Iot-Enabled Smart Monitoring and Protection System for HVDC Transmission

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***Abstract*—High Voltage Direct Current (HVDC) transmission has emerged as an efficient solution for long-distance power transfer due to its reduced losses and improved system stability compared to conventional AC systems. However, real-time monitoring and protection remain critical challenges in ensuring reliable operation. This paper presents the design and implementation of a compact IoT-based smart monitoring and protection system for an HVDC power feeding prototype. The proposed system utilizes an Arduino Uno microcontroller integrated with voltage, current, temperature, humidity, and gas sensors for continuous parameter monitoring. An ESP32 module enables real-time wireless data transmission to remote platforms. The system incorporates a relay-based protection mechanism that automatically disconnects the load under abnormal conditions such as overvoltage, overcurrent, excessive temperature, and gas leakage. Experimental results demonstrate that the proposed system provides improved reliability, rapid fault response, and efficient monitoring, making it suitable for modern smart grid and industrial applications.**

Index Terms*—High Voltage Direct Current (HVDC), IoT-Based Monitoring, Arduino Uno, ESP32, Smart Power System, Voltage and Current Sensing, Fault Detection, Relay Protection, Real-Time Monitori.

I. INTRODUCTION

Efficient and reliable power transmission is a fundamental requirement of modern electrical networks. High Voltage Direct Current (HVDC) transmission systems have gained significant importance due to their ability to reduce transmission losses, enhance power transfer capability, and improve system stability, especially over long distances and in submarine or underground applications.

Despite these advantages, conventional HVDC systems face several challenges, including complex infrastructure, high installation cost, and limited real-time monitoring capabilities. The absence of continuous monitoring and rapid protection mechanisms can lead to system failures and equipment damage during fault conditions.

Recent advancements in embedded systems and Internet of Things (IoT) technologies have enabled the development of intelligent monitoring systems capable of real-time data acquisition, analysis, and remote access. By integrating sensors with microcontrollers and wireless communication modules, it is possible to design compact and cost-effective solutions for power system monitoring and protection.

This work proposes a smart HVDC prototype that integrates sensor-based monitoring, microcontroller-based control, and IoT communication to enhance system reliability, safety, and operational efficiency.

II. LITERATURE SURVEY

High Voltage Direct Current (HVDC) transmission systems have become increasingly important in modern power networks due to their ability to transmit electrical energy efficiently over long distances with lower losses compared to conventional AC systems. Several research works have focused on enhancing HVDC performance through advanced fault detection techniques, protection strategies, and real-time monitoring systems to improve reliability and operational safety.

Recent advancements in embedded systems, sensor technologies, and wireless communication have enabled the development of intelligent monitoring and control mechanisms in power systems. However, most existing studies primarily emphasize simulation-based models or large-scale HVDC infrastructures, with limited focus on compact and cost-effective hardware implementations.

A study by Pragati et al. (2023) provided a detailed review of HVDC protection methods used in modern grids. The research analyzed various techniques such as fault detection algorithms, DC circuit breakers, and fault current limiters. The study highlighted that HVDC systems require fast and reliable protection due to low impedance and rapid fault current rise, and emphasized the need for intelligent and adaptive protection systems.

Todkar et al. (2025) proposed an advanced protection approach for HVDC transmission lines using real-time monitoring combined with data analysis techniques. Their system utilized sensors along with machine learning and signal processing methods to detect and classify faults, thereby improving accuracy and response time in HVDC networks.

In addition, studies on HVDC control architectures underline the importance of continuous monitoring and diagnostics in converter stations. Parameters such as voltage, current, and temperature are constantly observed to ensure safe and stable operation. Communication between control and protection units through high-speed interfaces enables effective system management and quick detection of abnormal conditions.

III. PROPOSED SYSTEM

The proposed system is designed as an intelligent HVDC power feeding prototype that combines sensing, control, and protection functionalities with IoT-based monitoring.

Multiple sensors are employed to continuously monitor critical parameters such as voltage, current, temperature, humidity, and gas levels. The Arduino Uno microcontroller acts as the central processing unit, acquiring sensor data and comparing it with predefined threshold limits.

When abnormal conditions such as overvoltage, overcurrent, excessive temperature, or gas leakage are detected, the controller immediately activates a relay driver circuit to disconnect the load, thereby ensuring system protection.

An ESP32 module is integrated to enable real-time wireless communication. This allows remote monitoring of system parameters and enhances user accessibility and control. The overall system is compact, cost-effective, and suitable for practical implementation in smart monitoring application.

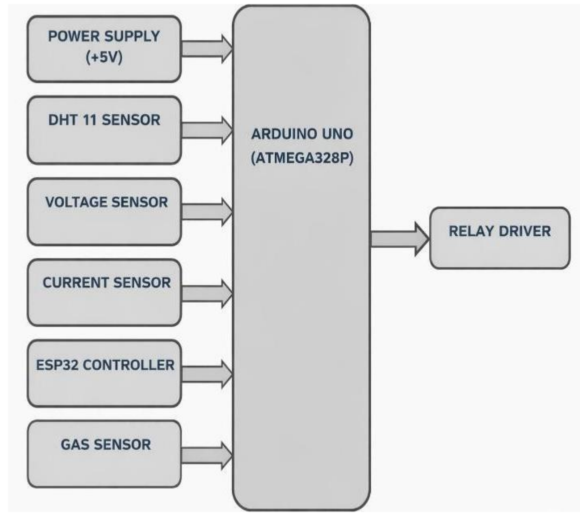

Figure 1 Block Diagram for HVDC prototype system

3.1. System Architecture

This section explains the overall design of the HVDC power feeding prototype. The system consists of a regulated power supply, Arduino Uno microcontroller, multiple sensors, a relay driver circuit, and an ESP32 communication module. The sensors continuously monitor electrical and environmental parameters, while the microcontroller processes the data and controls system protection mechanisms.

3.2. Power Supply Design

The power supply unit converts the available input voltage into a stable +5V DC output required for the microcontroller and sensors. It includes a step-down transformer, rectifier circuit, filter capacitor, and voltage regulator. A stable supply ensures accurate sensor readings and reliable operation of the control circuit.

3.3. Sensor-Based Monitoring

- Multiple sensors are integrated to monitor system parameters.
- Voltage Sensor measures the input or load voltage.
- Current Sensor measures the current flowing through the circuit.
- DHT11 Sensor monitors temperature and humidity.
- Gas Sensor detects harmful gases.

- These sensors provide real-time data to the microcontroller for continuous system monitoring.

3.4. Microcontroller-Based Control

The Arduino Uno acts as the central controller of the system. It reads sensor data, processes the values using its internal ADC, and compares them with predefined threshold limits. If abnormal conditions such as overvoltage, overcurrent, or high temperature are detected, the controller initiates protective actions.

3.5. Protection Mechanism

A relay driver circuit is used to control the load and protect the system from faults. When the Arduino detects abnormal parameters, it sends a signal to the relay driver. The relay then disconnects the load to prevent damage to the system.

3.6. IoT-Based Remote Monitoring

The ESP32 module enables wireless communication using Wi-Fi or Bluetooth. It sends real- time sensor data to a remote monitoring platform or cloud server. This allows users to monitor system performance remotely and receive alerts during abnormal conditions.

IV. RESULTS AND DISCUSSION

The developed HVDC prototype was tested under various operating conditions to evaluate its monitoring and protection capabilities. The system successfully measured voltage, current, temperature, humidity, and gas levels in real time, and the acquired data was processed accurately by the Arduino microcontroller.

During normal operating conditions, all parameters remained within predefined safe limits, and the system operated without interruption. When abnormal conditions were introduced, such as increased load leading to overcurrent or elevated temperature levels, the system responded effectively by triggering the relay mechanism to disconnect the load.

The response time of the system was observed to be within a few milliseconds, ensuring rapid fault detection and protection. The integration of multiple sensors improved the reliability of fault detection by providing a comprehensive assessment of system conditions.

The ESP32 module enabled continuous wireless transmission of sensor data, allowing remote monitoring without delay. This feature enhances system usability and supports real-time decision-making.

Overall, the results confirm that the proposed system provides improved safety, fast response, and efficient monitoring compared to conventional systems lacking integrated IoT and protection mechanisms.

Table 4.0: Sensor Readings Under Different Conditions

PARAMETER	NORMAL RANGE	WARNING	CUT OFF	ACTION
Voltage	11.0V -13.8 V	<11.0V or>13.8V	<10.5V or > 14.4V	Cutoff + Alert
Current	<0.65A	>0.8A	>1.0A	Monitor only
Temperature	20^0C – 35^0C	>40^0 C	>45^0C	Cutoff + Alert
Gas Level	<300	>500	>800	Cutoff + Alert
Humidity	30% - 70%	<20% or >85%	-	Alert Only

The results demonstrate that the system effectively detects abnormal conditions such as overvoltage, overcurrent, high temperature, and gas leakage. The relay mechanism is successfully activated under fault conditions, ensuring system protection and reliability.

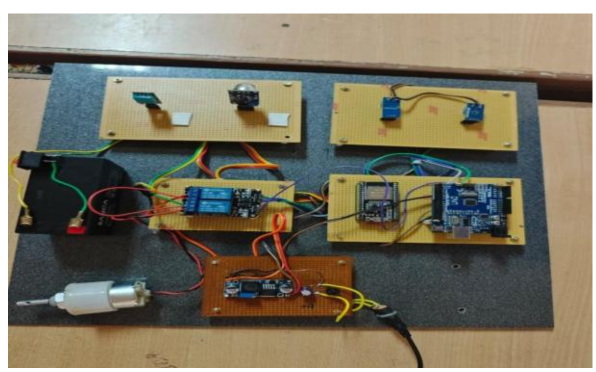

Figure 2 Hardware Setup

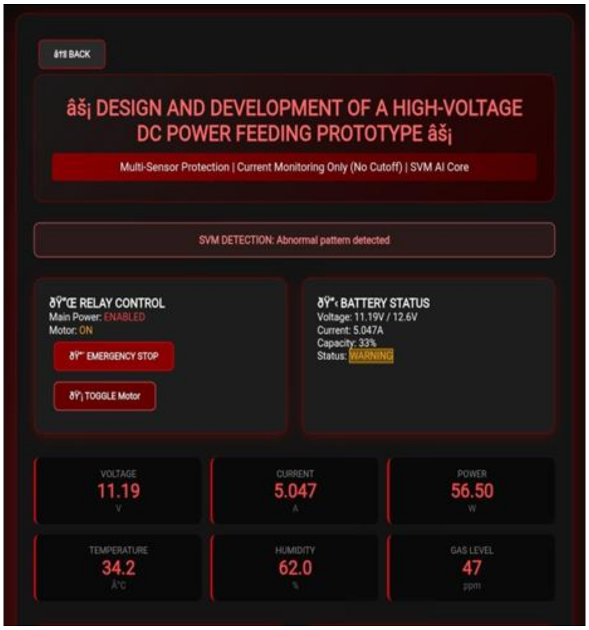

Figure 3 Web Page for Monitoring Sensors level

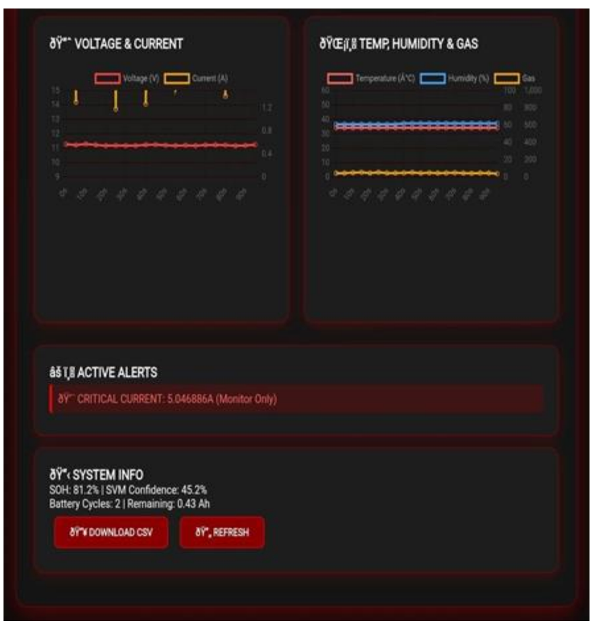

Figure 4 Sensors Plot Diagram

V. CONCLUSION

This paper presented the design and implementation of a smart IoT-based monitoring and protection system for an HVDC power feeding prototype. The system effectively integrates multiple sensors, a microcontroller, and wireless communication to achieve real-time monitoring and automated protection.

The experimental results demonstrate that the proposed system can accurately detect abnormal electrical and environmental conditions and respond quickly to ensure system safety. The relay-based protection mechanism provides reliable load control, while the ESP32 module enables remote monitoring and enhances system accessibility.

The proposed solution is compact, cost-effective, and suitable for applications in smart grids, industrial power systems, and renewable energy integration. Future enhancements can include cloud-based analytics, mobile applications, and intelligent fault prediction techniques to further improve system performance.

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