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SUBSTATION MONITORING USING IoT

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Abstract:

In the current era of automation, ensuring the safe supply of electricity to consumers is crucial, and monitoring and controlling substations play a vital role in this task. However, the risk of blackouts, brownouts, and fires is on the rise due to outdated distribution grid configurations and the lack of automation systems to monitor critical conditions within substations. Substations comprise various electronic components like transformers, breakers, and relays, making them susceptible to issues like overheating, transformer fluid leakage, and insulation breakdown. The conventional approach of manual system checks is both imprecise and time-consuming, especially for substations in urban areas. To address these challenges, we propose a cost-effective, user-friendly substation monitoring system that operates in automatic mode, eliminating the need for manual labor and reducing electricity loss. Our system offers various ways to display the results, ensuring that multiple individuals can monitor and control the parameters for safety and protection reasons. Notably, the uniqueness of our system lies in its ability to simultaneously display results on both desktop and mobile devices. To validate the system's performance in real-time monitoring, data logging, and controlling, we have successfully tested it on the CAYENNE platform. The positive outcomes of this test affirm the effectiveness of our proposed system.

Introduction:

The basic variable related with the Substation protection, Control and Monitoring include current, voltage, frequency, time, power factor and temperature.Electrical energy is transmitted from large generating stations to distant load centers through a series of substations. Each substation requires specific measurements, supervision, control, and protection functions. A control room is present in every substation, housing relay and control panels. These control-relay panels oversee the various circuit breakers, tap changes, and other devices. In smaller independent substations, operators can perform supervision and normal service operations with the assistance of analog and digital control systems on-site. The breakers can be remotely operated from the control room. In case of faults or abnormal conditions, protective relays take automatic action, operating the breakers to ensure the safety and stability of the system. Generally, in substations the primary control is of two types and these are,

- Routine operations are carried out by operators through manual commands.
- The system operates automatically through the actions of protective relays and control system.

  In conventional substation control, the three functions - protection, control, and monitoring - are not completely integrated. However, in modern interconnected systems, these functions are interconnected using digital processing devices and power carrier links to achieve seamless integration.

In traditional hard wired systems are relays and circuit breaker operate during abnormal operating conditions. The routine and emergency control functions are performed at individual ‘Unit’ level systems with the held of substation equipment such as circuit-breaker, tap changes etc. Control and monitoring functions are performed by separate equipment installed on respective panels. Each substation control room operated almost independently all instructions are received from Control Centre via Power Line carrier telephone communication link.

With the present trend and availability of powerful microcontrollers a low price, the protection, control and monitoring system in substations have undergone a radical change. The system architecture now includes, microcomputer based digital system control protection and monitoring systems installed in (1) load centers (2) Sub-station control room (3) Generating station control room. The control and protection systems are integrated and there is interaction and information transfer by means of communication channels.

As technology continues to advance rapidly, internet connectivity is expanding, even to remote areas. As a result, the Internet of Things (IoT) has gained immense popularity as a transformative technology. The primary objective of IoT is to create a better living environment by monitoring various activities, including energy management. Through IoT, innovative and smart solutions can be developed to address various problems and significantly conserve energy. Electricity has become an indispensable part of people's lives, and it serves as a fundamental requirement for both individuals and industries in a country. The effective utilization of electrical energy is vital for a country's development. Given the growing population and industrialization, energy plays a crucial role in the current scenario. However, meeting the escalating energy demands has become challenging, particularly because a significant portion of the energy is generated from non-renewable sources.

Therefore, in this context, energy conservation and monitoring are of utmost importance to address the ever-increasing demand for energy and promote sustainable practices, especially considering the reliance on non-renewable energy sources [1].

In contemporary society, the Internet of Things (IoT) technology [2] is gaining widespread adoption. It involves integrating small and intelligent objects with computational capabilities, utilizing various existing technologies like Wi-Fi, Bluetooth, and sensors. As a result, numerous hardware and software platforms have been developed to facilitate the creation and deployment of objects and services following the principles of IoT.

Power distribution companies strive to maximize profits by ensuring a dependable and continuous power supply. The critical components of power distribution include transformers, substation transformers [3], and high-voltage wires. Substation transformers are equipped with various functionalities such as overcurrent protection [4], ground protection, and other differential power protection [5]. The monitoring and control of substations are essential tasks in the age of automation to guarantee the secure delivery of electricity to consumers.

The potential for blackouts, brownouts, and fires is on the rise due to outdated distribution grid configurations (substations) and the lack of automation systems to monitor critical conditions within substation systems. Substations contain various electronic components like transformers, breakers, and relays, which are susceptible to problems such as overheating, transformer fluid leakage, and internal insulation breakdown. The conventional approach involves periodic manual system checks that lack accuracy. Moreover, physically inspecting substations in urban areas is more difficult and time-consuming, adding to the complexity of related tasks.The substation can experience several significant faults, such as:

- Under and over voltage fault.
- Fault due to overload.
- Fault due to reduction of oil level.
- Elevated temperature of the transformer.

The significance of substation protection becomes evident considering the various risks these faults pose to both the transformer and the environment. However, traditional methods for substation protection have proven to be slow, resource-intensive, and costly. To overcome these limitations, this research article proposes a user-friendly, cost-effective system that offers real-time monitoring and data logging of the system's performance, enabling timely actions to prevent losses.

The primary objectives of the proposed system are as follows:

- Measure transformer parameters.
- Protect the substation transformer from overrating of voltage, current, temperature, and empty oil level.
- Implement automatic voltage control of the substation through multi-taping.
- Utilize IoT-based monitoring, controlling, and data logging.

By achieving these objectives, the proposed system aims to enhance the efficiency and reliability of substation protection while reducing operational complexities and costs.

Literature survey:

Authors in [6] proposed a frame work for measuring voltage, current and oil level of transformer using IoT and LoRa technologies. LCD is used for presenting the measured parameters.Arduniois used for collecting the inputs and provides results equally.

A smart monitoring system is proposed to measure various parameters of the substation such as voltage and current using Arduino controller. The collected parameters are transmitted to end user for monitoring purpose. It also calculates power factor and frequency using the detector of reference value of zero [7].

For providing the safe electricity to consumers, the authors in [8-10] proposed a efficient substation monitoring system.They proposed a low cost system and reduces the interference of manual labour.

An energy monitoring system is proposed in [12-14], which calculates the energy consumed by the load connected to circuit. It makes use of IoT based Arduino controller for measuring the energy.

Substation monitoring system:

To implement a condition-based maintenance scheme, the initial step involves monitoring, which entails gathering essential parameters from an asset. The collected data plays a crucial role in conducting comprehensive analyses, determining the asset's condition, and making informed decisions regarding maintenance to prevent breakdowns and faults. Monitoring substations can be complex due to the large number of features involved. Depending on the asset and the required diagnosis, monitoring can be conducted either online, offline, or a combination of both. This process necessitates the use of suitable sensor data collection and software. Moreover, substations are often constructed using assets from various manufacturers, which adds to the complexity of the monitoring process.

The benefits of employing IoT for substation monitoring and control are as follows:

- System for wireless monitoring and control.
- Swift control action.
- Automated control action.
- Precise system operation.
- Detection of various types of constraints.
- Implementation of relays for system protection.
- Prevention of system instability.
- Ensuring uninterrupted power supply.

Proposed Substation Monitoring system:

Substation transformers are at risk of damage from various factors, including exceeding temperature limits, low oil levels, heavy loads, and high current transfers. As the temperature increases, the likelihood of internal damage to the transformers also rises, making thorough inspection and monitoring crucial.

In our proposed system (refer to fig. 1), the controller incorporates a sensing mechanism to monitor diverse substation parameters, including voltage, frequency, current, oil level temperature, and humidity. The processing system connects to a digital display, enabling real-time monitoring of parameter values and relevant technical procedures at the substation.

The microcontroller is designed to detect heavy loads and overcurrent streams in the internal windings, which could potentially lead to equipment failure. The Arduino IDE (ESP32) [5] is programmed to continuously monitor the transformer and update the parameters at regular intervals.Utilizing the built-in IoT module, the Arduino IDE captures the substation parameter values and transfers them to a web page and mobile phone, ensuring remote access and monitoring of the data.

Circuit and working

The IoT-based system for substation monitoring and control involves the measurement of various electrical parameters using diverse sensors, including the ACS712 current sensor, AC voltage sensor, DHT11 (digital humidity and temperature) sensor, and frequency sensor.

To determine the total current consumption, the ACS712 current sensor is connected in series with the mainline, while the voltage sensor is connected in parallel to measure the overall voltage flowing through the system. Frequency sensors are utilized to count the number of current cycles per second. Additionally, the DHT11 sensor, operating at 5V DC, is employed to measure humidity and temperature within the substation.

The data from all the sensors is collected and processed by a microcontroller powered by a 5V DC supply. The microcontroller displays the parameter values on a serial display. Moreover, the microcontroller is programmed and integrated with the ESP module (Wi-Fi module). This allows real-time data transmission from the microcontroller to a mobile device or PC connected to the same network via the Internet, enabling remote access and real-time monitoring of the substation's parameters.Below are the hardware specifications utilized in the system model.

Step-down transformer:

The device serves as a high-to-low voltage converter [6], transforming high primary voltages into lower secondary voltages. The transformer's primary winding contains more turns than the secondary winding. In the proposed model, a step-down transformer is used to supply 12V DC to the voltage sensor, as depicted in Figure 3.

Relay:

The relay acts as a switch that responds to applied pulses on its coil, allowing it to open or close as needed for the circuit. In our proposed model, we utilize a 5V DC single-pole double-throw (SPDT) relay [7]. This relay is essential for protection and control purposes and can be operated either through the Arduino or via the internet.

In our prototype, each phase at the input side of the transformer is equipped with a dedicated relay to streamline and enhance control and protection using internet connectivity. Initially, the relays are set in the normally open condition, and they will switch off according to the programmed conditions for tripping assets.

Auto transformer:

An autotransformer, as depicted in Figure 5, is a transformer with a common single winding for both the primary and secondary sides. The term "auto" signifies its ability to automatically adjust the voltage input (i/p) variation or decrease the single winding usage. Autotransformers find application in scenarios where electrical protection between the input and output windings is unnecessary. In our proposed model, the autotransformer features five tapings with a difference of 25V each.

ESP-32 Micro controller:

The ESP32 is a high-performance 32-bit microcontroller featuring built-in Wi-Fi, which facilitates straightforward implementation of IoT programs using the Arduino IDE and Arduino Wire language. This IoT module combines both WIFI and Bluetooth functionalities, making it suitable for various applications. Additionally, it incorporates an integrated USB interface, allowing seamless integration with any IoT product. The ESP32 serves as a versatile physical gadget system, enabling efficient transmission of data using these modules.

Voltage sensor:

To detect over and under load conditions, voltage measurement is essential. The advantage of using this sensor lies in its ability to easily control the voltage value through a potentiometer, allowing the creation of over and under voltage scenarios

Current sensor:

The current sensor serves to detect the RMS current of the system and to measure over-load conditions, effectively preventing faults that could potentially harm the load or the transformer. In the prototype, an ACS712 current sensor [8] with a 5A rating is utilized, employing the Hall Effect to measure the AC current.

Frequency sensor:

The frequency sensor was specifically designed in PCD (Printed Circuit Design) with the assistance of a zero-crossing detector circuit [9]. This detector operates by comparing the voltage waveform to detect when it crosses from positive to negative, corresponding to the zero-voltage state. The sensor employs the IC LM398 comparator, which compares the two input voltages and relays the result to the microcontroller.

Temperature sensor:
To sense the temperature, the DHT11 [10] sensor is utilized, which can measure both humidity and temperature. This sensor is employed to detect the overheat condition of the transformer, enabling the activation of the cooling system to prevent any potential damages to the transformer.

Oil sensor:
The oil level in the transformer is determined using an Ultrasonic sensor. This sensor functions by sending signals and measuring the time taken for them to be received back, allowing it to measure the length and depth of the oil. The oil level is classified into three levels: low, medium, and full.

Data logging and IoT:
The ESP32 module is a central component of the proposed system, responsible for acquiring analog data through an analog to digital converter (ADC). This data is then made accessible on the Wi-Fi network through a web server. When queried using MQTT [11], the web server responds by providing the corresponding data value. Additionally, the ESP32 module can be accessed and managed through the CAYENNE cloud [12], which serves as a storage and data management platform.

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