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230 kV GIS Installation, Pre-Commissioning, and Energization Best Practices

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ABSTRACT

This paper presents a critical analysis of best practices for the installation and commissioning of 230 kV Gas Insulated Switchgear (GIS), aiming to enhance reliability and operational efficiency within high-voltage power systems. Specifically, it addresses key research questions regarding procedural elements and technical considerations essential to successful GIS implementation. This study explores site-specific preparation, precision equipment handling, SF6 gas management protocols, comprehensive pre-commissioning testing regimes, and controlled energization strategies. By demonstrating the interdependence of these factors and their impact on long-term performance, the paper reveals key findings that highlight the effectiveness of adhering to manufacturer specifications, relevant international standards, and established industry best practices. These guidelines mitigate risks, optimize operational efficiency, and ensure the longevity of these critical assets. Furthermore, this analysis contributes to a deeper understanding of the intricacies involved in GIS installation and commissioning, promoting a systematic approach to achieving enhanced grid reliability and performance. Ultimately, this paper provides a comprehensive framework for stakeholders involved in GIS projects, encouraging the adoption of these best practices to ensure the successful implementation and operation of 230 kV in modern power systems.

1. INTRODUCTION

The increasing demand for reliable and efficient power transmission has driven significant advancements in substation technology. Gas-Insulated-Switchgear (GIS) has emerged as a crucial component of modern power infrastructure. Compared to traditional air-insulated Switchgear (AIS), GIS offers a multitude of advantages, including a compact footprint, enhanced safety, and reduced maintenance requirements. Their enclosed design minimizes the risk of electric shock and arcing accidents, while their high reliability and minimal maintenance needs make them particularly well-suited for densely populated areas and industrial zones where space is limited. However, the successful deployment of GIS hinges on meticulous execution throughout the entire project lifecycle, from initial installation to final energization. This paper presents a comprehensive guide to best practices for the installation, pre-commissioning, and energization of 230 kV GIS, with a focus on ensuring optimal performance, safety, and sustainability.

The paper addresses critical aspects of the process, starting with site preparation and encompassing detailed considerations for environmental factors and foundation requirements. Stringent equipment handling protocols are outlined to mitigate potential damage during transportation and installation, followed by comprehensive guidance on assembly and connection procedures. The paper also provides comprehensive recommendations for SF6 gas handling protocols, a critical insulating medium in GIS, including safe evacuation and filling procedures, effective leak detection methodologies, and adherence to permissible limits for gas impurities to ensure the integrity and durability of the GIS. Pre-commissioning procedures, including electrical tests such as insulation resistance tests, high-voltage tests, and partial discharge measurements are also presented to ensure optimal insulation performance. Finally, energization best practices are outlined, advocating for a controlled and phased approach with continuous monitoring of system parameters to ensure a safe and stable transition to operational status. By diligently adhering to these guidelines, utilities can ensure the safe and reliable operation of 230 kV GIS, ultimately contributing to a robust and efficient power grid capable of meeting the growing demands of modern society.

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2. INSTALLATION BEST PRACTICES

The installation phase is the foundation upon which the GIS long-term performance and reliability are built. Therefore, significant attention during this stage is crucial to prevent potential issues that could arise during the pre-commissioning or operation. This section provides a comprehensive overview of site preparation, equipment handling, assembly, and gas handling procedures.

2.1 Site Preparation

Prior Gas-Insulated-Switchgear (GIS) equipment is mobilized to the substation, the site must be prepared to ensure smooth and successful installation. This preparation encompasses several key aspects. Firstly, the foundation must be stable, leveled, and capable of supporting the substantial weight of the GIS modules. Any settling or movement of the foundation can lead to misalignment and stress on the GIS components, potentially causing damage and compromising the integrity of the system. The foundation is designed and constructed according to relevant building codes and standards. Concrete foundations are commonly used for GIS installations, and their design should account for factors such as compressive strength, reinforcement, and grounding requirements. Proper curing of concrete is essential to achieve the required strength and prevent cracking, which could compromise the stability of the foundation. In addition to structural integrity, the foundation should also be designed to facilitate proper drainage and prevent water accumulation around GIS equipment.

GIS is highly sensitive to environmental contaminants such as dust, moisture, and other particulates. Consequently, the site must be adequately prepared to minimize the ingress of these contaminants both during and after installation. The GIS building should be completed and HVAC systems functional prior GIS installation. In case the HVAC system

readiness is not achieved, temporary enclosures and ventilation should be provided around the installation area. The temporary enclosures will help create a controlled environment and can be built utilizing materials such as insulated panels or heavy-duty tarpaulins to effectively seal off the area from external contaminants while providing adequate ventilation to prevent heat and humidity buildup. Implementing dust control measures, which may include regular cleaning and the use of protective mats, air filtration systems, and humidity control mechanisms like dehumidifiers, is critical to maintain acceptable conditions, especially in regions with high humidity or during heavy rainfall.

Moreover, facilitating adequate access for equipment delivery, unloading, and positioning is essential for successful installation. Careful planning for crane access and lifting areas should consider the weight and dimensions of the equipment to ensure that the crane has sufficient capacity and reach for safely lifting and positioning the modules. It is also important to comprehend and execute the equipment lifting manual provided by the GIS vendor during the lifting process. Moreover, proper lighting and ventilation should be established to facilitate safe working conditions and prevent the accumulation of hazardous gases. A detailed site plan should be created to outline the location of each GIS module, cable trenches, and any auxiliary equipment.

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2.2 Equipment Handling

Proper handling of GIS equipment during transportation, storage, and positioning is crucial to prevent damage and ensure its integrity. Recognizing that GIS modules are sensitive to shocks and vibrations, it is imperative to utilize appropriate transportation methods and secure the equipment adequately to avoid any damage that could compromise its functionality. Vibration/shock sensors are mounted to each module during transportation. The module ensures

that equipment is not subjected to harmful mechanical stresses and provides verifiable data for quality assurance. The GIS equipment should be fastened securely to the vehicle using appropriate restraints to prevent movement and impact during transportation. Furthermore, careful planning of the transportation route to the site is necessary to avoid rough roads or other conditions that could subject the equipment to excessive vibrations or shocks.

Accurate positioning and alignment of the GIS modules are critical for their proper functioning and to avoid mechanical stress that could lead to premature failure. To achieve this, precision measuring tools and techniques, such as laser alignment systems and theodolites, should be employed to ensure accurate alignment in accordance with the manufacturer's specifications. Any deviations from the specified tolerances need to be rectified before proceeding with the installation. The modules should be leveled and aligned in all three dimensions horizontal, vertical, and axial to ensure a proper fit and minimize stress on the connections.

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2.3 Assembly and Connections

The assembly and connection of GIS components require accuracy and precision to ensure electrical and mechanical integrity. Busbar connections are critical for the electrical integrity of the GIS, which is the most time-consuming activity during the installation. Proper alignment and tightness of the connections are essential to minimize contact resistance and prevent overheating, which could lead to equipment failure and safety hazards. Visual inspections of the connections should be conducted to verify proper contact, ensuring the absence of any gaps or deformities while confirming that contact surfaces are clean and free from contaminants prior to making connections. The busbar should be assembled in incremental segments and perform quality checks after each completed segment.

Disconnectors and earthing switches must be installed and connected correctly to ensure the proper isolation and grounding of the GIS compartments. This is vital for the safety of personnel during maintenance and to prevent accidental energization of isolated sections. The mechanical operation of these devices should be verified to ensure smooth and reliable operation. Proper contact alignment is essential to minimize contact resistance and prevent arcing or overheating during operation. The operating mechanisms of disconnectors and earthing switches should be inspected and tested to ensure they function correctly and provide reliable isolation and grounding.

2.4 Gas Handling

Sulfur Hexafluoride (SF6) gas is utilized as the primary insulating medium in GIS due to its excellent dielectric properties. However, SF6 is a potent greenhouse gas, and its handling requires strict adherence to safety and environmental regulations. Before filling with SF6 gas, Gas Quality must be verified and typically %99.9 pure SF6 gas is acceptable. The GIS compartments must then be evacuated to remove air and moisture, which can compromise the insulation properties of SF6. The industry standard dictates that the compartment must be evacuated to a level less than 1mbar and the holding time will vary depending on the size of the compartment but standard time is usually 24hrs for the initial phase. A vacuum pump with appropriate capacity should be used, and the vacuum level should meet the manufacturer's specifications. The evacuation process should be carefully monitored to ensure that the required vacuum level is achieved and maintained for the specified duration. This process removes any residual air and moisture that could compromise the dielectric strength of the SF6 gas. The vacuum pump should be equipped with appropriate filters and traps to prevent oil or other contaminants from entering the GIS compartments. Filling the GIS compartments with SF6 gas should be done slowly and carefully to avoid trapping air pockets, which can lead to partial discharge and insulation failure. The gas pressure and purity should be monitored during gas filling to ensure they are within acceptable limits.

Gas purity analyzers are used to measure the concentration of impurities such as moisture, air, and other decomposition products. Maintaining high gas purity is essential to prevent insulation breakdown and ensure the long-term reliability of GIS. The filling process should be performed using calibrated equipment and following the manufacturer's recommended procedures.

Item	Voltage Level	Typical SF6 Pressure (Absolute)
1	72.5kV	3.5 – 4.5 bar
2	145kV	4.5 – 5.5 bar
3	245kV	5.5 – 6.5 bar
4	420kV and Above	6.5 – 7 bar

Table 1. SF6 Pressure

2.5 Visual and Mechanical Inspection

A thorough visual and mechanical inspection of the GIS installation is a crucial step before commencing with pre-commissioning process. This inspection serves to verify that all components have been installed correctly according to the design drawings and specifications. The inspection should include all aspects of the installation, paying close attention to busbar connections, ensuring gaskets and sealing joints are properly aligned, tightened to the correct torque using calibrated torque wrenches, and free from any signs of corrosion or damage. The earthing switches and disconnector switches are already pre-assembled from factory and so there is no possibility to inspect the contacts. However, integrity is confirmed through contact resistance measurement in reference to FAT test values. In addition to the contact resistance measurements, the components must be checked for proper alignment, lubrication, and correct installation, which should be checked and compared against the manufacturer's specifications.

3.1 SF6 Gas Test

Prior Gas-Insulated-Switchgear (GIS) is energized and operated, a comprehensive assessment of SF6 gas is crucial for verifying the integrity of the insulation system and ensuring the long-term reliability and safety of the GIS installation. The assessment involves a series of meticulous tests, each designed to evaluate specific characteristics and properties of the SF6 gas, guaranteeing its ability to provide reliable insulation within the GIS.

One of the crucial tests conducted is a gas leakage test, which aims to detect any leaks within the GIS compartments, flanges, and connections. To achieve this, all gas compartments joints are wrapped using plastic cling wrap and after 24 hours, a highly sensitive gas detector is employed to identify any leak in the GIS system. Furthermore, leak detection methods using soap bubbles can be included for further investigation to visually identify leaks. Any detected leaks should be repaired immediately using appropriate sealing methods and materials, and the repaired areas should be re-tested to ensure their integrity. It is imperative to address any detected leaks promptly and conduct further testing after repairs to prevent SF6 gas from escaping into the atmosphere. This is not only for maintaining the integrity of the insulation system but also for minimizing environmental impact, as SF6 is recognized as a potent greenhouse gas with significant global warming potential.

Following the gas leakage test, gas quality is performed using a gas analyzer to determine the SF6 gas quality parameters such as gas concentration, dew point, moisture content, temperature, gas pressure and gas density. These can be compared against the acceptance criteria provided by the GIS equipment manufacturer. Excessive moisture can severely compromise the gas's dielectric strength, potentially leading to insulation breakdown and costly equipment failures. Therefore, it is vital to maintain the dew point below the manufacturer's specified limit to ensure optimal insulation performance and to prevent hazards associated with moisture contamination. Another test in this series is the density test, which measures the density of the SF6 gas, a critical parameter directly related to its pressure and temperature. Maintaining the correct gas density is essential to ensure that the gas performs effectively as an insulator within GIS. The gas density should consistently fall within the manufacturer's specified range, as deviations can adversely affect the gas’s ability to withstand high voltages and effectively quench arcs during switching operations.

Figure 1: HD Power SF6 Gas analyzer

3.2 Electrical Tests

Electrical testing is a critical stage in the GIS pre-commissioning process, designed to thoroughly assess the integrity and proper functioning of all electrical components within the system. This phase involves a series of tests targeting specific aspects of the GIS electrical performance to ensure its compliance with relevant standards and the system readiness for safe and reliable operation.

3.2.1 Contact Resistance Test

Contact resistance testing is a critical procedure for evaluating the integrity of electrical contacts within crucial Gas Insulated Switchgear (GIS) components, including circuit breakers, disconnectors, and earthing switches. This test method assesses the quality of the electrical connection between conducting surfaces within these components. High contact resistance can have several detrimental consequences.

Firstly, excessive heat generation can occur due to the increased resistive losses. This localized heat can lead to elevated temperatures within the equipment, potentially causing damage to components and accelerating their aging process. Secondly, high contact resistance can facilitate arcing phenomena. Arcing can result in equipment damage, disrupt power supply, and pose significant safety hazards to personnel.

Furthermore, increased energy losses occur as a direct result of higher resistive losses within the contact interface. These increased losses contribute to reduced system efficiency and a corresponding increase in energy consumption. Additionally, high contact resistance can accelerate the degradation of the contact surfaces. This accelerated wear and tear leads to a reduction in the equipment's lifespan and necessitates more frequent maintenance interventions. Finally, high contact resistance can contribute to system instability and potentially trigger cascading failures within the electrical grid.

The testing procedure typically involves injecting a known DC current, typically 100 Amperes for 230 kV GIS system, into contact. The voltage drop across the contact is then measured. By applying Ohm's Law, which states that Resistance equals Voltage divided by Current, the contact resistance is calculated. The measured resistance values are subsequently compared against the manufacturer's specified limits and acceptance criteria. If any measured resistance value exceeds the acceptable limits, further investigation is warranted. Potential corrective actions, such as thorough contact cleaning or surface refurbishment techniques, may be necessary to restore the contact integrity and ensure the reliable and safe operation of the GIS equipment.

3.2.2 Earth Switch Insulation Test

Within a 230kV Gas-Insulated Switchgear (GIS) system, the earth switch plays a critical role in safely grounding the energized circuit. Ensuring the proper functioning of the earth switch is significant for the safety of personnel and the reliable operation of the entire substation. A crucial step in the commissioning process involves conducting a high-voltage insulation test specifically designed for the earth switch. This test rigorously evaluates the ability of the earth switch mechanism and its associated insulation to withstand a specified high voltage without experiencing any form of electrical breakdown, such as arcing or flashovers.

The test involves an AC high-voltage, typically 10kV, applied to the earth switch contacts. This voltage is increased at a rate of 1kV per second and maintained at 10kV for 1 minute, or as outlined in the manufacturer's instructions or relevant international standards. Throughout the test, meticulous monitoring for any signs of electrical breakdown, including arcing, sparking, or other abnormal behavior, is essential.

Standard acceptance criteria for earth switch insulation test is achieved if the entire test duration the leakage current is less than 1mA without electrical breakdown. However, if any arcing, sparking, or other abnormal behavior is detected, the test is considered failed. In such instances, a thorough investigation is necessary to identify the root cause of the failure. This may involve inspecting and cleaning contact surfaces, tightening loose connections, or even replacing faulty components. Addressing these issues is crucial before proceeding with further commissioning activities and ensuring the safe and reliable operation of the GIS system.

3.2.3 Current Transformer Tests

Current transformers (CTs) are essential components in a GIS, aimed to precisely measure the current flow. Several tests are conducted to assess the reliability to guarantee their dependability and accuracy. A ratio test is performed to confirm that CT's secondary current accurately reflects the primary current according to its specified ratio. This ensures accurate measurement and proper operation of protection systems. By injecting a known current in the primary and measuring the corresponding secondary current, the accuracy of the CT's transformation ratio is verified. Any deviations from the expected designed ratio could point to flaws in the CT's function or potential damage. Furthermore, a polarity test is carried out to validate the correct polarity of the CT, which is crucial for accurate measurement and proper relay operation. Since relays depend on the correct phase relationship between primary and secondary currents, ensuring proper polarity is essential. This test involves applying a momentary DC voltage to the primary winding and observing the direction of the induced current in the secondary winding. Incorrect polarity can result in inaccurate measurements and malfunctioning protection systems. Winding resistance tests utilize a low-resistance ohmmeter to measure the resistance of the CT's windings. This helps identify potential errors such as open or short circuits that could compromise the transformer's accuracy and performance. High resistance values indicate poor connections or damage to the windings, while low values might indicate a short circuit within the windings. An insulation resistance test is also conducted to evaluate the integrity of the insulation between the primary and secondary windings, and the transformer core. This ensures the absence of any leakage current between these components, which could impact measurement accuracy and potentially create safety hazards. Burden test must also be performed to verify if the CT can supply the required current to the connected burden such as relays and also operate within the correct class without errors. This test is performed by connecting a known load (burden) to the CT secondary and injecting primary current and measure the secondary current to determine the burden and class.

3.2.4 Voltage Transformer Tests

Voltage transformers (VTs) are equally important in a GIS, providing accurate voltage measurements. Similar to CTs, VTs undergo a series of tests to ensure their reliability and accuracy. Ratio test is performed to verify that the VT accurately steps down the voltage to the secondary side according to its specified ratio, which is crucial for accurate measurement and proper protection system operation. This test involves applying a known primary voltage and measuring the secondary voltage to confirm the accuracy of the VT's transformation ratio. Any deviations from the expected ratio can indicate errors in the VT's function or potential damage. Polarity tests confirm the correct polarity of the VT, essential for accurate measurement and proper relay operation. This test involves applying a DC voltage to the primary winding and observing the polarity of the induced voltage in the secondary winding. Incorrect polarity can lead to erroneous measurements and malfunctioning protection systems. Winding resistance tests measure the resistance of the VT's windings using a low-resistance ohmmeter to identify any potential issues such as open circuits or short circuits, which could affect the accuracy of measurements. High resistance values indicate poor connections or damage to the windings, while low resistance values indicate a short circuit within the windings. Lastly, insulation resistance tests assess the insulation integrity between the VT's windings and core, ensuring no leakage currents that could compromise measurement accuracy or pose safety hazards. Burden test must also be performed to verify if the VT can supply the required voltage to the connected burden (Load) such as protection relays and also operate within the correct class without errors. This test is performed by connecting a known load (burden) to the VT secondary and injecting primary voltage and measuring the secondary voltage to determine the burden.

3.2.5 Circuit Breaker Timing Test

The timing test is a critical assessment of a circuit breaker's ability to respond quickly and accurately to fault conditions within an electrical system. This test measures the time required for the circuit breaker to open or close its contacts, ensuring that it operates within the specified time limits. Accurate timing is crucial for several reasons. Firstly, it minimizes the duration of fault currents, thereby limiting the potential for damage to equipment and infrastructure within the electrical system. Secondly, it ensures the safety of personnel by rapidly isolating faulted sections of the system.

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Specialized timing equipment, such as high-speed event recorders or dedicated timing analyzers, is employed to precisely measure key parameters during the test. These parameters include the opening time, which is defined as the time interval between the initiation of the trip signal and the complete separation of the contacts. The closing time is also measured, which is the time interval between the close command and the full closure of the contacts. Additionally, contact bounce, the duration of any unwanted oscillations or bounces of the contacts during the opening or closing operation, is carefully monitored.

Timing tests are typically conducted under simulated fault conditions, such as short circuits or ground faults, to evaluate the circuit breaker's performance under realistic operating scenarios. The measured timing values are then compared against the manufacturer's specifications and relevant industry standards for the specific type of circuit breaker, such as air circuit breakers or SF6 circuit breakers.

Several factors can influence the timing performance of a circuit breaker. Mechanical issues, such as wear and tear on moving parts, inadequate lubrication, or a jammed mechanism, can significantly impede the breaker's operating speed. Furthermore, malfunctions within the control circuit, including problems with the trip unit or the control circuitry itself, can also adversely affect the timing accuracy of the breaker.

Accurate and consistent timing is essential for effective coordination between circuit breakers and other protective devices within the electrical system. This coordination is crucial to ensure selective tripping, where only the faulted section of the system is isolated, while maintaining power supply to other critical areas of the grid. By minimizing service interruptions and mitigating the impact of faults, proper coordination enhances the overall reliability and stability of the electrical system.

3.2.6 High-potential Test

High Potential (Hi-Pot) testing is a critical procedure performed on 230kV Gas Insulated Switchgear (GIS) to evaluate the integrity of the insulation of electrical components and ensure they can withstand high voltage conditions without breakdown. The primary objectives of conducting Hi-Pot testing on 230kV GIS include validating the insulation integrity of critical switchgear components, such as busbars, circuit breakers, surge arresters, and current and voltage transformers. The Hi-Pot test aims to identify any insulation defects or deterioration that may have occurred during manufacturing or installation.

During the Hi-Pot test, a voltage significantly higher than the normal operating voltage is applied for a specified duration, which allows the testing group to verify the condition of the insulation and minimize potential failures during service.

The Hi-pot test kit is connected to the GIS busbar connection point as per system design and since the test kit has limited load capacity, the bus section is divided into circuit segments to ensure appropriate loading of the Hi-pot kit. Under or overloading of the test kit will result in the failure of the kit to establish resonance and hence failure to inject the required voltage into the system. Testing is performed on a one phase, one circuit at a time basis. The test kit is connected using adapter flanges to the test point which will require vacuuming and gas filling to ensure proper electrical isolation. If the GIS has surge arrestors, the busbar links must be removed to isolate the surge arrestors since they cannot sustain the high voltage level required for Hi-pot.

The AC withstand Voltage for GIS system ranges from 700 – 500kV (Line voltage), which is typically 1.5 to 3 times the Peak rated system voltage.
Example for a 230kV system:
The Test voltage on a 230kV system (Line Voltage) is calculated as follows,
Test Voltage = (Um/□3) x(3□/245) =2.5 x404 = 2.5kV
(Where Um is the highest system voltage for 230kV system).
In this case the test voltage is set at 2.5 times the system phase voltage. Usually each Manufacturer will apply some derating factors and in this case the test voltage might be 380kV instead of 404kV.

Since the higher voltage applied during Hi-pot induces abnormal stress conditions that could lead to insulation failure, the procedure requires that ramping up the test voltage from zero to the conditioning voltage level to stabilize the insulation system and prevent sudden surges that could induce stress to the insulation. The standard conditioning voltage is usually set between %80-70 of the test voltage and held for 3 mins. The voltage will then be ramped up to the nominal test voltage and held for 1 min. The duration of the Hi-Pot test is commonly set between 1 to 15 minutes, depending on specific manufacturer requirements and recommendations from relevant industry standards. During this period, the applied voltage should remain stable, and the testing team must monitor the equipment carefully for any discharge. Partial discharge in GIS switch gear is audible to the human ear and can be heard as a loud metal bang, and so it’s fairly easy to detect partial discharge just by listening. During a typical Hi-pot test for a GIS system, it is not possible to monitor leakage current as performed in cable Hi-pot. In GIS systems, the acceptance criteria are that the Hi-pot test will pass if there is no flashover or test equipment trip during the test. Leakage current is only measured while performing Surge arrestor testing.

After the completion of the Hi-pot test, the applied voltage is gradually reduced to zero to safely de-energize the insulation system. If the GIS has surge arrestors, the surge arrestors will need to be connected to the system and tested for leakage current. This is usually accomplished by installing the surge arrestor busbar links. Surge arrestor test voltage at %100-80 of the system voltage will be injected and leakage current (□A) value will be recorded and these values should be in line with the surge arrestor datasheet. Following this, comprehensive measurements are taken to assess the condition of the insulation, focusing on key parameters such as insulation resistance and dielectric strength. Evaluating the insulation at this stage helps ensure it meets the established performance criteria. Results obtained from the Hi-Pot testing are documented and analyzed for deviations from expected values. Any identified discrepancies necessitate further investigation and might indicate issues such as moisture ingress, material degradation, or manufacturing defects. If insulation failures are detected, corrective actions such as resealing, drying of insulation, or replacing damaged components may be required to restore the integrity of the GIS.

Successful completion of the Hi-Pot testing confirms that the insulation of the 230kV GIS can withstand the stresses expected during operation, thus providing confidence in the equipment's reliability and readiness for service. This preventive testing plays a vital role in ensuring the long-term safety and performance of high-voltage electrical systems.

3.2.7 Partial Discharge Test

Partial discharge (PD) testing is an essential diagnostic procedure conducted on 230kV Gas Insulated Switchgear (GIS) to assess the condition of the insulation system. This test is conducted in conjunction with the Hi-pot test and after completing the Hi-pot. The test voltage level will be reduced to the Partial discharge test level and PD measurements are conducted. The test seeks to identify the existence of partial discharges, assess their severity, and determine their potential impact on the longevity and reliability of the GIS equipment. Additionally, PD testing helps ensure that insulation integrity complies with industry standards, thereby enhancing the overall safety and performance of the electrical system.

The partial discharge testing procedure for 230kV GIS involves several key steps essential for ensuring accurate measurement and analysis. The procedure begins with selecting appropriate test equipment, typically utilizing PD measurement systems sensitive to detecting discharges. These systems can include ultrasound detectors, electromagnetic sensors, or specialized PD analyzers that can detect high-frequency signals associated with partial discharges. Prior to testing, all necessary preparations should be made. This involves verification that the installation and assembly has been performed in accordance to the quality specifications which guarantees the GIS is free from contaminants or defects that can lead to partial discharge. The equipment is then typically isolated from the electrical network to allow for accurate measurements without noise interference from other operational devices. Once preparations are complete, the PD testing is initiated by applying a test voltage to the GIS components, often at their rated voltage or at a specified level that simulates operational conditions. This voltage is applied gradually to avoid sudden stress on the insulation. During this phase, the PD measurement system continuously monitors for any discharges that may occur within the insulation system.

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The results from the PD testing are recorded and analyzed. This analysis focuses on several parameters, including the magnitude, frequency, and phase distribution of the partial discharges. Any detected partial discharges are quantified, and data is analyzed to ascertain their impact on insulation integrity. If the partial discharge levels exceed acceptable thresholds as defined by industry standards, further investigation is required.

to electrical disturbances, and assessing the effectiveness of the control and protective systems. Additionally, these tests evaluate the sensitivity of protective relays, which is essential for maintaining system integrity during fault conditions.

The stability testing for 230kV GIS involves several critical steps to ensure accurate evaluations. The test phase begins by applying operational conditions to the GIS, simulating normal operating voltage and current levels. A key aspect of this testing is injecting a current equivalent to approximately %30 of the normal load into the disconnector. During this phase, the GIS is subjected to various electrical tests to evaluate its performance under steady-state and transient conditions. Measurements of key parameters such as voltage, current, and frequency are continuously monitored to collect data on the behavior of the system.

The example below provides an illustration of the stability test being performed for one of the circuits on a 230kv GIS system with a double bus bar single breaker arrangement. This system has a bus couplers and bus ties.

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3.2.8 Stability Test

A stability test is crucial for evaluating the GIS's ability to withstand disturbances, Isolate Faults and maintain stable operation within the larger power system. A stability test on 230kV GIS includes verifying the operational behavior of the switchgear, ensuring that it responds appropriately to electrical disturbances, and assessing the effectiveness of the control and protective systems. Additionally, these tests evaluate the sensitivity of protective relays, which is essential for maintaining system integrity during fault conditions.

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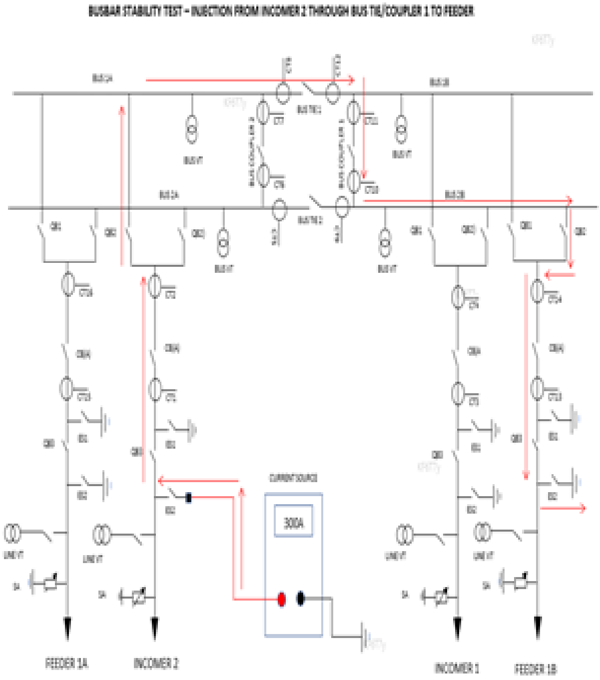

**Figure 2. B
us Stability Test**

Current is injected through the Incomer 2 onto the busbar 1A and the zones under test Bus tie 1, Bus Coupler 1 and Outgoing Feeder 1B are closed to mimic a stable condition (normal current flow). The CT polarity in zone under test is then reversed one at a time to create an unstable condition and the protection relays for the busbar A and B should pick-up differential current. The differential current magnitude and phase angle for normal and abnormal conditions are compared to verify correct application and once differential current is picked up by the relay, the protection relay should generate a trip to isolate the abnormal zone with the reversed CT polarity generating the fault. In case of Busbar fault, all feeders connected the faulty busbar should open and disconnect from the busbar.

Then, the focus shifts to assessing the sensitivity of protective relays. This involves subjecting the system to fault simulations, such as short circuits or overload conditions, to determine the relay's response times and sensitivity levels. Test equipment injects predetermined fault scenarios into the system, allowing for the evaluation of relay settings and their adequacy in detecting potential abnormalities in the system. Key aspects analyzed during this part of the testing include trip times, which measure how quickly relays disconnect the circuit upon detecting a fault, pick-up levels, which denote the minimum current or voltage required to trigger the relay action, and reset times, which indicate the duration needed for the relay to return to its normal state after a fault condition is cleared. Data collected from the sensitivity tests are analyzed to evaluate whether the protective relays operate within the defined parameters and industry standards. Any necessary adjustments to relay settings can be made based on the findings.

3.3 Functional Tests

Functional tests are paramount in ensuring the safe and reliable operation of a 230kV GIS, rigorously validating the performance of critical components and systems before energization. These tests simulate real-world operating scenarios and fault conditions, such as circuit breaker operations under load and fault conditions, disconnector and earthing switch operations, and protection relay tripping and reclosing. By subjecting the GIS to these simulated events, the tests is verified the correct operation of auxiliary circuits, control systems, and protection relays. This includes testing the functionality of control panels, including HMI operations and local/remote control, alarm annunciation and logging, safety interlocks, and data communication between the GIS and other substation equipment. Successful completion of these tests is crucial to ensure the GIS can operate safely, reliably, and efficiently in actual service, minimizing the risk of equipment damage, safety hazards, and system outages.

3.3.1 Interlocking Test

Two interlocking tests are performed in order to stand against operational errors. Interlocking mechanisms stand as the guardians of safe GIS operation, diligently preventing any action that could jeopardize personnel safety or lead to equipment damage. These tests rigorously examine both the physical and electrical facets of this safety-critical function.

One type of interlocking testing is mechanical interlocking, which is known as a physical barrier for enhanced safety. This process involves physically confirming the presence and effectiveness of mechanical constraints that enforce the correct operational sequence. For instance, the test involves simulating different scenarios to open a disconnector switch while the associated circuit breaker is closed, verifying that the mechanical interlocks physically obstruct this action. This hands-on approach provides tangible assurance that human error or mechanical malfunction cannot lead to a hazardous switching scenario. This meticulous verification process may involve checking the proper alignment of interlock linkages, verifying the operation of auxiliary switches that provide feedback to the control system, and confirming the integrity of any mechanical flags or indicators that visually display the interlock status.

The Electrical interlocking test is another type, which is known as intelligent control for seamless Operation. Complementing the physical barriers, electrical interlocking relies on control circuits and logic to govern the switching sequence. The test will simulate various operational scenarios, such as attempting to close a grounding switch while the circuit breaker is closed. The anticipated response is for the control system to immediately trip the circuit breaker and prevent it from being closed until the grounding switch is opened, ensuring a safe and controlled switching sequence. This involves injecting test signals into the control circuits to simulate different switch positions and verifying the corresponding logic outputs, ensuring that the interlocking scheme functions correctly under all conditions.

3.3.2 Control System Functional Tests

The control system functions as the brain of the GIS, protecting and monitoring all aspects of its operation. These tests rigorously evaluate the control system's ability to perform its duties reliably and effectively. The GIS must be controllable both from the local control panel at the substation and from a Remote-control center, allowing for both on-site and remote management. Tests will be conducted with a series of operations from both locations, verifying seamless functionality, prompt response times, and accurate execution of commands. This includes testing the human-machine interface (HMI) at both locations, ensuring a clear display of information, intuitive navigation through menus, and accurate representation of the GIS status.

Protection relays are the sentinels of the GIS, vigilantly monitoring faults and initiating swift isolation of faulty sections. Each relay type, including overcurrent, differential, and earth fault relays, undergoes meticulous testing. The test includes simulating fault conditions, such as a short circuit or ground fault, by injecting controlled currents or voltages into the relay circuits. The objective of the test is to observe the relay's response, verifying that the relay accurately detects the fault, initiates a trip signal to the corresponding circuit breaker within the specified time, and provides clear indications of its actions. This may involve testing different fault magnitudes and types to assess the relay's sensitivity and selectivity.

Modern GIS installations often integrate with Supervisory Control and Data Acquisition (SCADA) systems, enabling remote monitoring, control, and data logging. These tests delve into the communication link between the GIS and the SCADA system, verifying that data is exchanged accurately and promptly. The test objective is to confirm that real-time data from the GIS, such as voltage, current, and gas pressure readings, are transmitted to the SCADA system without errors or delays. They also ensure that control commands issued from the SCADA system are received and executed correctly by the GIS, enabling remote operators to effectively manage and control the substation. GIS is equipped with a comprehensive alarm system to alert operators of any abnormal conditions that may arise. These tests deliberately trigger each alarm condition, such as high temperature within a compartment, low SF6 gas pressure, or the operation of a protection relay. The test then verifies that the alarm is properly annunciated both locally at the substation through audible and visual indicators, and remotely at the control center via SCADA alarms or dedicated communication channels, ensuring that operators are promptly informed of any developing issues.

3.3.3 Auxiliary Systems Tests

Auxiliary systems are indispensable for the overall health and reliable operation of the GIS. These tests ensure these systems are functioning as designed.

Gas Density Monitoring is aimed to ensure the integrity of the insulating medium of SF6 gas, with its exceptional insulating and arc-quenching properties. These tests focus on the gas density monitoring system, verifying that it accurately measures the SF6 gas pressure within the compartments. The system should generate alarms if the pressure drops below predefined thresholds and initiate interlocks to prevent operation if the pressure falls to a critical level, safeguarding the integrity of the GIS. This may involve testing the pressure sensors, alarm relays, and interlock circuits to ensure their proper calibration and response.

GIS compartments are equipped with heaters to prevent condensation, especially in humid environments, and ventilation systems to regulate temperature and prevent overheating. These tests involve activating the heating and ventilation systems and monitoring their performance using temperature sensors and airflow meters. The test will verify that the heaters maintain the compartments above the dew point to prevent moisture buildup and that the ventilation system effectively regulates the temperature within the specified operating range, ensuring optimal conditions for the GIS components.

3.3.4 Circuit Breaker Functional Tests

Circuit breakers are the heart of the GIS, responsible for interrupting fault currents and isolating circuits to protect the power system. These tests confirm their reliable operation under various conditions.

The circuit breaker is subjected to repeated open and close operations, simulating normal switching duties. Tests meticulously analyze the breaker's performance, measuring the speed of operation using high-speed timing devices, ensuring proper contact alignment through visual inspection and contact resistance measurements, and verifying that the breaker operates smoothly without any signs of mechanical distress. This may involve analyzing the breaker's operating waveforms to assess the contact timing and performance. One important monitoring system within a circuit breaker is pole discrepancy, where individual poles of the circuit breaker do not operate simultaneously and one pole is out of sync with the other poles. This indicates breaker failure and so this can be detected during functional or speed test.

Trip circuit functionality is another test focusing on the circuit breaker's ability to respond correctly to trip signals received from protection relays or the control system. The test simulates various fault scenarios, sending different trip signals to the breaker using specialized test equipment. They verify that the breaker trips reliably and consistently, interrupting the current flow within the specified time limits, and providing clear indications of its status through auxiliary contacts and status indicators.

3.3.5 Disconnector and Earthing Switch Tests

Disconnectors and earthing switches are essential components that provide visible isolation points within the GIS, safeguarding maintenance personnel and facilitating safe access to de-energized equipment. The tests conducted on these devices ensure their reliable operation and confirm their coordination with the other components within the GIS.

During the testing phase, both disconnectors and earthing switches undergo repeated open and close operations to evaluate their functionality. These operations are monitored for smoothness of action and reliability in establishing firm electrical contact when closed. Operators verify that mechanical indicators provide accurate visual representations of their operational status and that the devices can effectively isolate sections of the GIS as intended. Furthermore, the functionality of earthing switches is scrutinized, as their role is to connect circuit systems to the ground, ensuring adequate discharge paths during maintenance activities. Testing these devices involves simulating their operation in various conditions, confirming that they respond accurately and without delay controlling signals.

In addition to functional checks, inspections are carried out to ensure that any mechanical linkages within the disconnectors and earthing switches are properly aligned and lubricated, addressing potential wear and tear. Detailed documentation of the test outcomes aids in maintaining compliance with safety regulations and industry standards, ultimately contributing to the safe and efficient operation of the GIS.

4. Energization Best Practices

The energization of a 230 kV GIS marks a critical milestone in the project, as it signifies the transition of the system from a static assembly to a live and operational component of the power grid. The process involves the introduction of high-voltage electricity to the GIS which requires planning, coordination, and adherence to safety protocols to ensure a smooth and successful transition, minimizing stress on the equipment and safeguarding personnel. Energization should be carried out in a controlled manner, with continuous monitoring and verification of system parameters to ensure the system's integrity and stability

4.1 Safety Precautions

Safety is paramount during the energization process, as the high voltages involved pose significant risks to personnel. Therefore, a comprehensive safety protocol should be established and strictly adhered to throughout the entire procedure to mitigate these risks and ensure the well-being of all individuals involved. This protocol encompasses various critical aspects that contribute to the overall safety of the operation.

4.1.1 Lockout/Tagout Procedures

Effective lockout/tagout (LOTO) procedures are fundamental to preventing accidental energization during maintenance and energization activities. Establishing a detailed LOTO protocol involves several important steps. Initially, it is necessary to identify all energy sources connected to the GIS, including circuit breakers, disconnectors, and any auxiliary equipment associated with the system. Subsequently, all energy sources must be physically locked out using robust locking mechanisms to ensure that inadvertent operation is prevented. Each lock should be equipped with a unique key that is accessible only to authorized personnel engaged in the work.

In addition to the locks, safety tags must be affixed to each lockout device, clearly indicating the reason for the lockout, the individual responsible for the lockout, and the date of implementation. Effective communication among team members regarding the lockout status of all equipment is crucial in reducing the risk of accidental energization. Implementing clear procedures lessens misunderstandings and reinforces the importance of safety during this critical phase.

4.1.2 Grounding

Grounding all components of the GIS is critical for protecting personnel from electric shock during the energization process. Before any energization activities commence, it is essential to ensure that all conductive parts of the GIS are properly grounded. This involves establishing a reliable ground grid to which all conductive elements are connected using appropriate grounding equipment.

During the grounding process, specific guidelines should be established, which include defining the types and sizes of grounding conductors used, identifying the designated grounding points, and outlining precise verification methods to ensure that proper grounding is achieved. This grounding provides a safe pathway for fault currents to flow directly into the earth, thereby preventing any dangerous currents from passing through personnel and leading to serious injuries.

4.1.3 Personal Protective Equipment (PPE)

All personnel involved in the energization process must wear appropriate electrical arc rated personal protective equipment (PPE) to provide protection against electrical hazards. The selection of PPE should be based on a thorough risk assessment that factors in the potential hazards related to electrical work at high voltage levels. Essential components of PPE for engaging in energization tasks include insulating gloves rated for the specific voltage encountered, safety glasses that meet impact resistance standards, and arc flash suits designed for the energy levels associated with the equipment being handled.

It is also essential that suitable head protection, such as hard hats, and hearing protection, when applicable, be worn to protect against environmental hazards. Regular inspections and maintenance of PPE are critical to ensuring that these protective measures function effectively. Training personnel on the proper usage of PPE, including its limitations and maintenance requirements, is equally essential to enhancing safety outcomes during energization.

4.1.4 Training and Preparedness

Comprehensive safety training for all personnel involved in the energization process is essential to ensure safety and effectiveness. This training should encompass key topics, including electrical safety principles, identification of the hazards associated with high voltage, specific procedures related to the GIS being energized, and well-defined emergency response protocols in case of any incidents.

The training program must also address safe working practices around high-voltage equipment and detail how to use PPE effectively. It is important that personnel are familiarized with emergency response plans, including actions to take in response to electrical faults, equipment failures, or personal injuries. Regular refresher training sessions should be conducted to reinforce adherence to safety protocols and to keep all team members updated on any changes to procedures or equipment.

4.2 Energization Process

Energization of the GIS needs to proceed methodically and systematically, following a step-by-step approach to minimize stress on the equipment and allow for close monitoring of system parameters. A phased approach is typically employed, where the GIS is energized in stages, starting with individual compartments or sections and gradually extending to the entire system. This allows for close monitoring of each section as it is energized, enabling the identification and resolution of any potential issues before proceeding to the next section. For example, the busbars are energized first, followed by the disconnectors and earthing switches, and finally the circuit breakers. This phased approach minimizes the impact of any unexpected events and allows for a more controlled and manageable energization process. Throughout the energization process, voltage and current levels should be continuously monitored using appropriate metering equipment. The monitoring helps to detect any abnormalities, such as voltage fluctuations or excessive currents. Any unusual readings should be investigated immediately to identify the cause and prevent potential damage to the GIS or other parts of the power system. Real-time monitoring systems with alarms can be used to provide immediate notification of any abnormal conditions, allowing for prompt corrective action. The protection system should also be verified during energization to ensure that protective relays, circuit breakers, and other control devices are functioning correctly and responding as expected to various system conditions. Protection system verification ensures that the GIS is protected from faults and can be operated safely and reliably. Tests involve simulating various fault conditions to verify the correct operation of the protection relays and circuit breakers, ensuring that they can quickly and effectively isolate faults and protect the equipment.

Effective communication and coordination among all team members engaged in the energization process are key. It is crucial to establish clear communication protocols that facilitate team collaboration and promote situational awareness throughout the operations. Regular meetings at key phases and discussions regarding progress, readiness, and emerging challenges maintain a unified response to the energization activities.

Maintaining thorough documentation is essential during the energization process. Detailed records of safety checks, monitoring data, and any anomalies observed during energization should be documented, along with the actions taken in response. This data serves as vital information for compliance checks, aids in troubleshooting potential problems, and provides a historical reference for future operations or upgrades. Moreover, emergency procedures must be clearly established and communicated to all personnel before initiating the energization process. Predefined protocols that outline evacuation options, fault isolation strategies, and emergency repairs empower personnel to react effectively and swiftly in the event of an incident.

5. CONCLUSION

The successful implementation of a 230 kV Gas-Insulated Substation (GIS) project necessitates a comprehensive and meticulous approach, encompassing diligent planning, execution, and adherence to best practices throughout its lifecycle. From the initial site preparation and foundation design to the final operational tests following energization, each stage demands rigorous attention to detail, coordination, and quality control.

As the demands for electricity continue to escalate and power systems become increasingly complex, the adoption of GIS technology and the steadfast adherence to best practices will play a vital role in ensuring a reliable, resilient, and sustainable electrical infrastructure for the future. GIS represents a significant advancement in power engineering, enabling utilities to effectively address the challenges of modern power systems while minimizing environmental impact and maximizing safety and efficiency. By embracing these best practices, the industry can ensure that GIS system continues to provide reliable and sustainable power delivery for generations to come.

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