Smart Control and Monitoring System for Switchyard Floodlight Towers with Fault Detection

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Abstract **– Switchyard floodlight towers are very important for the operation of electrical substations at night. However, the conventional switchyard lighting system has limitations in energy wastage and fault detection due to the lack of automation and monitoring capabilities in the existing switchyard lighting system. This paper proposes the design and implementation of the Smart Control and Monitoring System for the Switchyard Floodlight Towers using the IoT-based ESP32 architecture. This system is able to switch the floodlights ON during low ambient light conditions and OFF during the daytime using the BH1750 digital light sensor. Moreover, the lamp status is monitored in real-time using the cloud integration (Blynk IoT platform), which is remotely monitored from the control room. Additionally, the fault detection of the individual lamp is achieved using the ACS712 current sensors, which analyse the AC signal swing characteristics to achieve fault detection. This system is validated using the four-lamp tower and is accurate in automation and fault detection capabilities.**

Keywords– ESP32; IoT; Switchyard Automation; Floodlight Tower; Fault Detection; ACS712 Smart Substation.

I. INTRODUCTION

Switchyard management relies on visibility. A high-performance lighting system is necessary for safety. Switchyard floodlight towers provide lighting. However, traditional floodlight systems have limitations. They use switching or timer techniques. These methods can't detect lamps easily.

The Internet of Things (IoT) technology has improved grids. Microcontroller-based systems can be integrated with switchyard floodlight systems. This research proposes a Smart Control and Monitoring System for Switchyard Floodlight Towers with Fault Detection.

This research is about making a Smart Control and Monitoring System for Switchyard Floodlight Towers with Fault Detection using the ESP32-S3 Microcontroller. The system uses a BH1750 light sensor to detect the light and turn the floodlights on and off. It also uses an ACS712 sensor to detect faults in the lamps.

By automating the switching process and using fault detection, the system can help reduce energy waste, make things easier to manage and make the operation safer and more reliable. The system is a solution that meets the needs of a grid system. The proposed system can be seen as a solution that meets the requirements of a smart grid system.

II. LITERATURE SURVEY

There are several research works carried out on the development of IoT-based lighting automation systems.

1. Mustafa A. Al-Sheikh in his research paper published in 2024 proposed the design of an adaptive indoor lighting system using the IoT platform along with the ESP32 microcontroller, LDR sensor, and IoT cloud platform, achieving a 34.8% efficiency.
2. Md. Sazol Ahmmed in his research paper published in 2018 proposed the development of an automatic street lighting system using the LDR sensor and PIR sensor to enhance the efficiency of the street lighting system.
3. Urvi R. Bhagat in his research paper published in 2019 proposed the design of an IoT-based street light control system using the ESP32 microcontroller, Wi-Fi, and MQTT protocol.

From the above research papers, it is clear that the existing literature has focused on the development of street lighting systems. There is a lack of research on the development of industrial switchyard lighting systems. This research has enhanced the development of the existing literature by incorporating the following components in the system.

- Industrial monitoring
- Individual lamp current-based fault detection
- Real-time cloud dashboard supervision
- Control room visualization

III. METHODOLOGY

1. Overview of the System

The system uses ESP32, BH1750 sensor and ACS712 current sensor. It switches floodlights on and off automatically. Detects faults in real-time.

2. Power Supply Arrangement

ESP32, BH1750, and ACS712 current sensors are used in the system. Floodlights are automatically turned on and off. detects errors instantly. Configuration of the Power Supply with a 5V DC supply for the low-power microcontroller logic and a 230V AC supply for the high-intensity light bulbs, the system uses a dual-stage power architecture to handle various operating requirements. Relay modules are used as a crucial protective barrier to safely connect these two environments. By acting as electromagnetic switches, these relays protect the control logic from power surges while allowing the low-voltage microcontroller to control high-voltage lighting circuits with total electrical isolation.

3. Role of ESP32 (Main Controller)

The ESP32 is the controller of the system. It reads intensity values from the BH1750 sensor takes commands from the Blynk mobile application and turns the bulbs on and off using relays. It also takes values from the ACS712 sensor for fault detection. The system has two modes: manual. In mode it turns the bulbs on and off based on the light. In mode the user can turn the bulbs on and off using a push button or the Blynk application.

The system also has a relay control section, which acts as a switch to connect or disconnect the AC power source to the bulb. The fault detection system uses the ACS712 sensor to sense the current passing through the bulbs. If there is no too much current it may indicate a fault.

The system communicates with the cloud server using Wi-Fi, which lets the user view the bulb status control the bulbs and receive notifications.

The working process of the system is as follows: the system is powered on the ESP32 connects to Wi-Fi the mode is detected and the relays are switched on. The sensors sense the current and any fault is detected and notified to the user.

4. Automatic Mode Operation

The system operates as an independent, light-sensitive network in Automatic Mode, coordinating lighting with current environmental requirements.

The BH1750 ambient light sensor, which continuously measures the ambient intensity in Lux units, is the central component of this system. This is compared with the threshold value by the ESP32 microcontroller. Then it switches on the relay and, hence, the bulbs as soon as there is a fall in the light level, owing to the time of day or cloud cover. It eliminates the inefficiency of the existing method and makes use of energy only when there is a critical level of visibility, thus increasing the longevity of the product and reducing electricity costs.

5. Manual Mode Operation

The user is in complete control of the bulbs in manual mode.

There are two methods to operate the system manually:

- Using a physical push button.
- Using the Blynk application via Wi-Fi.

When the user switches to manual mode, the automatic light sensing is bypassed, and the bulbs operate as per the user's input.

6. Relay Control Section

Each bulb is connected to a relay. This way, all four bulbs can be controlled individually.

This relay acts as a switch that can be controlled electronically. It either connects or disconnects the AC power source at 230V to the bulb when it receives a signal from the ESP32.

This is a safe way to do it as the high voltage circuit does not get connected to the microcontroller.

7. Fault Detection Using Current Sensors

To improve the system's dependability, I've integrated an intelligent fault detection mechanism that tracks each bulb's current draw in real time using ACS712 sensors. Through constant analysis of these power signatures, the ESP32 is able to rapidly differentiate between potentially hazardous over-current conditions, such as short circuits, and a blown filament, in which a light bulb is connected but is drawing zero current. Once an anomaly is detected, it takes preventive measures to initiate a safety shut-down via the relay and quickly alerts the user via the Blynk app rather than waiting for manual inspection. The lighting setup will be safer and more intelligent

than conventional systems when reactive maintenance is replaced with predictive maintenance.

8. Communication Process

The ESP32 module is able to connect to the Wi-Fi network and communicate with the cloud server of the Blynk application. This allows the user to:

- View the status of the bulbs.
- Control the bulbs.
- Receive notifications when there is an issue with the bulbs.

9. Working Procedure

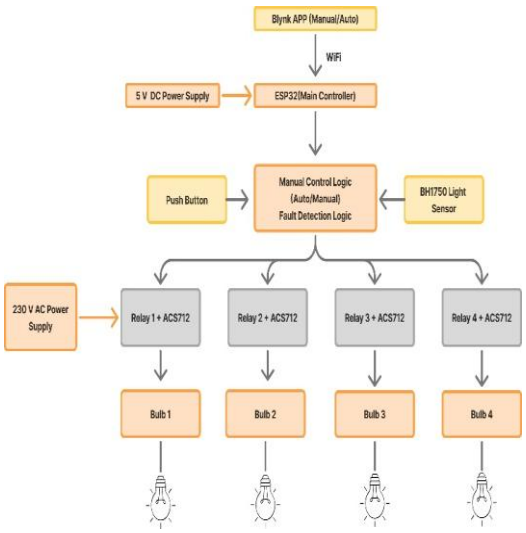
The complete working process of the system is as follows:

1. The system is powered ON.
2. ESP32 is connected to the Wi-Fi.
3. The mode (Auto/Manual) is detected.
4. In the Auto mode, the intensity of the light is detected and compared with the set value.
5. In the Manual mode, the commands are processed.
6. The relays are switched on.
7. The sensors sense the current of the bulb.
8. Any fault is detected and the user is notified.
9. The process is repeated continuously.

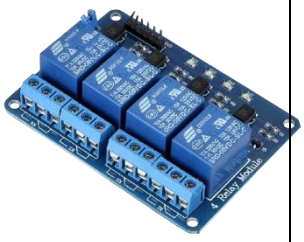
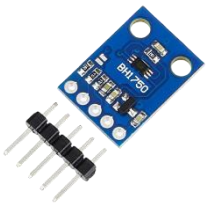
Conclusion of Methodology

This approach guarantees that the lighting system is safe, energy-efficient, and intelligent. The system offers a workable solution for contemporary smart homes by fusing IoT technology, automatic sensing, manual control, and fault detection.

IV. Block Diagram



V. Circuit Components

	**ESP 32 S3 Module**
	**4 Channel relay Module**
	**BH 1750 Module**
	**Push Button**
	**ACS712**
	**Jumper Wire**

. Prototype Development



Figure 1: Developed Hardware Prototype Model

1. Overall System Architecture

The system has been developed as a prototype to mimic the actual operation of switchyard floodlight towers in the real world. While developing the system, the major focus was not only to automate the switching process but also to monitor and identify the faults through IoT technology. The complete assembled hardware prototype is as follows: Figure 1: The complete assembled hardware prototype

This is the figure that shows the complete integrated setup, including the ESP32-S3 board, BH1750 light sensor, current sensor module, relay module, and lamp load, as an integrated system.

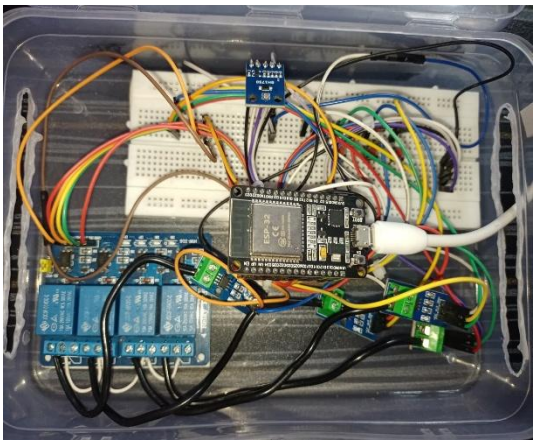


Figure 2: Hardware Circuit Diagram of the Proposed System

2. Hardware Circuit Design

To ensure the safety and stability of the proposed system, an appropriate hardware circuit design was developed before the actual hardware circuit implementation. The hardware circuit diagram of the proposed system is shown in Figure 2.

The hardware circuit includes the following components:

- ESP32-S3 microcontroller
- BH1750 sensor interfaced via I²C protocol
- ACS712 sensor interfaced via the analog interface
- 4-Channel relay module interfaced via digital interface
- AC load circuit for the floodlight

Proper electrical isolation was maintained between the two circuits to ensure the safety and stability of the proposed system.

3. Automatic Operation Logic

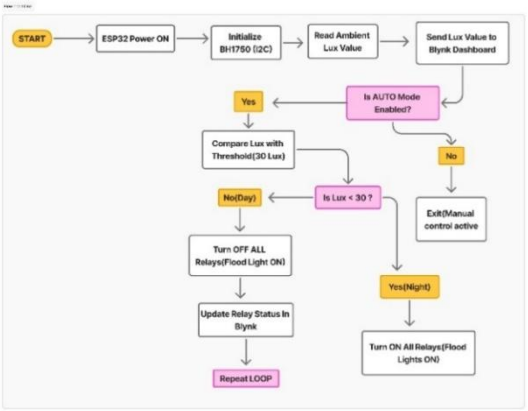


Figure 3: Flow Chart of Automatic Floodlight Operation

The automatic controlling mechanism is based on the intensity of the ambient light. The logical representation of the automatic operation is depicted in the following flow chart.

As per the above flow chart:

1. ESP32 is initialized, and BH1750 sensor data is read.
2. Data is sent to the Blynk dashboard.
3. Check if AUTO mode is enabled.
4. If AUTO mode is enabled, data is compared with threshold data of 30 lux.
5. If lux < 30, it is night; all relays will be enabled and floodlights will be ON.
6. If lux > 30, it is day; all relays will be disabled and floodlights will be OFF.
7. Data is updated on the dashboard.
8. Loop is repeated indefinitely.

4. Manual Control Mode

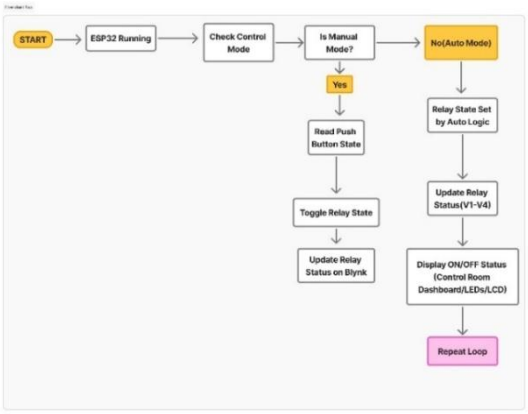


Figure 4: Flow Chart of Manual Operation Mode

In addition to the automatic control method, the manual control option was also incorporated to increase the flexibility of the system. The control logic for the manual control method is depicted in Figure 4.

When the AUTO mode is disabled:

- System stops the automatic comparison process.
- It receives control commands through the Blynk dashboard.
- It changes the relay states according to the manual control.
- It sends the feedback to the dashboard.

5. Intelligent Fault Detection Mechanism

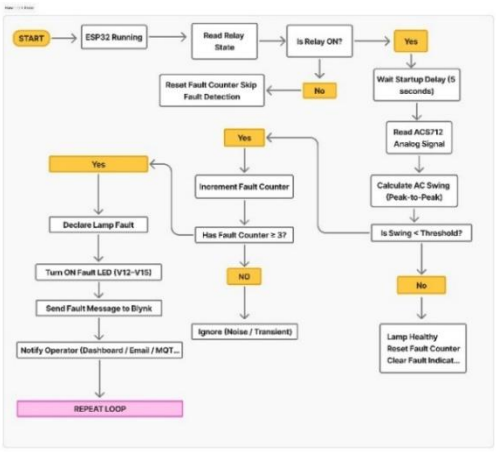


Figure 5: Flow Chart of Fault Detection Using ACS712

Fault detection is probably the most important contribution of the proposed prototype. The complete fault detection algorithm is as follows, as presented by the flow chart given in Figure 5.

As per the logic presented by the flow chart, the following steps are taken for fault detection:

1. The system is always checking for the status of the relay, i.e., if it is ON or not.
2. When the relay is ON, the system checks for 5 seconds before the actual fault detection.
3. The analog signal is read using the ACS712 module.
4. The AC waveform swing is calculated.
5. When the current swing is found to be less than the threshold, the fault is suspected.
6. The fault counter is increased.
7. When the fault counter reaches 3, the lamp is declared faulty, the fault LED indicator is ON, the fault is notified by Blynk, and the operator is notified.
8. The fault counter resets automatically when the current values return to normal.

6. IoT Monitoring Dashboard

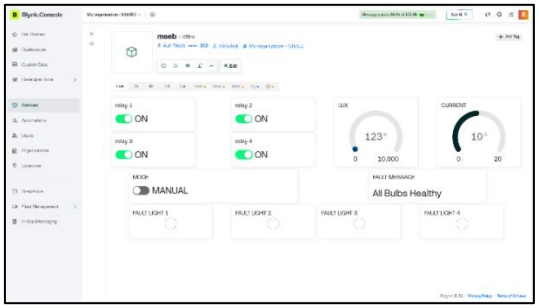


Figure 6: Blynk Dashboard for Real-Time Floodlight Monitoring

In order to facilitate central control, the system has been integrated with a cloud-based Blynk platform. The real-time monitoring interface has been shown in Figure 6.

The interface offers the following functionalities:

- Ambient lux value
- Individual relay ON/OFF status
- Current monitoring values
- Fault alert notifications
- Manual control

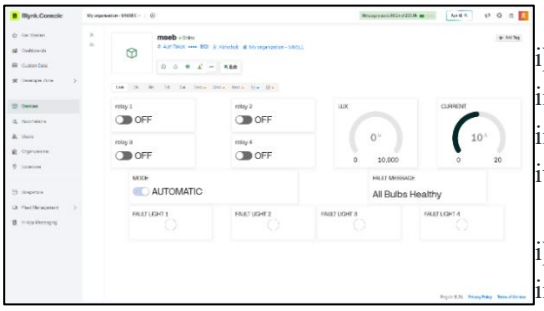
This interface allows the monitoring of the system without the need to physically visit the control room to check the status of the towers in the switchyard.

VII. Results and discussion

The system has been tested in different scenarios as depicted in the following figure:

Case 1: Daylight Condition

Lux > 30 → Lamps OFF → Dashboard updated correctly.

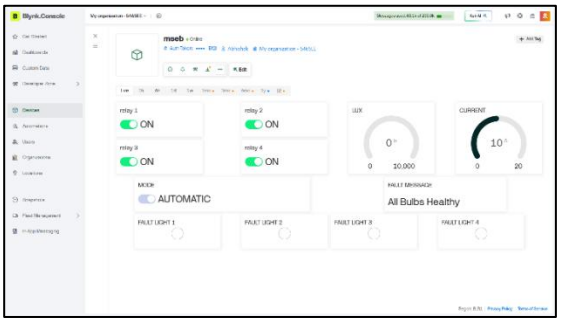


i)
ii)
iii)
iv)

Case 2: Night Condition

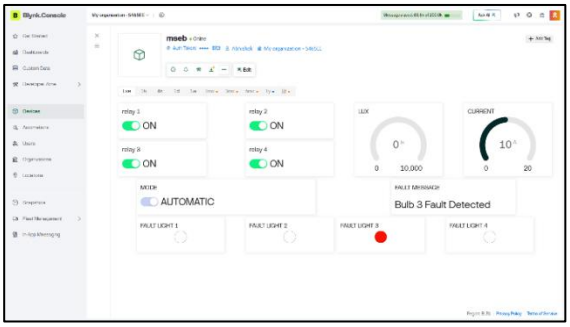
i)
ii)
iii)
iv)

Lux < 30 → Lamps ON → Switching of the relay confirmed.



Case 3: Lamp Removal

Current swing < threshold → Fault detected within 3 cycles.



Case 4: Noise Condition

Transient noise ignored due to confirmation counter logic.

Based on the results obtained, the following can be stated:

Automation accuracy: 100%

Fault detection response time: ~6 seconds

Wi-Fi communication was stable

Individual lamp monitoring was accurate

VIII. CONCLUSION

This paper has proposed a "Smart Control and Monitoring System for Switchyard Floodlight Towers with Fault Detection." The proposed system has successfully integrated the control, IoT monitoring, and lamp health detection into a compact embedded system.

1) The proposed system has the following benefits:

Energy wastage reduction

Improved operational safety

Improved predictive maintenance

Improved architecture

2) Future enhancements of the proposed system:

SCADA system integration

CT sensor-based industrial current sensing.

GSM alert backup

AI-based failure prediction

3) The following are some ways that the suggested system supports the Sustainable Development Goals:

1. Goal 7 of the Sustainable Development Agenda: Accessible and Sustainable Energy.
2. Goal 9 of Sustainable Development.

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