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Overview of IoT-based Protection Scheme in a Gas Insulated Transmission Line

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ABSTRACT
Gas-insulated transmission lines (GITL) are vital for modern power systems, ensuring efficient and reliable electrical transmission. Sulfur hexafluoride (SF6) and Nitrogen is commonly used as an insulating gas Mixture in these systems to prevent electrical breakdown. However, faults and SF6 degradation can impact GIL performance. This paper explores various faults like partial discharge, gas leakage, and SF6 property degradation in GILs. A comprehensive monitoring system with IoT principles, state-of-the-art sensors, and communication tech is proposed for real-time data acquisition and analysis. The IoT-based protection scheme employs strategically placed sensors to monitor gas pressure, temperature, and composition, using advanced analytics for early fault detection. This system provides timely information for prompt decision-making and preventive maintenance, enhancing fault detection and enabling remote monitoring and control, ultimately improving the overall reliability and longevity of GIL systems.

KEYWORDS
Gas insulated transmission line
Internet of things
Insulating gas
Smart protection scheme

1. INTRODUCTION

A gas-insulated transmission line (GITL) utilizes an insulated gas as the medium for electrical power transmission, serving as an alternative to traditional overhead lines or underground cables. The primary objective of employing GITL is to reduce the physical space required for transmission, thereby enhancing the reliability and efficiency of the power transmission system. This system employs concentric aluminum cylindrical tubes, where the inner tube carries current to mitigate skin effect, and the outer tube houses the conductor and insulating gas, typically a 20% SF6 and 80% N2 mixture at 7-8 bar to address environmental concerns, which effectively quenches arcs and prevents conductor corrosion. Epoxy cast resin post insulators secure the conductors. Stability in GITL is crucial for reliable power transmission, system security, and equipment protection [1],[2],[6],[7].

It ensures that GITL operates within designed parameters, preventing outages and contributing to grid reliability while minimizing downtime. Stable GITL adapts to dynamic changes, maintains voltage levels, integrates into modern power systems, and reduces environmental impacts. To ensure the stability of a transmission line, it is crucial to establish a smart protection scheme capable of monitoring and making decisions during faults. This is accomplished by effectively monitoring gas-insulated transmission line parameters and integrating an efficient protection system with the Internet of Things [3],[4],[5].

2. INSULATING GAS AND ITS MONITORING ANALYSIS

Monitoring and analyzing insulating gas is crucial for ensuring reliability and stability.

2.1 Insulating Gas as a Backbone of GITL

Since The insulating gas, which is a mixture of 20% SF6 and 80% of nitrogen, often serves as the backbone of gas-insulated transmission lines (GITLs) by providing excellent insulating properties. Its ability to efficiently insulate, quench electrical arcs and its role in maintaining the dielectric strength of the insulating gas makes it a crucial component in maintaining the stability and reliability of the transmission line [4],[8],[10],[13],[14]. However, any deviation or fault in the gas chamber can have profound consequences on the overall stability of the transmission system. The gas pressure inside the chamber is a critical parameter that directly influences the performance of the GITL [9],[10],[11],[12]. A fault within the gas chamber can lead to a sudden and drastic change in pressure and its dielectric strength. This change is primarily associated with the thermal effects caused by the fault. During a fault event, an increase in current results in a surge of heat, causing the insulating gas to undergo thermal expansion, vaporization, or decomposition. This, in turn, leads to a significant rise in pressure within the confined space of the chamber. Any loss of stability in the gas pressure can compromise the insulation properties, potentially leading to partial discharges, breakdowns, or even catastrophic failures [5].

2.2 Monitoring based on IOT based protection scheme

Using IoT-based protection, all monitoring sensors are connected to a monitoring center where all data are gathered in gas-insulated transmission lines.

The integration of IoT in monitoring gas-insulated transmission lines enhances reliability, enables proactive maintenance, and contributes to overall system efficiency. The Internet of Things (IoT) can significantly enhance the monitoring of insulating gas in gas-insulated transmission lines through various mechanisms. It employs sensors to measure insulating gas concentration, with data transmitted in real-time through a network. This enables continuous monitoring, and advanced analytics can identify patterns or anomalies. IoT allows remote monitoring, providing real-time access to data for engineers [6],[7],[15],[16],[17].

Furthermore, predictive maintenance is facilitated through historical data analysis and machine learning, reducing downtime. Integration with existing maintenance systems ensures swift responses to identified issues through automatic alerts to maintenance teams [7],[8]. Timely detection of abnormal gas pressure variations is crucial for preventing these adverse events.

- Dielectric Strength Monitoring: Dielectric strength, measuring the gas's insulation ability, must be monitored to ensure it withstands high voltages without breakdown. Changes in dielectric strength may indicate contamination or insulation degradation. Continuous monitoring allows for early issue detection and proactive maintenance.
- Fault Detection: Rapid changes in insulating gas properties, like pressure and dielectric strength, often occur during electrical faults. Monitoring these parameters enables operators to swiftly identify and locate faults. Early detection allows timely isolation of the faulty section, minimizing overall system impact and reducing downtime [8].

2.3 GITL Model to be Protected.

GITLs have a metal enclosure around the conductor to insulate and protect it. The line has some resistance, called the combined conductor and enclosure resistance, in series with the inductance, while conductance and capacitance are connected in parallel with the line as shown in Fig 1 which can cause energy losses [20],[21],[25],[26]. To minimize these losses, the resistance of the enclosure should be as low as possible. The GITL is designed to minimize losses and ensure safe and reliable operation. This is achieved by using a positive sequence circuit. Since GITL uses a special gas mixture to insulate its conductor. This gas mixture is very good at preventing electricity from leaking out due to less loss factor the conductance of the circuit per km is equal to zero [6]

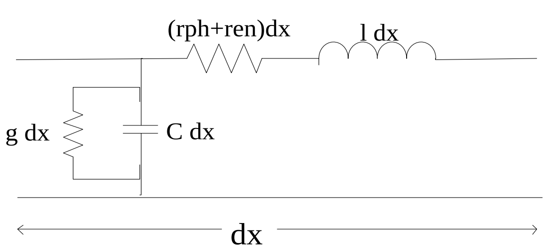

Fig. 1 Positive sequence GITL model for small element 'dx'

Where ,

rph = Conductor's resistance per km

ren = Enclosure's resistance per km

l = Inductance per km

c = capacitance per km

g = conductance per km

Monitoring the enclosure resistance, line inductance, and capacitance of gas-insulated transmission is essential for ensuring its reliable operation. Any abnormality in electrical parameters like resistance, inductance, or capacitance can be detected by measuring sensors to facilitate safety decision-making.

3. VARIOUS FAULTS IN GITL

Gas-insulated transmission lines (GITL) can encounter various faults, akin to other power transmission systems, necessitating prompt detection and corrective measures for uninterrupted operation. Common fault types include electrical issues like short circuits and open circuits, mechanical problems such as faults in connectors, joints, or insulators, environmental challenges like contamination and gas leaks, transient faults like lightning strikes, and switching transients as shown in Fig 2.

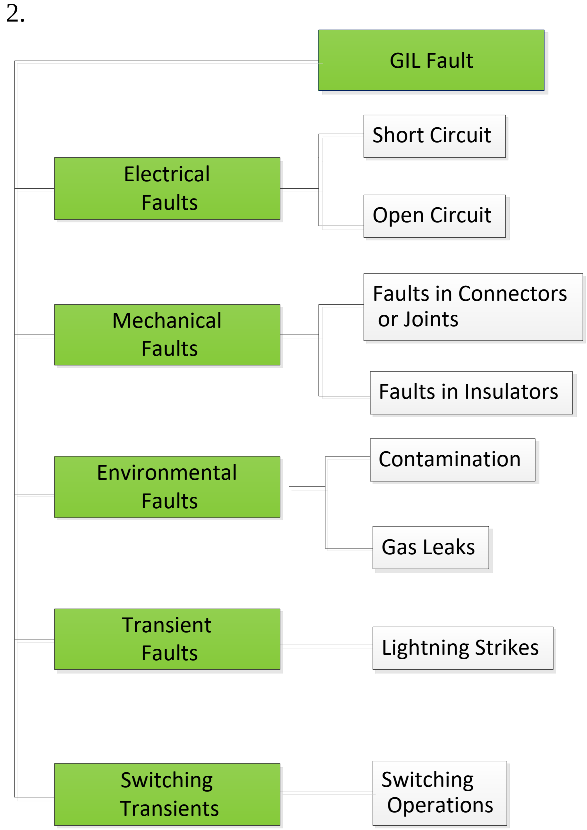

Fig. 2 Various fault in GITL

Monitoring systems measuring parameters like pressure, temperature, and dielectric strength are employed for fault detection, while regular inspections, maintenance, and diagnostic testing are vital for ensuring GITL's reliable

operation.
Detecting and diagnosing faults in gas-insulated transmission lines often involves the use of monitoring systems that measure parameters such as pressure, temperature, and dielectric strength of the insulating gas. Regular inspections, maintenance, and diagnostic testing are crucial to ensuring the reliable and stable operation of gas-insulated transmission lines [9],[10],[11].
Gas-insulated transmission lines can experience transient faults triggered by various factors, including switching transients during circuit breaker operations, lightning strikes causing high voltage surges, rapid changes in circuit conditions leading to switching surges, faults in neighboring systems causing sudden changes in current and voltage, capacitive coupling induced by nearby conductors, voltage sag or swell disturbances in the power grid, harmonic disturbances from nonlinear loads, temporary overvoltage from switching operations, and environmental factors like temperature variations or gas contamination. To mitigate these issues, protective measures such as surge arresters, voltage limiters, and proper insulation design are crucial. Regular monitoring and maintenance are also essential for identifying and addressing potential problems associated with transient faults, ensuring reliable operation of gas-insulated transmission lines [11],[12],[31].

4. FAULT DIAGNOSIS USING IOT BASED PROTECTION SCHEME

By integrating IoT technologies as shown in Fig 3 we can make a smart protection scheme, Gas Insulated Lines (GITLs) can be enhanced with advanced sensors and communication devices, facilitating real-time monitoring of insulating gas conditions.

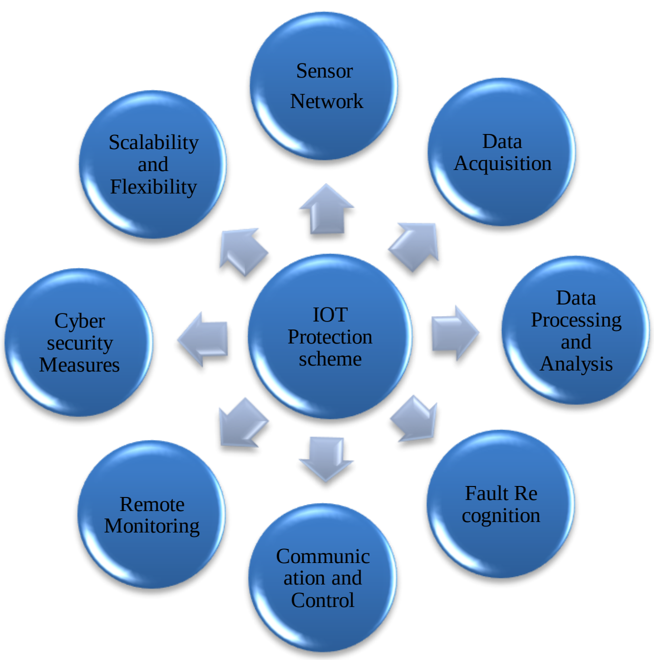

Fig. 3 Block diagram for IOT based protection scheme

Here's a conceptual framework for such a system: These sensors, capable of detecting subtle changes in gas composition, pressure, and temperature, transmit data through the IoT network, enabling remote monitoring and analysis as shown in flowchart in Fig 4. The primary advantage of IoT in this context lies in its early fault detection capability. An integrated protection system, empowered by IoT, can swiftly identify abnormal behavior in the insulating gas, such as sudden changes in pressure or temperature, signaling potential faults. The rapid communication and data processing speed of IoT devices enable quick decision-making to minimize downtime and enhance overall reliability. Furthermore, IoT facilitates predictive maintenance, allowing proactive measures to address potential issues before they escalate into significant faults [13],[14],[29],[30].

- Sensor Network: IoT Sensors: Install IoT sensors at key points along the gas-insulated transmission line to monitor electrical parameters. These sensors could measure variables such as current, voltage, temperature, and pressure [15].
- Data Acquisition: (Real-time Data Collection) The sensors continuously collect real-time data on the electrical parameters. This data is then transmitted to a central monitoring system through wireless communication or a wired network.
- Data Processing and Analysis: Utilize edge computing for local data processing at sensor nodes, reducing latency and facilitating swift decision-making. Implement machine learning algorithms to analyze collected data, training the system to identify deviations signaling potential faults by recognizing patterns in normal operating conditions.
- Fault Recognition: In anomaly detection, algorithms are employed to pinpoint unusual patterns or deviations from normal electrical behavior, such as sudden changes, irregularities, or abnormal trends, which could indicate a fault or potential issue. Additionally, pattern recognition involves training the system to identify specific fault patterns by analyzing historical data and known fault scenarios [15],[16].
- Communication and Control: Integrate IoT protection with SCADA systems to enable centralized control and monitoring. Implement automated responses for identified faults, including isolating the affected area, reconfiguring the network, and notifying operators for manual intervention.
- Remote Monitoring: The system aims to achieve cloud integration, enabling remote monitoring and management through cloud platforms. This facilitates real-time data access and alerts from any location. Additionally, a user-friendly interface is being developed for operators to visualize the gas-insulated transmission line's status, access historical data, and receive notifications.
- Cybersecurity Measures: (Security Protocols) Implement robust cybersecurity measures to secure communication channels and protect the system from cyber threats. This is critical to ensuring the integrity and reliability of the protection scheme [17].
- Scalability and Flexibility: The provided sentences emphasize the importance of a scalable architecture for a power system, enabling the addition of more

sensors and devices as the system evolves. Additionally, there is a focus on interoperability, ensuring that the IoT protection scheme can seamlessly integrate with current power system components and devices [18].

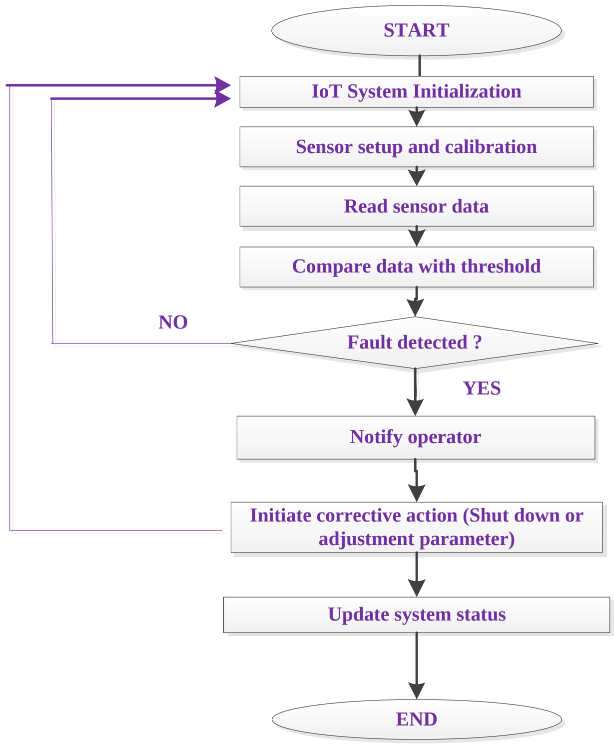

Fig. 4 Flow chart for IOT based protection scheme in GIL

4.1 Simulating Tool for Iot Based Protection Scheme:

Simulating IoT-based protection schemes for gas-insulated transmission lines involves complex modeling and integration of various components. While specific tools dedicated solely to this might not exist, we can use a combination of software tools and platforms for simulation and analysis. Here are some tools and approaches to consider:

- Power Systems Simulation Tools: Software like MATLAB/Simulink, PSCAD, DIgSILENT, or ETAP can simulate power systems, including transmission lines. You can model the gas-insulated transmission line and its behavior under various conditions.
- IoT Simulation Platforms: Tools like Contiki, OMNeT++, or IoTIFY can simulate IoT devices and networks. While they might not specifically simulate gas-insulated lines, they can help simulate the behavior of IoT devices used in monitoring or protecting these systems.
- Circuit Simulation Tools: Tools like SPICE (Simulation Program with Integrated Circuit Emphasis) can simulate electronic circuits. While more focused on electronics, they can help simulate certain aspects of protection devices used in gas-insulated lines.
- Custom Simulation Environments: Sometimes, custom simulation environments are developed using a mix of programming languages (Python, C++, etc.), simulation libraries, and specialized models to replicate the behavior of gas-insulated lines and IoT-based protection schemes.

4.2 Comparison between IOT based protection scheme and traditional protection scheme:

IoT-based protection schemes leverage interconnected devices to provide real-time monitoring, analysis, and remote accessibility. Traditional protection schemes, on the other hand, rely on fixed parameters and hardware with less real time adaptability but often have better security measures in place. Both have their strengths and weaknesses as shown in Table 1. with IoT-based systems offering enhanced flexibility and real-time insights while requiring more attention to cybersecurity [9],[19].

Table. 1 Comparison table between IOT based protection scheme and traditional protection scheme

Aspect	IoT-Based Protection Scheme	Traditional Protection Scheme
Technology used	Uses Internet of Things (IoT) devices	Relies on conventional hardware
Data collection	Collects real-time data from sensors	Relies on predefined parameters
Monitoring	Continuous monitoring and real-time updates	Periodic checks or manual monitoring
Accessibility	Remote access and control over devices	Often limited to on-site access
Data analysis	Uses analytics for predictive analysis	Relies on set thresholds or rules
Adaptability	Adaptable to dynamic changes in environment	Less adaptable without reprogramming
Response time	Quick response due to real-time data	Response time may vary
Cost	Initial setup costs might be higher	Potentially lower initial costs
Maintenance	Regular software updates and maintenance	Traditional maintenance of hardware
Security	Vulnerable to cyber threats	Generally more secure
Integration	Easily integrates with other IoT systems	May have limited integration

4.3 Monitoring Sensors

The conductor is hotter than the enclosure pipes because it carries more power. An infrared temperature measurement system is used to measure the temperature of the conductor because it is cheap, easy to use, and widely available. The CT of Optris as shown in Fig 4 is a specific infrared temperature measurement system that has a wide temperature measurement range. The sensor is designed to be easily accessible and replaceable in real-world applications, without disrupting operations [17],[27],[28].

Fig. 5 IR-Sensor with connected electronic unit
Source: www.optris.com

Infrared sensors measure temperature by detecting the infrared radiation emitted by objects. Gas-insulated transmission lines typically contain gases such as sulfur hexafluoride (SF6), which may have different temperatures at various points along the transmission line due to factors such as load variations, environmental conditions, or equipment malfunctions. Pressure sensors used in gas-insulated transmission lines typically operate on the principle of detecting the force exerted by the gas molecules on a sensitive element. There are various types of pressure sensors, but one common type used in such applications is the capacitive pressure sensor. In a gas-insulated transmission line, such pressure sensors are typically installed at strategic points along the line to monitor the pressure of the insulating gas [22],[23],[24].

This helps in maintaining optimal operating conditions and detecting any abnormal pressure conditions that may indicate a leak or other issues within the system. The interface of a data path from a sensor to a control center typically involves several components to ensure efficient and reliable transmission of data. Here's an overview of the main elements as shown in fig 5.

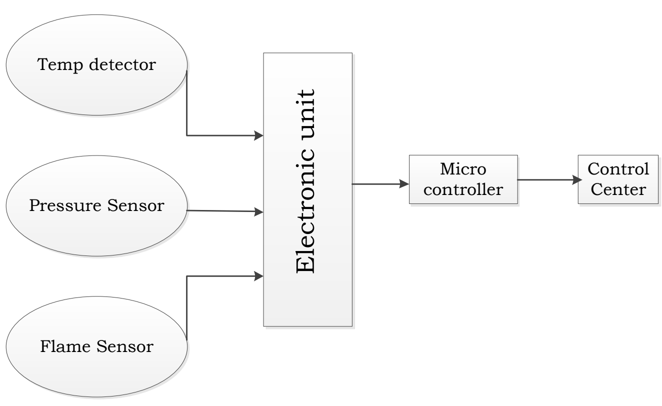

Fig. 6 Data path from Sensor to control center

5. CONCLUSION

The implementation of an Internet of Things (IoT) based protection scheme in gas-insulated transmission lines is highlighted as a transformative advancement for ensuring the stability and reliability of critical infrastructures. A described protection Scheme enables online monitoring of gas pressure and temperature measurement of GITL conductors, allowing for precise forecasting of the GITL's overload capability. Additionally, relevant ambient parameters can be taken into account, enabling the system operator to operate the GITL at its thermal limits. This facilitates effective load scheduling, reducing blackout risks and enhancing system stability, reliability, and availability. Overall, the adoption of IoT in protection schemes is deemed crucial for achieving and maintaining exceptional stability and reliability in power delivery, contributing to a resilient and robust energy infrastructure. The benefits include real-time monitoring, data analytics, and early fault detection, allowing for proactive measures and reduced downtime. By integrating IoT sensors, data analytics, and automated control, this smart protection scheme can enhance fault detection capabilities, reduce response times, and contribute to the overall stability and reliability of the gas-insulated transmission line. The integration of IoT enhances fault detection accuracy, optimizes resource utilization through data analytics, and improves communication among protection scheme components. Regular updates and maintenance are essential to adapt the system to changing conditions and emerging threats. So, in the future, using GIL for connecting power grids with new transmission lines could be a good idea and setting up new networks in the future.

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