ISSN 2616-5767 Vol.6, Issue 11: 63-69, DOI: 10.25236/AJETS.2023.061110

Study on the insulation test technology of secondary loop for relay protection

Xiangguo Yin*, Xiaodong Wei

State Grid Ningxia Electric Power Co., LTD., Ultra High Voltage Company, Yinchuan, 750011, China
**Corresponding author: yonxiangguo2022@126.com*

Abstract: *Currently, our lives and production heavily rely on electricity. As the number of power users continues to grow, the demand for electricity is also increasing rapidly. In this context, it becomes imperative to enhance our power supply systems in order to meet the surging demand. The implementation of a secondary relay protection loop is vital for ensuring the stability of our power system. However, in practical applications, issues related to insulation in the secondary relay protection loop can lead to errors or malfunctions in the relay protection system, thereby jeopardizing the overall stability of the power grid. With this in mind, this paper focuses on the insulation testing technology for the secondary loop. It introduces an insulation testing method designed specifically for the secondary loop to ensure its safe and stable operation, which is crucial for maintaining the reliability of the entire power system.*

Keywords: *Secondary loop, insulation, power grid, test technology*

1. Introduction

The secondary circuit of relay protection plays an indispensable and critical role in the power system. The integrity of this circuit directly influences the reliable operation of the protected electrical equipment. As the scale of substations continues to expand, so does the equipment and secondary cable infrastructure. If insulation weaknesses within the operating relay protection devices and secondary circuits go undetected and become damaged, they can lead to issues such as DC ground loss, high-resistance contact closures, and multiple-point grounding in AC/voltage circuits. These problems can result in abnormal operation of the protected equipment, false tripping, or a reluctance to trip during internal faults. In severe cases, these issues may even pose a fire hazard, putting the safe and stable operation of the entire power system at risk [1-5].

Insulation weaknesses within the secondary circuit often do not manifest as immediate faults upon energization but rather develop slowly through a breakdown process, making them challenging to detect during routine operation. Consequently, they are prone to being overlooked, and the underlying risks must be promptly addressed. Therefore, it is of utmost importance to enhance insulation testing for relay protection equipment and secondary circuits during the installation, commissioning, or regular maintenance of substations to promptly identify insulation defects.

This article primarily focuses on insulation testing techniques for secondary circuits in relay protection systems. It delves into the root causes of insulation faults within the secondary circuit and discusses various methods for conducting insulation testing in the secondary circuit.

2. Relay protection secondary loop brief introduction

2.1 Secondary equipment

Secondary equipment encompasses the following categories:

(1) Measurement instruments such as electricity meters, current meters, voltmeters, active energy meters, reactive energy meters and temperature meters are essential tools for accurate data collection.

(2) Control equipment which includes public measurement and control components, individual unit measurement and control devices, remote communication systems, automatic time calibration mechanisms, monitoring backgrounds and other related equipment plays a crucial role in managing and

ISSN 2616-5767 Vol.6, Issue 11: 63-69, DOI: 10.25236/AJETS.2023.061110

maintaining various systems.

(3) Relay protection and safety automatic devices comprising essential protection devices for main transformers, lines, buses, capacitors and other key components, as well as devices for load reduction, disconnection, waveform recording and event logging are critical for ensuring the safety and reliability of electrical systems.

(4) Signal equipment encompassing communication transmission systems, distribution mechanisms, and photoelectric conversion components forms the backbone of communication infrastructure in many industries.

2.2 Secondary loop

The secondary loop mainly includes the following categories:

(1) The AC circuit (measurement circuit) is responsible for collecting primary system voltage and current signals and is composed of various measuring instruments and related circuits.

(2) The control loop is composed of a transmission mechanism and an execution (or operation) mechanism for control switches and control objects, such as circuit breakers and isolation switches.

(3) The adjustment loop refers to the regulating automatic device, such as the transformer on-load voltage regulation and the capacitor cutting device. It is composed of a measuring mechanism, transmission mechanism, regulator, and actuator.

(4) The signal loop comprises the signal transmitting mechanism and signal relay, which reflect the working state of the primary and secondary equipment.

(5) The power circuit is composed of power supply equipment and a power supply network, often including a DC power supply system and an AC power supply system.

(6) The relay protection and automatic device loop are composed of a measurement loop, comparison part, logic part, and execution part, working together to ensure the protection and automatic operation of the system.

2.3 Basic schematic diagram of the secondary loop

The basic schematic diagram of the secondary loop is shown in Figure 1.

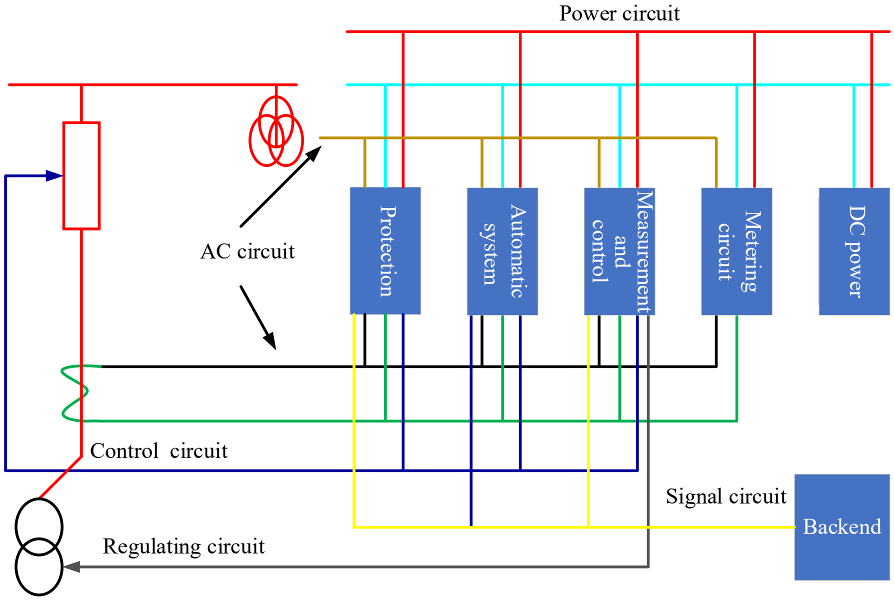

Figure 1: Schematic diagram of the relay protection secondary loop

ISSN 2616-5767 Vol.6, Issue 11: 63-69, DOI: 10.25236/AJETS.2023.061110

3. Common fault of the relay protection for the secondary circuit

3.1 Common fault classification

(1) Short Circuit Fault

This is the most common type of insulation fault. It occurs between different phases or within the same phase of conductors, causing current to bypass the normal path, potentially leading to equipment overheating or damage.

(2) Open Circuit Fault

This type of fault occurs when one or more conductors in a circuit break, preventing the normal flow of current. This can result in equipment losing its functionality or efficiency.

(3) Ground Fault

When insulation is compromised, allowing current to flow through the insulation to the ground, a ground fault occurs. This can introduce electrical shock hazards and affect the performance of equipment and circuits.

(4) Cable Damage Fault

Cables may sustain mechanical damage during use, such as crushing, bending, or puncturing, which can damage the insulation layer and eventually lead to insulation faults.

(5) Cable Aging Fault

Cables and insulation materials can become brittle and lose their insulating properties over time, leading to insulation failure.

(6) Voltage Surge and Overvoltage Fault

Sudden voltage surges or overvoltage conditions can damage insulation, leading to faults. These situations are often associated with lightning strikes, switch operations, or power system issues.

(7) Faults Due to Contamination and Humidity

Surface contamination, moisture, or humidity on insulation can reduce its effectiveness, ultimately leading to faults.

(8) Electromagnetic Interference and Noise

Interference or noise from other electromagnetic sources can disrupt insulation performance, resulting in faults.

The occurrence of insulation faults can lead to abnormal operation of electrical systems, equipment damage, and even electrical hazards. Therefore, maintaining and monitoring insulation conditions are of paramount importance in ensuring the safety and reliability of power systems.

3.2 Common fault classification

In the context of relay protection, various factors can lead to failures in the secondary circuit. These factors are commonly observed and can be described as follows:

(1) Conductor or Connection Failures

Breakage, wear and tear, corrosion, or loose connections in conductors or components, such as relay connectors and cables, may give rise to signal transmission issues within the secondary circuit.

(2) Cable Damage

Cables may undergo mechanical damage during their operational lifespan, including crushing, bending, puncturing, or external damage, all of which can compromise the cable's insulation.

(3) Electromagnetic Interference

Signal transmission within the secondary circuit can be disrupted by interference originating from external electromagnetic sources, potentially resulting in erroneous relay protection operations.

(4) Relay Component Failures

ISSN 2616-5767 Vol.6, Issue 11: 63-69, DOI: 10.25236/AJETS.2023.061110

Components within the relay's secondary circuit, such as current or voltage transformers, may experience failure due to aging, damage, or abnormal operation.

(5) Power Supply Issues

The power supply for the secondary circuit can be affected by power interruptions, battery failures, or voltage instability, leading to failures within the relay protection secondary circuit.

(6) Misoperation of Relay Protection Equipment

Erroneous signal transmission within the secondary circuit can occur due to incorrect settings, parameter misconfigurations, or misoperations of relay protection equipment.

(7) Contamination and Humidity

The performance of relay protection equipment and the secondary circuit may be impacted by contamination, moisture, or humidity, potentially resulting in signal distortion or misoperations.

(8) Grounding Failures

Damage to grounding lines or grounding electrodes within the secondary circuit may cause signal distortion or errors in relay protection equipment.

These factors, whether occurring individually or in combination, can lead to failures in the relay protection secondary circuit, potentially affecting the reliability and safety of the electrical power system. Consequently, the maintenance and monitoring of the status of relay protection secondary circuits are of utmost importance to ensure their proper operation and the timely detection of faults within the electrical power system.

3.3 Hazards of the insulation fault of the secondary circuit used for relay protection

Insulation faults in the secondary circuit of relay protection can have several adverse effects on the course, including:

(1) Inaccurate Protection Operations

The compromised insulation in the secondary circuit may lead to erroneous signal transmission, causing protection devices to misoperate or fail to detect and locate faults accurately. It can result in unnecessary equipment trips, system shutdowns, or an inability to respond promptly to genuine faults.

(2) Electrical Safety Risks

Insulation faults in the secondary circuit can pose electrical safety hazards. For instance, if compromised insulation prevents the accurate detection of ground faults, it may lead to current flowing through the insulation to the ground, increasing the risk of electrical shocks. Furthermore, misoperations and inaccurate protection actions may cause equipment or circuit damage, heightening electrical safety risks.

(3) Undetected Faults

Insulation faults in the secondary circuit may lead to signal loss, rendering protection devices incapable of accurately detecting actual faults or abnormal conditions. This may result in untreated circuit faults, potentially triggering more severe damage or causing system instability.

(4) Power System Stability Issues

Insulation faults in the secondary circuit can render the relay protection system unable to respond correctly to power system faults, making the power system more susceptible to issues such as overcurrents, overloads, and short circuits. It can lead to system instability or collapse, causing more extensive outages or equipment damage.

(5) Maintenance and Repair Costs

Addressing insulation faults in the secondary circuit may require significant time and resources. Maintenance and repair efforts can lead to extended downtime, adding to the operational costs of the power system.

As such, insulation faults in the secondary circuit of relay protection can have substantial consequences on the circuit and the entire power system, encompassing safety concerns, equipment damage, system instability, and increased maintenance expenses. Therefore, the maintenance and

ISSN 2616-5767 Vol.6, Issue 11: 63-69, DOI: 10.25236/AJETS.2023.061110

monitoring of insulation conditions in the secondary circuit of relay protection are paramount in ensuring the power system's proper operation.

4. Inducement of secondary circuit insulation failure

The causes of secondary loop insulation failure are mainly as follows:

4.1 Construction Process Challenges

Issues arise during the construction or technical renovation process due to installation quality problems. For instance, in cable secondary wiring construction, errors occur when construction personnel cut the cable ends too forcefully, inadvertently damaging the cable core insulation. Furthermore, outdoor high-voltage transformer junction boxes exhibit problems, such as inadequately secured hot-galvanized steel cable protection pipes at both ends, or an accumulation of cables passing through the protection pipe and entering the transformer terminal box.

4.2 Equipment and Product Quality Concerns

Quality defects in equipment and products, along with unreasonable structural designs, pose challenges. In the rainy season or during transformer spray tests, shortcomings like poor sealing effects in gas relay oils or temperature thermometers can lead to unplanned shutdowns. Similarly, low-quality secondary cables may result in reduced insulation within the secondary circuit.

4.3 Circuit Design Issues

Challenges emerge due to suboptimal secondary circuit design, wiring paths, and spatial layouts. Negligence by designers can lead to issues during on-site debugging, particularly when two groups of DC power supplies cross paths within the remote communication loop of the secondary circuit, especially if both share common endpoints.

4.4 Site Assembly Challenges

The competence of site assembly line personnel or the quality of factory assembly lines may fall short. Problems may include wires crossing during wiring, or the improper connection of components between two sets of power supplies during factory manufacturing.

4.5 Environmental Factors

Adverse operating conditions can weaken the insulation strength of the secondary circuit. In high-temperature and high-humidity environments, secondary circuit cables that have been operational for several years may suffer from severe aging, cracking, and insulation layer damage. Additionally, excessive dust accumulation in high-dust environments, particularly during infrastructure development or expansion, can lead to insulation breakdown when dust accumulates on adjacent terminals or contacts of operational equipment and mechanisms. In rare instances, insulation breakdown incidents have been attributed to the deposition of small animal excrement on the equipment.

5. Insulation detection of the secondary loop

5.1 Daily test

Mealulims meters are typically employed for daily monitoring, and they have specific detection requirements:

(1) The insulation resistance of each circuit, with the exception of the signal circuit, should be tested using a 1000V megohmmeter and should measure over 10 MΩ. The insulation resistance of the signal circuit should exceed 1 MΩ, and the total insulation resistance of all circuits should be more than 1 MΩ.

(2) For the signal loop with a low power supply, a 500V megohmmeter should be used.

ISSN 2616-5767 Vol.6, Issue 11: 63-69, DOI: 10.25236/AJETS.2023.061110

The relationship between the voltage level of the equipment and the megohmmeter selection is illustrated in Table 1.

Table 1: Selection of equipment voltage grade and Megohms meter

Equipment Voltage Level (V)	Megometer voltage class (V)	Megohlims minimum range (MΩ)
<100	250	50
<300	500	100
<3000	1000	2000
<10000	2500	10000
≥10000	2500 or 5000	10000

Use the daily detection method to judge the insulation condition of the secondary circuit according to the detection requirements.

5.2 Online insulation resistance detection of asymmetric bridge DC system

The principle of this detection technique is as follows:

In the protection device, the common relay wiring in the dotted box, resistance R3, is the total resistance of the relay coil loop, including the internal resistance and current limiting resistance of the relay coil. Ground the analog relay coil with the switch "K". Vl and V2 are the positive and negative buses.

When the relay coil grounding moment, the voltage at both ends of the relay coil is V2. In general, the operating voltage of the relay loop is 50-70 % of the DC system voltage V. When the DC system is well insulated, that is, R-and R + are infinite, then V1=V2=0.5 V is 50 % of the DC system voltage, and the relay coil loop grounding generally does not act. Only when the coil voltage at the grounding moment is greater than 50%.

To simplify the calculation, we can take the equilibrium bridge detection principle as an example, in which R1 equals R2 and both are equal to R.

Let C + =C- =C, negative electrode insulation resistance R-=∞.

The ground voltage of the cathode is V2 (0), the charge and discharge of the capacitor is over, the negative voltage is V2 (1), and the ground voltage of the capacitor is V2, which can be calculated according to Figure 2:

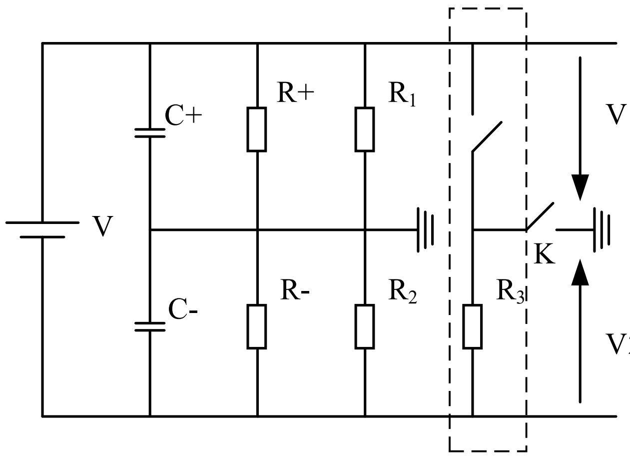

Figure 2: The equivalent circuit of coil circuit

$$V2(0)=V*R/(R+R//R_+)$$

$$V2(1)=V*R//R_3/(R//R_3+R//R_+)$$

$$V2=V2(1)-(V2(1)-V2(0))*e\text{-}t/\tau$$

$$\text{Where } \tau=R//R_3*C$$

The voltage V2 at both ends of the coil is related to the DC system voltage V, the bridge resistance

ISSN 2616-5767 Vol.6, Issue 11: 63-69, DOI: 10.25236/AJETS.2023.061110

R, the cathode insulation resistance R+, the coil circuit resistance R3, the ground capacitor C of the DC system, and the charge and discharge time t. When the grounding passes through the action time delay of the relay, if the voltage V2 at both ends of the coil is still greater than or equal to the action voltage of the relay, the relay operates.

Under the following conditions:

(1) Relay coil circuit resistance R3=10;12.1 kΩ.

(2) Positive and negative electrode to ground capacitor of DC system C=10; 20; 30 uF.

(3) Relay operation time: 5; 10; 15 mS.

(4) Relay action voltage: 60% * V

(5) Balanced bridge resistance R=50; 100 kΩ.

The relay coil loop is grounded and can move, and the corresponding positive electrode insulation resistance value can be calculated using the formula shown in Table 2. To ensure that the relay coil is not faulty, the positive electrode insulation resistance must be greater than the corresponding resistance value in the table. By comparing the size of the insulation resistance and the corresponding resistance value, the insulation fault of the secondary loop can be quickly judged:

Table 2: Minimum positive electrode insulation resistance value (kΩ)

Coil inner block R3		10k						12.1k	
Earth capacity C		10uf		20uf		30uf		30uf	
Actuation time	Bridge resistance R	50kΩ	100kΩ	50kΩ	100kΩ	50kΩ	100kΩ	50kΩ	100kΩ
5ms	Positive electrode insulation resistance R+	76.0	147.7	88.13	170.8	90.8	179.7	91.3	180.5
10ms		60.2	113.6	76.1	147.7	82.9	162.6	83.9	163.9
15ms		49.1	89.9	67.4	129.0	76.1	147.8	77.4	149.6

6. Conclusion and suggestion

The environment of the secondary circuit on site is varied. In the daily operation and maintenance process, the insulation of the secondary circuit should be tested to find the abnormal insulation phenomenon of the circuit in advance and avoid accidents. The daily detection method proposed in this paper can find the insulation abnormal phenomenon of the loop in advance. On-line insulation resistance detection method of DC system using asymmetric bridge. The grounding fault of the feed branch is determined based on the detection of the ground DC leakage current to judge the insulation fault effectively.

References

[1] Zhang Zhenxing. Analysis of 220V DC system [J]. Integrated circuit applications, 2018, 35 (12): 97-98.
[2] Shi Jiyin, Zou Huanxiong, Shi Sheng, et al. CT secondary loop crossing station can restore two-point grounding protection error event analysis [J]. Electrical Applications, 2017, 36 (22): 36-39.
[3] Zhao Qun. An event analysis caused by two-point grounding of a secondary circuit [J]. Power System Equipment, 2020 (8): 124-125
[4] Liao Hongtao. Analysis of the faults outside the main transformer differential protection zone caused by the two-point grounding of the current secondary circuit [J]. Comprehensive Smart Energy, 2015, 37 (1): 55-57.
[5] Wang Yan. Analysis of damp failure of secondary cable insulation of electrical equipment [J]. Value Engineering, 2019, 38 (30): 199-201.