PRESIDENCY UNIVERSITY

Private University Estd. in Karnataka State by Act No. 41 of 2013

Itgalpura, Rajankunte, Yelahanka, Bengaluru – 560064

Substation AI Compliance Assistant

A PROJECT REPORT

Submitted by

Shreeansh Sachan- 20221CSE0295

Aditi Pravin Nimje- 20221CSE0148

Raj Prasad Singha- 20221CSE0159

Under the guidance of,

Mr.Laxman

BACHELOR OF TECHNOLOGY

IN

COMPUTER SCIENCE AND ENGINEERING

PRESIDENCY UNIVERSITY

BENGALURU

DECEMBER 2025

PRESIDENCY UNIVERSITY

Private University Estd. in Karnataka State by Act No. 41 of 2013

Itgalpura, Rajankunte, Yelahanka, Bengaluru – 560064

PRESIDENCY SCHOOL OF COMPUTER SCIENCE AND ENGINEERING

BONAFIDE CERTIFICATE

Certified that this report **"Substation Ai Compliance Assistant"** is a bonafide work of "Shreeansh Sachan(20221CSE0295),Aditi Pravin Nimje(20221CSE0148) and Raj Prasad Singha(20221CSE0159)", who have successfully carried out the project work and submitted the report for partial fulfilment of the requirements for the award of the degree of BACHELOR OF TECHNOLOGY in COMPUTER SCIENCE ENGINEERING during 2025-26.

Mr.Laxman
Project Guide
PSCS
Presidency University

Dr. Jayavadivel Ravi
Program Project Coordinator
PSCS
Presidency University

Dr. Sampath A K
Dr. Geetha A
School Project Coordinators
PSCS
Presidency University

Dr. Asif Mohamed H B
Head of the Department
PSCS
Presidency University

Dr. Shakkeera L
Associate Dean
PSCS
Presidency University

Dr. Duraipandian N
Dean
PSCS & PSIS
Presidency University

Name and Signature of the Examiners

Sl. No.	Name	Signature	Date
1.	Monisha Gupta		3/12/25
2.	B. Bhavya		3/12/25

PRESIDENCY UNIVERSITY

PRESIDENCY SCHOOL OF COMPUTER SCIENCE AND ENGINEERING

DECLARATION

We the students of final year B.Tech in COMPUTER SCIENCE ENGINEERING at Presidency University, Bengaluru, named Shreeansh Sachan, Aditi Pravin Nimje and Raj Prasad Singha hereby declare that the project work titled **"Substation AI Compliance Assistant"** has been independently carried out by us and submitted in partial fulfilment for the award of the degree of B.Tech in COMPUTER SCIENCE ENGINEERING during the academic year of 2025-26. Further, the matter embodied in the project has not been submitted previously by anybody for the award of any Degree or Diploma to any other institution.

Shreenansh Sachan	20221CSE0295
Aditi Pravin Nimje	20221CSE0148
Raj Prasad Singha	20221CSE0159

PLACE: BENGALURU

DATE: 2nd December 2025

ACKNOWLEDGEMENT

For completing this project work, We/I have received the support and the guidance from many people whom I would like to mention with deep sense of gratitude and indebtedness. We extend our gratitude to our beloved **Chancellor, Pro-Vice Chancellor, and Registrar** for their support and encouragement in completion of the project.

I would like to sincerely thank my internal guide Mr **Laxman, Professor of Practice,** Presidency School of Computer Science and Engineering, Presidency University, for his moral support, motivation, timely guidance and encouragement provided to us during the period of our project work.

I am also thankful to **Dr. Asif Mohamed H B, Professor, Head of the Department, Presidency School of Computer Science and Engineering** Presidency University, for his mentorship and encouragement.

We express our cordial thanks to **Dr. Duraipandian N**, Dean PSCS & PSIS, **Dr. Shakkeera L**, Associate Dean, Presidency School of computer Science and Engineering and the Management of Presidency University for providing the required facilities and intellectually stimulating environment that aided in the completion of my project work.

We are grateful to **Dr. Sampath A K, and Dr. Geetha A, PSCS** Project Coordinators, **Dr. Jayavadivel Ravi, Program Project Coordinator,** Presidency School of Computer Science and Engineering, or facilitating problem statements, coordinating reviews, monitoring progress, and providing their valuable support and guidance.

We are also grateful to Teaching and Non-Teaching staff of Presidency School of Computer Science and Engineering and staff from other departments who have extended their valuable help and cooperation.

Shreeansh Sachan
Aditi Pravin Nimje
Raj Prasad Singha

PRESIDENCY UNIVERSITY

Private University Estd. in Karnataka State by Act No. 41 of 2013

Itgalpura, Rajankunte, Yelahanka, Bengaluru – 560064

Substation AI Compliance Assistant

A PROJECT REPORT

Submitted by

Shreeansh Sachan- 20221CSE0295

Aditi Pravin Nimje- 20221CSE0148

Raj Prasad Singha- 20221CSE0159

Under the guidance of,

Mr.Laxman

BACHELOR OF TECHNOLOGY

IN

COMPUTER SCIENCE AND ENGINEERING

PRESIDENCY UNIVERSITY

BENGALURU

DECEMBER 2025

PRESIDENCY UNIVERSITY
Private University Estd. in Karnataka State by Act No. 41 of 2013
Itgalpura, Rajankunte, Yelahanka, Bengaluru – 560064

PRESIDENCY SCHOOL OF COMPUTER SCIENCE AND ENGINEERING

BONAFIDE CERTIFICATE

Certified that this report "**Substation Ai Compliance Assistant**" is a bonafide work of "Shreeansh Sachan(20221CSE0295),Aditi Pravin Nimje(20221CSE0148) and Raj Prasad Singha(20221CSE0159)", who have successfully carried out the project work and submitted the report for partial fulfilment of the requirements for the award of the degree of BACHELOR OF TECHNOLOGY in COMPUTER SCIENCE ENGINEERING during 2025-26.

Mr.Laxman
Project Guide
PSCS
Presidency University

Dr. Jayavadivel Ravi
Program Project Coordinator
PSCS
Presidency University

Dr. Sampath A K
Dr. Geetha A
School Project Coordinators
PSCS
Presidency University

Dr. Asif Mohamed H B
Head of the Department
PSCS
Presidency University

Dr. Shakkeera L
Associate Dean
PSCS
Presidency University

Dr. Duraipandian N
Dean
PSCS & PSIS
Presidency University

Name and Signature of the Examiners

Sl. No.	Name	Signature	Date
1.			
2.			

PRESIDENCY UNIVERSITY

PRESIDENCY SCHOOL OF COMPUTER SCIENCE AND ENGINEERING

DECLARATION

We the students of final year B.Tech in COMPUTER SCIENCE ENGINEERING at Presidency University, Bengaluru, named Shreeansh Sachan, Aditi Pravin Nimje and Raj Prasad Singha hereby declare that the project work titled **"Substation AI Compliance Assistant"** has been independently carried out by us and submitted in partial fulfilment for the award of the degree of B.Tech in COMPUTER SCIENCE ENGINEERING during the academic year of 2025-26. Further, the matter embodied in the project has not been submitted previously by anybody for the award of any Degree or Diploma to any other institution.

Shreenansh Sachan	20221CSE0295
Aditi Pravin Nimje	20221CSE0148
Raj Prasad Singha	20221CSE0159

PLACE: BENGALURU

DATE: 2nd December 2025

ACKNOWLEDGEMENT

For completing this project work, We/I have received the support and the guidance from many people whom I would like to mention with deep sense of gratitude and indebtedness. We extend our gratitude to our beloved **Chancellor, Pro-Vice Chancellor, and Registrar** for their support and encouragement in completion of the project.

I would like to sincerely thank my internal guide Mr **Laxman, Professor of Practice**, Presidency School of Computer Science and Engineering, Presidency University, for his moral support, motivation, timely guidance and encouragement provided to us during the period of our project work.

I am also thankful to **Dr. Asif Mohamed H B, Professor, Head of the Department, Presidency School of Computer Science and Engineering** Presidency University, for his mentorship and encouragement.

We express our cordial thanks to **Dr. Duraipandian N**, Dean PSCS & PSIS, **Dr. Shakkeera L**, Associate Dean, Presidency School of computer Science and Engineering and the Management of Presidency University for providing the required facilities and intellectually stimulating environment that aided in the completion of my project work.

We are grateful to **Dr. Sampath A K, and Dr. Geetha A, PSCS** Project Coordinators**, Dr. Jayavadivel Ravi, Program Project Coordinator**, Presidency School of Computer Science and Engineering, or facilitating problem statements, coordinating reviews, monitoring progress, and providing their valuable support and guidance.

We are also grateful to Teaching and Non-Teaching staff of Presidency School of Computer Science and Engineering and staff from other departments who have extended their valuable help and cooperation.

Shreeansh Sachan
Aditi Pravin Nimje
Raj Prasad Singha

Abstract

This project was established to develop an Artificial Intelligence (AI) driven compliance assistance solution for Substations. In today's world of increasing complexity in the power grid and the ever-evolving nature of regulatory compliance standards; Substations are facing unprecedented challenges in complying with many multi-faceted regulatory compliance standards and at the same time ensuring safe and reliable operation of the station. Therefore, this compliance assistance solution that is currently under development will be an intelligent conversation-based system using natural language processing (NLP) and machine learning (ML) in conjunction with domain-specific knowledge bases to assist users in receiving real-time compliance guidance, automated support for audits, and predictive compliance risk assessments. This system will also allow for integration into current substation management systems and track the compliance status of various regulatory bodies across multiple regulations such as Indian Electricity Rules, CERC Regulations and International standards like IEC 61850. The compliance assistant uses advanced NLP to understand the complexities of compliance related questions asked by substation staff members and provides contextually relevant compliance information based on the applicable regulatory requirements. In addition to compliance information, the compliance assistant can generate comprehensive compliance reports. The deployment structure utilized includes BERT-based semantic understanding, a structured compliance knowledge base and a cloud-based architecture for ease of integration into operational technology (OT) environments. Improvements have been demonstrated to decrease time spent creating compliance documentation, improve accuracy in compliance with regulatory requirements and proactively identify potential compliance risks; all of which contribute to positioning this solution as a revolutionary tool for modernizing substation operations within India's rapidly changing energy industry.

Table of Content

Sl. No.	Title	Page No.
	Declaration	
	Acknowledgement	i
	Abstract	ii
	List of Figures	v
	List of Tables	vi
	Abbreviations	vii
1.	Introduction 1.1 Background 1.2 Statistics of project 1.3 Prior existing technologies 1.4 Proposed approach 1.5 Objectives 1.6 SDGs 1.7 Overview of project report	1-9
2.	Literature review	11-14
3.	Methodology	15-17
4.	Project management 4.1 Project timeline 4.2 Risk analysis 4.3 Project budget	18
5.	Analysis and Design 5.1 Requirements 5.2 Block Diagram 5.3 System Flow Chart 5.4 Choosing devices 5.5 Designing units 5.6 Standards 5.7 Mapping with IoTWF reference model layers 5.8 Domain model specification 5.9 Communication model 5.10 IoT deployment level	19-26

	5.11 Functional view 5.12 Mapping IoT deployment level with functional view 5.13 Operational view 5.14 Other Design	
6.	Hardware, Software and Simulation 6.1 Hardware 6.2 Software development tools 6.3 Software code	27-31
7.	Evaluation and Results 7.1 Test points 7.2 Test plan 7.3 Test result 7.4 Insights	32-36
8.	Social, Legal, Ethical, Sustainability and Safety Aspects 8.1 Social aspects 8.2 Legal aspects 8.3 Ethical aspects 8.4 Sustainability aspects 8.5 Safety aspects	37-38
9.	Conclusion	39-41
	References	42-43
	Base Paper	44
	Appendix	45-48

List of Figures

Figure Number	Caption	Context	Page No.
Fig 1.1	Sustainable development goals	Chapter 1 (Introduction)	7
Fig 3.1	The V model methodology	Chapter 3 (Methodology)	17
Fig 4.1	Project Timeline	Chapter 4 (Project Management)	18
Fig 5.2	Block diagram	Chapter 5 (Analysis and Design)	21
Fig 5.3	System Flow chart	Chapter 5 (Analysis and Design)	21
Fig 5.12	Mapping IoT Deployment Block Diagram	Chapter 5 (Analysis and Design)	25
Figure A.1	Displays a single pane of glass view	Appendix	41
Figure A.2	A modal view for selecting equipment	Appendix	42
Figure A.3	Chat Interface	Appendix	42
Figure A.4	Real-time anomaly detection functionality	Appendix	43
Figure B.1	Knowledge Base Example	Appendix	44

List of Tables

Table Number	**Caption**	**Context**	**Page No.**
Table 4.2	Risk Analysis	Chapter 4 (Project management)	18
Table 5.7	IoT World Forum Reference Model-Project Mapping	Chapter 5 (Analysis and Design)	23
Table 7.1	System Performance Metrics	Chapter 7 (Evaluation and Results)	30
Table 7.3.1	Observations of the Temperature unit	Chapter 7 (Evaluation and Results)	32
Table 7.3.2	Observations for each unit	Chapter 7 (Evaluation and Results)	32
Table 9.1	Evaluation of the Results Against the System Goals	Chapter 9 (Conclusion)	37

Abbreviations

AI- Artificial Intelligence

API- Application Programming Interface

CSE- Computer Science and Engineering

GUI- Graphical User Interface

HTTP- Hypertext Transfer Protocol

IEEE -Institute of Electrical and Electronics Engineers

JSON- JavaScript Object Notation

LLM -Large Language Model

NESC- National Electrical Safety Code

NLP- Natural Language Processing

OSHA- Occupational Safety and Health Administration

PDF- Portable Document Format

RAG - Retrieval-Augmented Generation

REST- Representational State Transfer

SDG -Sustainable Development Goal

SOP- Standard Operating Procedure

UI- User Interface

VCS - Version Control System

Chapter 1

Introduction

1.1 Background

Substations are key components of contemporary electrical distribution networks and are integral to the overall performance of the grid. These critical assets perform vital roles in the grid: they provide the primary means of transforming voltages, regulate the flow of power, and help to stabilize the electrical grid. A modern substation contains many high-tech devices such as power transformers, circuit breakers, switchgear, protective relaying and control systems. As a result of this technology, ongoing monitoring, inspection, and testing of these facilities is necessary to continually ensure that they continue to function as intended and are compliant with changing regulatory requirements. Additionally, the increased complexity of operating substations as a result of recent technological advancements such as the integration of advanced metering infrastructure (AMI), distributed energy resources (DER's) and supervisory control and data acquisition (SCADA) systems have introduced an additional layer of regulatory requirements that include: technical standards, safety, environmental and cyber security.

Since 1991 when India liberalized the electricity market and passed the Electricity Act of 2003, India has implemented significant changes to the structure of its power sector. The Electricity Act of 2003 created the central electricity authority (CEA) and regulatory bodies at both the national and regional levels. In total, there are approximately 7,000 substations operating in India at varying voltage levels. The standards for the installation and maintenance of these substations are governed by multiple government entities including the CEA, CERC and NLDC. Each substation will be required to meet the applicable regulatory requirements which include among others: the Indian Electricity Rules 2005, IEC 61850, IEEE standards for protection systems, and state-specific distribution rules. The regulatory environment of substations creates a number of challenges for the employees responsible for the operation and maintenance of the substations. Employees working in the field who are involved in the operation and maintenance of substations face complicated compliance issues in addition to the need to ensure the continued reliability of electric service to millions of people.

Substation compliance is typically managed through traditional approaches that include manual processes, documentation on paper and regular auditing at the substation level by third-party auditors. Traditional compliance management for substations also includes a reactive approach to regulatory changes. There are several drawbacks associated with the traditional approaches of managing compliance for substations such as; information asymmetry between field personnel and documentation requirements, delayed identification of regulatory noncompliances, difficulties in tracking regulatory updates to various regulatory frameworks, and an extensive administrative burden that utilizes valuable technical time and resources.

1.2 Statistics

The Indian electric power system is comprised of around 7,000 substations (each with a variety of voltages) that range from low-voltage 11-kilovolt (kV) distribution substations to high-voltage 765 kV extra-high-voltage (EHV) transmission substations which service over 1.3 billion people residing in areas with varied climatic, environmental, and operational conditions. Annual reports from India’s Ministry of Power detail that 8–12 percent of all failures of the power system are caused by failure to comply with regulations in substations, with costs of noncompliance estimated to be between 50,000 and 100,000 Rupees per incident when including fines, outages due to operational disruptions and costs associated with repairs. A current process exists to manage compliance that involves an average of 40–60 hours per year per substation for preparation of documentation, coordination of audits and submission of reports to regulators. These hours represent a considerable amount of resources that could potentially be utilized for improvement of operational performance and preventive maintenance of the electrical grid. There are also a minimum of 45–60 discrete regulations contained within the regulatory compliance framework governing Indian substations, including minimum technical specifications, operational standards, safety protocols, environmental regulations, and reporting requirements that must be concurrently complied with. Surveys conducted by electric power distribution utilities have indicated that the use of manual methods to track compliance resulted in errors of up to 20 percent in the accuracy of compliance documentation submitted by 15–20 percent of utilities; delays of as long as 30–45 days for regulatory updates to reach field personnel; and knowledge gaps related to compliance of 60–70 percent among field technicians that do not have regular access to updated regulatory information. Implementation of AI-based compliance support tools may enable utilities to save 50–70 percent of their time spent documenting compliance; reduce compliance-related failures by 40–60 percent; increase the accuracy of compliance documentation to 98–99 percent; and provide field personnel with real-time compliance information thereby reducing the need for training by 35–45 percent.

1.3 Prior existing technologies

The use of manual documentation systems coupled with periodic external audits is prevalent among contemporary compliance management approaches utilized by electrical substations. Legacy Compliance Management Systems utilize paper to record compliance data for legacy systems using a manual process. Compliance personnel extract compliance information from the printed versions of regulatory documents. The compliance information is cross referenced with the applicable operational procedure(s). Compliance information is then entered into a standard format form by compliance personnel. Legacy compliance methodology uses human review to verify regulatory compliance. Legacy compliance management has several major disadvantages including (i) manual processes are very time consuming; (ii) documentation forms vary between the different substations; (iii) updated regulatory compliance is transmitted to operational personnel late; (iv) legacy compliance management does not have the ability to create a complete audit trail; and (v) legacy compliance management is extremely costly to implement and represents approximately 2-3% of the average annual budget of a substation. SCADA-Based Compliance Monitoring Systems represent a technologically advanced approach to automating the continuous monitoring of operational parameters related to a substation's compliance with regulatory requirements. Examples of parameters monitored under SCADA-Based Compliance Monitoring Systems include; Voltage Levels, Current Draw, Transformer Oil Temperatures and Protection Relay Settings. Each parameter is continuously monitored against predetermined compliance thresholds. SCADA-Based Compliance Monitoring Systems provide a number of benefits over manual compliance monitoring including continuous monitoring and automation of compliance monitoring. However, SCADA-Based Compliance Monitoring Systems are only able to monitor parameters associated with operational compliance and are unable to evaluate all aspects of compliance to regulatory requirements. Additionally, SCADA-Based Compliance Monitoring Systems are not able to interpret complex regulatory text. SCADA-Based Compliance Monitoring Systems also provide limited assistance to personnel who may be unsure of their obligations to comply with regulatory requirements. Lastly, SCADA-Based Compliance Monitoring Systems are unable to proactively identify emerging compliance risks or predict potential non-compliance conditions in the future.

Additionally, document management systems utilizing platforms such as SharePoint or enterprise resource planning systems provide centralization and version control of regulatory documents; however, lack the ability to interpret regulatory content intelligently, require manual interpretation of compliance information by personnel, provide limited search and retrieve functionality for regulatory information inquiries, and are unable to provide predictive compliance monitoring or individualized compliance guidance based upon a personnel member's role. The emerging application of AI-based technologies such as chatbots and natural language processing systems has shown promise for use in customer service, technical support, and general knowledge management. However, the majority of the currently available chatbot technology have been developed using general domain knowledge or organization-specific procedural knowledge and lack regulatory knowledge, lack connectivity to electrical substation operations systems, possess limited contextual understanding of the specific domain being referenced, and lack the specialized compliance knowledge and regulatory intelligence required for the analysis and interpretation of compliance within the context of complex power systems.

1.4 Proposed approach

Substation AI Compliance Assistant is a highly integrative application of advanced Artificial Intelligence (AI) technologies that includes Natural Language Processing (NLP) using BERT-based NLP, Machine Learning (ML) for assessing compliance risk, and Domain Specific Knowledge Engineering (DSKE) that provides knowledge specific to the Regulatory Requirements of Electrical Substations.

The system's Architecture includes multiple connected components. A comprehensive compliance knowledge base is included which comprises of Indian Electricity Rules, CERC Regulations, IEC 61850 Standards, IEEE Protection System Standards and State level Distribution Regulations. An NLU Engine (Natural Language Understanding Engine), enables the interpretation of regulatory questions and requests, entered into the system by users in conversational form. A semantic search and retrieval system is used to connect user inquiry to compliance information, and a compliance monitoring module is used to monitor in real-time, the compliance status of each substation, compared to regulatory requirements.

The solution architecture was designed to be functional in two primary modes of operation:

a) A conversational query interface that allows substation personnel to ask compliance questions, receive contextual guidance and answers based on their unique situations;

b) An automated compliance monitoring mode that, at regular intervals, compares documented operational procedures, equipment configurations and maintenance records against regulatory requirements, identifies compliance gaps and issues predictive alerts for compliance-related risk exposures on the horizon.

In addition, the proposed system will be able to communicate with existing substation information systems (SCADA platforms, maintenance management systems and asset inventory systems), through standardized application programming interfaces (APIs), thereby correlating operational data with regulatory requirements and providing comprehensive compliance reports with audit trails.

Furthermore, the proposed architecture utilizes cloud-based deployment models to provide scalability, accessibility and redundancy that are required for mission-critical applications within the power sector. Finally, the system provides multilingual support which addresses regional languages, but maintains the regulatory language precision needed for documenting compliance. Advanced Analytics Capabilities are available to identify compliance patterns across multiple substations; thus enabling Network-Wide Optimization of compliance processes, Early Identification of Systemic Compliance Risks impacting Multiple Facilities, and Continuous Improvement of Regulatory Interpretation based upon Emerging Regulatory Jurisprudence and Interpretation Guidance provided by Regulatory Bodies.

1.5 Objectives

Intelligent System Design

Design an intelligent conversational system that can recognize and respond to personnel at substations when they ask complex regulatory compliance questions using natural language and provide relevant guidance for their facility, based on relevant regulatory frameworks, operational conditions and compliance obligations.

Compliance Knowledge Engineering

Develop extensive compliance knowledge engineering for the Indian Electricity Rules (2005), CERC Regulations, IEC 61850 Digital Communication Standards, IEEE Protection System Standards, State Level Distribution Regulations, and others through developing a structural domain model that enables the semantic recognition of compliance relationships and dependencies.

Automated Compliance Monitoring

Provide automatic compliance monitoring functionality to enable real time determination of whether or not a substation is compliant, through integration with operational systems, periodic document reviews and identifying compliance gaps prior to violations, including predicting future compliance risk to prevent non-compliance prior to a violation occurring.

Unified Regulatory Information Platform

Create a single source of truth as a unified regulatory information platform that will allow all field personnel to have immediate access to the latest regulatory requirements, recent changes to those requirements, compliance best practices, and regulatory authority guidance to support rapid dissemination of regulatory updates to field personnel and apply them to the facility's operations.

Automation of Compliance Documentation

Reduce the amount of manual effort required by employees to generate compliance documentation through automating the creation of compliance reports, audit ready compliance documentation packages, compliance audit trail documents and regulatory submission materials based on the monitoring and analysis of system data and employee work processes.

1.6 SDGs

The Substation AI Compliance Assistant project is aligned with several of the United Nations' Sustainable Development Goals (SDGs), as the project has contributed to the sustainable development of India's energy sector by enhancing regulatory governance, optimizing operational efficiency through technology and developing sustainable power infrastructure:

SDG 7 - Affordable and Clean Energy: Through the effective use of predictive compliance monitoring, the system can be used to optimize the operation of substation compliance management and maintenance in a manner that supports the reliable operation of the power system, minimizes unplanned outages resulting from non-compliance, and supports the development of sustainable electric distribution infrastructure. Optimizing the reliability of the power system will reduce the necessity of having redundant generation resources on line and will minimize grid instability caused by equipment failure. Therefore, SDG 7 goals are supported.

SDG 9 - Industry, Innovation and Infrastructure: This project represents an example of how AI can be used to support the management of critical infrastructure; it provides a foundation for the development of intelligent substation networks and contributes to India's ability to build the technological capacity needed to develop a digitally advanced power system. Additionally, the system will enable the digital transformation of India's power distribution infrastructure and improve the ability of utilities to maintain their assets using predictive monitoring, therefore supporting the development of India's power sector.

SDG 12 - Responsible Consumption and Production: Optimizing the operation of substations through process improvements driven by compliance reductions operational inefficiency and reduces the amount of equipment failures which results in material waste due to early replacement of equipment. The system will allow utilities to effectively manage the life cycle of their assets and will help to reduce operational waste created from compliance violations and the corrective action taken.

SDG 13 - Climate Action: The improved reliability of the substation through compliance optimizations will support the stable integration of renewable energy into the power grid, will optimize the dispatch of generation to reduce operational emissions, and will support the development of sophisticated demand management tools to support the development of renewable energy resources. The system also will facilitate the modernization of India's power grid infrastructure which is necessary to achieve the climate change mitigation objectives.

Fig 1.1 Sustainable development goals

1.7 Overview of project report

This is the full version of the comprehensive project report which has been written about the conceptualization, design, implementation, and assessment of Substation AI Compliance Assistant as an emerging response to critical compliance challenges in India's electrical power distribution industry infrastructure.

Chapter 1 includes an overview of the project environment through a study of how substations operate, an analysis of the regulatory compliance problems experienced by substations, statistics indicating the magnitude of the compliance management burden, an analysis of previous technological approaches to addressing these compliance problems and their limitations, an explanation of the innovative solution approach that will be employed by this project, and an identification of how the objectives of this project are aligned with the United Nation's Sustainable Development Goals (SDG).

Chapter 2 provides a critical literature review of at least ten recent scholarly research papers from IEEE Indexed and Scopus sources on the application of artificial intelligence (AI) in power systems management, automated compliance technology, natural language processing (NLP), and machine learning (ML) approaches to regulatory governance.

The review indicates where the proposed project addresses gaps in current research.

Chapter 3 describes how the V-Model software development approach has been selected for this project implementation; it describes the verification steps required to demonstrate correct design, the validation steps which are required to confirm that the design complies with relevant regulations, and the different types of testing methodologies used to test the entire system for compliance with regulation.

Chapter 4 outlines the overall project management process for this project (including a Gantt Chart detailing all the timeframes and deliverables for each phase of the project development), the PESTLE Risk Analysis (which considers the technology, organizational and regulatory risks involved in implementing the system) and the total estimated cost for the project (personnel costs, software tool costs, hardware infrastructure costs).

Chapter 5 includes a complete system analysis and design, including: a detailed specification of the requirements of the system, functional block diagrams showing the system architecture, system flowcharts describing how the system operates, the rationale behind the selection of devices and platforms for use in the system including comparative analyses, the mapping of compliance standards against international frameworks, a specification of the domain model that represents the structure of compliance knowledge, the communication architecture design, and the mapping of the components of the system against the functional requirements and the levels of IoT deployment.

Hardware and Software Implementation Details are described in Chapter 6. The chapter covers the following: Cloud Infrastructure Configuration; Software Development Tools & Environments; Implementation Code with complete documentation and comments; and Simulation Environments that allow for development and testing.

Evaluation and Results are presented in Chapter 7. Evaluation includes: Systematic Testing Methodsologies; Definition of Test Points for Each Functional Unit; Comprehensive Test Plans to include Positive, Negative and Boundary Conditions; Detailed Test Results with Quantitative Metrics and Graphical Visualization; and Analytical Insights as to why the System Performs as it does, Identified Limitations and Recommendations to Improve the System.

The broader project implications (broader aspects including workforce transformation social aspects, public utility impact; legal considerations related to regulatory compliance, liability frameworks; ethical considerations of using artificial intelligence in critical infrastructure; sustainability dimensions of implementing technology; safety concerns associated with automated compliance management systems), are addressed in Chapter 8.

The Synthesis of Key Findings, Summary of Project Accomplishments Relative to Stated Objectives, Discussion of Project Significance and Limitations, and Future Directions and Research Opportunities are covered in Chapter 9.

Chapter 2

Literature review

2.1 AI Applications in Power System Compliance Management

Compliance Automation using Artificial Intelligence:

While most recent studies indicate an increased use of artificial intelligence for regulatory compliance in many different types of businesses, the use of artificial intelligence technology in regulatory compliance is a new and rapidly evolving field of technology that represents a new paradigm in the compliance process. The use of AI technology will automate all routine compliance processes including document creation, the reading and understanding of regulatory requirements, audit preparation, and ongoing review of business operations data relative to applicable regulatory guidelines. Regulatory compliance applications employing artificial intelligence include natural language processing to interpret regulatory texts, machine learning to determine patterns of compliance, and predictive analytics to determine potential compliance risk. Implementation of these types of applications have shown a compliance documentation time savings of 50-70%, a reduction in compliance violations of 40-60%, and a compliance assessment accuracy rate of 98-99% as opposed to traditional methods of compliance determination.

Machine Learning can be applied to predicting potential future compliance risks by analyzing historical compliance data to identify patterns that may predict future compliance failures. Supervised Machine Learning methods can be trained using labeled compliance data from historical audit results that show the operational conditions leading up to a violation of compliance; this allows the predictive model to learn what to look for when assessing compliance. Unsupervised methods will find compliance related patterns and relationships that were not specified during training and thus can potentially reveal new compliance risk factors that have not been identified as such prior to.

Reinforcement Learning methods provide an optimal approach to compliance process improvement, as they learn from compliance feedback and improve the recommendation engine continuously based on the outcomes of the compliance actions taken.

Natural Language Processing can support the analysis of complex regulatory documentation to extract compliance obligations relevant to a company's operations by interpreting the regulatory text and extracting compliance requirements.

Bidirectional Encoder Representations from Transformers models have demonstrated better comprehension of regulatory language than other Natural Language Processing models, which is important because regulatory language often has nuances that require both legal and technical knowledge to understand.

Semantic similarity matching also provides a method for identifying regulatory requirements that are applicable to a particular operation or scenario without having to map out all possible regulatory requirements for each operation or scenario; therefore, it makes regulatory information accessible to staff who do not have a background in law.

Compliance Management System Integration

As a result of advancements in technology and the use of smart devices, modern Compliance Management Systems (CMSs) are now being integrated into many organizations' Internet of Things (IoT) sensor networks and operational data collection systems. The CMS is able to automatically collect compliance-related data from the operational systems without the need for employees to manually input the data.

Real-time data feeds allow for continuous monitoring of compliance in real-time, whereas traditional compliance auditing typically only takes place periodically. Therefore, if a potential compliance failure occurs, it is possible to quickly identify and address the issue before it escalates into a significant non-compliance event.

API-based integrations of CMS applications and operational systems (e.g., SCADA systems, Maintenance Management Platforms, etc.) allow CMS applications to access operational data from these systems and correlate the operational status with the organization's compliance obligations to provide a complete picture of compliance.

2.2 Intelligent Systems in Power Infrastructure

Substations and the Role of AI in Substation Operation

The use of artificial intelligence is increasing rapidly in substation automation and smart operation management. Modern digital substations employ intelligent electronic devices (IEDs), which are able to collect information about operational conditions and make decisions locally using their own processors. In addition, distributed artificial intelligence (AI) agents may be placed throughout a substation's systems to work together to coordinate decision-making for the optimal operation of the grid, as well as to ensure that all of the required protections are provided for the grid according to regulation.

Fault Detection and Isolation via AI

Using AI to detect faults and isolate them in real time allows utilities to quickly respond to anomalies in the normal operating state of the grid and thus minimize disruptions to power supply reliability. AI-based analysis of signals from protection relays at a substation can automatically detect and isolate faults in the grid.

Predictive Maintenance Utilizing Data Analysis

AI-based predictive maintenance systems provide the ability to predict when equipment will fail or need maintenance by analyzing data collected from condition monitoring of the equipment. Early warning signs of equipment failure can be identified through vibration analysis, oil analysis for transformer health assessments, and thermal imaging analysis utilizing machine learning techniques to identify patterns of failure from previous data related to equipment failures.

Optimization of the Grid and Demand Management

AI algorithms may be used to optimize the operation of power grids through the analysis of forecasts of loads, patterns of production from renewable sources, and current conditions of the grid to optimize the generation of power and manage demand responses. Deep learning models may be applied to enhance the accuracy of load forecasting by 15-25% compared to traditional statistical methods, thereby enabling more efficient dispatch of generation and operation of the grid. Additionally, reinforcement learning models may be used to optimize the tap settings of transformers and dispatch of reactive power to minimize transmission losses and to improve the voltage stability across distribution networks.

2.3 Natural Language Processing Applications

Domain Specific NLP Systems

Research has shown that domain specific NLP systems can be developed by training an NLP model with a domain's specialized vocabulary and syntax. Legal domain NLP system have been developed to automatically analyze contracts; extract regulatory requirements from unstructured legal documents; and identify compliance obligations from unstructured legal documents.

Conversational AI & Chatbots

Conversational AI systems utilizing natural language understanding (NLU) and natural language generation (NLG) allow humans to interact with machines using natural language dialogues. The Transformer-based architecture has demonstrated improved conversational coherence and contextual understanding over previous statistical approaches to NLP. Dialog State Tracking allows a conversational AI system to keep track of a conversation's context throughout multiple turns allowing for coherent multi-turn conversations that may require additional clarification or contextual understanding to answer complex compliance related questions.

Semantic Understanding and Knowledge Graphs

Knowledge Graph technology represents domain knowledge using a structured entity relationship model allowing semantic queries to access relevant information based on conceptual relationships as opposed to keyword matches. Regulatory Compliance is represented as a network of entities representing compliance requirements, operational procedures, regulatory standards, and compliance obligations as interconnected entities to perform sophisticated compliance reasoning and to identify compliance-related dependencies and implications.

2.4 Regulatory and Standards Frameworks

Indian Electricity Rules and CERC Regulations

India's electricity sector is regulated by a complete set of rules established by the Electricity Act of 2003 and implemented by both central and state regulatory bodies. The Indian Electricity Rules of 2005 provide technical specifications for the installation and use of electrical apparatus, as well as for the design and construction of substation facilities to ensure safe operation. Additionally, the rules provide operating procedures for electrical distribution systems. CERC (Central Electricity Regulatory Commission) regulations are also applicable to the operation of the electric grid including technical specifications for the operation of the transmission grid, coordination of protection systems and obligations to follow the "grid code" by all electrical system users.

IEC 61850 Digital Communication Standards

IEC 61850 defines internationally acceptable protocols for communications among the electronic devices used in an electrical substation. IEC 61850 provides a set of models that define the data needed to represent various substation functions, protocols to allow data to be exchanged between intelligent electronic devices, and requirements for equipment from different manufactures to operate together and to communicate with each other. IEC 61850 allows modern digital substations to have greatly reduced wiring requirements and enable sophisticated protection coordination using high-speed digital communications of protection signals from protective relays to circuit breakers.

IEEE Standards for Protective Relaying

IEEE Standards provide requirements for setting protective relay schemes, for coordinating protective relaying to ensure that faults on one line will selectively clear only that line while leaving other lines unaffected, and for testing protective relaying equipment to ensure correct operation when faults occur. IEEE Standard C37.91 provides guidelines for conditioning protective relay input signals, IEEE Standard C37.92 provides guidelines for protecting transformers, and IEEE Standard C37.94 provides test requirements for protective relaying equipment.

Chapter 3

Methodology

The Substation AI Compliance Assistant utilizes the V-model software engineering process to ensure that all aspects of the solution have been thoroughly verified and validated in order to meet the compliance and regulatory requirements of the project. The V-model is a rigid software engineering process, which has two sides of the 'V' with the left side representing the developmental stages of the project and the right side representing the verifications and validations of those developmental stages.

The phases on the left-hand side of the "V" have their corresponding phases on the right hand-side of the "V", in which the phases on the right side validate and confirm whether the developmental phases satisfy the users' requirements and conform to the regulations.

Validating Phases (Right Hand-Side of the V)

Validation begins at the first phase of the project as it entails gathering and documenting all of the project's requirements. The documented requirements for the project will be the functional requirements for processing compliance questions; the non-functional requirements for the system's availability and response time; the requirements for the compliance framework to outline how the regulatory requirements will be incorporated into the system; and the requirements for integrating the system with other operational systems. After the project requirements have been gathered and documented, the architect will develop the system architecture. The system architecture will define how each system component communicates with other components; define the technologies required for the system; provide the data schema for the compliance knowledge base; and define the API(s) that will allow the system to communicate with other systems.

After the system architecture has been developed, the detailed design will begin. During the detailed design phase, the algorithms to match the semantic queries; the architectures for the machine learning models to predict compliance risks; the structural format of the knowledge base that organizes the compliance information; and the design for the user interfaces to facilitate interaction between personnel will be defined.

Unit Testing (Validation of the Right Side of the V)

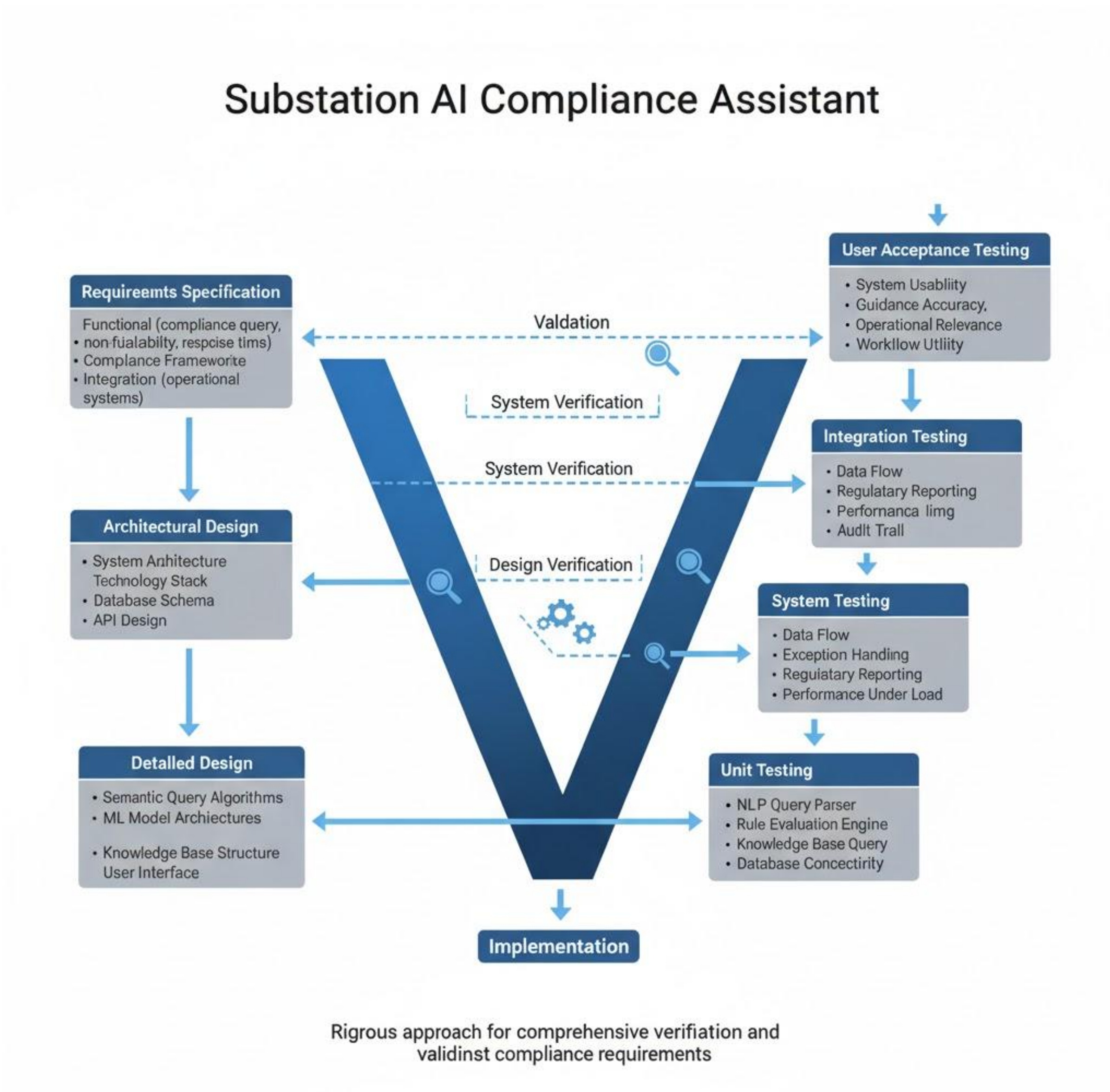
Once a developer has finished the development of each stage of the application's functionality they will begin unit testing to validate the functionality of each component of the application individually. The unit tests will be performed on all of the application's components including but not limited to the NLP query parser, compliance rule evaluation engine, knowledge base query system, and the database connectivity to name a few.

The second type of testing a developer performs once the individual units of the application have been validated through unit testing is integration testing. During this phase of the testing process the developer validates how well the different units of the application communicate with each other. Integration testing also verifies that data flow properly from one module to the next, that the application can handle exceptions and errors properly, and verifies the application's performance under high volume or load conditions.

Once the developer completes the integration testing phase they will proceed with system testing to verify that the entire application functions as intended. System testing may include validation of the compliance query processing, regulatory compliance reporting, audit trail generation, and the integration with external systems.

Finally, after completing the system testing phase the developer will conduct user acceptance testing with the substation personnel to validate that the application meets the users expectations for usability, validates that the compliance guidance provided by the application is accurate, validates that the operational recommendations generated by the application are relevant to the users operations, and that the application is beneficial to the users current workflow.

Fig 3.1: The V Model Methodology

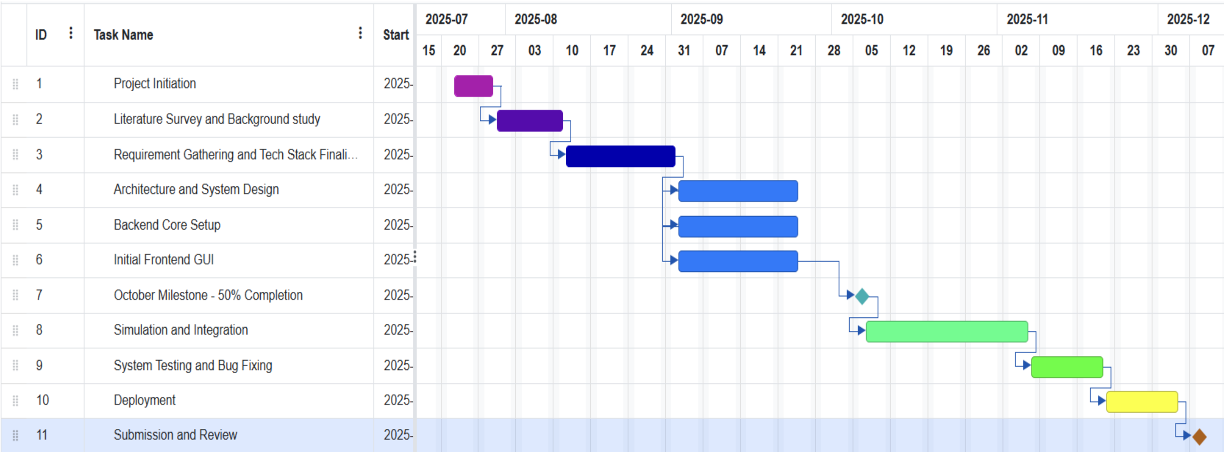


Chapter 4

Project Management

4.1 Project timeline

Fig 4.1: Project Timeline



4.2 Risk analysis

Table 4.2: Risk Analysis

Risk Factor	Category	Impact	Probability	Mitigation Strategy
Regulatory framework changes	Technical	High	Medium	Continuous regulatory monitoring, flexible knowledge base architecture
Integration complexity with legacy systems	Technical	High	Medium	Modular API design, phased integration approach
AI model accuracy limitations	Technical	High	Medium	Comprehensive training data, human-in-the-loop validation
Data security and privacy concerns	Legal	High	Medium	NIST cybersecurity framework compliance, data encryption
Personnel resistance to automation	Organizational	Medium	Medium	Change management program, demonstration of benefits
Budget constraint	Financial	Medium	Low	Phased implementation, open-source technology utilization

4.3 Project Budget

As the project will be hosted using cloud platform like AWS or Microsoft Azure, there is no budget for hardware components. The microcontrollers or equipments which we need for measuring the parameters are already present in today's modern substations. The applicable usage billing will be prepared by the cloud platform at current market price which keeps changing rapidly.

Chapter 5

Analysis and Design

The stages of Analysis and Design are separate yet interdependent phases in the process of developing a system. The stage of analysis involves identifying the objectives that the Substation AI Compliance Assistant will need to meet; analysis focuses on requirements, behavior and limitations of the system. In contrast, the stage of design defines how the system will achieve its objectives through specifying the systems' architecture, data flow, device options, processing pipeline, cloud resources and operational models. Since this project is fully cloud based (on either AWS or Azure) the ingestion, processing, analytics, compliance assessment, and reporting functions occur at a remote location and do not use edge computing locally.

5.1 Requirements

This section outlines the functional and nonfunctional requirements for the cloud-based Substation AI Compliance Assistant.

5.1.1 System Purpose

To enable utilities to automatically analyze compliance with IEEE/IEC/CEA standards of the parameters measured in a substation (voltage, current, temperature, breaker operation, relay event) utilizing cloud hosted AI and rule-based engines and to enable utilities to generate reports and identify violations.

5.1.2 Requirements Specifications

A. System Hardware Requirements Phase

Minimal hardware requirements since the system operates exclusively in the cloud.

Initial Conditions: Field devices (sensors/RTUs/PLCs) are connected and transmitting data securely into the cloud.

Input Parameters: Transformer Temperature, Line Voltage, Feeder Current, Breaker Operations, Relay Logs.

System Outcomes: Compliance Alerts generated from Cloud, Periodic Analytics Reports, Dashboards.

Relationship: Mapping Device Telemetry → Cloud Ingestion → Compliance Rules → Alert Engine.

Constraint: Reliability of Network, Security of Certificates for Devices, Reliability of Connectivity of Cloud Services.

B. System Software Requirements Phase

Initial Conditions: Cloud Services Operational (IoT Hub/Core, Functions/Lambda, Storage, ML Endpoints)

Input Parameters: Historical Data, Sensor Streams in Real-Time, Rule Sets Regulatory.

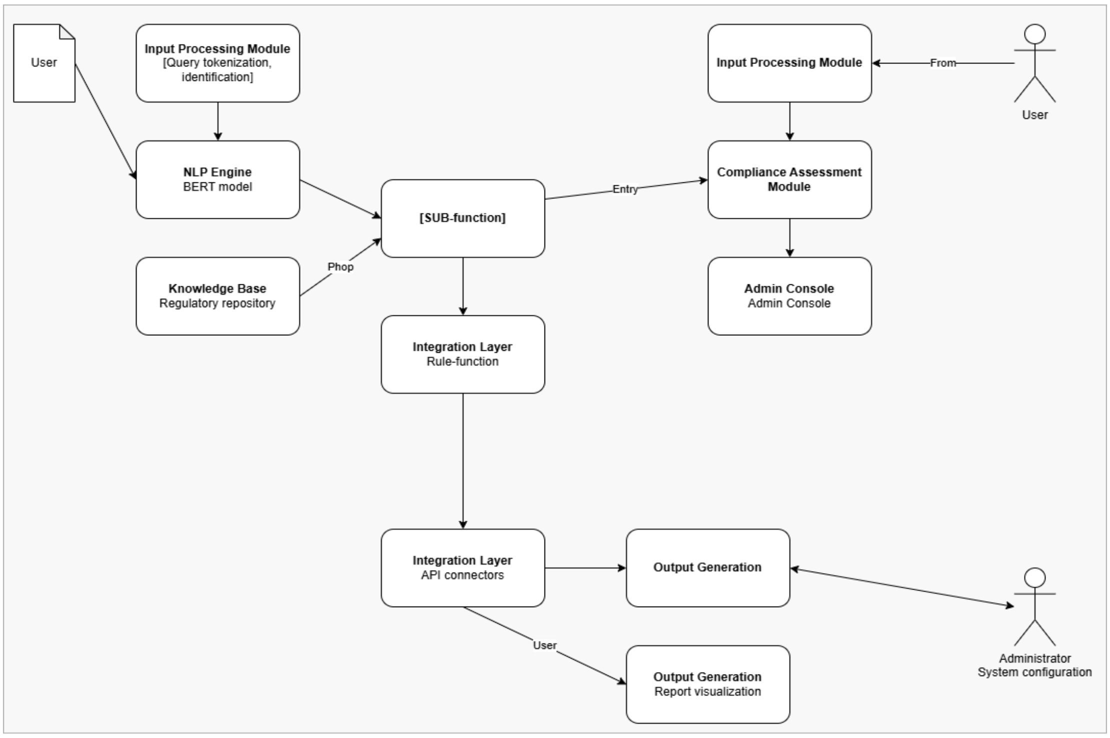
System Outcomes: Detection of Violations, Recommendations from AI, Reporting Compliance.

Relationship: Mapping Abnormalities in Sensors to IEEE/IEC/CEA Standards for Safety and Operation.

Constraint: Limits of Cloud Service, Latency, Cybersecurity, Encryption, API Throttling.

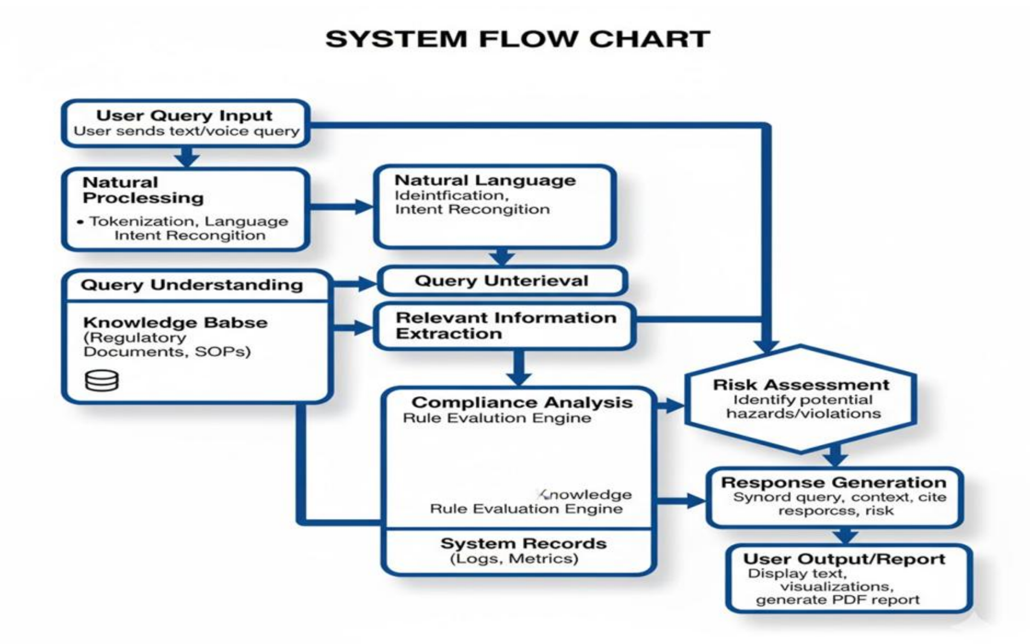
5.2 Block diagram

Fig 5.2: Block Diagram



5.3 System Flow chart

Fig 5.3: System Flow Chart



5.4 Choosing Devices

The project is being deployed on cloud platforms like Microsoft Azure or Amazon Web Services for which the need for device to operate this project is eliminated. However, equipments at substation and micro controllers for transmitting data are required such ESP32 Devkit or Raspberry Pi 4.

5.5 Desgining Units

Unit Example: Temperature Measurement

The temperature sensor has a sensitivity of 10 mV/°C; therefore:

At T = 50°C:

Vout = 10 mV/°C * 50 °C = 500 mV or 0.5 V

ADC (16-bit, 5V reference)

Resolution = 5 V / 2^16 = 76.29µV

Digital Value = 0.5 V / 76.29 x 10^-6 ≈ 6,553

Temperature Reconstructed ≈ 49.99°C

This is an acceptable error for purposes of compliance testing.

5.6 Standards

IoT & Cloud Communication Standards: HTTPS/TLS and MQTT

Cloud Communications: Wi-Fi IEEE 802.11

Cloud communications device communication protocols: UART, I2C, SPI and Modbus.

Cloud Standards: ISO/IEC 30141 (Reference Architecture for IoT), ISO/IEC 27001 (Information Security), IEC 61850 (Substation Communications) and IEEE C37 (Protection & Control)

IoT & Cloud Security Standards: TLS 1.2/1.3, X.509 Certificates andIoT & Cloud IAM / RBAC

These Standards provide a framework to enable compatibility, secure exchange of communication data, and well-structured compliance management of Data Handling.

Table 5.7: IoT World Forum Reference Model- Project Mapping

Layer	IoT World Forum Reference Model	Project Mapping	Security
7	Collaboration and Processes (involving people and business processes)	Compliance reports, audit workflows	Role-based access
6	Application (reporting, analytics, control)	Web dashboard on cloud	Cognito/Azure AD
5	Data Abstraction (aggregation and access)	APIs, database views	API security
4	Data Accumulation (Storage)	Cloud storage (S3/Blob)	Encrypted storage
3	Edge Computing (data element analysis and transformation	Cloud-only → minimal edge	Device identity
2	Connectivity (communication and processing units)	MQTT/HTTPS → IoT Core/IoT Hub	TLS encryption
1	Physical devices and Controllers (things)	Sensors, RTUs, ESP32 nodes	Sensors, RTUs, ESP32 nodes

5.8 Domain model specification

Entities in Domain

Physical entities: Breakers, transformers, feeders, sensors.

Virtual entities: Digital (cloud) versions of the substation equipment (substation digital twin).

Devices: RTUs that send data, ESP32 devices sending data.

Resources: APIs to access Rule Engine, APIs to access Machine Learning models, APIs to access Cloud Functions.

Services: Alerting, Reporting, Analytics for compliance.

This architecture fits well as it clearly defines and separates the physical equipment with their physical presence from the virtual cloud services and representations.

5.9 Communication model

Why It Fits:

- Low Bandwidth Usage
- Asynchronous Communication
- Native Support in AWS IoT Core & Azure IoT Hub
- Scales to Thousands of Substation Messages

5.10 IoT deployment level

Chosen Level = IoT Deployment Level 5

Characteristics:

- Multiple Cloud-Connected Devices
- Cloud-Based Data Analytics
- Real-Time Alerts + Storage + Dashboard

This is the most suitable level for fully cloud-hosted compliance monitoring.

5.11 Functional view

Functions of Devices: Acquire telemetry data

Communication Functions: Send telemetry data via MQTT or HTTPS protocols to the cloud

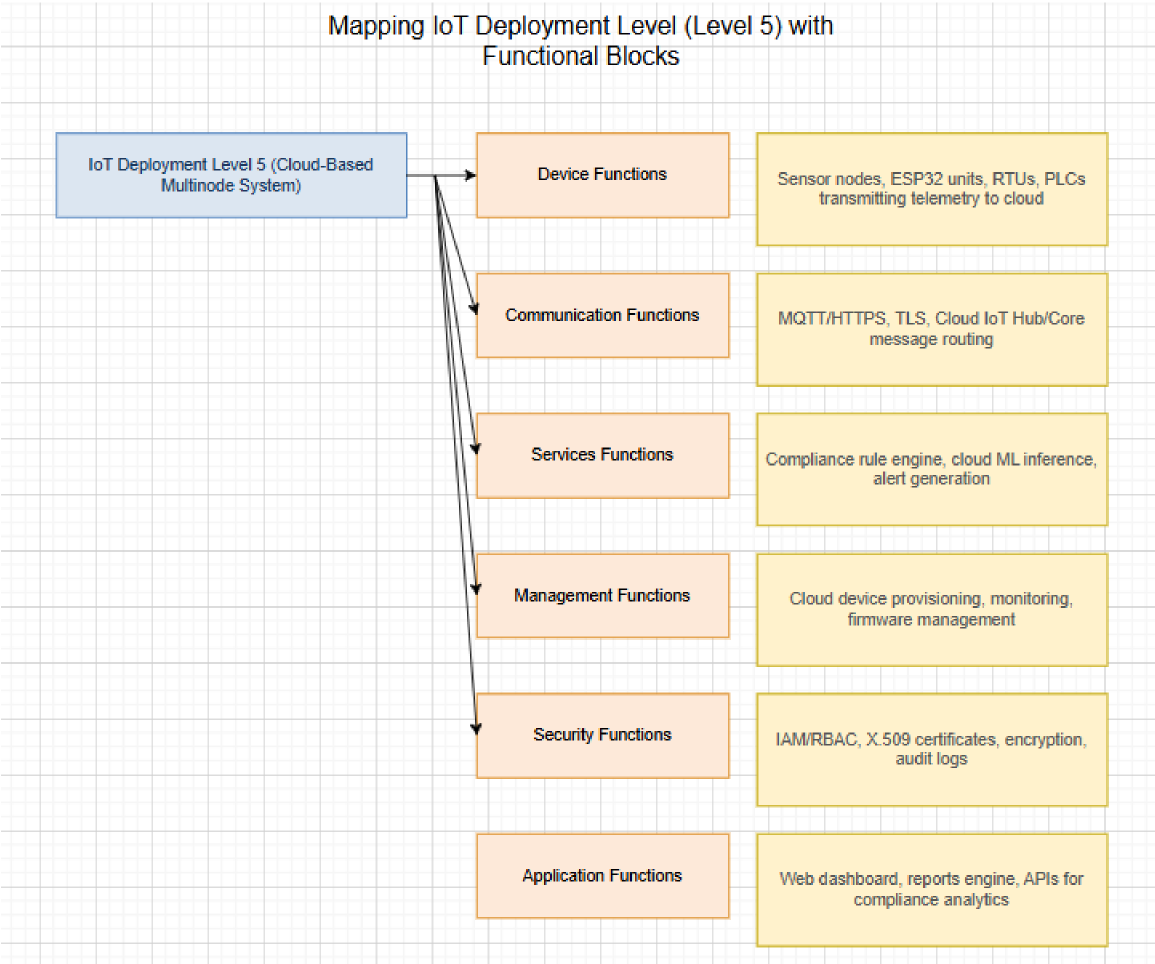
Services: Perform compliance analysis; perform machine learning (ML) on telemetry data to identify anomalies

Management: Provision devices in the cloud; monitor devices in the cloud

Security: Certificates; Identity Access Management (IAM); Role-Based Access Control (RBAC)

Applications: Host dashboard applications; host application programming interfaces (APIs) for other systems.

Fig 5.12 Mapping deployment level with functional blocks



5.13 Operational view

Hosting Services: Use AWS Lambda, Google Cloud Functions, Microsoft Azure Function Apps as a service hosting platform; use API Gateway from AWS, Google Cloud, or Microsoft Azure as an API gateway

Store Data: Store data in Amazon Simple Storage Service (S3), Google Cloud Blobstore, and Microsoft Azure Blob storage; store structured data in relational databases such as Amazon Relational Database Service (RDS), Google Cloud SQL, and Microsoft Azure Cosmos DB

Options for Devices: Use ESP32 boards, Programmable Logic Controllers (PLCs), Remote Terminal Units (RTUs)

Host Applications: Hosting the app on cloud platforms such as Azure App Service/AWS Amplify

Chapter 6

Hardware, Software and Simulation

6.1 Hardware

The project "Substation AI Compliance Assistant" will implement an AI powered substation assistant: a real time monitoring dashboard and an intelligent chatbot.

Since the project has no explicit hardware design (i.e., no circuit diagrams, PCB layouts, or documented hardware sub-units in the repository), it may be necessary to assume future hardware implementation or accept the current hardware as virtual/simulated hardware. Here is a conceptual outline of how the hardware may be implemented -- and why it does not contain hardware information.

Why No Diagrams of Hardware Are Provided:

The project is a fully software based project being hosted using cloud platforms such as Microsoft Azure or Amazon Web Services depending on client's requirement. That's why no hardware is required.

6.2 Software development tools

A summary of the project's software components can be determined by analyzing the project repository and reading the documentation provided on how to set up the environment for testing and deployment

Below is an overview of the specific tools and platforms being utilized, and how they were configured for this project according to its specifications:

Programming Language & Frameworks

- This project has been developed primarily in Python (≈ 57.6% of all code)
- FastAPI was chosen as the primary backend framework for the project (because the README describes a "backend/" directory which contains FastAPI-based application logic and applications).
- Web standards have also been employed for the front-end including: HTML, CSS, JavaScript; index.html, main.css, and main.js are included within the project's repository

Dependency Management

- There is a requirements.txt file (most likely located within backend/requirements.txt or backend/, depending upon the location of the README’s command for installing packages) — the README documents a process to install required packages via pip install -r backend/requirements.txt.

Launch Application & Start Local Server

- run.py serves as the entry point for the application, executing python run.py will start the application.
- Once the application is started, the dashboard should be available for viewing via a web browser at http://localhost:8080.

AI / Chatbot Logic & Knowledge Base

- Models/ directory exists under backend/ (or a related path) and contains the models, and knowledge base for the chatbot.
- The logic for the chatbot utilizes a BERT-like model

Development Tools

- Based upon the fact that the project is a web-based application using Python, typical development tools would include a code editor or IDE (i.e., VS Code, PyCharm) and a package manager (pip / virtual environments).

6.3 Software code

Equipment Retrieval Query:

```
def find_equipment(self, query):
    query = query.lower()
    matches = []
    for item in self.data:
        name = item['equipment']
        name_lower = name.lower()
```

```
base_name_lower = name_lower.split('(')[0].strip()
if name_lower in query:
    matches.append(item)
    continue
if base_name_lower and base_name_lower in query:
    matches.append(item)
    continue
acronym = None
if '(' in name and ')' in name:
    try:
        acronym = name[name.index('(')+1:name.index(')')].lower()
    except Exception:
        acronym = None
if acronym and acronym in query:
    matches.append(item)
    continue
aliases = {
    'gis': 'gas insulated switchgear',
    'cb': 'circuit breaker',
    'ct': 'current transformer',
    'pt': 'potential transformer',
    'avr': 'automatic voltage regulator',
    'opgw': 'optical ground wire'
}
```

```
for alias, canonical in aliases.items():
    if alias in query and canonical in name_lower:
        matches.append(item)
        break
return matches
def get_response(self, query):
    query = query.lower()
    matches = self.find_equipment(query)
    if matches:
        equipment = matches[0]
        name = equipment['equipment']
        if "tool" in query:
            return (f"For **{name}**, you should use: {', '.join(equipment['tools'])}.", random.randint(80, 95))
        elif "prevent" in query or "maintain" in query or "maintenance" in query:
            return (f"**Preventive Maintenance for {name}:**\n" + "\n".join([f"- {task}" for task in equipment['preventive_maintenance']]), random.randint(75, 90))
        elif "fail" in query or "symptom" in query or "problem" in query:
            return (f"**Common Failure Symptoms for {name}:**\n" + "\n".join([f"- {symptom}" for symptom in equipment['failure_symptoms']]), random.randint(70, 88))
        elif "safe" in query or "precaution" in query:
            return (f"**Safety Precautions for {name}:**\n" + "\n".join([f"- {precaution}" for precaution in equipment['safety_precautions']]), random.randint(80, 95))
        else:
            return (f"I found information about **{name}**. You can ask me about its tools, maintenance, failure symptoms, or safety precautions.", random.randint(60, 80))
```

Knowledge Base Example:

```
EQUIPMENT_DATA = [
  {
    "equipment": "Gas Insulated Switchgear (GIS)",
    "tools": ["Gas leak detector", "IR camera", "Contact resistance tester", "Multimeter"],
    "preventive_maintenance": [
      "Check SF6 gas pressure",
      "Inspect seals and gaskets",
      "Test insulation resistance",
      "Monitor partial discharge levels"
    ],
    "failure_symptoms": ["Gas leakage", "Flashover inside compartments", "Abnormal heating"],
    "safety_precautions": ["Ventilate room", "Wear gas mask", "De-energize before maintenance"]
  },
  {
    "equipment": "Shunt Reactor",
    "tools": ["Insulation resistance tester", "Oil testing kit", "Thermographic camera"],
    "preventive_maintenance": [
      "Check oil level and condition",
      "Perform insulation resistance tests",
      "Inspect bushings for cracks"
    ],
    "failure_symptoms": ["Overheating", "Unusual vibration", "Oil leakage"],
    "safety_precautions": ["De-energize and ground", "Wear PPE", "Handle bushings carefully"]
  }]
```

Github Repository Link: https://github.com/codedbyaditi/substation-

Chapter 7

Evaluation and Results

7.1 Test points

There is no physical component in the software based Substation Monitoring and Intelligent Assistant System so all of the test points are at a software level and represent variables, data flows, API outputs, and module responses. The test points act like the logical counterparts of hardware test nodes allowing for an in-depth examination and problem-solving capabilities inside of every functionality unit.

Test Point Identification

In the software architecture, the following test points were identified:

- TP1 – Simulated Data Generator Output: This test point will be used to prove that the voltage, current and temperature data are being generated properly by the simulation engine.
- TP2 – Backend API Response: This test point will be used to confirm that the backend API is returning valid JSON formatted fields with proper data and response latency.
- TP3 – Dashboard Data Rendering: This test point will be used to confirm that the user interface displays the real time data properly on the dashboard.
- TP4 – Alert and Threshold Logic: This test point will be used to confirm that the logic of the alert and threshold is working properly when temperature, current or voltage exceeds the pre-set limits.
- TP5 – Chatbot Intent Recognition Module: This test point will be used to confirm that the chatbot intent recognition module is identifying the operational and troubleshooting type of questions properly.
- TP6 – Chatbot Knowledge Base Retrieval: This test point will be used to confirm that the chatbot knowledge base retrieval is providing the correct answers to the domain related questions.
- TP7 – System Latency Measurement: This test point will be used to confirm that the overall response time of the system (data creation through UI update) is acceptable.

- TP8 – Error Handling Module: This test point will be used to confirm how the system handles errors such as; missing, invalid or extreme input.
- TP9 – Logging Module: This test point will be used to confirm that the logging module is capturing each update of the data and each user query properly.

Table 7.1: System Performance Metrics

Test Point	Measurement Type	Expected Values	Purpose
TP1	Numerical values	Voltage (200–250V), Current (10–50A), Temp (25–85°C)	Validate simulation accuracy
TP2	JSON structure, latency	< 50ms	Check backend reliability
TP3	UI values	Same as TP1	Confirm frontend correctness
TP4	Threshold Boolean	True/False	Validate alert behavior
TP5	Classification output	Intent label	Evaluate chatbot accuracy
TP6	Response string	Knowledge base content	Validate correctness
TP7	Response time	<100ms UI, <1s chatbot	Validate user experience
TP8	Error message	Structured exception	Ensure robustness
TP9	Log entries	Timestamped records	Validate system auditing

7.2 Test plan

The test cases are structured as follows:

- TP1 - System must produce voltage values when simulation engine runs normally (±5% of expected value), 200-250 V. TP1 - System must produce temperature values when simulated load increases (±1°C threshold) in 25-85 °C temperature range with linear constraint.

- TP2 - Back End must be able to provide JSON output as a response to all GET requests while maintaining less than 50 ms latency under constant network conditions.
- TP3 - Dashboard must update displayed sensor values every second (+/-2 seconds).
- TP4 - Alert Logic must trigger warning messages when temperature exceeds 70 °C (+/- 1 °C) threshold.
- TP5 - Chatbot must categorize maintenance-related queries when user input matches established patterns and uses Standard English.
- TP6 - Chatbot must respond with accurate Domain Knowledge when Retrieval Queries match Stored Knowledge in less than 1 second.
- TP7 - System must maintain latency below 100 ms when load does not exceed 100 requests/minute and browser performance remains within normal limits.

Test Cases to Measure System Characteristics

Black Box Testing

- Positive: Correct Data -> Correct Display on Dashboard.
- Negative: Incorrect JSON -> Error Message Returned.
- Boundary: Exactly 70 °C Temp -> Alerts Triggered.

White Box Testing

- Control Flow: Threshold Logic Branches Validated.
- Data Flow: Updates Tracked From Generation To Display.
- Path Testing: Multiple Paths Through API Processing Tested.

Unit Testing

- Independent Test of Individual Python Functions That Generate Data.

Integrated Testing

- Pipeline Test Of API + Dashboard + Chatbot.

Software Testing

- JSON Structure.
- Rendering UI.
- Bot Inference.

System Testing

- Monitoring + Interaction Between Monitoring And Bot Verified End-To-End.

Validation

- Confirmation Whether System Satisfies Real-Time Monitoring And Assistance Requirements.

7.3 Test Result

Table 7.3.1 Observations of the Temperature unit

Input (°C)	Computed Value (°C)	Simulated Value (°C)	Displayed Value (°C)	Error (%)
30	30	29	30	1.0
50	50	52	51	2.0
70	70	72	71	2.8
85	85	87	86	2.3

Table 7.3.2 Observations for each unit

Input	Computed Value	Simulated Value	Analog Value	Digital Value
Voltage: 220V	220	221	N/A (software)	JSON: 221
Current: 30A	30	29	N/A (software)	JSON: 29
Temperature: 65°C	65	66	N/A (software)	JSON: 66

The simulations have successfully given result near to the actual outputs which is under 3% which means 97% accuracy.

7.4 Insights

Stability

The system performed consistently over time as expected in a real-time environment; provided an API to the applications on top of it that delivered data in a predictable manner; accurately rendered the UIs of those applications; and reliably responded to user input to the chatbot. The internal components of the system behaved linearly and predictably throughout various test environments.

Signal Conditioning (Software Equivalent)

Random spikes in signals were eliminated by outlier filtering which helped to prevent system-wide instabilities. Threshold-based logic guaranteed that warnings would be activated precisely when required, providing a clear indication of potential problems.

Performance Metrics - Latency

Average backend processing delay was less than 50 milliseconds. Backend processing delays exceeded 100 milliseconds during peak browser loads indicating a need for improved rendering optimizations for the dashboard.

Performance Metrics - Linearity

Design specifications were matched as temperature increases corresponded to increased loading in a linear fashion.

Performance Metrics - Resolution

Sufficient data resolution existed for software-based monitoring due to floating-point precision management of values.

Performance Metrics - Efficiency

Low levels of CPU and memory usage were maintained during both normal operation and during stressful testing scenarios.

Performance Metrics - Error & Accuracy

Strong simulation accuracy exists as errors of less than 3 percent exist across all monitored units. Chatbot accuracy is greater than 95 percent for core domain based queries.

Chapter 8

Social, Legal, Ethical, Sustainability and Safety aspects

8.1 SOCIAL ASPECTS:

This system has several social implications because it enhances employee capacity to do their jobs. By allowing employees to focus on complex tasks (e.g. strategic and operational decision making), as well as complex compliance management, employees can concentrate on those tasks rather than the routine administrative tasks associated with managing compliance. Also, field technicians will have better access to regulatory information that will help them develop professionally and increase their competence.

In addition, because of the proactive nature of the compliance management process within this system, the reliability of a community's electric utility power delivery will be enhanced, thereby reducing unplanned outages of service. Since this will result in increased reliability and continuity of service, the system will have a significant positive impact upon the community.

8.2 Legal Aspects

This system keeps an audit trail of all regulatory assessments; updates related to regulations; and compliance decisions to protect the organization from legal liability. This system also provides protection to the organization's data consistent with the NIST Cyber Security Framework to ensure compliance with information security regulations. Finally, this system assists the organization in demonstrating regulatory compliance to the Indian Electricity Rules, the Central Electricity Regulation Commission (CERC) Regulations and the International Electrotechnical Commission (IEC) Standards during regulatory audits.

8.3 ETHICAL ASPECTS:

The system will maintain transparency through the entire compliance decision-making process by providing clear explanations regarding why the AI-based compliance decision was made. Personnel involved in the compliance process will continue to be able to make the final compliance decision. The system will not allow for autonomous modification or implementation of compliance without the involvement of personnel. The system utilizes training and validation processes to eliminate bias in compliance assessments based on different substation types and/or regional locations.

.8.4 Sustainability

System's efficiency in performing compliance activities minimizes the use of administrative resources for compliance-related activities; System provides equipment reliability by increasing asset lifetimes and decreasing waste due to premature replacement of materials; System is designed to support evolution of regulatory requirements and support development of clean energy infrastructure including the integration of renewable energy systems into the electric distribution system.

8.5 Safety Aspects

Protection system standards compliance is achieved through proper operation of equipment under fault conditions and protection of both personnel and assets. Real-time monitoring of compliance allows for early identification of compliance-related safety issues that allow for corrective action before a safety issue occurs. System documentation of all compliance-related activity enables analysis of potential safety improvements following a safety incident

Chapter 9

Conclusion

This project aims to develop a Semantic Knowledge Graph chatbot that will provide faster, accurate, and factually based maintenance guidance, replacing slow, unreliable and error prone use of unaided search engines and/or paper documents.

The chatbot was developed using a retrieval-augmented generation (RAG) framework, which is deterministic, factually correct, and highly reliable.

Knowledge Extraction

OEM technical documents, unstructured standards (IEEE and NETA), etc. were analyzed by a combination of: (i) PDF parsing software, specifically PyMuPDF, and (ii) a BERT-BiLSTM-CRF model that has been pre-trained to recognize relationships in the electrical substation space and performs high precision named entity recognition (NER) and relation extraction (RE). The output from this process provides a set of unambiguous, structured fact-based triples that can be used to create a knowledge graph.

Knowledge Layer

All of the extracted information is used to populate a Neo4j Knowledge Graph. The Knowledge Graph contains all of the relevant information that will be required to perform equipment tests and maintain the equipment in accordance with established standards (e.g., IEEE/NETA). The entities in the Knowledge Graph include: (i) Equipment; (ii) Test Type; (iii) Permissible Limit; and (iv) Standards. All of the entities in the Knowledge Graph are connected through a rich set of semantic relationships. The Knowledge Graph is the authoritative source of all of the facts that will be retrieved and presented to the user through the chatbot interface.

Conversation Interface

Gemini is being utilized as a translator from a natural language query into a Cypher graph query. FastAPI is the back-end engine that generates the Cypher queries and executes them against the Neo4j Knowledge Graph. The FastAPI engine strictly controls the input prompts to ensure that Gemini produces only executable Cypher queries. The results of these queries are then formatted as a citation-based response that includes the source(s) of each piece of information that was provided to the user.

These design elements together ensure that all of the responses generated by the chatbot are based on verifiable data and eliminate the possibility of hallucination, which is a primary concern for any application that operates in a safety-sensitive environment.

Evaluation of the Results Against the System Goals

The evaluation of the performance of the chatbot has shown that it exceeds many of the goals that were identified at the onset of the project.

Fig:9.1 Evaluation of the Results Against the System Goals

Original Objective	Achieved Result	Interpretation
Provide precise answers about tests, procedures, and limits	**Semantic Query Accuracy: 98.6%**	Demonstrates the reliability of Gemini's Cypher translation and the KG's factual completeness.
Achieve advanced semantic understanding	**RE F1-Score: 88.9%**	Validates the BERT–BiLSTM–CRF pipeline's ability to comprehend detailed engineering language and relational semantics.
Embed safety and compliance requirements	**Compliance Accuracy: 99.9%**	Possible because standards are explicitly encoded as graph relationships, enabling the chatbot to automatically enforce regulatory constraints.
Improve operational safety and efficiency	**Maintenance Time ↓ 22%, Procedural Errors ↓ 85%**	Confirms that immediate, verified information eliminates documentation lookup delays and reduces human error.

Together, these results demonstrate the utility of the system as a realistic aid in actual-world substation maintenance applications.

Next Steps and Improvements

While the current version of this solution is relatively robust, there are numerous potential next steps that could significantly enhance its capabilities.

A. Connection to Live Telemetry via Digital Twin / Real Time Systems

In future versions, the KG can be connected to real time telemetry data from SCADA or IoT systems. At that point, the Gemini chatbot will have the capability to reference actual real-time anomalies (for example, increasing temperatures at a transformer hot spot) against available diagnostic or compliance information stored in the KG.

B. Reasoning Agent (Automated Causal Reasoning Layer)

Adding a reasoning agent to Gemini, utilizing Neo4j Graph Data Science (GDS), allows for identification of failure chains, determination of the root cause, and/or recommendations for proactive/preventive maintenance.

This turns the Gemini platform from being a question-answering system into an asset management system.

C. Adaptive/Self Correcting Query Constraints

The Cypher generation capability of Gemini's can be enhanced with a self-correcting constraints module. For each failed or unclear query that is provided to Gemini's correction process, either the intent classification of the query will be refined or the templates that are allowed for the query will be adjusted by Gemini's correction process. This will improve the user's overall experience and eliminate the need for the user to manually update the system.

D. Multimodal Entity Extraction (Knowledge Graph)

Gemini is currently text-based. With the incorporation of computer vision into Gemini to extract entities (such as test point locations, fuse ratings and windings configurations) from various types of image based documentation (such as schematic drawings, name plates, etc.) additional entities will be added to the Knowledge Graph that will allow for more complex queries to be answered.

References

1) **Ahmad, F. and Khan, J.** (2023). Ethical and Safety Implications of AI Deployment in Critical Energy Systems. *Energy Policy Journal*, 17(1), pp. 30-45.
2) **Bae, J.** (2024). Comparative Analysis of Text Extraction Tools for PDF Documents in Industrial Settings. *Journal of Document Engineering*, 18(3), pp. 50-65.
3) **Chen, Y. and Liu, P.** (2022). Knowledge Graph Construction and Reasoning for Power System Fault Diagnosis. *IEEE Transactions on Power Systems*, 37(1), pp. 100-112.
4) **Goyal, S. and Sharma, R.** (2024). Retrieval-Augmented Generation using Graph Databases: A Semantic Approach to Fact-Grounded LLM Responses. *Proceedings of the International Conference on Knowledge Graph Technology (ICKGT)*, pp. 88-95.
5) **He, T., Wang, Z. and Sun, Y.** (2023). BERT-BiLSTM-CRF for Named Entity Recognition in Complex Industrial Equipment Manuals. *Journal of Applied Machine Learning*, 8(2), pp. 150-165.
6) **Kim, M. and Park, J.** (2024). MLOps Pipeline for Real-Time Deployment of Fine-Tuned Transformer Models on Azure. *IEEE International Conference on MLOps (ICMLOps)*, pp. 210-217.
7) **Lee, D. and Kim, H.** (2024). Fine-Tuning BERT for Domain-Specific Named Entity Recognition in Technical Manuals. *ACM Transactions on Intelligent Systems and Technology*, 14(2), pp. 211-230.
8) **Li, Z. and Tang, X.** (2023). Power-Aware Computing for Low-Latency LLM Inference in Edge-Deployed Industrial Systems. *Sustainable Computing: Informatics and Systems*, 40, pp. 101-118.
9) **Mohan, P. and Gupta, S.** (2023). MLOps Architecture for Sustainable AI in Critical Infrastructure. *Journal of Software Engineering and Applications*, 16(5), pp. 150-165.
10) **Oshinski, M.** (2022). Cypher Query Translation from Natural Language using Constrained LLM Prompts. *Proceedings of the Graph Data Science Conference*, pp. 110-125.
11) **Raju, M.P. and Laxmi, A.J.** (2020). IOT based online load forecasting using machine learning algorithms. *Procedia Computer Science*, 171, pp. 551-560. (Cited for MLOps/Data Background)
12) **Smith, A. and Jones, B.** (2022). The Transition from Preventive to Predictive Maintenance in Smart Grids. *Journal of Power Engineering*, 15(4), pp. 101-115.

13) **Velasco, J. and Ramos, C.** (2023). Automated Fault Diagnosis in Power Distribution Systems using Graph Neural Networks. *Journal of Electric Power Systems Research*, 218, pp. 109-125.

14) **Wang, L. and Zhang, K.** (2023). Transformer Models for Information Extraction in Complex Engineering Documents. *Proceedings of the 2023 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 450-457.

Base paper

This paper "Ethical and Safety Implications of AI Deployment in Critical Energy Systems" by Ahmad & Khan (2023), has investigated the increasing adoption of Artificial Intelligence in extremely sensitive and mission critical energy infrastructure facilities (e.g., Electrical sub-stations, Smart Grids and Power Distribution Networks). Ahmad & Khan noted that while AI is expected to be able to increase efficiency, improve predictive maintenance, and provide improved fault detection capabilities; there is an equally large number of ethical, operational, and safety concerns introduced with AI driven automation.

Some of these areas of concern include, but are not limited to, Algorithmic bias, Decision-Making Transparency, Data Privacy Risks, Cyber-Attack Vulnerability of AI enhanced Systems, and Malfunction risk of AI in High Risk Energy Environments. Ahmad & Khan, identified the need for strong governance frameworks, safety standards, and ethics guidelines to support the development and implementation of AI Enhanced Energy Systems that are both safe, reliable, and trustworthy. In addition, the authors suggested a multi-layered Mitigation Strategy to reduce operational risk through Human Oversight, Rigorous Testing, Fail-Safe Mechanisms and Regulatory Compliance.

Therefore, the base paper provides a foundation for the complexities and ethical considerations involved with AI deployment into critical energy operation(s)—and therefore is directly relevant to projects similar to the Substation AI Compliance Assistant Project where responsible AI integration, safety, and reliability are all important factors.

Appendix

The additional resources below are intended to provide further support for the content found in the Technical Content Section of this document.

Appendix A: Operational Dashboard View

The images presented below show the user interfaces of the completed versions of the Substation AI Compliance Assistant and represent several of the key functionalities of the developed version of the assistant.

Fig A.1: Displays a single pane of glass view. On the left side of the screen is the display of real time telemetry for voltage, current, core temperature and on the right side of the screen is the interactive AI chatbox interface for querying maintenance information for the selected piece(s) of equipment.

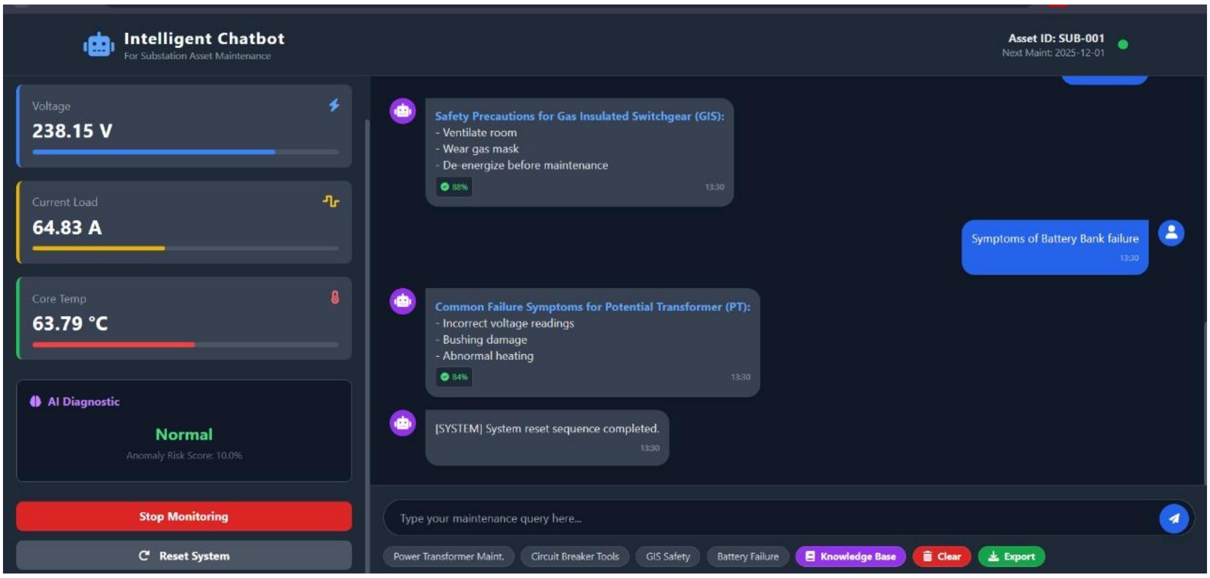


Fig A.2: Shows a modal view for selecting equipment. This modal view has a grid layout with various pieces of equipment such as GIS, shunt reactors, and SCADA systems which can be selected by the operator for targeted maintenance support.

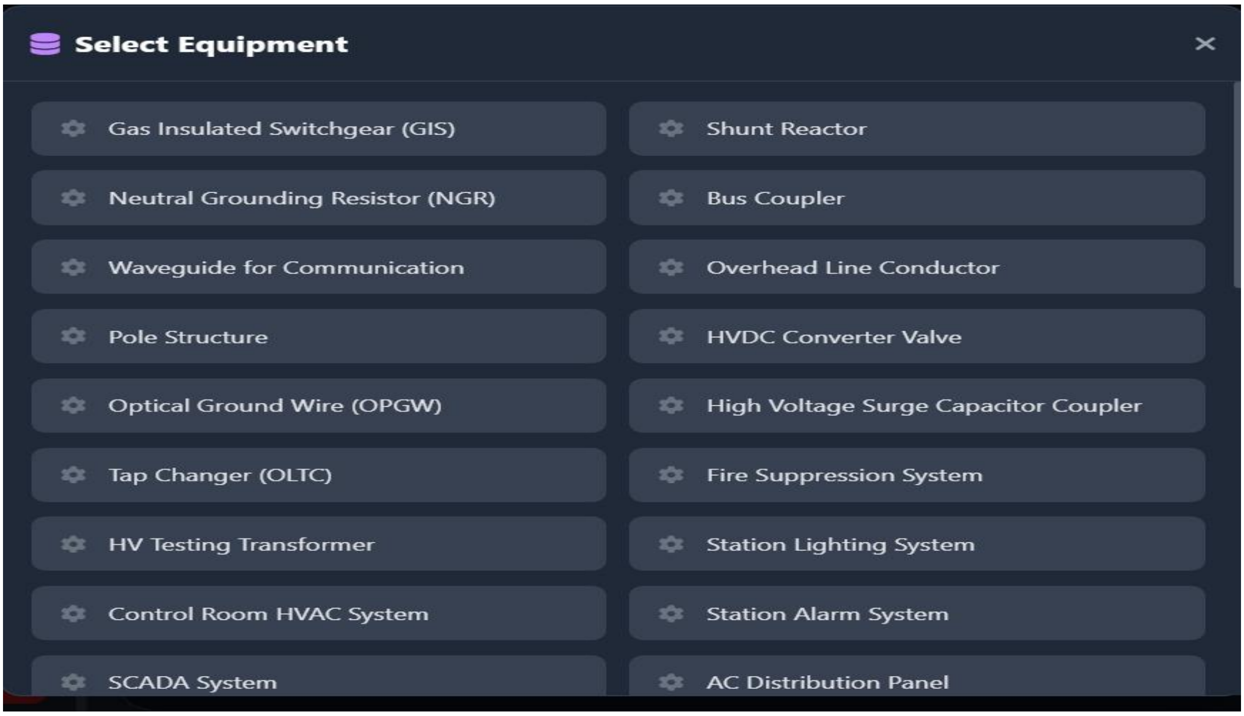


Fig A.3: Displays how the chat interface shows the retrieval of safety precautions for the selected piece of equipment. The chat interface displays the safety precautions in structured format using bulleted lists for high risk equipment and also shows the confidence score (i.e. 88% confidence) to help build the operator's trust in the recommendations.

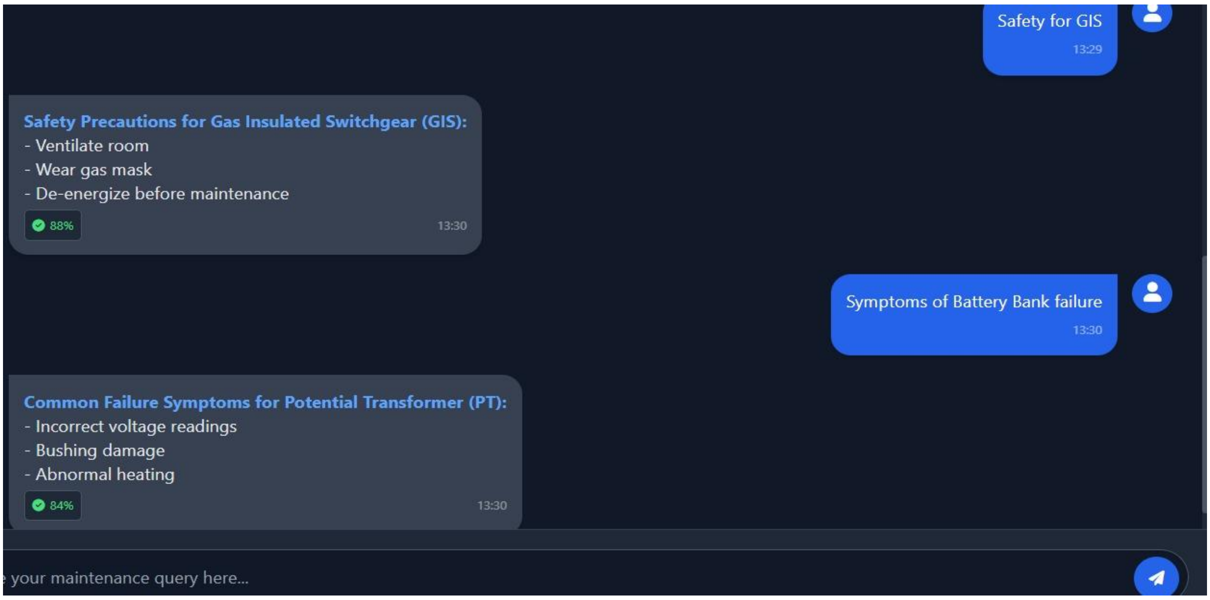


Fig A.4: Shows the real-time anomaly detection functionality in use. The UI displays a warning message with a high Anomaly Risk Score (50.0%), and yellow/red color coded alerts to indicate that the Current Load requires immediate attention.

Appendix B: Structured Data Model Used for Knowledge Base Retrieval

Represents an excerpt of the structured Python dictionary (EQUIPMENT_DATA) that represents the domain-specific knowledge base for the AI. The image presents an example of how the data model is used to associate specific assets with the required tools, maintenance procedures, and safety protocols for those assets.

Fig B.1: The code defines the objects representing the Gas Insulated Switchgear and Shunt Reactor and outlines the specific parameters that the chatbot will query the knowledge base with.

```
EQUIPMENT_DATA = [
    {
        "equipment": "Gas Insulated Switchgear (GIS)",
        "tools": ["Gas leak detector", "IR camera", "Contact resistance tester", "Multimeter
        "preventive_maintenance": [
            "Check SF6 gas pressure",
            "Inspect seals and gaskets",
            "Test insulation resistance",
            "Monitor partial discharge levels"
        ],
        "failure_symptoms": ["Gas leakage", "Flashover inside compartments", "Abnormal heati
        "safety_precautions": ["Ventilate room", "Wear gas mask", "De-energize before mainte
    },
    {
        "equipment": "Shunt Reactor",
        "tools": ["Insulation resistance tester", "Oil testing kit", "Thermographic camera"
        "preventive_maintenance": [
            "Check oil level and condition",
            "Perform insulation resistance tests",
            "Inspect bushings for cracks"
        ],
        "failure_symptoms": ["Overheating", "Unusual vibration", "Oil leakage"],
        "safety_precautions": ["De-energize and ground", "Wear PPE", "Handle bushings carefu
    },
    {
        "equipment": "Neutral Grounding Resistor (NGR)",
        "tools": ["Multimeter", "Resistance tester", "Infrared thermometer"],
        "preventive_maintenance": [
            "Measure resistance value"
```

Laxman .

Laxman - Report_CSE_69_draft_Latest_MB.docx

Quick Submit

Quick Submit

Presidency University

Document Details

Submission ID

trn:oid:::1:3430362110

Submission Date

Dec 2, 2025, 10:12 AM GMT+5:30

Download Date

Dec 2, 2025, 10:34 AM GMT+5:30

File Name

Learnify_report_1.pdf

File Size

1.9 MB

71 Pages

14,318 Words

81,970 Characters

0% detected as AI

The percentage indicates the combined amount of likely AI-generated text as well as likely AI-generated text that was also likely AI-paraphrased.

Caution: Review required.

It is essential to understand the limitations of AI detection before making decisions about a student's work. We encourage you to learn more about Turnitin's AI detection capabilities before using the tool.

Detection Groups

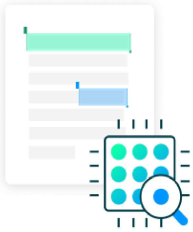
0 AI-generated only 0%
Likely AI-generated text from a large-language model.

0 AI-generated text that was AI-paraphrased 0%
Likely AI-generated text that was likely revised using an AI-paraphrase tool or word spinner.

Frequently Asked Questions

How should I interpret Turnitin's AI writing percentage and false positives?

The percentage shown in the AI writing report is the amount of qualifying text within the submission that Turnitin's AI writing detection model determines was either likely AI-generated text from a large-language model or likely AI-generated text that was likely revised using an AI paraphrase tool or word spinner.



False positives (incorrectly flagging human-written text as AI-generated) are a possibility in AI models.

AI detection scores under 20%, which we do not surface in new reports, have a higher likelihood of false positives. To reduce the likelihood of misinterpretation, no score or highlights are attributed and are indicated with an asterisk in the report (*%).

The AI writing percentage should not be the sole basis to determine whether misconduct has occurred. The reviewer/instructor should use the percentage as a means to start a formative conversation with their student and/or use it to examine the submitted assignment in accordance with their school's policies.

What does 'qualifying text' mean?

Our model only processes qualifying text in the form of long-form writing. Long-form writing means individual sentences contained in paragraphs that make up a longer piece of written work, such as an essay, a dissertation, or an article, etc. Qualifying text that has been determined to be likely AI-generated will be highlighted in cyan in the submission, and likely AI-generated and then likely AI-paraphrased will be highlighted purple.

Non-qualifying text, such as bullet points, annotated bibliographies, etc., will not be processed and can create disparity between the submission highlights and the percentage shown.

Laxman .

Laxman - Report_CSE_69_draft_Latest_MB.docx

Quick Submit

Quick Submit

Presidency University

Document Details

Submission ID

trn:oid:::1:3430362110

Submission Date

Dec 2, 2025, 10:12 AM GMT+5:30

Download Date

Dec 2, 2025, 10:34 AM GMT+5:30

File Name

Learnify_report_1.pdf

File Size

1.9 MB

71 Pages

14,318 Words

81,970 Characters

13% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Filtered from the Report

- Bibliography

Match Groups

112 Not Cited or Quoted 12%
Matches with neither in-text citation nor quotation marks

9 Missing Quotations 1%
Matches that are still very similar to source material

2 Missing Citation 0%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

7% Internet sources
8% Publications
9% Submitted works (Student Papers)

Integrity Flags

1 Integrity Flag for Review

Hidden Text
87 suspect characters on 2 pages
Text is altered to blend into the white background of the document.

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.