Research on Maintenance Method of Safety-level Switching Power Supply Module in Nuclear Power Plant

Huanyu Wang¹, Guixia Zhu², Xiaolei Teng¹, Xin'an Sun¹, Yugang Qian² and Yuying Hu²

¹Jiangsu Nuclear Power Co., Ltd., Lianyungang City, Jiangsu Province, 222002
²China Nuclear Power Operation Technology Corporation, Ltd., Wuhan City, Hubei Province, 341000

Abstract: With the technological development in the domestic electronic industry and the urgent demand of cost reduction and efficiency improvement in nuclear power plant, the electrical equipment in nuclear power plant has changed from replacing with brand-new equipment regularly or after failure to reusing after aging mitigation. At present, it is very urgent to research the maintenance methods of safety-level electrical equipment. Through the research on the failure mode and influence analysis, vulnerable components and parts, post-repair test and post-repair service life calculation of the safety-level switching power supply module, the maintenance methods are systematically sorted out. Through specific case analysis, the aging of power supply module can be mitigated and the reliability of it can be improved. At the same time, the method can be extended to other safety-level electrical equipment maintenance with one of the characteristics of unavailability of spare parts, high price, and large quantity or reverse demand.

Keywords. safety-level switching power supply, maintenance method, aging mitigation, reliability improvement

1. Introduction
In recent years, with the continuous and rapid growth of the world's electronic information and the domestic electronic industry, the domestic electronic components and parts industry, as the foundation of the electronic information industry, has also developed rapidly, laying a solid technical foundation for the inspection and maintenance of electronic component equipment in nuclear power plant. In order to realize the coordination of safety and economy in the development of nuclear power, nuclear power plant should adhere to the principle of "strengthening internal cost control and 'reducing costs and increasing efficiency'". At present, most of the electrical equipment in nuclear power plant in operation is imported, and the proportion of imported equipment that has been in operation for more than five years is even higher. With the tide of localization, the preventive maintenance mode of electrical equipment in nuclear power plant has also changed from replacing with brand-new equipment regularly or after failure to reusing after aging mitigation. Considering the mature technology in the domestic electronic components and parts industry, the relatively independent power supply module has become a valuable subject of research on maintenance methods. Additionally, the nuclear power plant currently has an urgent demand for safety-level equipment maintenance. However, due to the limitations in the industry itself, there are limited references available for this study. Combining with power electronics and reliability
technology, this paper introduces the standard specification, theoretical analysis and cases related to the maintenance methods of safety-level switching power supply module in nuclear power plant.

2. Related regulations and standards

2.1. NB/T 20197.3-2014

NB/T 20197.3-2014 Reliability and Aging Detection for Instrumentation and Control Equipment in Nuclear Power Plant, Part 3: Power Supply.

NB/T 20197.3-2014 specifies the characteristic parameters, reliability and aging detection methods of the power supply (conversion devices that provide stable AC or DC power to the instrument and control equipment) used in the instrument and control system of nuclear power plant. It is suitable for the power supply of the instrumentation and control system of nuclear power plant, but not for the uninterruptible power supply[1].

In the process of research made in this paper, the main reference is 7.1.2: "Detection Classification" of the standard. Table 1 lists the corresponding testing items for spare parts acceptance, burn-in screening and testing, regular/aging status detection, functional verification after aging mitigation and failure analysis. For the verification of the power supply module after maintenance, reference can be made to the test items verified after aging mitigation.

Table 1 Detection Classification of Power Supply and Test Items

| S/N | Test items | Spare parts acceptance | Burn-in screening and detection | Regular/aging status detection | Functional verification after aging mitigation | Failure analysis | Corresponding chapter number of this part |
|-----|------------|------------------------|---------------------------------|-------------------------------|-----------------------------------------------|-----------------|------------------------------------------|
| 1   | Appearance and structure | ● | ● | ● | ● | ● | 5.2, 6.2 |
| 2   | AC input characteristics | ● | ● | ● | ● | ○ | 5.3.1, 6.3.1 |
| 3   | Output voltage and current ratings | ● | ● | ● | ● | ○ | 5.3.1/5.3.2, 6.3.2 |
| 4   | Output voltage adjusting range | ● | ● | ● | ● | ○ | 5.3.4, 6.3.3 |
| 5   | Voltage stability | ● | ● | ● | ● | ○ | 5.3.5, 6.3.4 |
| 6   | Load stability | ● | ● | ● | ● | ○ | 5.3.6, 6.3.5 |
| 7   | Interaction effect | ● | ● | ● | ● | ○ | 5.3.7, 6.3.6 |
| 8   | Ripple voltage and noise | ● | ● | ● | ● | ○ | 5.3.8, 6.3.7 |
| 9   | Transient recovery time and overshoot amplitude | ● | ● | ● | ● | ○ | 5.3.9, 6.3.8 |
| 10  | Maintenance time | ● | ● | ● | ● | ○ | 5.3.10, 6.3.9 |
| 11  | Output voltage overshoot of start-up | ● | ● | ● | ● | ○ | 5.3.11, 6.3.10 |
| 12  | Efficiency and power factor | ● | ● | ● | ● | ○ | 5.3.12, 6.3.11 |
| 13  | Temperature coefficient | ● | ● | ● | ● | ○ | 5.3.13, 6.3.12 |
| 14  | Output over-current protection | ○ | ○ | ○ | ○ | ○ | 5.6.1, 6.3.13 |
### 2.2. NB/T 20088-2012

NB/T 20088-2012 Requirements for the Replacement of Parts and Components for Safety-level Electrical Equipment in Nuclear Power Plant.

This standard specifies the basic requirements for the replacement of parts and components of safety-level electrical equipment in nuclear power plant. It is applicable to the replacement of components of safety-level electrical equipment in nuclear power plant, including type selection, substitution argument, installation and test and not applicable to the replacement of the whole set of safety-level electrical equipment and the whole unit of large-scale equipment (such as medium and high voltage motors, switchboards, etc.) in nuclear power plant[2].

In the process of research made in this paper, the main reference was made to Chapter 5: "Basic Requirements for Parts and Components Replacement", Chapter 7: "Item Replacement" and Chapter 8: "Replacement of Parts and Components". The procedure of "item replacement" is shown in Figure 1.
2.3. **GB/T 13625-2018**

GB/T 13625-2018 Seismic Qualification of Safety-level Electrical Equipment for Nuclear Power Plant.

This standard specifies the implementation method and document requirements for conducting the seismic qualification to verify that safety-level electrical equipment can perform its safety function during and/or after an earthquake. It is suitable for seismic qualification of safety-level electrical equipment in nuclear power plant, including any interface components or equipment whose failure will have harmful effects on the performance of safety systems [3].

In the process of the research made in this paper, the main reference was made to Chapter 5: "Methods for Seismic Qualification of Equipment" and Chapter 8: "Test".

3. **Research on maintenance methods**

The research on maintenance methods of safety-level switching power supply includes common failures and analysis, vulnerable components and parts, management of alternative materials, post-repair test and post-repair service life calculation.
3.1. Common failures and analysis of power supply module

Generally speaking, the failure causes of power supply module can be divided into product design problems, production processing problems, installation and commissioning problems and operating environment problems. Failures caused by product design problems and production processing problems can only be improved by suppliers in the new module. Installation and commissioning problems and operating environment problems can be solved after problems are found. For a mature power supply module, its failures are generally divided into random failure and aging failure. Random failure can be repaired through corrective maintenance and replacing faulty components. For aging failure, components with short service life need to be analyzed and replaced to improve the post-repair service life and reliability\[4\].

3.1.1. Product design problems

Product design problems generally include incorrect component selection, insufficient parameter margin design, failure to consider the actual application environment, and failure to meet certain specific working conditions. The production processing technology of the power supply module is also an important part of reliability. Common processing failure modes are as follows.

**Table 2. Modes and Analysis of Failures Caused by Production Processing of Power Supply Module**

| S/N | Failure mode                                      | Impact analysis                        |
|-----|--------------------------------------------------|----------------------------------------|
| 1   | Poor welding                                     | Failure after a period of operation    |
| 2   | Bad contact of connector                         | Failure after transportation or vibration |
| 3   | Assembly technology - crushing components        | Failure, or failure after a period of operation |
| 4   | Assembly technology - poor thermal conduction    | Failure after a period of operation    |

3.1.2. Operating environment problems

The application environment of the power supply module is also the key to influence the reliability of the power supply. For example, temperature and humidity exceeding the specification will accelerate the aging of power supply module, and electronic components and parts and circuit boards will be corroded quickly in the salt-spray environment, thus greatly shortening the service life of the module. The following table is a summary.
Table 3. Application Environmental Impact and Analysis of Power Supply Module

| S/N | Influence factor                  | Impact analysis                                                                 |
|-----|-----------------------------------|---------------------------------------------------------------------------------|
| 1   | Harsh electromagnetic environment | It will affect the normal operation of the circuit, or continue to work in an abnormal state, resulting in increased stress and failure of some components |
| 2   | High temperature                  | The overheated components and parts will suffer from short life or failure.       |
| 3   | High humidity and high salinity   | The metal components and parts will be corroded, resulting in failure.           |
| 4   | Dust accumulation                 | Insulation fails, and ignite among wires; It is not easy to dissipate heat        |
| 5   | Altitude                          | It will require higher insulation grade designs at high altitudes                |

In addition, after the power supply module runs for a long time, the performance of some components will decline to a certain extent, resulting in the deterioration of some performances of the power supply modules, such as EMI characteristics and lightning resistance, but it can still meet the requirements of input and output functionally.

Table 4. Common Failure Modes and Effects of Power Supply Module Components

| S/N | Failure components   | Failure mode                  | Failure effect               |
|-----|----------------------|-------------------------------|-----------------------------|
| 1   | Fuse                 | Open circuit                  | No output                   |
| 2   | Electrolytic capacitor | Capacity fading              | Unstable output/no output/others |
| 3   | Thin-film capacitor  | Capacity fading              | Unstable output/no output/others |
| 4   | Ceramic capacitor    | Crack/short circuit          | Unstable output/no output/others |
| 5   | Power semiconductor  | Short circuit                 | No output                   |
| 6   | Controlling semiconductor | Not working                | No output                   |
| 7   | Resistor             | Open circuit                  | Unstable output/no output/others |
| 8   | Magnetic core device | Magnetic core crack/coil short circuit | No output |
| 9   | Power relay          | Contact failure              | No output/others            |
| 10  | Potentiometer        | Open circuit/unstable contact | No output/others            |
3.2. Common vulnerable components and parts of power supply module

3.2.1. Electrolytic capacitor
Electrolytic capacitor is widely used in different fields of power electronics, mainly for smoothing and storing energy or filter after AC voltage rectification, and also for non-precise timing delay. When predicting the Mean Time Between Failure (MTBF) of switching power supply, model analysis shows that the service life of switching power supply is mainly affected by the electrolytic capacitor.

3.2.2. Thin-film capacitor
The thin-film capacitor is formed by overlapping metal foil electrodes and plastic films such as polyethylene, polypropylene, polystyrene or polycarbonate and winding them into a cylinder. The thin-film capacitor is generally sensitive to temperature and power frequency. Therefore, when used under high temperature or high power frequency, some parameters of the capacitor need to be reduced in line with the requirements. Otherwise, its service life may be shortened and become a major defect of the circuit. For some power supply modules, the thin-film capacitor isolating the primary and secondary sides of the driver transformer is also an important factor affecting their service life. After long-term operation, the capacitance and the impedance of the thin-film capacitor will decrease, which results in the switch control signal cannot be transmitted from the control panel to the switching tube, and even the capacitor cannot output signals. In addition, after EMC filter thin-film capacitor operates for a long time, its capacitance will attenuate, or even its impedance will change, which makes EMC characteristics of power supply module become poor and even interferes with the normal operation of other equipment.

3.2.3. Optocoupler sensor
Common isolated switching power supply adopts optocoupler sensor to transmit the signals from primary and secondary sides. After long-term operation of optocoupler, the transmission coefficient will change on account of light attenuation of LED, which may cause some functions of the power supply module to attenuate, such as poor load regulation rate or failure to operate at full load.

3.2.4. Fuse
The fuse for the switching power supply is selected in accordance with its characteristics. Most of the switching power supplies with medium and small power adopt non-replaceable fuses, i.e. the fuse is usually not repairable and replaceable after switching power supply failures occur. The fuse is impacted by the pulse current at the moment of starting, lightning surge and other transient pulse currents. Therefore, the fuse for the equipment which frequently powers on and off is prone to be damaged, and is usually designed to be replaceable.

3.2.5. Input relay
High-power switching power supply generally uses power current-limiting resistor to reduce the current pulse at the moment of starting. After the machine runs normally, regulate the short circuit current-limiting resistor of the relay to improve the efficiency of power supply. For the equipment which frequently powers on and off, the relay is also vulnerable.

3.3. Alternative material management
Because the production of safety-level power supply modules takes a long time, the production of some components and parts has been suspended or upgraded, and raw materials cannot be purchased from market. In order to ensure that the alternative materials can equally replace/exceed the performance of the original materials and improve the reliability of the power supply module after repair, it is necessary to compare and analyze the specifications and parameters of the alternative materials, and conduct the tests related to the alternative materials to verify their feasibility. For more details, please refer to NBT 20088-2012 Requirements for the Replacement of Parts and Components for Safety-level Electrical Equipment in Nuclear Power Plant.
3.4. Test of power supply module after repair

Certain tests after repair need be carried out to verify the reliability of the power supply module. Since there are no uniform specifications or requirements for the function or performance parameters of the power supply module, it is necessary to carefully read the specifications of the power supply module and then carry out the tests on the basis of the specification. For more details, please refer to NB/T 20197.3-2014 Reliability and Aging Detection for Instrumentation and Control Equipment in Nuclear Power Plant, Part 3: Power Supply and NBT 20088-2012 Requirements for the Replacement of Parts and Components for Safety-level Electrical Equipment in Nuclear Power Plant.

3.5. Post-repair service life calculation of power supply module

Post-repair service life refers to the time span from the power supply module being repaired to the occurring of the first failure. In order to obtain this time span, we generally adopt two methods, one of which is high temperature aging test, also known as accelerated service life test, and the other is reliability prediction based on physical of failure (PoF) model.

4. Case analysis

The safety-level power supply module A of a nuclear power plant has been in operation for more than 14 years, so its defects increase year by year along with aging problem due to long-term operation. In recent years, its failure rate is also on the rise. For some reason, the safety-level power supply module A cannot be purchased, so it is imperative to find out maintenance methods that can slow down its aging. According to the information provided by the manufacturer, the service life of its circuit board is 40 years upon continuous aging mitigation.

4.1. Introduction to circuit topology of power supply module A

The main circuit topology of power supply module A is mainly composed of the first-stage Boost PFC convertor and the second-stage double-tube forward isolation converter, as shown in the dotted box at the upper part of Fig.2; the multi-level EMI filter is provided at the input end of the power supply, and multi-level ripple filter, circuit control panel display part and other components are provided at the output end, as shown in the dotted box at the lower part of Figure 2.

![Figure 2. Circuit Topology Diagram of Power Supply Module A](image_url)

Figure 2. Circuit Topology Diagram of Power Supply Module A

Figure 3 shows the circuit structure of power supply module A, which consists of power amplifier board, control panel, output board, input EMI filter, output network filter, temperature sensor, voltmeter, ammeter and communication wire.
4.2. Failure data analysis of power supply module A

Table 5 shows the historical failures classification data of power supply module A, including component failures and preventive maintenance. Fig.4 is the histogram of component failures. Failures of electrolytic capacitors C6~C8 (output filter capacitors in the first-stage Boost PFC circuit) account for more than 80% and begin to appear in the eighth year. Bad conditions of semiconductor (FET V5/V6, diode V2/V4) occur both at the initial stage and at the end of service life, mainly due to product quality problems (such as electrostatic damage/welding process/heat dissipation measures) at the initial stage. While at the end of service life, the bad conditions mainly result from the severe conditions (overvoltage/overcurrent) such as over-short circuit/lightning surge during use, or the increase of semiconductor voltage and current stress caused by the decrease of electrolytic capacitors C6~C8 capacity, or overheat breakdown triggered by the failure of aged heat conduction measures. Bad conditions of the main control panel A1 occur at the end of its service life, which is mainly due to the service life expiring of key components, such as optocoupler, relay, ceramic capacitor.

Table 5. Historical Failures Classification of Power Supply Module A

| Year  | Electrolytic Capacitor C6-C8 | FET/V5/V6 Breakdown | Diode V2/V4 Breakdown | Damaged Triode V20 | Damaged Control Panel A1 | Loose X29 Temperature Sensor Connector | Replace Electrolytic Capacitor C12-C150 (Preventive) | Replace Power Device V17/V20/V21 (Preventive) | Replace Power Resistor R10/R11 (Preventive) | Replace Power Resistor R2/R4/R5/R6, R14, etc. (Preventive) | Others |
|-------|-----------------------------|---------------------|-----------------------|-------------------|-------------------------|----------------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|-------|
| Y01   | 0                           | 1                   | 0                     | 0                 | 1                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y02   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y03   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y04   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y05   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y06   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y07   | 1                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y08   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y09   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y10   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y11   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y12   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y13   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Y14   | 0                           | 0                   | 0                     | 0                 | 0                       | 0                                      | 0                                 | 0                                | 0                                | 0                                | 0     |
| Total | 58                          | 5                   | 2                     | 4                 | 94                      | 1                                      | 70                                | 75                               | 1                                | 0                                |       |
Figure 4. Histogram of Component Failures
Figure 5 is the histogram of the preventive maintenance and replacement of components. Preventive replacement mainly focuses on electrolytic capacitors and power resistor components. Because the electrolytic capacitor bears the long-term resistance of ripple current and relatively high temperature (ambient temperature and self-loss), with electrolyte drying up, the capacitance value decreases continuously, and the internal impedance increases continuously. Moreover, if power components (resistors) bear the long-term heat generated by high voltage or large current impact, the impact resistance or heat dissipation capability of the devices will become worse, or even invalid.

Figure 5. Histogram of the Preventive Maintenance of Components

4.3. Analysis of alternative material for power supply module A maintenance
Because the production of power supply modules A takes a long time, the production of some components has been suspended or upgraded, and raw materials cannot be purchased from the market. In order to ensure that the alternative materials can equally replace/exceed the performance of the original materials and improve the reliability of the power supply module after repair, the specifications and parameters of the original materials and the alternative materials are compared and analyzed, and the key parameters are tested to verify the feasibility of the alternative materials. After that, it shall be reported to the Security Bureau.
with reference to *NBT 2008-2012 Requirements for the Replacement Parts and Components for Safety-level Electrical Equipment in Nuclear Power Plant*.

4.3.1. Analysis of alternative material for electrolytic capacitor

(1) Electrolytic capacitor C150

The original material model of electrolytic capacitor C150 is MALR2136-51102E3 from Vishay. Upon enquiry, that material is no longer available in the market and may have been discontinued. Through investigation and analysis, the upgraded model MAL2146-51102E3 from Vishay is adopted. The comparison of key parameters between the two types of capacitors is shown in Table 6. The original model is only slightly superior to the alternative material in terms of maximum ripple current, equivalent resistor and leakage current. However, the alternative material has great advantages in service life, which is 5,000 hours at 125 Degrees Celsius; according to the service life conversion formula of capacitor, the alternative material will have a service life of 20,000 hours at 105 Degree Celsius. Considering other parameters, the service life index of the alternative material is better.

**Table 6. Comparison of Parameters between New and Old Materials for C150 Electrolytic Capacitor**

| Index name                  | MALR2136-51102E3 | MAL2146-51102E3 |
|-----------------------------|------------------|-----------------|
| Maximum ripple current (mA) | 2,200@105°C      | 2,100@125°C     |
| Service life index          | 10,000h@105°C    | 5,000h@125°C    |
| Maximum equivalent impedance (Ohm) | 0.03        | 0.031           |
| Leakage current (μA)        | 500              | 503             |
| Loss tangent (%)            | 10               | 10              |
| Working temperature range   | -55 - 105°C      | -55 - 125°C     |
| Outline dimension           | 16*31mm          | 16*25mm         |

(2) Electrolytic capacitor C115/C116/C117

The original material model of electrolytic capacitor C115/C116/C117 is MALEKE00KL422H00K from EKE, a subsidiary of Vishay. Upon inquiry, the material is no longer available in the market, so MAL2146-51222E3 from Vishay is used as the alternative material. The comparison of the key parameters of the two types of capacitors is shown in Table 7. It shows that the alternative material is superior to the original model in all performance indexes, especially the service life index.
**Table 7. Comparison of Parameters between New and Old materials for C115/C116/C117 Electrolytic Capacitors**

| Index name                          | MALEKE00KL422H0 0K | MAL2146-5122 2E3 |
|-------------------------------------|-------------------|-----------------|
| Maximum ripple current (mA)         | 2,300@105°C       | 3,000@125°C     |
| Service life index                  | 5,000h@105°C      | 6,000h@125°C    |
| Maximum equivalent impedance (Ohm)  | 0.034             | 0.022           |
| Leakage current (μA)                | 1100              | 1103            |
| Loss tangent (%)                    | 14                | 12              |
| Working temperature range           | -40 - 105°C       | -55 - 125°C     |
| Outline dimension                   | 18*35.5mm         | 18*35mm         |

(3) Electrolytic capacitors C10/C22 and C1-C10

The original material model of electrolytic capacitors C10/C22 and C1-C10 is KM101M063G125A from Capxon in Taiwan. After consulting the supplier, the material is rarely produced now, and its upgraded material model is KF101M063G125A. The comparison of the key parameters of the two types of capacitors is shown in Table 8. It shows that the alternative materials have larger ripple current resistance, longer service life index, smaller loss tangent angle and longer comprehensive service life index than the original materials under the same size.

**Table 8. Comparison of Parameters between New and Old Materials for C10/C22 and C1-C10 Electrolytic Capacitors**

| Index name                          | KM101M063G125A    | KF101M063G125A |
|-------------------------------------|-------------------|----------------|
| Maximum ripple current (mA)         | 230               | 550            |
| Service life index                  | 2,000h@105°C      | 5,000h@105°C   |
| Equivalent impedance (Ohm)          | /                 | 0.15           |
| Leakage current (μA)                | 63                | 63             |
| Loss tangent (%)                    | 9                 | 8              |
| Working temperature range           | -40 - 105°C       | -40 - 105°C    |
| Outline dimension                   | 10*12.5mm         | 10*12.5mm      |

4.3.2. Analysis of alternative material for ceramic capacitor

The original material picture of ceramic capacitor C108 is shown in Fig. 6. There are two kinds of materials with a foot distance of 5 mm. While, the specific supplier and model of the capacitor have not been identified. According to the function of the capacitor in the circuit, MKP2 series from VIMA with the same capacity and 400V withstand voltage are used as the
alternative material. The specifications and dimensions of the alternative material are shown in Figure 7. MKP2 series are a metal polypropylene thin-film capacitor, which is suitable for oscillating circuit or high-frequency decoupling. Therefore, it is applicable to the primary winding of isolation driver transformer where C108 is located. That is to say, it has high-frequency AC component, and the selected model is 400V withstand voltage, with large voltage margin, which can realize long-term operation.

![Figure 6. Picture of C108 Ceramic Capacitor Original Material](image)

![Figure 7. Specifications and Dimensions of C108 Alternative Material](image)

4.4. Research on the test of power supply module A after repair

By reading the specifications of power supply module A, according to the specifications and referring to NBT 20197.3-2014 Reliability and Aging Detection for Instrumentation and Control Equipment in Nuclear Power Plant, Part 3: Power supply and NBT 20088-2012 Requirements for the Replacement of Parts and Components for Safety-level Electrical Equipment in Nuclear Power Plant, the tests for power supply module A after repair are shown in Table 9.
Table 9. Test List of Power Supply Module A after Repair

| S/N | Test item description | Reference standard | Remarks |
|-----|-----------------------|--------------------|---------|
|     |                       | Nuclear power plant standards | Power Supply Specifications | Industrial standards |         |
| 1   | Appearance inspection | √                   |         |         |         |
| 2   | Insulation test       | √                   |         |         | Using insulation impedance test |
| 3   | Functional test       |                     | √       |         |         |
| 4   | Output characteristic test | √   | √       |         | Using dynamic load test |
| 5   | Limit test            | √                   |         |         | Including wide input range test and high and low temperature test |
| 6   | Temperature rise test |                     |         | √       |         |
| 7   | Ripple test           |                     | √       |         |         |
| 8   | EMI wireless test     |                     | √       |         |         |
| 9   | Noise test            |                     | √       |         |         |
| 10  | Voltage fluctuation test |                 | √       |         |         |
| 11  | Starting current test |                     | √       |         |         |
| 12  | Effectiveness test    |                     | √       |         |         |
| 13  | Third-harmonic component test |               |         | √       |         |
| 14  | Dynamic response to unbalance voltage input |               |         |         | √       |
| 15  | 82-day full load test |                     | √       |         |         |
| 16  | Seismic assessment    |                     |         | √       |         |

4.5. Post-repair service life calculation of power supply module A

In order to further carry out scientific reliability management of power supply module A, it is necessary to evaluate the remaining service life of the post-repair module according to the reliability prediction method based on the PoF model, so as to calculate the average failure time interval of the equipment after aging mitigation.\cite{5,6}.\cite{5,6}
5. Conclusion
The research on maintenance methods of safety-level switching power supply module in nuclear power plant comprehensively consider the standards and specifications that nuclear power plants must follow, the requirements of equipment reliability management and the calls for reducing costs and increasing efficiency, which provides a method reference for maintenance of safety-level electrical equipment in nuclear power plant. At the same time, the weak links of the equipment are found through the calculation of the post-repair service life, which lays a technical foundation for the localization and optimization of the equipment. By researching the maintenance methods of nuclear power plant electrical equipment, the information of nuclear power plant component management database can be continuously expanded and revised to maximize the service life of equipment. Further, from the aspect of preventive maintenance management of nuclear power plant electrical equipment, the cost control can be fundamentally strengthened to enhance the competitiveness of nuclear power.

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