Article

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Analysis of Abnormal Secondary Voltage of 500 KV HGIS Line

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Abstract: A 500kV HGIS line experienced an abnormal voltage data alarm for the 3U0 voltage. Through on-site sampling verification, loop temperature measurement, and theoretical analysis, it was determined that a grounding fault existed in the secondary internal circuit of the line voltage transformer (PT), causing abnormal secondary voltage sampling outputs from two sets of line protection systems. This article provides a detailed account of the abnormal event, on-site inspection findings, fault cause analysis, and the results of the return-to-factory inspection, along with proposed corrective measures. The aim is to provide a reference for the investigation and prevention of similar issues.

Keywords: HGIS; PT; voltage circuit; sampling anomaly

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1. Introduction

As a critical primary device within power systems, the voltage transformer (PT) plays a fundamental role in ensuring the accuracy and reliability of relay protection and measurement instruments. Any abnormalities occurring in the secondary voltage output of the PT can result in false trips or failures of protective devices, which in turn can severely compromise the safe and stable operation of the entire power grid. This article presents a comprehensive analysis of a fault incident involving a 500 kV transmission line, where the secondary voltage of the PT exhibited abnormal behavior. The analysis systematically details the fault symptoms observed, the thorough on-site inspection procedures conducted, the root cause determined through diagnostic efforts, and the findings from the return-to-factory testing of the faulty equipment. Based on these investigations, the article further proposes targeted corrective measures aimed at preventing similar incidents in the future and enhancing the overall reliability of power system operations.

2. Overview of Anomalies

2.1. Ground Fault in Voltage Transformer

The monitoring system at a 500kV substation detected an abnormality in the open-circuit voltage (3U0) of a specific line. The system indicated that the primary voltage of phase B was 4kV lower than that of phases A and C. On-site inspection revealed an anomaly in the secondary voltage sampling of the second set of line protection for the 500kV line. The secondary voltage inside the junction box was 57V (other secondary voltages were 59 V), and infrared temperature measurement showed signs of overheating in the voltage circuit wiring. After requesting the dispatch to switch the corresponding protection to signal mode, the secondary load was disconnected. Measuring the ground voltage of the secondary winding revealed an abnormality, leading to the preliminary conclusion that there was a grounding fault inside the voltage transformer [1].

2.2. Equipment Information

The 500 kV part of the equipment in the 500 kV substation adopts HGIS equipment and two-thirds wiring mode. The specific equipment information is as follows:

1) 500 kV combined electrical appliances: HGIS combined electrical appliances (including voltage transformers), manufacturer: New Northeast Electric (Shenyang) High Voltage Switch Co., LTD., model: ZHW-550.
2) Voltage transformer: manufacturer: Liaoning Xinming Transformer Co., LTD. Shenyang branch, model: JDQXH-500.

3. Abnormal Inspection Conditions

Following the occurrence of the anomaly, the operation and maintenance personnel promptly conducted a comprehensive investigation to diagnose the issue. This involved reviewing the remote measurement data obtained from the monitoring background systems and the measuring and controlling devices, as well as analyzing the sampled data collected from the protection devices [2]. Additionally, they performed direct measurements of the secondary voltage of the transformer to verify its electrical condition. To further assess the physical state of the equipment, infrared temperature measurements were carried out to identify any abnormal heat signatures, alongside insulation resistance testing to evaluate the integrity of the transformer's insulation. These combined diagnostic measures provided a thorough assessment of both the electrical and thermal aspects of the system to pinpoint the cause of the anomaly [3].

3.1. Remote Sensing Data

The background telemetry data are shown in Table 1:

Table 1. Monitoring Backend Telemetry Data.

Ranging measurements	No.3 main transformer 500kV (Same serial device)	A line
Uab: kV	511.21	510.83
Ubc: kV	511.31	505.45
Uca: kV	513.18	513.35
3U0: V	0	0

The remote monitoring background shows that the voltage of phase B is lower than that of phase A and phase C.

3.2. Sampling Data of Protection Device

The sampling data collected from the protection device provide important insights into the electrical condition of the protected line segment. For the first set of line protection, the three-phase voltage measurements indicate that phase A registered voltages of 59.44 V, 58.45 V, and 59.39 V at three distinct sampling points, demonstrating relatively stable voltage levels. In contrast, phase C exhibited voltages of 59.74 V, 53.68 V, and 59.63 V, with a notably lower reading of 53.68 V at the second sampling point. This deviation suggests a potential anomaly or transient disturbance affecting phase C. These detailed voltage measurements are critical for accurately assessing the operational status of the system and play a vital role in the timely detection and diagnosis of faults or irregularities within the line protection zone [4].

3.3. Secondary Voltage Measurement of Pressure Variation

The secondary (metering) of the potential transformer shows A phase at 59.35V, B phase at 58.30V, and C phase at 59.24V; the secondary (first set of protection and measurement) shows A phase at 59.34V, B phase at 58.30V, and C phase at 59.23V; the secondary (second set of protection) shows A phase at 59.32V, B phase at 53.48V, and C phase at 59.23V; the open delta voltage is 2.535V. The secondary connection box for the potential transformer measures: the first secondary at 58.27V, the second secondary at 58.26V, the third secondary at 57.57V, and the open delta at 101.8V. The actual voltage measurement data are shown in Figure 1 and Figure 2.

Figure 1. Phase B Voltage of PT Tertiary Winding.

Figure 2. Phase B Voltage of PT Quaternary Winding.

3.4. Infrared Temperature Measurement

Infrared temperature measurements were conducted on the voltage circuit components of both the transformer junction box and the intelligent component cabinet to assess thermal conditions. The results revealed that the temperature of the secondary line within the transformer junction box reached 46.9℃, while the temperature measured at the secondary terminal strip was even higher, registering at 52.4℃. Considering that the ambient temperature at the site was only 15℃, these elevated temperatures were identified as abnormal and indicative of potential thermal stress or electrical faults within the system. The infrared temperature measurement results obtained during the site inspection are illustrated in Figure 3 and Figure 4, providing visual confirmation of the hotspots detected.

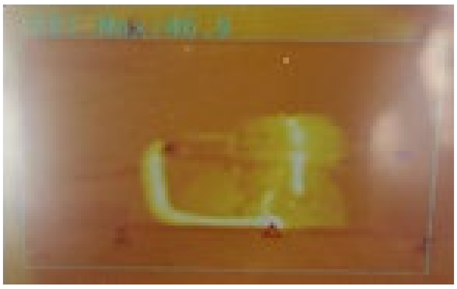

Figure 3. Infrared Temperature Monitoring of PT Terminal Box Secondary Circuits.

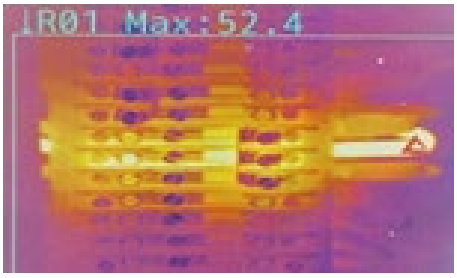

Figure 4. Temperature Monitoring of PT Terminal Blocks.

3.5. Protect the Inspection Situation after Shutdown

After requesting the dispatch to modify the corresponding protection signal, further inspection revealed that the secondary current of the heating circuit was approximately 44.5A. After disconnecting the third secondary load from the B phase transformer terminal box, the third secondary voltage 59.24V inside the terminal box was re-measured, with the 3a terminal to ground voltage being 0V and the 3n terminal to ground voltage being 59.24V. After disconnecting the internal wiring on the terminal block, the voltage remained unchanged upon re-measurement [5]. Similarly, after disconnecting the 3a terminal from the terminal post, the voltage also remained unchanged upon re-measurement. After disconnecting the third secondary load from the A phase transformer (normal phase) terminal box, the 3a terminal to ground voltage was 22V, and the 3n terminal to ground voltage was 32.5V. The actual measured data for the corresponding voltages are shown in Figure 5, Figure 6, Figure 7, and Figure 8.

Figure 5. Phase B to Ground Voltage.

Figure 6. Neutral-To-Ground Voltage on Phase B Circuit.

Figure 7. Phase A to Ground Voltage.

Figure 8. Neutral-To-Ground Voltage on Phase A Circuit.

The insulation test of the secondary cable from phase B junction box to intelligent component cabinet and terminal strip in junction box is good.

4. Cause Analysis of Failure

According to the abnormal phenomenon and on-site inspection results, the preliminary analysis concluded that the fault was caused by a ground short circuit in the internal phase line of the phase voltage transformer of phase B.

The general equivalent circuit diagram of the PT secondary voltage circuit. Under normal conditions, the secondary current of the potential transformer is minimal, and the voltage drop across the internal resistance is also minimal, keeping the external measured voltage within the normal range. However, in this abnormal situation, the measured B phase voltage is approximately 53.48V, significantly lower than the normal value. Additionally, the N phase line of the potential transformer is overheating, with a measured current of about 44.5A, far exceeding the current under normal load conditions. This indicates an abnormal grounding fault in the secondary circuit of the potential transformer, where multiple grounding points have formed a short-circuit current. Further inspection revealed that the cable insulation from the potential transformer junction box to the intelligent component cabinet is good, ruling out the possibility of grounding issues in the external circuit.

The equivalent circuit diagram of PT secondary voltage circuit disconnection from external wiring. After the external wiring of the transformer junction box is disconnected, the measured B phase line-to-ground voltage is close to 0V, indicating that the grounding point is located in the transformer junction box and the B phase line is grounded.

Further hypothesis verification: At the indicated location, two grounding points (one of which is the normal grounding point for the secondary voltage circuit) cause a ground short circuit. Due to the low resistance, a large current is generated, leading to abnormal heating in the circuit, consistent with the infrared temperature measurement. As the current increases, the voltage drop across the internal resistance of the potential transformer also increases, causing the voltage at the red-marked position in the diagram to decrease, directly resulting in a lower B-phase voltage sampling.

The above analysis and inference process can explain the reasons for the secondary output voltage deviation of the transformer and the abnormal circuit heating, but whether it is the real reason for the abnormality remains to be further verified after the transformer is returned to the factory for disassembly.

5. Return to Factory for Disassembly Verification

To further ascertain the root cause of the fault, a power outage plan was formally submitted and approved to facilitate the removal of the abnormal pressure transformer from the system. Subsequently, the faulty pressure transformer was carefully extracted and sent back to the manufacturing facility for comprehensive inspection and detailed analysis. This step was essential to enable a thorough investigation under controlled conditions, allowing the identification of potential manufacturing defects or operational issues that could have contributed to the malfunction.

5.1. Return Factory Test

1) DC resistance test: The test results show that the DC resistance value of each secondary winding is slightly lower than the factory value, but the difference is not large.
2) Insulation resistance test: The insulation resistance between windings 1a-1n,2a-2n, da-dn, and to the enclosure is all greater than 2500MΩ. However, the insulation resistance between windings 3a-3n and each other is 2500MΩ, but the insulation resistance between windings 3a-3n and the enclosure is 0 MΩ, indicating a ground short circuit in winding 3a-3n. Detailed test data after returning to the factory are shown in Table 2.

Table 2. DC Resistance of Secondary Winding of Voltage Transformer.

Return factory DC resistance value (75℃)(Ω)	Rated DC resistance (75℃)(Ω)
1a-1n: 0.0225	1a-1n: 0.0251
2a-2n: 0.0227	2a-2n: 0.0259
3a-3n: 0.0235	3a-3n: 0.0274
da-dn: 0.0693	da-dn: 0.0723

5.2. Disassembly Inspection

After disassembling the transformer terminal panel, a thorough inspection revealed no abnormalities in the wiring connections. However, testing the ground resistance between the 3a and 3n terminals indicated a value of 0 MΩ, confirming the presence of a short circuit. Upon removal of the transformer casing, the insulation resistance of the secondary winding was measured, which verified that the 3a-3n winding was indeed grounded to the casing. During further examination, noticeable burn marks were found on the surface of the glass enamel insulation tube at the end of lead 3a, specifically on one of the two parallel windings within the 3a-3n pair. Subsequent disassembly and closer inspection revealed that the protective paint coating on the flat copper wire at this critical location had been damaged, likely contributing to the insulation failure and resulting short circuit (Figure 9).

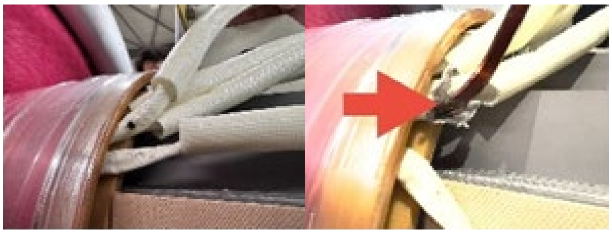

Figure 9. Damage Identified on Internal Secondary Wiring during PT Disassembly Inspection.

5.3. Cause Analysis after Disassembly

After careful disassembly and thorough analysis, it was determined that the fault originated from a lapse in the assembly process, specifically the failure to individually inspect the condition of the flat copper wires during the assembly of the secondary coil of the voltage transformer. This oversight resulted in the flat copper wire located at the end of the 3a winding being excessively pressed against the right-angle section of the core clamp. Notably, despite this issue, all factory inspections — including winding insulation resistance measurements and the 3 kV, 1-minute power frequency withstand voltage tests of the secondary winding — were within acceptable standards. However, over an extended period of operation, the inherent vibrations of the transformer caused continuous friction between the tightly pressed flat copper wire and the core clamp. This persistent mechanical abrasion progressively damaged the insulation layer surrounding the conductor, eventually leading to a ground short circuit fault. This case highlights the critical importance of meticulous assembly inspection procedures to prevent hidden mechanical stresses that can cause insulation failure over time.

6. Rectification Measures

In response to the abnormal secondary voltage event observed in this potential transformer (PT), a series of rectification measures have been proposed to address the underlying causes and prevent future occurrences. First, a thorough review of the production process will be conducted, with particular emphasis on enhancing the training programs for winding personnel to improve their technical proficiency and workmanship. Quality control checkpoints will be added throughout the assembly process to ensure rigorous inspection at critical stages, especially to verify that the secondary leads are properly centered after assembly, which is crucial for maintaining insulation integrity. Second, during scheduled power outage maintenance, it is recommended to use a 2500 V meg-ohmmeter to perform insulation resistance tests on the secondary windings of the operating voltage transformers. The measured insulation resistance between windings as well as between windings and ground should consistently exceed 1000 MΩ, thereby confirming the adequacy of insulation and ensuring the safe and reliable operation of the equipment. These corrective actions collectively aim to enhance the manufacturing quality and operational safety of the PT units.

7. Conclusion

Through a detailed analysis of the secondary voltage abnormality event related to the line voltage, it was confirmed that the root cause of the fault stemmed from long-term insulation degradation. This degradation was primarily attributed to deficiencies in the internal assembly process of the potential transformer (PT), which compromised the insulation integrity over time. To effectively prevent the recurrence of such faults and to ensure the continued safe and stable operation of the power system, it is essential to strengthen production process controls. This includes implementing stricter quality management during assembly, enhancing the technical skills and training of assembly personnel, and conducting regular, comprehensive insulation testing. By adopting these measures, the reliability of the equipment can be significantly improved, thereby reducing the risk of insulation-related failures and enhancing overall system stability.

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