulated Substation, GIS) systems is becoming more and more common. Due to the extremely strong de-ionization ability of SF6 gas, fast transient overvoltage with extremely high frequency will appear on the bus when the switch is operated, and the pulsed electromagnetic field with extremely steep rising edge is radiated into space, which becomes a more intense source of interference with a wide frequency band. Its electromagnetic environment is extremely harsh, and the EMC problem is even more prominent. We summarize the electromagnetic interference sources of the substation switch yard as follows: (1) high-voltage switch operation; (2) lightning; (3) power equipment in operation; (4) system short-circuit fault; (5) radiated electromagnetic field; (6) Electrostatic discharge; (7) Power system harmonics.

4. Research on Testing Technology of Relay Protection Device Based on Domestic Chip

4.1. Climate and environmental impact test

If the temperature of the equipment is too high or too low during operation, when it exceeds the allowable limit value, it may cause the device to malfunction. At present, there are two main forms of installation of relay protection devices in smart substations: relay protection cabins and prefabricated integrated cabins, both of which can provide temperature and humidity control for the protection devices placed in them. The climate and environmental impact test items carried out for the type test of relay protection devices mainly include
1) High and low temperature operation test: check the ability of the device to withstand high and low temperatures during operation.

2) High and low temperature storage test: check the ability of the device to withstand high and low temperatures during storage.

3) Temperature change test: check the device's ability to withstand rapid temperature changes during operation.

4) Damp heat test: check the device's ability to withstand long-term exposure to high humidity atmosphere (constant damp heat test); check the device's ability to withstand exposure to high humidity condensation atmosphere (alternating damp heat test).

According to the general technical requirements of relay protection devices [1 4], indoor relay protection devices should operate at high temperature +55°C; low temperature at -10°C; high temperature storage at +55°C; low temperature storage at -25°C; temperature change in the range of -10°C ~ +55°C; constant damp heat at humidity 93% with temperature at 25°C; alternating damp heat alternating between humidity 93% at temperature 40°C and humidity 97% at temperature 25°C. However, considering that domestic chips are far from European and American chips in terms of function, performance, power consumption, yield, and software support, during the test, we should continuously monitor the different ranges of current and voltage applied to the device, the communication status, the status of power supply voltage and temperature and other parameters; at certain intervals, the protection setting should be modified, different protection action excitations should be applied, and the action accuracy, action time, input and output of the device should be verified. Also the device message should be checked whether the fault recording is complete and correct. When conditions permit, the temperature of different boards inside the device can be monitored to provide a basis for device design and advanced applications. After the test, the cumulative effects of different tests should be considered, and the function and performance of the device should be checked and verified from time to time.

4.2. Electromagnetic compatibility test

Corresponding to the aforementioned electromagnetic interference phenomenon in substations, we usually use the electromagnetic compatibility immunity test items and their assessment levels of power system products shown below:

1) Conducted electromagnetic compatibility immunity test
   a. Electrostatic discharge (Level III), which simulates electrostatic discharge from operators or nearby objects;
   b. Electric fast transient pulse group (Level B), which simulates the fast transient pulse group generated in the power grid due to switching operations. We can test the immunity of power supply ports, signal ports and control ports of the device when subjected to such disturbances;
   c. Surge (level III), simulate lightning disturbance, and we can test the immunity of equipment subjected to such disturbances;
   d. Damped oscillation wave (level III), which simulates the disturbance of the damped oscillating magnetic field generated by the operation of the isolation switch.

2) Radiated electromagnetic compatibility immunity test
   a. Power frequency magnetic field (Level IV), which simulates power frequency magnetic field disturbance near the high current bus;
   b. Radio frequency electromagnetic field (Level III), which simulates the disturbance of high frequency magnetic field emitted by staff using walkie-talkie, etc.;

The latest international standard IEC 61000-4 series is equivalent to the latest national standard GB/T 17626 series. The electromagnetic compatibility test of the relay protection device using the domestic chip still uses the above test content. However, in the electromagnetic compatibility test process, the focus should be on the damage of electronic components under the action of electromagnetic interference energy, especially in the case of surge test, electrical fast transient pulse group, electrostatic discharge interference, during and after the test process, It is necessary to strengthen the comprehensive
verification of the functions and performance of the current loop, voltage loop, power supply loop, switch-in and switch-out loop of the device. When conditions permit, functional tests for the core components of the device should be carried out after the test.

4.3. Power module reliability test
According to statistics, among the 2472 relay protection device defects that occurred in the relay protection system of 220kV and above in the State Grid in 2017, 280 times were defective in the power plug-in unit, accounting for 11.33% of the total number of defects that year; 384 times were defective in the CPU plug-in, which accounted for 15.53% of the total defects that year. In order to ensure the reliability of relay protection devices using domestic chips, it is necessary to carry out reliability tests of power modules.

The accelerated aging test is to increase the test stress (such as thermal stress, wet stress, electrical stress, mechanical stress, etc.) to stimulate the product to produce the same failure as the normal stress level in a short time, which shortens the test cycle [15-16]. Then use the accelerated aging model to evaluate the reliability characteristics of the product under normal working stress, which is suitable for verifying whether the life of the power module of the relay protection device meets the design requirements.

During the experiment, we put the test sample at room temperature into the test box in the normal position and connect the related equipment (such as: power input line, specified load, voltage, ripple monitoring equipment, etc.), it is recommended to test no less than 10 samples; we adjust the temperature and humidity of the test chamber to the values specified in the test, the temperature rise rate in the chamber is not more than 1℃/min (not more than the average value of 5min) and the humidity rises within 1h to reach the condition test. After setting the temperature and humidity, make the environment of the test sample stable.

When the temperature and humidity in the box reach the specified value, we power up the sample and turn on the monitoring equipment. Meanwhile the timing switch starting to work, we turn on the power supply, delay the disconnection of the power supply, and repeat until the theoretical test time is reached. During the test, we monitor the output of the power supply and make a record. It is required that the variation of the output voltage shall not exceed 5% of the rated output voltage, or the ripple factor shall not exceed 5% according to the model product standard.

At the end of the test, the test sample is still kept in the test box, and the humidity is gradually reduced to the humidity value under the controlled recovery condition within 0.5h. Reduce the temperature in the box at a rate of greater than 1 degree/min (not more than the average value in 5 minutes) within 0.5h to the temperature value under controlled recovery conditions. The recovery time is usually 1h (depending on the actual situation). Finally the power module is tested for mechanical appearance and comprehensive electrical performance.

5. Conclusion
As the core equipment of the power grid, the relay protection device plays a very important role in the safe and stable operation of the power grid. This paper analyzes the performance index parameters of the core components of the relay protection device; studies the characteristics and performance of the core components; analyzes the influencing factors of temperature, humidity, electromagnetic interference, etc. Combined with the operating environment of the relay protection device; and at last proposes a test plan based on the general hardware part of the domestic core relay protection device providing a reference for the centralized detection of the relay protection device based on the “domestic core”.

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