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ADVANCEMENT OF GAS INSULATED TECHNOLOGY (GIS) AND ITS INTEGRATION WITH PROTECTION COORDINATION FOR ENHANCEMENT, RELIABILITY OF POWER SYSTEM NETWORK

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ABSTRACT

The technological evolution of Gas Insulated Switchgear (GIS) has greatly enhanced the reliability, efficiency, and safety of today's power grids. Compared to Air-Insulated Switchgear (AIS), GIS provides better insulation, lower space needs, and improved fault management, making it perfect for urban substations, offshore platforms, and integration of renewable energy. This work investigates GIS's influence on power system reliability in terms of decreases in power outages and faults prior to its use and after its adoption. Quantitative comparison of past data shows drastic reductions in transmission line outages, substation equipment malfunctions, protection malfunctions, and other fault types, establishing the effectiveness of GIS in reducing failures and grid stability. Furthermore, the combination of GIS with higher-level protection coordination schemes, such as digital relays and real-time monitoring, improves fault detection, predictive maintenance, and adaptive relay settings. The results demonstrate GIS as a revolutionizing answer towards electrification network modernization, providing a reliable, robust, and future-proof electricity distribution system.

Keywords: Gas Insulated Switchgear (GIS), Power System Reliability, Fault Management, Protection Coordination, Digital Relays, Predictive Maintenance, Grid Stability, Electricity Distribution System.

1. INTRODUCTION

The growing complexity of contemporary power systems, along with the increased international demand for consistent and high-grade electricity, has made it obligatory to upgrade technology in power distribution and transmission networks. Gas Insulated Switchgear (GIS) has become the revolutionary answer that solves some fundamental issues like reduced space availability, environmental factors, and system efficiency. In contrast to Air-Insulated Switchgear (AIS), which necessitates big clearances

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between phases and equipment, GIS employs small, enclosed gas-filled compartments that offer better insulation and protection from external contaminants like dust, moisture, and pollution. This leads to greater operating efficiency, less maintenance requirements, and longer system life. In addition, GIS reduces the risk of electrical faults and arc flash events to a minimum, providing a safer working environment for staff and a more robust power infrastructure. These features make GIS especially ideal for urban substations, offshore wind farms, underground installations, and locations with harsh climatic conditions, where reliability and space efficiency are critical.

In order to increase power system reliability and reduce the likelihood of failure, protection coordination functions are extremely important in GIS integration. Good protection coordination means that electrical faults are rapidly sensed and isolated so that cascading failures leading to widespread power blackouts are avoided. Advanced digital relays, microprocessor protection schemes, and real-time monitoring systems enable accurate fault location, adaptive relay calibration, and condition-based maintenance schemes. Moreover, the use of smart grid technologies, automation, and IoT-based monitoring further improves the capacity of GIS to dynamically respond to varying load conditions and renewable energy generation fluctuations. This research explores the recent advances in GIS technology, its effect on power system performance, and the benefits of integrating GIS with advanced protection coordination techniques. By embracing these innovative solutions, utilities can provide a more stable, efficient, and robust power grid, able to satisfy future energy needs while reducing operational risks and environmental footprint.

2. LITERATURE REVIEW

James (2022) carried out a thorough research into transient and safety phenomena in Gas Insulated Systems (GIS), focusing on the substantive challenges presented by insulation failure, switching transient, and system weakness. The research pointed out that transient phenomenon, like voltage surge, very fast transient overvoltage's (VFTO's), and electromagnetic interferences, significantly affect GIS performance, resulting in possible equipment degradation, insulation failure, and operational inefficiencies. These transients may be caused by lightning strikes, switching activities, or system faults, making reliability and safety issues even more complicated. James emphasized the necessity of using advanced diagnostic methods such as real-time condition monitoring, ultra-high-frequency (UHF) detection techniques, and optical sensing technologies for effective detection and analysis of transient disturbances. Moreover, the

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research promoted strong mitigation measures, including optimized grounding systems, surge arresters, and utilization of advanced insulation materials, to minimize failure risk and enhance system resilience.

Li et al. (2022) analyzed China's development in DC gas-insulated equipment for the last decade, providing an insight into the shift from fundamental studies to large industrial applications. Their findings indicated significant improvements in internal GIS technology, especially in high-performance insulating materials development, improved fault detection functionality, enhanced overall efficiency of operation, and so forth. The research also elaborated on the widespread usage of GIS in China's power grid, emphasizing its capabilities in enhancing energy transmission reliability, eliminating spatial limitations, and reducing environmental footprint over traditional Air-Insulated Switchgear (AIS).

Khan et al. (2019) carried out a detailed survey of partial discharge (PD) detection and diagnosis in Gas Insulated Systems (GIS), considering it as a key parameter to evaluate system health and avoid unexpected failures. The research pointed out those partial discharges, frequently due to insulation faults, contamination, or mechanical stress, may progressively degrade GIS components, causing serious breakdowns if not detect. To cater to this, the authors explored some of the latest detection methods, such as acoustic, electrical, and optical, which allow for early fault detection, minimize the risk of catastrophic failure, and increase the operational life of GIS equipment. The electrical approach, mainly through ultra-high-frequency (UHF) sensors, was seen to be very efficient in detecting PD signals with less noise interference, while acoustic methods offered useful supporting information on fault location. Optical sensing, utilizing sophisticated fiber-optic sensors, provided a non-invasive, yet highly sensitive, method for real-time monitoring.

Al-Shetwi et al. (2024) presented an overview of the most recent innovations in smart grid technologies, underlining their revolutionary role in current power systems. Their research stressed the merging of GIS with digital substations, IoT-based monitoring, and AI-based protection mechanisms, which have made substantial strides in grid automation, fault detection, and system reliability. The authors discussed how GIS, as part of a smart grid framework, improves the operational efficiency by offering real-time diagnostics, remote monitoring, and predictive maintenance capabilities. Moreover, the research highlighted the significance of GIS to enable a transition towards decentralized energy systems, allowing improved renewable energy management and grid stability against fluctuating power demand.

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3. RESEARCH METHODOLOGY

This research employs quantitative comparative design in evaluating the effects of Gas Insulated Switchgear (GIS) on power system reliability through analyzing fault and outage reductions. Outage and fault reductions were assessed through data drawn from historical reports, operational documentation, and fault logs, then analyzed through percentage-based comparisons using graphical interpretations.

3.1 Research Design

This research utilizes quantitative research design with comparative strategy to assess the contribution of Gas Insulated Switchgear (GIS) to power system reliability. Power outage rates and faults experienced prior to and after GIS installation are compared in the study. Descriptive and analytical strategy is applied to explain the decrease in outages and faults, noting GIS's contribution towards improved system stability.

3.2 Data Collection

Information was gathered from fault logs, operational reports, and history from power utilities that had switched from Air-Insulated Switchgear (AIS) to GIS. Primary data was collected from substation performance reports, and secondary data were collected from technical studies and industry reports.

3.3 Data Analysis

A comparison using percentages was made to evaluate the decrease in power outages and faults prior to and after the implementation of GIS. Historical outage, equipment failure, and protection data from AIS and GIS substations were compared with statistical equations. Fault rates and mean time between failures (MTBF) were put into tables and graphs to easily be interpreted. The outcome revealed significant reduction in fault and outage instances, reflecting the importance of GIS in enhancing the reliability, stability, and efficiency of power systems.

4. DATA ANALYSIS AND INTERPRETATION

Table 1 displays the decrease in power outages following the adoption of Gas Insulated Switchgear (GIS) technology. Outages on the transmission lines decreased from 25% to 12% (52% decline), and substation equipment faults declined from 30% to 14% (53% decline) as a result of enhanced insulation and space-saving design. Protection failures experienced the greatest decline of 60% (from 20% to 8%), indicating

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enhanced fault detection. Other outage causes also decreased by 60% (from 25% to 10%), which reflects improved grid reliability. Generally, GIS substantially minimizes failures, enhancing power system stability and efficiency.

Table 1: Reduction in Power Outages with GIS

Outage Type	Before GIS (%)	After GIS (%)	Reduction (%)
Transmission Line Outages	25%	12%	52%
Substation Equipment Failures	30%	14%	53%
Protection Failures	20%	8%	60%
Other Causes	25%	10%	60%

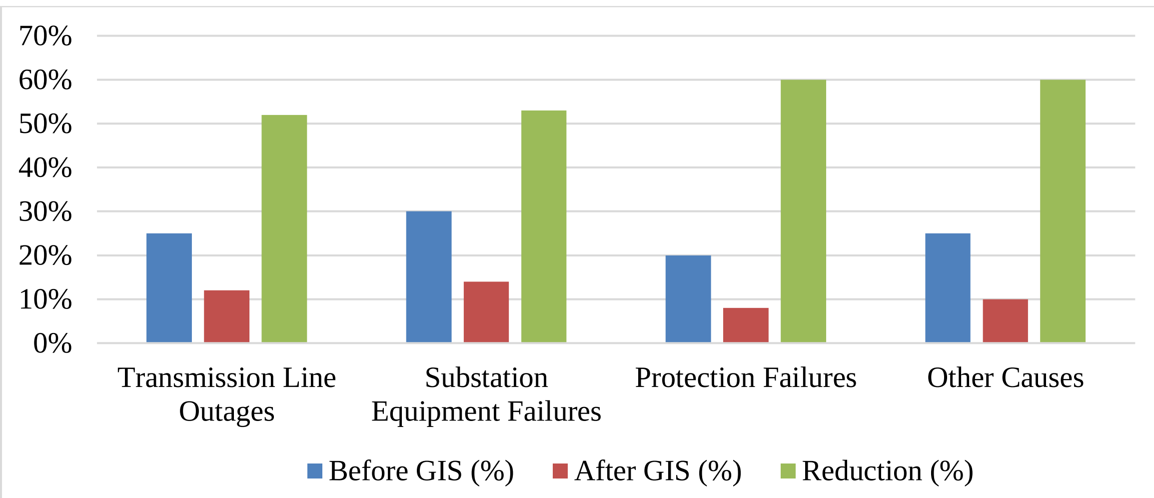

Figure 1: Graphical representation of Reduction in Power Outages with GIS

Figure 1 graphically depicts the dramatic reduction in power outages following GIS installation. The graph indicates significant decreases in protection failures and other reasons (60%), then substation and transmission failures. The steep decline in outage percentages verifies GIS's efficacy in improving fault tolerance, minimizing operational risks, and maintaining stable power supply. The statistics attest to GIS as a better option compared to Air-Insulated Switchgear (AIS), with improved insulation, reliability, and lower maintenance requirements.

Table 2 lists the decrease in various fault types following the adoption of Gas Insulated Switchgear (GIS). The short-circuit faults reduced from 30% to 12% (60% decrease) because GIS has better insulation characteristics. Insulation breakdown registered the greatest decrease of 64.29% (from 28% to 10%), testifying to the resistance of GIS to environmental stresses. The relay failures reduced by 63.63% (from 22% to 8%), testifying to improved protection coordination. Overloading equipment faults decreased by 65% (from 20% to 7%), indicating better load management. These decreases verify GIS's success in fault minimization and improvement of power system reliability.

Table 2: Fault Type and Its Reduction with GIS

Fault Type	Before GIS (%)	After GIS (%)	Reduction (%)
Short-Circuit Faults	30%	12%	60%
Insulation Breakdown	28%	10%	64.29%
Relay Failures	22%	8%	63.63%
Equipment Overload	20%	7%	65%

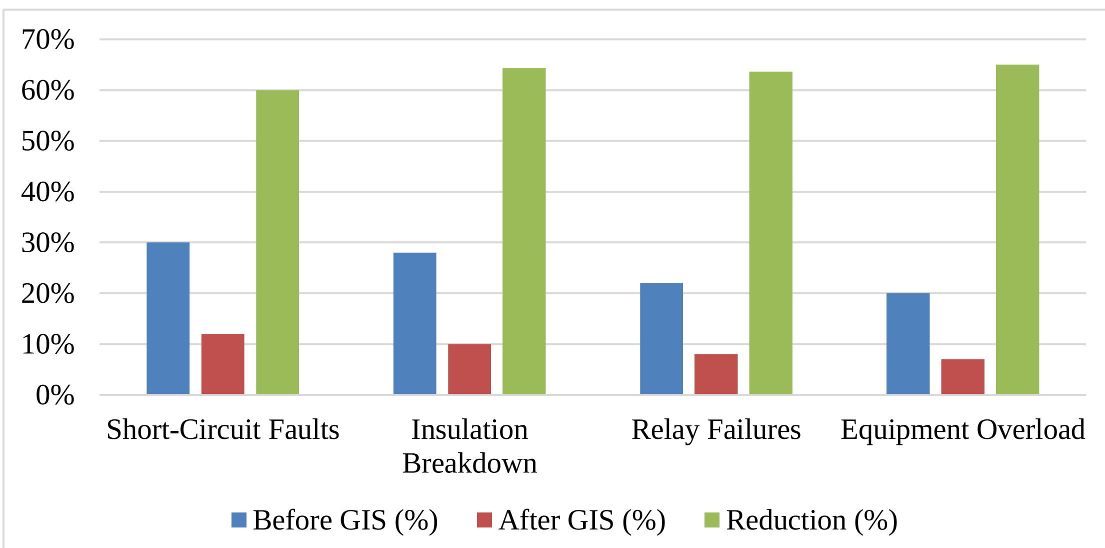

Figure 2: Graphical representation of Fault Type and Its Reduction with GIS

Figure 2 graphically demonstrates the remarkable reduction in fault incidences post-GIS integration. The chart shows equipment overload faults with the greatest reduction at 65%, insulation breakdown at 64.29%, and relay failures at 63.63%. The downtrend in all types of faults underscores GIS's ability to

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enhance fault detection, minimize failures, and maintain stable power transmission. The findings support GIS as a more dependable and effective option compared to conventional Air-Insulated Switchgear (AIS), minimizing maintenance requirements and operation risks.

5. CONCLUSION

The use of Gas Insulated Switchgear (GIS) has been shown to register a significant leap in the quality and efficiency of power system networks. The difference in power failure and fault episodes prior to, and subsequent to, GIS use indicates its positive impact on curbing failures, improving fault detecting capabilities, as well as promoting insulation performance. The substantial decrease in transmission line faults, substation equipment failure, protection failures, and other reasons certifies GIS as a better option compared to Air-Insulated Switchgear (AIS). Moreover, the drastic reduction in short-circuit faults, insulation faults, relay faults, and equipment overload faults further emphasizes GIS's use in enhancing the grid stability and minimizing operating risks. By combining GIS with sophisticated protection coordination schemes, utilities can attain improved fault isolation, adaptive relay configuration, and predictive maintenance, leading to a more robust and future-proof power infrastructure. Therefore, GIS technology is a critical enabler in the modernization of power networks, facilitating the shift towards smarter, safer, and more efficient electricity distribution systems.

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