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Fault Diagnosis Of Solar Street Lights Using Wireless Network

[1]Uday Boranche, [2]Onkar Chavan, [3]Boaz Binu, [4]Rakesh Dhumale

[1]Student, [2]Student, [3]Student, [4]Assistant Professor

[1]Electronics and Telecommunication,

[1]AISSMS Institute of Information Technology, Pune, India

Abstract: This solution is forward thinking for Fault Diagnosis of Solar Street Light using Wireless Network, which will make sure that the Solar powered street lights are reliable and efficient. This system integrates the wireless communication technology RF and GSM to monitor the health of lone components like solar panels, battery and circuits in an individual street light all the time and can detect whenever the fault enters in these components. Data obtained is transmitted over a network of street lights having a centralized node that is able to send the real time status of all street lights in the area to the maintenance office. This method enables easy determination and correction of difficulties and thereby it cuts off the downtime and the related maintenance expenses. The system promotes the sustainability of urban infrastructure in energy conservation and public safety by the means of uninterrupted street lighting with the use of wireless technology. In doing so, this project fulfills the requirements for efficient fault detection, provides support for the use of renewable energy as well as the development of smart city initiatives, through use of intelligent monitoring systems.)

Keywords- Solar Energy, Smart Street Lighting, Fault Detection and Diagnosis, Wireless Sensor Networks (WSN), IoT-Based Infrastructure

I. Introduction

The wireless network project for the Fault Diagnosis of Solar Street Light is in proliferation because of fast growing demands in monitoring solar street lighting systems using efficient and reliable ways. Solar street lights are an integral part of the urban and rural infrastructure and assurance of their uninterrupted running is necessary for the security of the public and conservation of energy. But like any electrical devices, solar street lights can malfunction; the malfunctions in the solar panels, batteries, bulbs and circuits will cause power outage or performance downgrade if not fixed in time.

Traditional manual methods of detecting these faults involve time, and the expenses involved are high, these methods are also not effective in identifying issues before they escalate. The idea of this project is to design an intelligent, wireless network based system which continually monitors the status of streetlights, detects faults in real time and transmits the data to a central node for assessing and taking the decision of maintenance. Due to RF communication and GSM technology the system makes sure that the data from each street light is transmitted in an efficient way, which will allow a fast and accurate reaction to any malfunction.

By implementing the solution proposed above, the amount of manual inspection can be minimized; maintenance costs of the street lights is reduced, and the lifespan of solar street lights extended. The real time fault diagnosis also helps in increasing the sustainability by means of optimal utilization of the renewable energy, power wastage avoid and raise the reliability of public lighting systems. This work is another step in smart city solution, thus, providing a scalable and energy efficient solution to control solar powered street lights for both urban and rural environment.

II. Literature Review

[1] Belloni et al. [1] examined the performance optimization of hybrid solar streetlamps through real-world electrical measurements and algorithmic simulations. Their study monitored a hybrid solar streetlamp in Italy for over a year, optimizing battery usage while minimizing grid dependency. Findings showed that a 30° tilt angle improved energy production by 12%, and optimized LED power profiles led to a 45% reduction in grid consumption. The research emphasizes the economic viability of hybrid solar lighting in urban environments.
[2] Pathak and Patil [2] focused on fault detection in solar panels using thermal imaging. They assessed the impact of pre-processing techniques such as Mean, Median, Gaussian, and Bilateral filtering, combined with histogram equalization, to improve fault segmentation accuracy. The study applied color thresholding and RGB-based segmentation, achieving an Intersection over Union (IoU) score of 0.54 for single-cell hotspot detection. Their findings highlight bilateral filtering as the most effective technique for enhancing thermal image analysis in predictive maintenance.
[3] Dhumale et al. [3] proposed a Wireless Sensor Network (WSN)-based system for solar streetlamp fault detection. Their model uses Zigbee for communication between slave nodes and a master node, which then relays fault data to a maintenance center via GSM. This automation significantly reduces downtime and improves the reliability of solar-powered streetlights, making it a scalable solution for both urban and rural deployments.
[4] Another study by Dhumale et al. [4] explored Condition-Based Monitoring (CBM) of renewable energy systems using WSNs. Unlike previous models, this system integrates IoT-based remote monitoring via a Visual Basic GUI. The research highlights that Zigbee-based WSNs enable real-time fault detection while reducing the need for manual inspections, improving the efficiency of solar infrastructure maintenance.
[5] Malve et al. [5] developed a real-time battery monitoring system for solar infrastructure, using an Arduino UNO-based setup with voltage and current sensors. Their approach includes a Python-based GUI for real-time data visualization and Excel integration for long-term storage. The system prevents battery overcharging and tracks voltage fluctuations caused by weather changes, making it a cost-effective solution for standalone solar installations.

III. System Design

The proposed system is a wireless fault detection and alerting mechanism for solar street lighting infrastructure. It is designed to minimize system downtime by identifying faults in critical components such as the solar panel, battery, charging circuit, and bulb. The system employs a modular architecture with three Arduino Nano-based nodes communicating via RF modules and utilizing GSM-based SMS alerts for remote notifications.
The design follows a hierarchical node structure:
Node 1 (Slave Node 1): Located at a remote streetlamp, responsible for detecting local faults.

Node 2 (Slave Node 2): Acts as a relay node. It first forwards the fault data from Node 1, then transmits its own data.

Node 3 (Master Node 3): Positioned centrally; it collects fault data from both nodes and sends consolidated fault alerts via the GSM module.

Each node uses analog sensors to monitor voltage and current values for fault detection. Logical decisions are made based on threshold analysis of sensor readings. Communication is carried out using 433 MHz RF modules, and alerts are delivered using a SIM800L GSM module.
Both Slave Node=1 and Slave Node-2 represent individual solar street light poles equipped with:
Solar Panel: Generates power for the system and battery.
Battery Charger: Manages the charging process of the battery the solar panel.
Battery: Stores the energy.
Bulb: The light fixture powered by the battery.

Fault Detection Subsystems:
Each slave node has fault detection systems:
Solar Panel Fault Detection: Monitors the solar panel for any issues, such as disconnection or low power generation.
Charging Circuit Fault Detection: Ensures the battery charger is functioning properly by checking for charging circuit errors.

Battery Fault Detection: Checks the health and charge levels of the battery to detect failures or low charge.
Bulb Fault Detection: Verifies whether the street light bulb is working correctly or has malfunctioned.

Controller:
Each slave node has a central controller (Arduino Nano):
Collects fault data from the four subsystems.
Sends information to the RF Transmitter in Node 1.
In Slave Node 2, the controller receives fault data from RF Receiver (from Slave Node 1) and sends combined fault information via the RF Transmitter to the master node.

IV. SYSTEM DESCRIPTION

The proposed system follows a structured methodology to ensure effective fault detection and communication:

A. Architecture Overview

The proposed system is based on a three-node architecture:

Slave Node 1: Collects 4-bit data on specific parameters (e.g., solar panel voltage and current) and transmits it to Slave Node 2.

Slave Node 2: Relays data from Slave Node 1 to Master Node 3 and sends its own 4-bit data separately.

Master Node 3: Aggregates data from both slave nodes for fault diagnosis and alert generation.

B. Components and Materials

1) Arduino Nano microcontrollers (3 units)
2) RF communication modules
3) Sensors for monitoring battery status, solar panel performance, charging circuit functionality, and bulb health
4) The Master Node is equipped with a GSM Module that sends alerts to the maintenance officer. The alerts are the fault data collected from nodes. The GSM system allows for long-range communication, ensuring that maintenance personnel are informed in real-time about any issues in the system.

C. Data Transmission and Communication Protocol

Data is transmitted using RF modules, ensuring efficient communication over a wireless network. Slave Node 2 processes and forwards data sequentially to Master Node 3 without combining inputs from Slave Node 1 and its own measurements.

V. RESULT AND DISCUSSION

The project was successfully implemented using three Arduino Nano-based nodes interconnected through RF communication modules and integrated with a GSM module for real-time alerting as shown in Fig.1.

Figure 1 Hardware Model

The system was tested under various fault conditions, and the following results were observed:

Node 1 accurately detected faults related to the solar panel, battery, and LED, especially during night conditions as determined by the LDR.

Node 2 correctly monitored the charging circuit and its own LED condition, while also receiving and forwarding Node 1's message to the Master Node.

Node 3 consistently received messages from both slave nodes, correctly interpreted the fault data, and successfully sent SMS alerts describing the fault condition to the predefined phone number.
Figure 2 shows the received SMS.

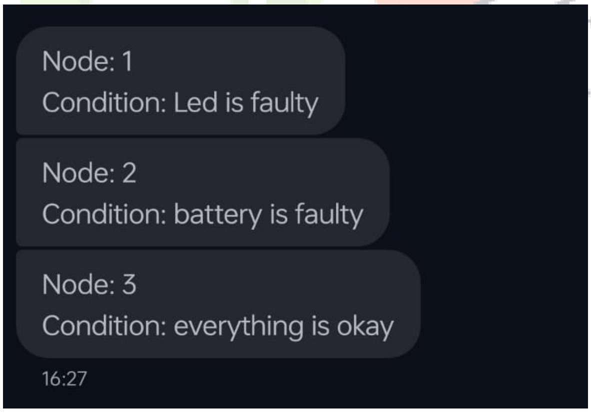

Figure 2 Received SMS

Message Integrity: Since RF messages are short and simple, the chances of data corruption are minimal. However, occasional message loss was observed, and introducing acknowledgment-based communication could improve robustness.

Power Management: The current prototype does not use any power-saving features. Implementing low-power sleep modes in future versions can significantly extend operational life in field deployments.
Scalability: The current system is limited to three nodes. However, the architecture allows expansion with minor modifications by adding unique node IDs and adjusting the message processing logic.

VI. Conclusion

The implemented system successfully addresses a key challenge in solar-powered street lighting infrastructure—timely fault detection and communication. By deploying a multi-node wireless network using Arduino Nano microcontrollers, voltage sensors, an LDR, RF modules, and GSM-based SMS alerts, the system enables remote fault identification and real-time diagnostics, significantly reducing maintenance downtime and manual inspection effort.

The use of RF communication for intra-network data transfer, combined with GSM-based SMS alerts, provides a cost-effective and reliable hybrid communication mechanism, making the system suitable for remote or rural deployment. This smart fault monitoring solution contributes to infrastructure automation and energy-efficient public lighting management, aligning with smart city and sustainable development goals.

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