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Design and Implementation of Control and Management System for Public Lighting

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Abstract—This work focuses on the real-time monitoring of a public lighting system powered by a photovoltaic source. A graphical interface has been developed to display sensor data, allowing real-time monitoring and control of this system. The results evaluate the accuracy and reliability of the sensor network, which is crucial for optimizing energy efficiency in public lighting. The monitoring concerns the electrical parameters of the lamps such as voltage, current, power, energy. In addition, the weather data is also displayed (irradiance, and temperature) in order to control the photovoltaic system powering the proposed lighting system.

Keywords—Public lighting, IoT, Smart lighting, Graphical Interface, Monitoring.

I. INTRODUCTION

Energy efficiency has become an essential priority for contemporary urban environments, which face increasing energy demands and the resulting environmental challenges [1-2]. Among energy-intensive sectors; public lighting stands out for its significant contribution to overall electricity consumption. Traditional public lighting systems, often outdated and inefficient, lead to energy overconsumption and high operational costs for municipalities. This inefficiency not only strains local budgets but also exacerbates environmental issues by increasing carbon emissions [3-5]. With the expansion of cities and the continuous rise in energy demand, the need for more sustainable solutions is becoming increasingly urgent. Renewable energy sources, such as photovoltaic (PV) systems, offer a promising alternative to conventional energy sources, providing cleaner and more sustainable energy for public lighting. However, transitioning to renewable energy alone is not sufficient. The integration of advanced technologies, such as the Internet of Things (IoT) and smart lighting systems are essential to fully optimize

energy consumption and improve the efficiency of public lighting infrastructures [6].

In 2022, public lighting in Algeria accounted for 59% of overall electricity consumption [7]. To lower this consumption, the public authorities have since raised the alarm. To do this, we must switch to a new smart public lighting system to conserve as much energy as we can. The implementation of sustainable solutions for public lighting, such as systems based on IoT technologies [6, 8], is crucial to addressing the growing challenge of energy consumption in modern urban environments. These solutions optimize energy efficiency, reduce operational costs, and mitigate environmental impact by lowering carbon emissions. By combining advanced hardware and software components, these intelligent systems offer the ability to monitor (via tele monitoring systems) and effectively control energy consumption (intelligent control of lighting points) while ensuring a reliable and continuous energy supply (hybrid PV inverter). In this context, we developed a real-time monitoring of the public lighting powered by photovoltaic source. we were able to establish wireless communication between the lighting points equipped with microcontrollers and the control center, which monitors and communicates in real-time the status and optimal functioning of public lighting (at its optimal power or in standby) according to the desired scenario. The ultimate goal is to design and implement a complete solution of control and management of public lighting based on IoT microcontrollers. This initiative aims to create reproducible models for more efficient energy management in the public lighting sector, thereby supporting national efforts to reduce electricity consumption.

II. SYSTEM OVERVIEW

The proposed smart lighting solution with a monitoring system utilizes a photovoltaic (PV) system to harness solar

energy, which powers the lighting prototype. This system is controlled and monitored by an IoT microcontroller, allowing for management and optimization of energy usage. The IoT microcontroller is wirelessly connected, enabling real-time data transmission and remote access for monitoring and control. The system's performance and energy consumption can be visualized through specialized software, providing insights for efficient operation and maintenance. This communication shortens the feedback loop and enhances the overall effectiveness of the smart lighting system. By integrating PV energy source with advanced control technology, and remote monitoring, smart public lighting system offers a sustainable and intelligent solution for modern urban environments.

III. CONCEPTION OF SMART LIGHTING SYSTEM

Figure 1 represents a diagram of the proposed and developed smart lighting solution with a monitoring system, divided into three main sections: Power Supply, Process Unit, and Web Server.

- The power supply section features a standalone PV System that generates electricity from solar power, providing the energy needed for the system. An LED Driver regulates this power for the LED Light Fixture, ensuring efficient and safe operation. Additionally, Monitoring Sensors collect data on parameters such as light intensity, energy consumption, and system status, sending this information to the process unit.
- In the process unit, the light fixture serves as the main lighting element, controlled by the LED Driver. A Motion Sensor detects movement and signals the Microcontroller (ESP8266) to manage the light fixture accordingly, such as turning light on or off based on occupancy. The Microcontroller acts as the central processing unit, receiving inputs from the motion and monitoring sensors, processing the data, and communicating commands to the LED Driver. It also interfaces with the web server via a Router, enabling data transmission and remote control.
- The Web server section includes an MQTT Broker, which handles communication between the Microcontroller and the web server using a lightweight messaging protocol common in IoT systems [9]. A Graphical Interface offers a user-friendly platform for monitoring and controlling the lighting system, allowing users to view real-time data and manage the lights remotely. Data from the monitoring sensors is stored in a Database on the web server, facilitating analysis and tracking.

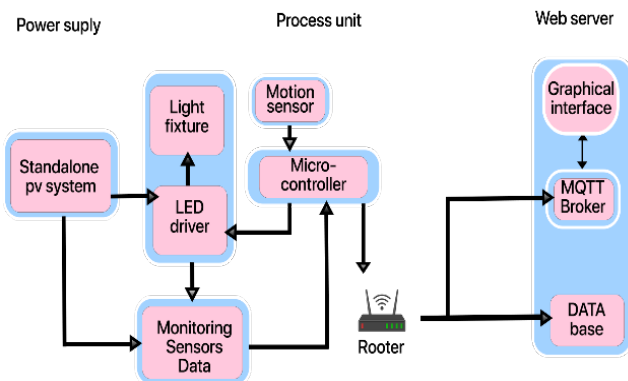


Fig. 1. Monitoring system architecture

IV. SMART LIGHTING MONITORING SYSTEM

A developed lighting monitoring system collects and analyzes various measured parameters such as brightness, motion, temperature, and energy consumption to continuously monitor and evaluate the performance of the lighting system. It ensures reliable and stable operation by tracking key indicators that reflect the quality of lighting provision and by promptly alerting to any potential faults, allowing quick intervention to rectify or eliminate them. This system is essential for maintaining optimal functionality and energy efficiency of the smart lighting infrastructure, ultimately contributing to cost savings and improved user experience.

V. IOT SMART LIGHTING

Figure 2 represents a schematic diagram of the developed smart lighting system, integrating the ESP8266 IoT microcontroller with various sensors and modules to enable efficient energy monitoring and control. The NodeMCU ESP8266 [10] (NODE1) acts as the main controller for the smart lighting system, powered by a 3.7V battery (BAT1) and connected to various components via its GPIO pins. The PIR sensor detects motion, sending signals to the NodeMCU, which then triggers the lamp (U2) to provide illumination. The lamp receives power from the AC line through the driver (S-220), which is controlled by the NodeMCU via the PZEM004T. The PZEM004T monitors the lamp's electrical parameters and communicates this data to the NodeMCU.

In a smart lighting system, the PIR sensor continuously monitors for motion. Upon detecting motion, it signals the NodeMCU ESP8266 controller to increase LED brightness to 100%. When no motion is detected, the NodeMCU utilizes PWM (Pulse Width Modulation) to reduce LED brightness to 20%, maintaining low-level illumination. The PZEM004T module monitors LED electrical parameters such as voltage, current, and power consumption, relaying this data to the NodeMCU for ongoing monitoring and control through the SS-200vH driver.

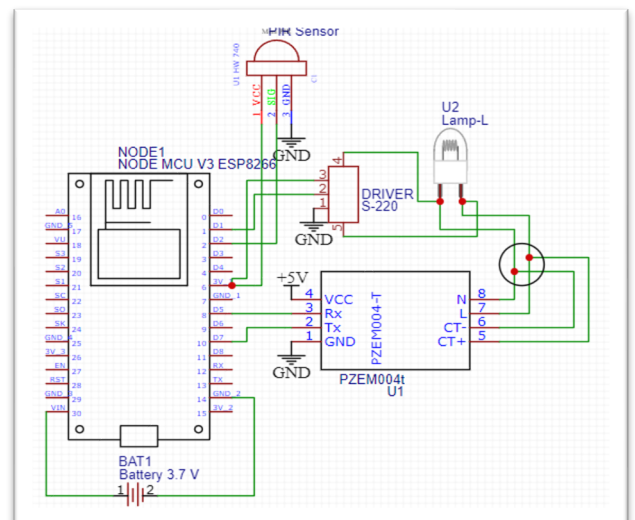


Fig. 2. Schematic IoT Based Smart Lighting

VI. PV SYSTEM INTEGRATION

The integrated PV system efficiently uses solar energy to power luminaires. This setup ensures a continuous and reliable power supply by utilizing solar energy effectively.

The PV solar panels capture sunlight and convert it into electrical energy, which is regulated by the charge controller to ensure the batteries are charged efficiently and safely. The charge controller outputs power to both the battery storage and the DC/AC inverter. The batteries store energy for use when there is no sunlight, while the inverter converts the stored DC power into AC power, suitable for luminaires. This AC power is then supplied to the lighting fixture, ensuring continuous and reliable illumination. The seamless integration of these components solar panels, charge controller, battery storage, and inverter ensure that the generated energy is efficiently converted, stored, and utilized to power the lighting system, providing a sustainable and dependable lighting solution (Figure 3).

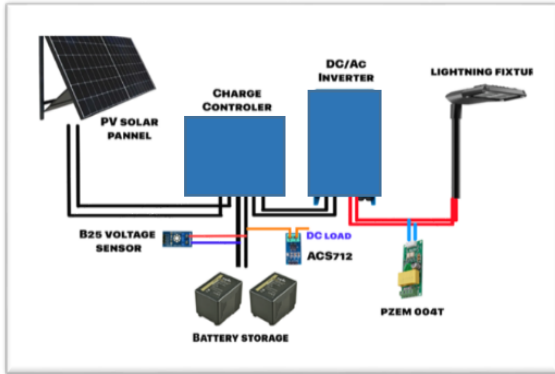


Fig. 3. Photovoltaic system integration

VII. RESULTS AND ANALYSIS

This section explores the precision of various sensors used in monitoring a developed smart lighting system and the implementation and development of a graphical interface using Node-RED software [11]. This analysis assesses the accuracy and reliability of the sensor network, which is crucial for optimizing energy efficiency and user comfort in smart lighting applications. Monitoring electrical parameters acquires data such as voltage, current, power, energy, frequency, and power factor from the electrical system. The additional. This monitoring interface ensures comprehensive tracking of environmental parameters, complementing the electrical parameter monitoring system. By utilizing Node-RED, a flow-based development tool for visual programming, the project aims to develop an intuitive and responsive graphical interface that seamlessly integrates sensor data, enabling real-time monitoring and control. The results highlight the performance of the sensor network, the effectiveness of the Node-RED interface, and the overall impact on the management and efficiency of smart lighting systems.

A. Electrical parameter monitoring

The Node-RED flow designed for monitoring electrical parameters acquires data such as voltage, current, power, energy, frequency, and power factor from the electrical system. This data is processed, transferred by using modbus tcp and visualized using real-time line charts, providing immediate insights into the system's performance. Figure 4. presents electric parameters dashboard interface.



Fig. 4. Electric parameters Dashboard interface

B. Meteorological parameters interface

The additional Node-RED flow captures and visualizes real-time temperature and irradiance data. Figure 5 Presents meteorological Dashboard interface

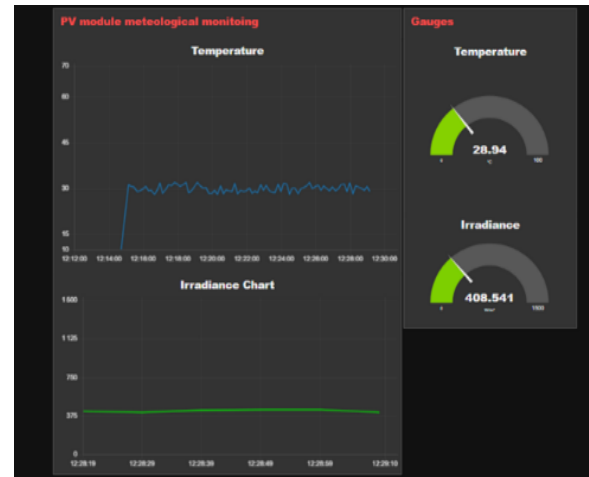


Fig. 5. Meteorological Dashboard interface

C. Controlling and notifying

The Node-RED flow includes nodes for controlling brightness and setting notification thresholds. The brightness control node adjusts the light intensity based on user input or predefined conditions. A notification node monitors the brightness levels and sends alerts if the values exceed or fall below set thresholds, ensuring optimal lighting and prompt user notifications of any significant deviations.

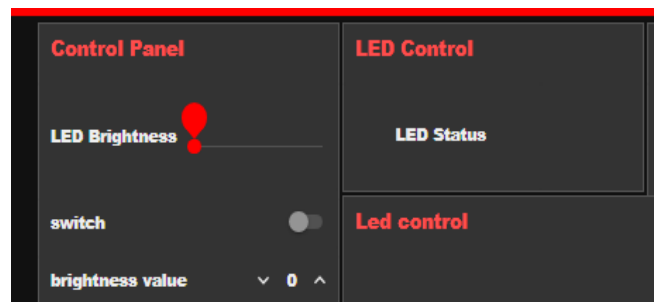


Fig. 6. Controlling Dashboard tools

The implementation of the monitoring system for lighting prototype has proven highly effective. Using Node-RED for real-time data acquisition and visualization has enabled comprehensive tracking of both electrical and meteorological parameters. This system ensures optimal performance and immediate issue resolution through dynamic control capabilities. The accurate data collection from various sensors, validated against reference measurements, highlights the robustness of the implemented monitoring system. By providing detailed insights into voltage, current, power, temperature, and irradiance, the system facilitates informed decision-making and improves the performance of the PV system powered the lighting prototype. This advanced monitoring approach not only supports the primary goal of reducing electricity consumption but also establishes a scalable and replicable model for other projects across Algeria, contributing to national efforts in energy efficiency and sustainable development.

VIII. CONCLUSION

The objective of this study is to develop and implement a monitoring system for public lighting using IoT technologies. This system can manage and control remotely and in real time (via a graphical interface) all the electrical parameters of public luminaires. The goal is to identify in real time the state of these luminaires, and to monitor their energy consumption. The final objective is to bring considerable energy savings and therefore expenses for communities. Regarding security, this system would also reduce the number of accidents, and minimize acts of break-ins or vandalism in public places.

The following suggestions should be considered for further research work:

- Test the developed system on a public place or road in order to optimize energy efficiency on a larger scale.
- Improve the accuracy and reliability of the sensors used for better management of lighting and reduced maintenance costs.
- Develop intelligent control algorithms to adjust lighting intensity based on environmental conditions and actual needs, maximizing savings of energy.
- Work with local communities and authorities to roll out pilot projects in various regions and assess the real impact of these technologies on energy consumption and the quality of life of citizens.

- Implementing AI in the system would enhance object and movement detection capabilities, leading to improved accuracy and additional energy savings through more precise control.

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