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Solar-Powered Street Lighting with Automatic Damaged Light Alert and Battery Deep Discharge Protection System

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ABSTRACT: This paper introduces a cost-effective, energy-efficient smart street lighting system built using an ESP 32-based microcontroller platform. The system integrates components such as LED luminaires, photovoltaic (PV) panels, charge controllers, motion and light sensors, and an IoT-enabled control module to enhance energy efficiency in rural, urban, and smart city areas. The main objectives include optimizing energy usage, lowering operational costs, and mitigating power shortages by replacing conventional energy-intensive lamps with solar-powered LED lighting solutions.The system features automated ON/OFF control based on ambient lighting and road traffic conditions, a solar tracking mechanism to maximize energy absorption, and a dimmer circuit to reduce power usage during periods of low traffic. Additionally, it incorporates real-time damage detection and location reporting to alert maintenance teams promptly, minimizing delays and manual labor. The system also ensures battery longevity by monitoring the state of charge (SOC), preventing overcharging, and maintaining optimal performance.By combining IoT technology with renewable energy, this smart street lighting system delivers an environmentally friendly, cost-efficient, and scalable solution to meet contemporary street lighting needs, addressing both energy conservation and sustainability goals.

KEYWORDS: Smart street lightning, ESP32 microcontroller, Photovoltaic (PV)panels, Motion sensor, Damage detection.

I. INTRODUCTION

As urbanization continues to grow rapidly across the globe, the need for sophisticated infrastructure in smart cities becomes more crucial. One essential component of this infrastructure is the street lighting system, which plays a vital role in enhancing public safety, managing energy use, and improving the overall quality of life in cities. While traditional street lighting is necessary, it often lacks the adaptability and efficiency required to meet the changing demands of modern urban environments. This report introduces an innovative smart street lighting system designed to address these challenges by leveraging advanced technologies like the Internet of Things (IoT), sensors, and adaptive control systems. This system marks a shift from static, manual control to a more flexible, data-driven solution.

By integrating sensors and connectivity, smart street lights can adjust their brightness in response to real-time factors such as pedestrian movement, traffic density, and ambient light conditions. This not only enhances public safety by ensuring appropriate lighting where it's needed most but also reduces energy consumption by dimming or turning off lights during periods of low activity. Additionally, the system supports predictive maintenance, with sensors tracking the status of each light to identify potential issues before they cause failures. This proactive approach helps reduce maintenance costs and ensures reliable operation.Beyond energy efficiency and maintenance advantages, the smart street lighting system contributes to broader smart city efforts. These lights are equipped with various sensors that collect environmental data such as air quality, temperature, and humidity, providing valuable insights that support urban planning and environmental monitoring. The communication infrastructure that supports these lights can also facilitate other smart city applications, including public Wi-Fi and enhanced communication networks, further

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connecting urban spaces.Functioning as multifunctional nodes in the urban ecosystem, smart street lights can integrate with traffic management systems to improve vehicle and pedestrian flow, decrease congestion, and boost safety. The real-time data gathered by these systems can help authorities adapt to changing traffic patterns, making necessary adjustments to urban infrastructure. Many smart street lighting systems are also paired with renewable energy sources like solar panels, further contributing to sustainability efforts. This aligns with global initiatives to combat climate change and helps cities achieve their environmental goals, making smart street lighting a critical component of a sustainable, connected urban future

II. LITERATURE SURVEY

Ashok et al. [1] introduced an IoT-based system for the automatic detection and management of faulty street lights. This intelligent solution aims to minimize power consumption during late-night hours by providing smart control over street lighting. The main objective of the project is to enable automatic detection and control of damaged street lights. The system is designed to be cost-effective and energy-efficient, offering prompt fault notifications and responses. Traditionally, street light issues are reported manually by residents, but this approach automates the process for faster and more efficient maintenance.

Abhiram et al. [2] presented a smart street lighting system for highways aimed at significantly reducing unnecessary energy consumption and related costs. The proposed setup utilizes motion and infrared sensors to activate streetlights only when movement from pedestrians or vehicles is detected. These sensors are powered by a battery that is charged using a solar photovoltaic array, with an additional backup power source connected to the main grid. The backup supply is used only when the battery fails to store adequate energy to run the sensors.

Prajna et al. [3] proposed new energy efficient lights, improved lighting design and advanced lighting controls are evolved. Photovoltaic (PV) is the best solution for the energy requirements in the future. This paper proposes a method to maximize the utilization of available solar energy for the efficient street lighting design. This paper presents the design and implementation of a grid-solar hybrid power supply scheme for LED street lighting.

Shivaleelavathi et al. [4] aimed to design a solar-powered street lighting system that incorporates a timer-based sun tracking mechanism. This system ensures the solar panel remains aligned perpendicularly to sunlight, capturing maximum solar energy throughout the day and across different weather and seasonal conditions. Additionally, it includes an LED dimming circuit to minimize energy usage when no movement is detected near the streetlight. To prevent battery overcharging, the system constantly tracks the battery's state of charge (SOC) and disconnects the charge controller once the SOC approaches full capacity.

III. METHODOLOGY OF PROPOSED SURVEY

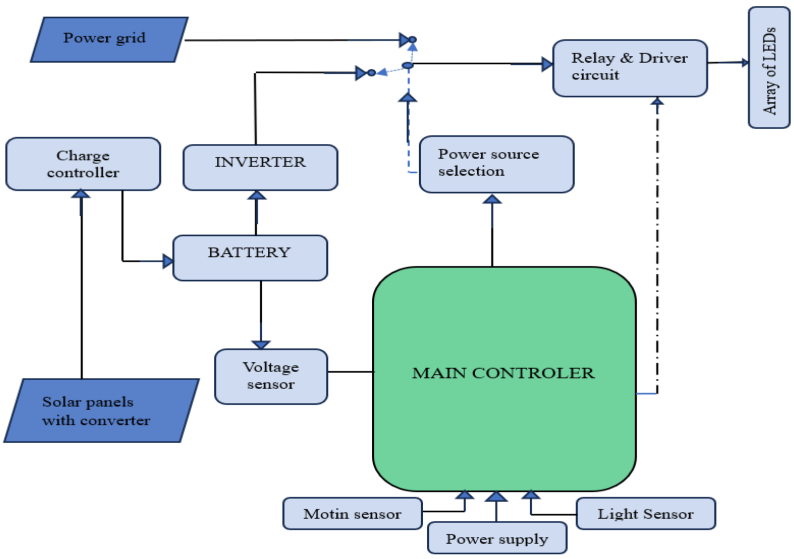

Figure 1: Block diagram of smart street light system.

This block diagram shows how a smart street light system works by using both solar energy and electricity from the power grid. During the day, solar panels collect sunlight and convert it into electrical energy. This energy goes through a charge controller and gets stored in a battery. When needed, the battery power is converted from DC to AC by an inverter, which can then be used to light the street lights. If the battery doesn't have enough charge, the system can also switch to using electricity from the power grid. ESP32 acts as the main controller. This controller is like the brain of the system. It decides whether to use power from the battery or the grid by checking the battery voltage usingVoltage sensor.

The system also has a motion sensor to detect movement and a light sensor to sense how dark it is outside. If it's dark and there's movement nearby, the main controller turns the street light on using a relay and driver circuit. If there's no movement or it's already bright outside, the lights stay off or dim to save power. This smart system helps save energy by using solar power when possible and only turning on lights when needed.

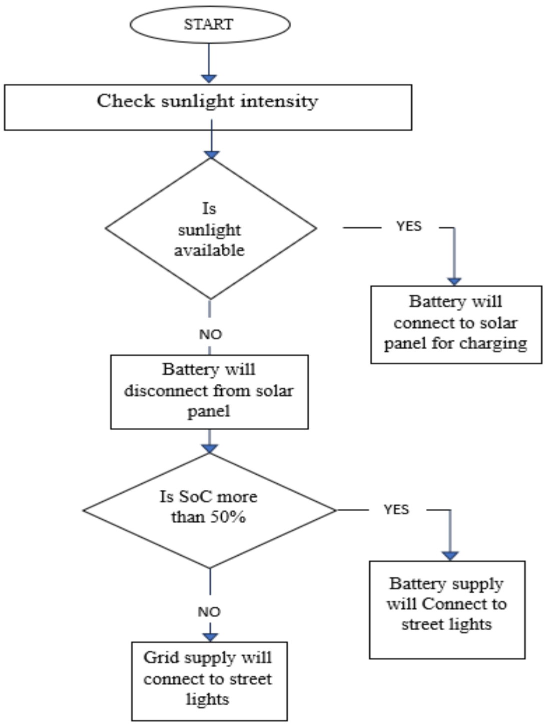

Figure 2: Flowchart for battery charging and streetlight powering

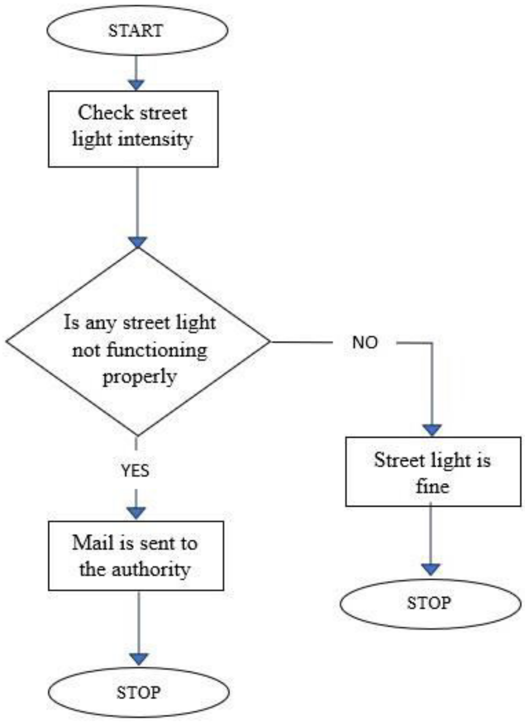

Figure 3: Flowchart for Damage light process

Battery charging is a essential detail of the proposed system. The charging strategies are regulated primarily based on the sunlight's intensity. If the measured irradiance value is high, main controller turns OFF all street lights and battery start charging. If the measured irradiance value is low, and the State of charge of the battery is above a specified limit i.e., 50%, then the street lights are related to the battery, and the streetlights are activated, making use of the energy from the solar charged battery. However, if the State of charge falls below 50%, the street lights are disconnected from the battery and connected to the grid power as given in fig 4.1.

An automated streetlight monitoring system's flowchart is as shown in the fig 4.2, is intended to identify and report broken streetlights. The intensity of the streetlights is checked first, through LDR sensors. Based on the LDR value, the system decides whether the streetlight is damaged or not. If every streetlight is working properly, the system concludes that everything is OK and no further steps are required. In case a streetlight is found to be damaged, the system automatically identifies it and sends an alert to the concerned department for rectification. This self-service method

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ensures timely identification and rectification of damaged lamps, enhancing energy efficiency, public safety, and smart city infrastructure.

IV. RESULT

The implementation of the solar-powered street lighting system shown in figure 4 integrated with automatic damage detection has yielded promising outcomes in terms of energy efficiency, autonomous operation, and maintenance responsiveness. The critical achievement was the real-time detection of non-functional streetlights. When a street light failed to turn on after vehicle detection, the integrated LDR sensors identified the anomaly. The system then sent a notification via email to the concerned authorities as shown in figure 5 and figure 6. This approach drastically improved maintenance efficiency by eliminating the need for manual inspections.The use of charge controllers and voltage sensors ensured optimal battery performance, avoiding overcharging and deep discharge scenarios. The automatic source selection between battery and grid maintained energy resilience, even during low solar irradiance conditions. When battery has sufficient stored energy, the main controller connects the battery for powering street lights. When battery stored energy is low the main controller connects the grid supply for powering street lights as shown in figure 5.7.

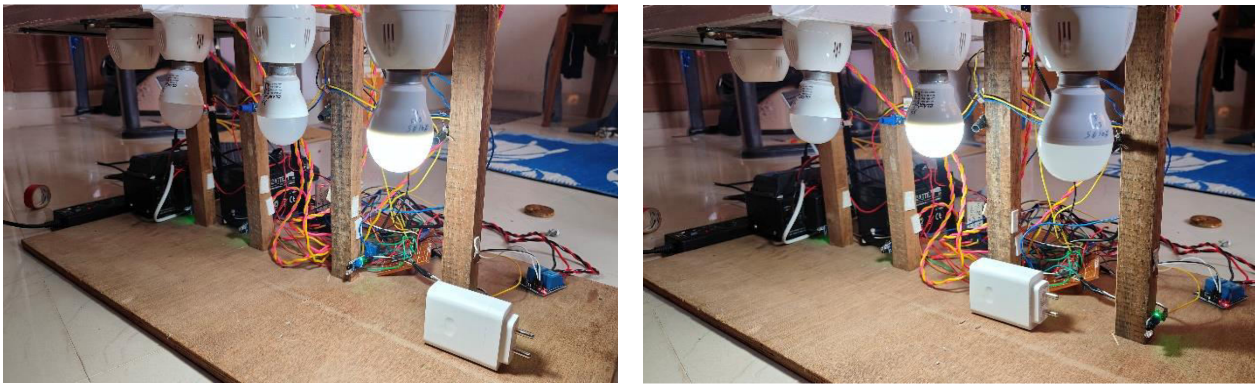

Figure 4: Street lights turned on corresponding to motion

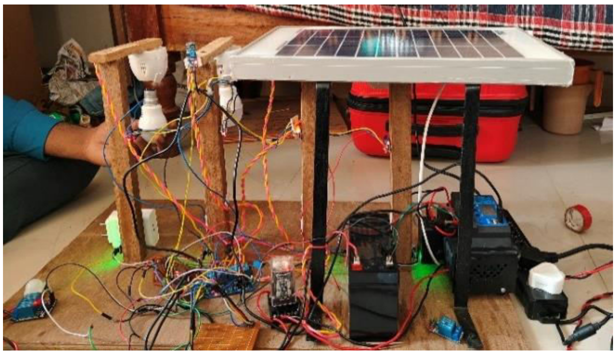

Figure 5: Indicating Street light malfunction

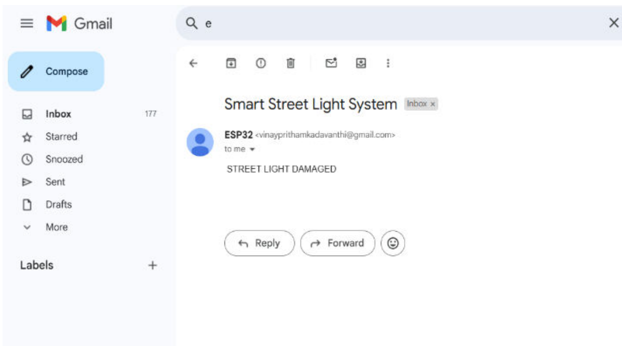

Figure 6: Alert mail received for damagelight detection.

The use of charge controllers and voltage sensors ensured optimal battery performance, avoiding overcharging and deep discharge scenarios. The automatic source selection between battery and grid maintained energy resilience, even during low solar irradiance conditions. When battery has sufficient stored energy hence the main controller connects the battery for powering street lights. When battery stored energy is low the main controller connects the grid supply for powering street lights by energizing 8-pin DPDT relay as shown in figure 7.

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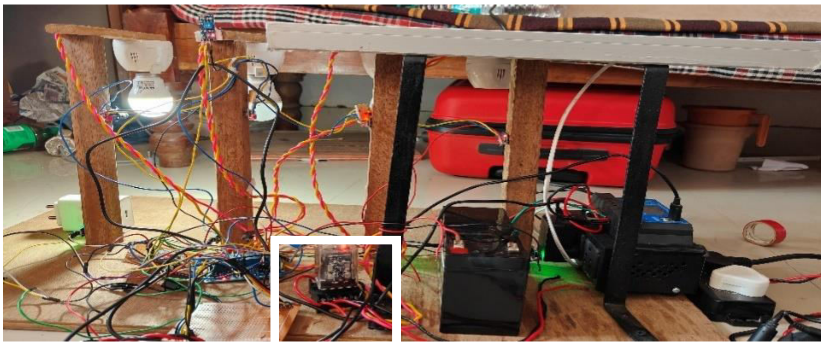

Figure 7: Street lights are powered by Grid supply

This system aligns with the sustainable development goals by reducing dependency on fossil fuels and minimizing operational costs. The integration of IoT for remote monitoring and alerts further enhances its scalability for smart city applications.

V. CONCLUSION AND FUTURE WORK

This smart street lighting system presents a practical, energy-efficient, and sustainable solution to modern urban lighting needs. By integrating solar energy with intelligent automation, that is using both renewable energy and grid power when stored battery energy is insufficient. This successfully reduces dependency on conventional electricity, cuts down energy costs. The use of motion and light sensors allows for dynamic lighting control. The ESP32 microcontroller not only enables smooth operation but also supports remote monitoring through IoT, enhancing system reliability. The real-time damage detection of street lights, which promptly notifies authorities, making maintenance faster and more efficient. Overall, this system contributes meaningfully to the goals of smart city infrastructure by combining renewable energy and automation.

Future improvements could include integrating cloud-based data analytics for performance tracking and predictive maintenance, making the system even more proactive. Expanding communication modules (such as GSM, LoRa, or NB-IoT) could enhance scalability and allow deployment in remote or large-scale city areas. The use of machine learning algorithms could optimize power usage patterns based on traffic trends or weather conditions. Additionally, incorporating environmental sensors (for air quality, temperature, etc.) can turn the lighting poles into multifunctional smart nodes. With these upgrades, the smart street light system can evolve from a lighting solution into a broader smart city asset.

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