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Transmission Line Sag and Temperature Monitoring System Using IoT

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ABSTRACT

The rising demand for electrical power and the integration of renewable energy sources necessitate more efficient and reliable transmission networks. Conventional manual inspection and static line rating methods are often inefficient, as they fail to account for real-time environmental changes that lead to conductor thermal expansion and increased line sag. To overcome these limitations, this paper proposes an IoT-based Real-Time Transmission Line Sag and Temperature Monitoring System. The primary focus of this research is to design and implement a robust IoT framework for real-time monitoring of transmission line parameters. The proposed system employs wireless sensor nodes strategically placed along the transmission lines to collect crucial parameters such as temperature and line sag. These sensors are equipped with IoT capabilities, enabling them to communicate wirelessly.

Keywords: Transmission Line Monitoring, Internet of Things (IoT), Sag Measurement, Conductor Temperature, Transmitter and receiver

I. INTRODUCTION

The rapid growth in electricity demand and the need for reliable power supply have led to the evolution of conventional power systems into smart grids, which focus on real-time monitoring and intelligent operation. Overhead transmission lines are a crucial component of these systems, but they are highly exposed to environmental conditions and electrical stresses.

One of the most important factors affecting transmission line performance is mechanical sag, which is the vertical distance between the conductor support and the lowest point of the conductor. As the load on the transmission line increases, higher current flows through the conductor, resulting in I^2R losses and resistive heating. This causes thermal expansion of the conductor, leading to an increase in sag. Environmental factors such as high ambient temperature and wind further contribute to this effect.

Excessive sag reduces ground clearance and can result in hazardous situations such as flashovers, conductor damage, power outages, and even fire accidents.

Therefore, continuous monitoring of sag and related parameters is essential for maintaining system safety and reliability.

Traditional monitoring techniques, including manual inspection and wired communication systems, are time-consuming, costly, and lack real-time data capabilities. To address these limitations, this project proposes an IoT-based transmission line monitoring system.

The system uses sensors to measure important parameters such as voltage, current, temperature, and sag. These sensors are integrated with NRF wireless modules, which enable efficient and long-distance data transmission without the need for complex wiring. The collected data is sent to a central monitoring station for real-time analysis and fault detection.

This approach enhances system reliability, reduces maintenance costs, and ensures safe operation of transmission lines, thereby supporting the development of a modern and intelligent electrical grid.

II. PROPOSED WORK

2.1 BLOCK DIAGRAM

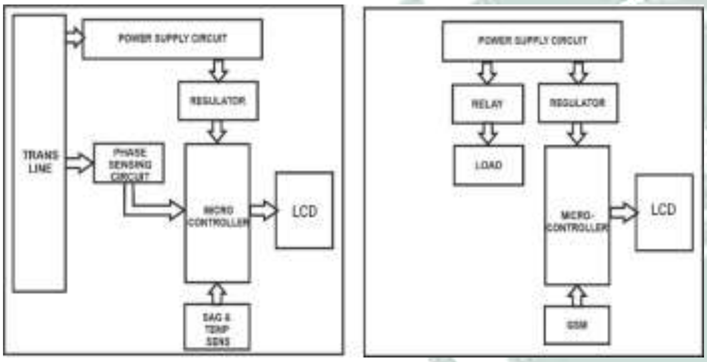


Fig 2.1

2.2 FLOWCHART

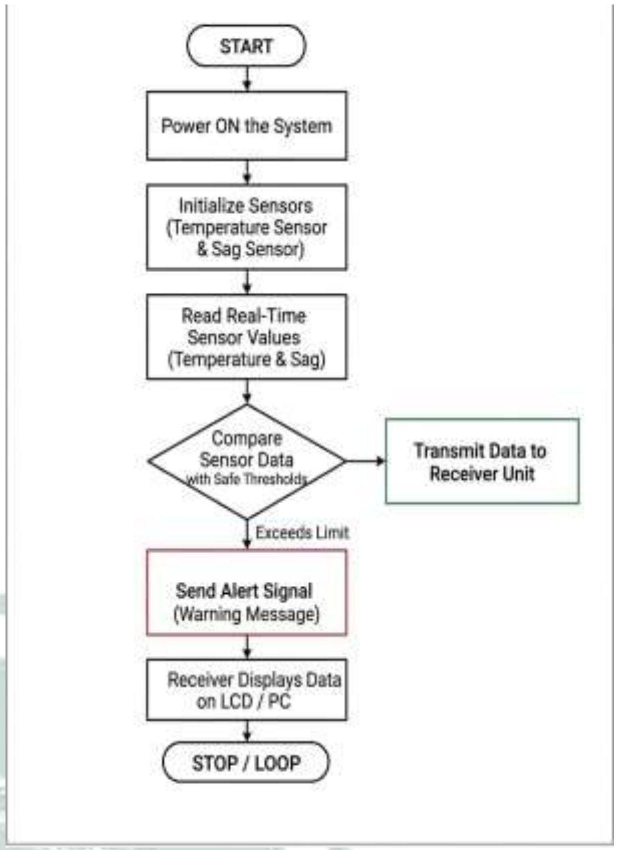


Fig 2.2

2.3 ESP32 Microcontroller

The ESP32 microcontroller is used as the main control and processing unit in the proposed system. It is a 38-pin microcontroller module with approximately 34 GPIO pins, supporting both digital and analog inputs through its 12-bit ADC channels. The ESP32 operates at a high speed of up to 240 MHz and includes built-in Wi-Fi and Bluetooth for wireless communication.

In this project, the ESP32 reads input data from temperature and sag sensors, processes the data, and compares it with predefined safety limits. Based on the analysis, it controls the relay and buzzer to indicate fault conditions. It also transmits real-time data through IoT and displays the monitored parameters on the LCD, ensuring efficient and reliable transmission line monitoring.

2.4 TRANSFORMER

The transformer, in a simple way, can be described as a device that steps up or steps down voltage. In a step-up transformer, the output voltage is increased, and in a stepdown transformer, the output voltage is decreased. The stepup transformer will decrease the output current, and the step-down transformer will increase the output current to keep the input and output power of the system equal.

2.5 RELAY

Relay is an electromagnetic device which is used to isolate two circuits electrically and connect them magnetically. They are very useful devices and allow one circuit to switch another one while they are completely separate. As Fig 4.5 shows the relay switch. They are often used to interface an electronic circuit to an electrical circuit which works at very high voltage. For example, a relay can make a 5V DC battery circuit to switch a 230V AC mains circuit.

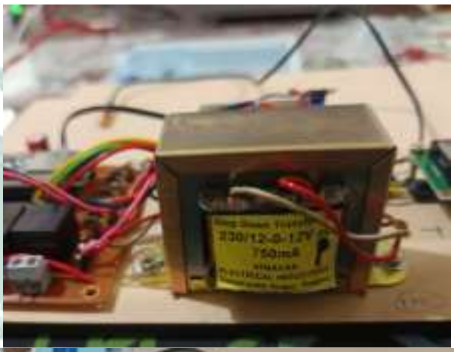
2.6 LIQUID CRYSTAL DISPLAY (LCD)

LCD is essentially used for display the information. Here we are using 2x16 LCD. It is used to display numbers, texts and graphics. This is in contrast to LEDs, which are limited to numbers and characters. The LCDs are fragile with only a few millimeter thickness. Since the LCDs utilize less power, they are efficient with low power electronic circuits, and can be charged for long terms. The LCDs don't provoke light and so light is needed to read the display. The LCDs have long lasting life and a wide operating temperature range.

III. PROPOSED SYSTEM ANALYSIS AND COMPONENT SELECTION

The hardware implementation utilizes industrial-grade components to ensure accuracy and durability. The core components of the prototype include:

- **ESP32 Microcontroller:** A dual-core, low-power system-on-a-chip (SoC) with integrated Wi-Fi and dual-mode Bluetooth. It is responsible for processing sensor data and managing the IoT communication stack.
- **Accelerometer (Sag Sensor):** Sensor is used to measure the angle of the conductor. By calculating the tilt of the line, the system can mathematically derive the sag without requiring ground-based sensors.
- **NTC Thermistor:** A high-precision thermal sensor used to monitor the surface temperature of the conductor. This provides the data necessary to correlate current loading with thermal expansion.
- **Step-Down Transformer:** In the prototype, this serves a dual purpose: powering the electronics and acting as a **Voltage Monitoring Circuit** to detect fluctuations or faults in the line.
- **LCD & Buzzer:** These serve as the local output unit, providing real-time readings and audible alarms at the tower location for maintenance personnel.



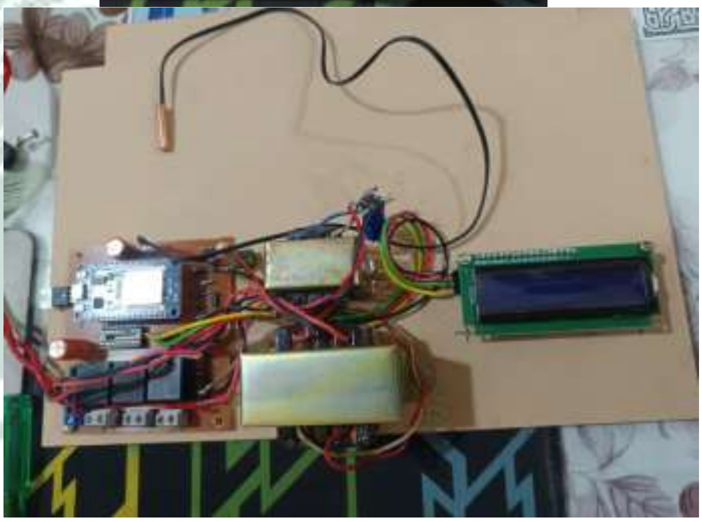


Figure 3.1: Sag and temp monitoring system of transmission line

IV. DESIGN CALCULATIONS AND WORKING PRINCIPLE

The system operates by converting high-voltage transmission parameters into low-voltage digital signals. Below are the specific mathematical steps involved in your prototype.

A. Power Supply and Voltage Regulation

The prototype uses a linear regulated power supply to provide a stable 5V and 3.3V DC to the ESP32 and sensors.

1. **Step-Down Stage:**

A center-tapped transformer reduces the 230V AC mains to 12V AC.
Vrms(*sec*)=12V

2. **Voltage Regulation:** To ensure a constant 5V output for the sensors and LCD, the regulator dissipates the excess voltage as heat.
Vout=5V DC (Constant)

B. Voltage Monitoring Calculation

The 12V secondary of the transformer is used to sense line voltage. Since the ESP32 ADC (Analog-to-Digital Converter) only accepts 0−3.3V, a potential divider is used.

- **Potential Divider Formula:**

If $R1$=10kΩ and $R2$=2.2kΩ:
Vout=Vin×($R2/(R1+R2)$)
If the line voltage is healthy (12V AC peak ≈17V), the ADC receives:
Vadc=17×(2.2/(10+2.2))=3.07V

C. Temperature Sensing (NTC Thermistor)

The NTC thermistor changes resistance based on conductor heat. The temperature is calculated using the **Steinhart-Hart Equation**:
$1/T=A+B\ \ln(R)+C(\ln(R))^3$
The ESP32 measures the voltage drop across the NTC and converts it:

- Rntc=Rfixed×(Vout/(Vcc-Vout))
- As T increases, *Rntc* decreases, allowing the system to detect overheating.

Temperature limit:
Temperature limit of the conductor is from -50°C to 50°C.

D. Sag Calculation (Accelerometer Method)

Instead of measuring distance directly, project uses the accelerometer to measure the tilt angle (θ) of the conductor near the insulator string.

1. **The Catenary Equation:**
   The conductor hangs in a catenary shape. For a span length (L) and a measured angle (θ) at the support:
   Sag(D)=$L/2$×tan($\theta/2$)
2. **Example Calculation:**
   Span (L): 100 meters
   Measured Tilt (θ): 5∘
   Calculated Sag:

D=100/2×tan(2.5∘)
D=50×0.0436≈2.18 meters
If the temperature increases, the metal expands, θ increases to 7∘, and the new Sag becomes ≈3.05 meters. The ESP32 constantly performs this calculation and compares it to the "Safe Clearance" constant stored in the code.

Sag Limit:
Sag angle limit; -25°to +25°

E. Relay and Buzzer Logic

The system uses a logic threshold:

- **IF**

(Tilt Angle < -25° OR Tilt Angle > +25°)
OR
(Temperature < -50°C OR Temperature > +50°C)

- → Buzzer ON
- → Relay TRIP

- **ELSE**:

System = Healthy

V. SIMULATION PARAMETERS AND RESULTS

The core of the proposed system's functionality is demonstrated through its real-time data visualization on the **ThingSpeak IoT Cloud platform**. The platform acts as a remote monitoring station where field data from the ESP32 is aggregated, timestamped, and analyzed.

A. Real-Time Dashboard Description

The dashboard provides a high-resolution graphical representation of the transmission line's physical and electrical state. Each data point is logged with a **unique Date and Time stamp**.

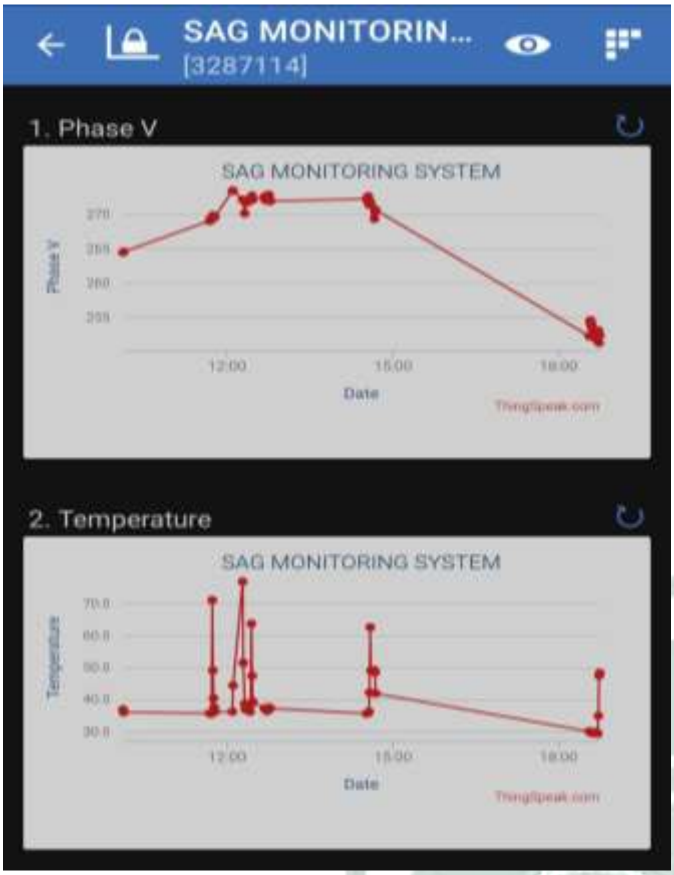
1. **Field 1: Temperature Monitoring Chart:** This chart displays the conductor temperature in real-time. The X-axis represents the timeline, while the Y-axis tracks thermal fluctuations. The system captures the instantaneous rise in temperature when the line load increases, providing the primary trigger for thermal expansion alerts.
2. **Field 2: Sag Measurement Chart:** Derived from the accelerometer data, this field visualizes the vertical displacement or tilt-angle changes. As the line heats up, the graph clearly shows a corresponding increase in, validating the mechanical modeling of the conductor.
3. **Field 3: Voltage Parameters:** This chart monitors the health of the line voltage. It ensures that the power quality remains within the standard tolerance. Any sudden drop in this graph indicates a potential fault or heavy inductive loading.

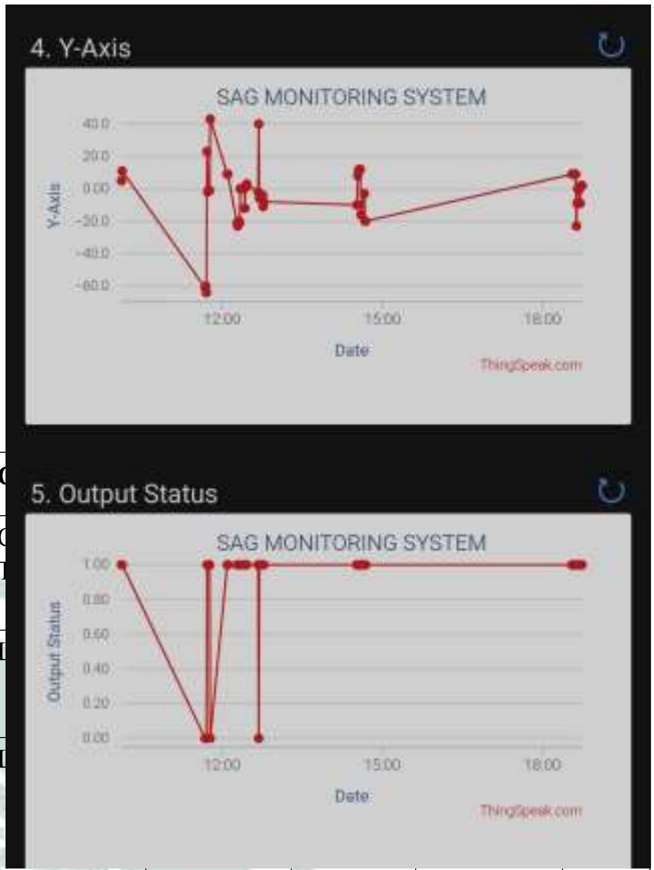
B. Data Logging and Time-Stamping

A critical feature of the ThingSpeak interface is the **Updated at** status. As seen in the results:

- **Synchronized Acquisition:** Every sensor reading is pushed to the cloud with a precise timestamp (e.g., *March 20, 2026, 10:23 AM*).

SIMULATION PARAMETERS FOR PROPOSED WORK





V. CONCLUSION

The design and implementation of the **IoT-Based Transmission Line Sag and Temperature Monitoring System** provide a robust, cost-effective, and scalable solution for modernizing power grid infrastructure. Through the integration of the **ESP32 microcontroller**, **NTC thermistors**, and **MEMS accelerometers**, the system successfully demonstrated the ability to capture high-precision physical data from simulated transmission lines.

In summary, this research proves that low-cost IoT frameworks can provide industrial-grade reliability for high-voltage monitoring. Future work will focus on integrating **Energy Harvesting** techniques—such as inductive power scavenging from the transmission line itself—to make the sensor nodes entirely self-sustaining for deployment in remote or inaccessible terrains.

V. REFERENCES

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