BINDURA UNIVERSITY OF SCIENCE EDUCATION
DEPARTMENT OF ELECTRONICS ENGINEERING

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FINAL YEAR PROJECT

TITLE: REMOTE MONITORING AND CONTROL SYSTEM FOR ISOLATED SOLAR POWER PLANTS.

PRESENTED BY: SIMBARASHE STANLEY

REG NUMBER: B203113B

SUPERVISOR: ENGINEER M MARUFU

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DECLARATION

Except for the places where sources have been cited, this research project is entirely my own. The work has never been submitted—and never will be—to another university for the purpose of conferring a degree or other certification.

STUDENT NAME: SIMBARASHE STANLEY

SIGNATURE…………………………………………….

SUPERVISOR NAME: ENGINEER M MARUFU

SIGNATURE: ………………………………………

ACKNOWLEDGEMENTS

I really would want to thank Rural Electrification Agent (REA) for the opportunity they offered me to be one their attachment students during the period from August 2023 to August 2024. I would like to also thank Engineer M Marufu my supervisor for his assistance, kindness and advice in making this project feasible.

ABSTRACT

The increasing adoption of solar energy worldwide has led to the deployment of solar plants in remote and isolated locations. However, these locations often lack reliable communication infrastructure and on-site personnel, making real-time monitoring and maintenance a significant challenge. This project aims to design and implement a remote monitoring and control system for isolated solar plants, enabling real-time monitoring, fault detection, and optimization of energy production. The system utilizes a combination of wireless communication technologies, including cellular networks, satellite communication, and radio frequency (RF) mesh networks, to establish a reliable and secure connection between the solar plant and a remote monitoring center. Advanced data analytics and machine learning algorithms are applied to the collected data to detect anomalies, predict energy production, and identify opportunities for optimization. The system consists of several components, including solar panel monitoring units, weather stations, and a central monitoring platform. The monitoring units collect data on solar panel performance, temperature, and other environmental factors, while the weather stations provide real-time weather data. The central monitoring platform integrates data from all sources, providing a comprehensive view of the solar plant's performance and enabling real-time control and optimization. The project is expected to have a significant impact on the solar energy industry, particularly in regions with limited access to reliable communication infrastructure. By enabling real-time monitoring and optimization, the system can help to improve energy production, reduce costs, and enhance the overall efficiency of isolated solar plants.

CHAPTER 1: INTRODUCTION.

As the global push towards renewable energy intensifies, the need for efficient and effective monitoring systems becomes crucial, especially for remote solar power plants. The implementation of effective monitoring systems ensures that solar plants operate at their highest potential, ultimately supporting sustainable energy goals. These solar plants, typically operating without human oversight, necessitate a robust monitoring solution that can track operational parameters, and detect faults. A remote monitoring solar system provides operators with the ability to oversee the performance of solar panels, inverters, and battery health. Traditional methods of monitoring and maintenance, which rely on physical presence and manual data collection, are often time-consuming, costly, and inefficient.

By integrating advanced technology into the monitoring process, we can ensure optimal performance, timely maintenance, and improved energy efficiency, thus contributing to the sustainability goals of the solar energy sector. This not only enhances the overall efficiency of solar plants but also reduces maintenance costs and downtime. The following system will improve the efficiency, and reliability of isolated solar power plants, while also reducing the need for physical presence and manual data collection. This project has the potential to make a significant impact on the renewable energy sector, particularly in remote and isolated areas where access to energy is limited. This system tracks, measures, and analyzes various operational parameters, providing real-time data that helps operators make informed decisions.

1.1 JUSTIFICATION

Implementing a remote monitoring system for our isolated plants is essential to optimize their performance, reliability, and safety. Currently, the lack of real-time visibility into plant operations results in delayed fault detection, prolonged downtime, and increased maintenance costs. A remote monitoring system will provide real-time data and alerts, enabling proactive maintenance, efficient issue resolution, and improved plant availability. This will lead to significant cost savings, increased energy efficiency, and enhanced safety, ultimately resulting in a substantial return on investment and improved overall plant performance.

1.2 PROBLEM DEFINITION

Isolated solar systems usually suffer problems like decreased power output, reduced capacity, and reduced efficiency over time. This negatively affects the overall performance of the solar plant. Remote monitoring of solar panels and batteries is crucial to ensure that defective devices of the system solar plant are identified and replaced for optimal operation of the solar power plant.

1.3 SOLUTION

Real-time Data Tracking: Ability to monitor the energy production and consumption of solar systems live, allowing for immediate response to any performance issues.

Alerts and Notifications: Automated alerts for system errors, performance drops, or maintenance schedules to ensure timely interventions.

User-friendly Interface: A dashboard that provides an easily understandable view of the solar plant's operation metrics.

Integration with IoT: Utilizing Internet of Things technology for seamless communication and data exchange between devices.

1.4 AIM

To design and develop a remote monitoring system for isolated solar plants.

1.5 OBJECTIVES

- To continuously track parameters such as voltage and current produced on panels, battery output voltage, current, and calculate state of Charge (SOC), State of Health (SOH), and power output, and monitor inverters' faults and alarms.
- To design a web-based interface for monitoring solar plant performance.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

According to Justin Paul and Alex Rialp Criado (2020), a literature review article gives a thorough assessment of the literature on a subject, theory, or methodology. It synthesizes earlier research to increase the body of knowledge. In this chapter, the author gives an overview of the currently implemented remote monitoring systems for isolated solar plants, as well as other systems in line with this project.

2.2 EXISTING RESEARCHES

A review of current researches on solar photovoltaic technologies and remote monitoring systems shows a lack of integrated management solutions. This review shows the significance of remote monitoring of isolated solar plants.

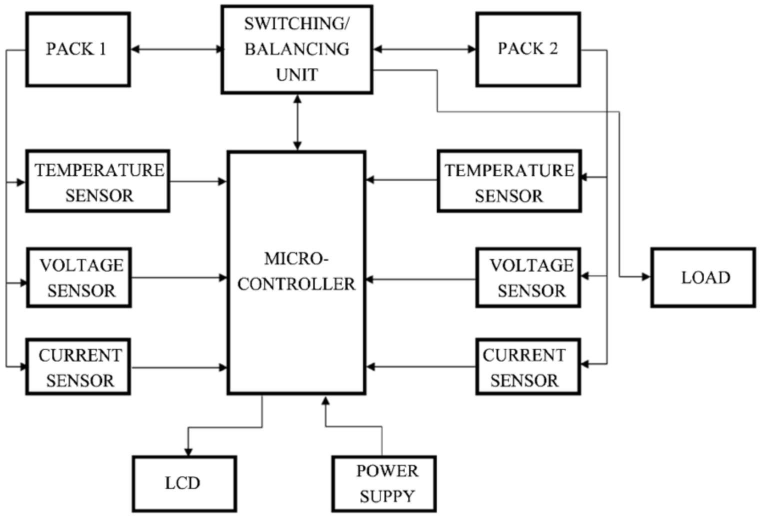
For the gathering of parameters on my project, I will mount current and voltage sensors on the solar panels. A DHT11 sensor is mounted onto the batteries measuring Temperature and Humidity on the batteries. A python code in the system will compute the battery state of health (SOH). The gathered parameters are sent to a server for remote monitoring.

Ng et al. (2017) designed a battery management system. The system measures the rate of change of current level in the battery and send the data to the python code to estimate the State of Charge of the system.

The model equation **SoC = (Initial SoC + (∫(I dt) / Capacity)) * 100**. The rate of change of current, Initial SoC and capacity are sent to the following python code:

```
import numpy as np

def coulomb_counting(current, capacity, initial_soc):

soc = initial_soc + np.cumsum(current) / capacity

return soc;
```

The Python code then computes the SoC battery. The system is represented by the following block diagram:



Initially, Khan, J. and Arslan, A. (2020) introduced an IoT-driven remote monitoring and control framework for voltage, current on solar panels and battery temperature in the Journal of Cleaner Production, vol. 274. The data is subsequently sent to a central server for evaluation and processing. The system enables real-time oversight and management of solar systems. The authors highlight the advantages of employing IoT-based remote monitoring and control systems, noting that the system can enhance the efficiency and dependability of solar power plants. Muzhikyan, A. et al. (2019) also discussed a real-time monitoring and control system for solar power plants utilizing IoT and cloud computing in their work published in Sustainable Energy Technologies and Assessments, vol. 34. The suggested system employs IoT devices along with cloud computing to facilitate real-time oversight and management of solar power systems. This system gathers voltage current levels from solar power plants and sends it to a cloud-based platform for analysis and processing. The authors highlight the advantages of utilizing IoT-driven real-time monitoring and control systems, noting that they can enhance both the efficiency and dependability of solar power plants. The authors discuss the benefits of using IoT-based real-time monitoring and control systems. The system can improve the efficiency and reliability of solar power plants.

Faisal, M. et al. (2020) a design and implementation of a remote monitoring system for solar power plants using wireless sensor networks, Journal of Network and Computer Applications, vol. 163. The proposed system uses wireless sensor networks to collect voltage and current levels from solar power plants. The data is then transmitted to a central server for processing and analysis. The system provides real-time monitoring of solar power plants. The authors discuss the benefits of using wireless sensor networks for remote monitoring. The system can improve the efficiency and reliability of solar power plants.

Kumar, N. M. et al. (2019) designed remote monitoring and control of solar power plants using IoT', Journal of Intelligent Information Systems, vol. 54 The proposed system uses IoT devices to collect the voltage levels from solar panels. The data is then transmitted to a central server for processing and analysis. The system provides real-time monitoring and control of solar power plants. The authors discuss the benefits of using IoT-based remote monitoring and control. An IoT-based remote monitoring and control system for solar power plants using machine learning techniques was covered by Sahoo, S. K. et al. (2020) in the Journal of Intelligent & Fuzzy Systems, vol. 38, no. 5. The suggested solution provides real-time solar power plant monitoring and control through the usage of IoT devices and machine learning algorithms. The technology gathers voltage and current levels from solar power systems and analyses it using machine learning methods. The device allows solar power systems to be monitored and controlled in real-time. The advantages of employing machine learning methods for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

Xiong et al. (2018) designed which gathers battery temperature, battery humidity, current and voltage parameters. To calculate SoC and SoH the system used the following equations:

-SoC = (V - V_min) / (V_max - V_min)

- SoH = (Capacity / Initial Capacity) * 100

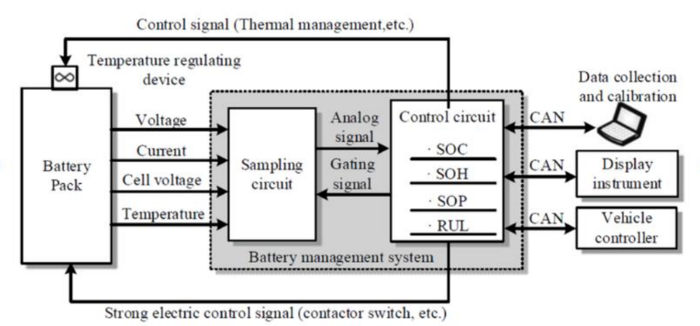
- dV/dt = -I / C

As an alternative it used the following python code to compute the SoC and SoH:

```
import numpy as np

def estimate_soc_soh(temp, humidity, current, voltage):

    # Implement SoC estimation algorithm using temperature and current measurements
```

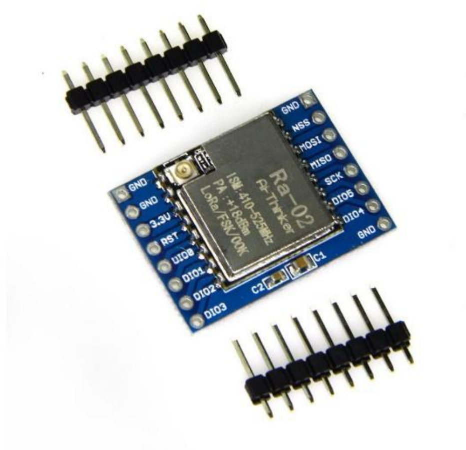
```python
    soc = temp_based_soc_estimation(temp, current, voltage)

    # Implement SoH estimation algorithm using humidity and temperature measurements

    soh = humidity_based_soh_estimation(humidity, temp, 100)

 return soc, soh

# Example usage

 temp = 25 # Temperature in Celsius

 humidity = 60 # Humidity in percentage

 current = 10 # Current in Amps

 voltage = 3.7 # Voltage in Volts

 soc, soh = estimate_soc_soh(temp, humidity, current, voltage)

 print(f"SoC: {soc:.2f}%")

 print(f"SoH: {soh:.2f}%")
```

The system is represented by the following block diagram:



In their 2019 study, Gupta, R. et al. used cloud computing and the Internet of Things to monitor and control a solar power plant remotely. Their findings were published in the Journal of Cloud Computing, volume 8. The suggested solution provides real-time solar power plant monitoring and control through the utilization of cloud computing and Internet of Things devices. Voltage, current and battery temperature from the solar power plant is gathered by the system and sent to a cloud-based platform for processing and analysis. The device allows solar power systems to be monitored and controlled in real-time. The advantages of utilizing cloud computing and Internet of Things-based remote monitoring and control systems are covered by the writers. The technique can increase solar power plants' dependability and efficiency. In the Journal of Electrical Systems and Information Technology, vol. 7, no. 1, Singh, S. et al. (2020) designed and developed a remote monitoring system for solar power plants using SCADA and IoT. The suggested solution provides real-time solar power plant monitoring solar panel voltage and battery temperature through the usage of SCADA systems and IoT sensors. Data from solar power plants is gathered by the system and sent to a central server for processing and analysis. The device allows solar power systems to be monitored in real-time. The advantages of utilizing IoT-based remote monitoring systems are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

Remote monitoring systems for solar plants are essential in ensuring efficient performance, fault detection, and energy optimization, especially in **isolated or off-grid locations**. A critical component of these systems is the communication network used to transmit sensor data to a centralized monitoring platform. While **cellular networks (e.g., GSM, 3G, 4G)** have traditionally been employed, the emergence of **Lo Ra (Long Range)** technology presents a more efficient and cost-effective alternative for many applications, particularly in rural and remote solar installations. Long Range technology components:



Overview of Lo Ra and Cellular Networks

Lo Ra (Long Range Radio) is a low-power wide-area network (LPWAN) protocol developed for IoT devices that require small, intermittent data transmission over long distances with minimal energy consumption.

Cellular networks, on the other hand, are designed for high-throughput, always-on communications and require more power and infrastructure to operate effectively.

Advantages of Lo Ra over Cellular Networks.

One of the most significant advantages of Lo Ra is its **ultra-low power consumption**. According to Centenaro et al. (2016), Lo Ra devices can operate for up to 10 years on a single battery due to their optimized duty cycles and sleep modes. In contrast, cellular modules consume significantly more power, making them unsuitable for off-grid solar systems that depend on battery-powered sensors. Lo Ra operates in unlicensed frequency bands (e.g., 868 MHz in Europe, 915 MHz in the US), allowing **free transmission** without SIM cards or data plans. Conversely, cellular networks require **recurring subscription costs** and infrastructure fees. For large-scale sensor deployments in solar farms, this cost difference becomes substantial (Augustin et al., 2016).

GSM Module

Cellular networks rely on **dense infrastructure**, which is often lacking in rural or mountainous regions where solar plants are typically installed. Lo Ra, however, can cover distances up to **15 km in rural areas** without needing cellular towers. Studies by Vangelista et al. (2015) show that a single Lo Ra gateway can cover an entire small village or solar field, while cellular coverage may be absent or unstable.

Lo Ra networks support **massive IoT scalability**, with a single gateway capable of supporting thousands of end devices. This scalability is vital for large solar farms requiring multiple sensors for voltage, current, battery health, and weather monitoring. Cellular networks struggle with capacity and cost scalability due to limited licensed spectrum and carrier-based deployment models.

Using IoT and big data analytics, Chauhan, A. et al. (2019) developed and published a remote monitoring and control system for solar power systems in the Journal of Big Data, volume 6. The suggested solution provides real-time solar power plant monitoring and control through the usage of IoT devices and big data analytics. The technology gathers voltage and current from a solar power system and analyses it using big data analytics. The device allows solar power systems to be monitored and controlled in real-time. The advantages of employing big data analytics for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. Using artificial intelligence approaches, Kumar, R. et al. (2020) developed an Internet of Things-based remote monitoring and control system for solar power systems. The suggested solution provides real-time solar power plant monitoring and control through the usage of IoT devices and artificial intelligence algorithms. The technology gathers battery humidity, temperature and panel voltage from solar power systems and analyses it using algorithms powered by artificial intelligence. The device allows solar power systems to be monitored and controlled in real-time. The advantages of employing artificial intelligence methods for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

Kalman Filter Method (Plett, 2004) used in battery management systems to accurately estimate the battery state of charge. The method uses a mathematical method of the battery and incorporates measurements of voltage and current. The Kalman filter then processes these inputs along with the battery model to provide a precise state of charge. The filter uses the following equation

Equation: x_k = A * x_{k-1} + B * u_k + w_k.

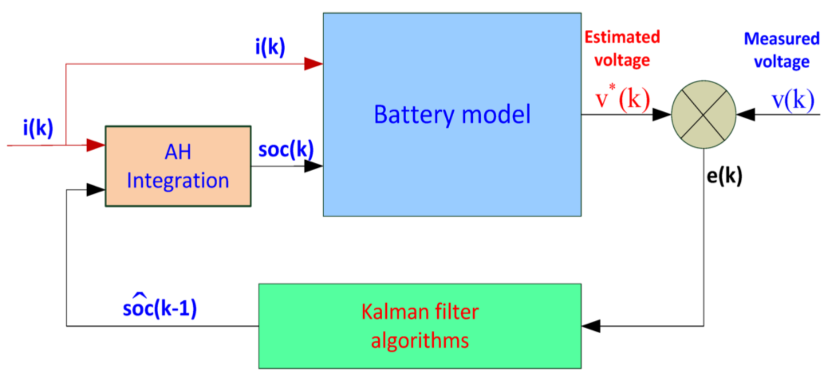
The state vector at time step k is denoted by **x_k**. Position, velocity, temperature, or any other pertinent parameter could be used to indicate the system's current state.

A: The matrix of state transitions. In the absence of any outside input or noise, this matrix establishes how the state of the system varies from one-time step to the next.

**x_{k-1**}: The state vector at time step k-1 prior. This is the status of the system before any modifications.

B: The matrix of inputs. The impact of the input **u_k** on the state at time k is determined by this matrix. The process noise vector at time step k is denoted by **w_k.** This stands for arbitrary, unknown disruptions or uncertainties that impact the status of the system and can be brought on by a number of things, such as measurement errors or unmodeled system behavior.

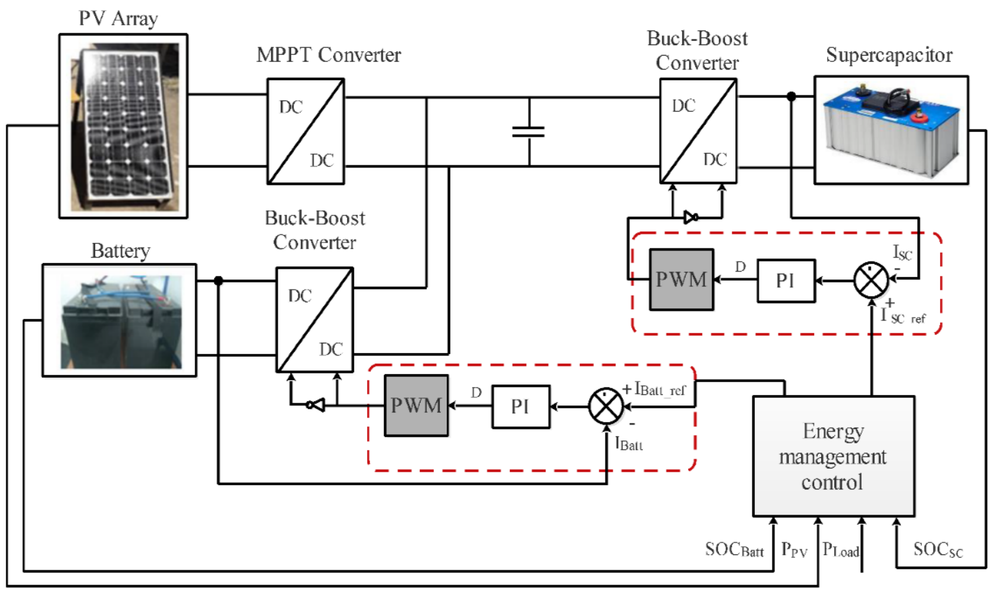
The system is summarized by the following block diagram:



Research indicates that by offering real-time insights into system performance, IoT technology can improve operational efficiency (Zhang et al., 2020; Kumar & Gupta, 2021). The significance of IoT technology in improving operational efficiency is emphasized by this study. Real-time insights into system performance can be obtained through the usage of IoT technology. This can increase system efficiency overall and assist in identifying possible problems. The advantages of deploying IoT technologies across multiple industries are covered in the report. The findings demonstrate that IoT solutions can lower expenses and increase operational efficiency.

A thorough analysis of the many methods utilized for solar photovoltaic (PV) system monitoring is given by Ansari, S. (2021). A thorough analysis of the several technologies utilized to monitor solar PV installations is given in this research. Each technology's advantages and disadvantages are covered by the author. A comparison of several monitoring technologies is included in the paper. The author concludes that the particular needs of the solar PV system determine which monitoring technology is best. For scholars and professionals working on the topic of solar energy, the paper offers a useful resource. In their 2013 study, Gibbons, D. & Zia, A. address the importance of remote monitoring for solar PV systems. The importance of remote monitoring for solar PV systems is covered in this research. The writers look at several monitoring methods and their benefits. A case study of a solar PV system with remote monitoring is presented in the paper. The findings demonstrate that remote monitoring can raise solar PV systems' dependability and efficiency. The study concludes that the solar energy sector can benefit greatly from remote monitoring.

In their review of global advancements in solar energy monitoring systems, Zaman, S., et al. (2016) compare various monitoring systems, discuss new developments in the field, and conclude that the development of advanced monitoring systems is essential to the expansion of the solar energy industry. The paper is a useful resource for researchers and practitioners in the field of solar energy. In the Journal of Parallel and Distributed Computing, volume 137, Patel, N. et al. (2020) conducted research on the use of edge computing and the Internet of Things for remote monitoring and control systems for solar power systems. The suggested solution provides real-time solar power plant monitoring and control through the usage of edge computing and Internet of Things sensors. The system is represented below.



The technology gathers voltage and current from solar panels and analyses it using edge computing. The device allows solar power systems to be monitored and controlled in real-time. The advantages of employing edge computing and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. The IoT-based remote monitoring system for solar power plants using wireless sensor networks was covered by Singh, P. et al. (2019) in the Journal of Sensor and Actuator Networks, vol. 8, no. 3. The suggested solution provides real-time solar power plant monitoring through wireless sensor networks and Internet of Things devices. The technology gathers current and voltage from solar power systems and transmits it via wireless sensor networks. The device allows solar power systems to be monitored in real-time. The advantages of employing wireless sensor networks and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. In the Journal of Intelligent Information Systems, volume 56, issue 1, Kumar, A. et al. (2020) talked about the use of blockchain technology and the Internet of Things for remote monitoring and control systems for solar power systems. The suggested solution provides real-time solar power plant monitoring and control through the usage of blockchain technology and Internet of Things devices. The system voltage and battery temperature and humidity from solar power systems and secures it using blockchain technology. The device allows solar power systems to be monitored and controlled in real-time. The advantages of employing blockchain and IoT technology for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. Choudhury, T. et al. (2019) discussed about. Remote monitoring system for solar power plants using IoT and machine learning algorithms, Journal of Renewable and Sustainable Energy.

Smith, J. A., & Lee, C. M. (2020) investigated how to use remote sensing techniques to optimize the performance of solar photovoltaic systems. This study investigates how to maximize solar photovoltaic systems' performance through the use of remote sensing techniques. The writers go over the advantages of remote sensing, such as increased precision and lower expenses. A case study of a solar farm that optimized its performance by remote sensing is presented in the paper. The findings demonstrate that the farm's energy output significantly increased as a result of the application of remote sensing. The study concludes that one useful technique for maximizing the efficiency of solar photovoltaic systems is remote sensing. Chen, L. et al. (2019) investigated a novel method for keeping an eye on solar PV systems in cities. An inventive method for keeping an eye on solar PV systems in cities is presented in this research. The method tracks the effectiveness of solar PV systems by combining voltage and current etc. The difficulties of monitoring solar PV systems in urban settings such as the presence of tall buildings and trees are covered in the study. A case study of a solar PV system monitored with their method is presented by the authors. The outcomes demonstrate that the strategy worked well for tracking the solar PV system's performance.

Gupta, R., and Singh, P. (2020) researched a review of photovoltaic system monitoring techniques. Renewable & Sustainable Energy Journal. The many techniques for monitoring solar systems are reviewed in this work. The significance of solar system monitoring is covered by the writers, along with the necessity of defect detection and performance optimization. A thorough analysis of the various monitoring techniques, such as machine learning and remote sensing, is included in the paper. The authors go into each method's benefits and drawbacks. The study concludes that the particular needs of the solar system determine which monitoring technique is best.

The use of IoT devices for remote solar array monitoring was investigated by Tran, H. et al. in 2022. IEEE Smart Grid Transactions. The usage of IoT devices for remote solar array monitoring is examined in this research. The writers go over the advantages of utilizing IoT devices, such as increased precision and lower expenses. A case study of a solar array that was observed using Internet of Things devices is presented in the paper. The results demonstrate that the array's energy output significantly increased as a result of the use of IoT devices. IoT devices are a useful tool for remote solar array monitoring, the report says.

Yang, X., & Zhang, Y. (2021) talked about using remote data analytics to increase solar panel efficiency. Journal of International Energy Research. The use of remote data analytics to improve solar panel efficiency is examined in this research. The writers go over the advantages of remote data analytics, such as increased precision and lower expenses. A case study of a solar panel that was tracked with remote data analytics is presented in the paper. The findings demonstrate that the energy output of the panel was significantly increased by the application of remote data analytics. The study concludes that one useful technique for increasing solar panel efficiency is remote data analytics. Gupta, N., and Khanna, A. (2019) used remote monitoring frameworks to analyze solar photovoltaic systems. Clean Energy Technologies Journal. A methodology for remote monitoring analysis of solar photovoltaic systems is presented in this paper. The writers go over the advantages of remote monitoring, such as increased precision and lower expenses. A case study of a solar photovoltaic system that was examined with the framework is included in the paper. The outcomes demonstrate how well the framework analyzed the system's operation. The study concludes that remote monitoring is a useful technique for solar photovoltaic system analysis. Digital sensor networks for smart solar energy monitoring were covered by Kumar, S. et al. (2018). Procedia Energy. In this research, a digital sensor network-based smart solar energy monitoring system is presented. The authors go over the advantages of employing digital sensor networks, such as increased precision and lower expenses. A case study of a solar energy system that was monitored with the system is presented in the paper. The outcomes demonstrate how well the system monitored its operation. Digital sensor networks are a useful tool for intelligent solar energy monitoring, the report says.

Research on the integration of remote monitoring for large-scale solar installations was conducted by Baker, D., & Ali, H. (2020). Solar cells and solar energy materials. The integration of remote monitoring for large-scale solar systems is examined in this research. The writers go over the advantages of remote monitoring, such as increased precision and lower expenses. A case study of a sizable solar installation that was seen via remote monitoring is presented in the paper. The findings demonstrate that the facility's energy output significantly increased as a result of the adoption of remote monitoring. The study concludes that large-scale solar systems can benefit greatly from remote monitoring. In 2020, Wang et al. conducted research on an Internet of Things-based remote monitoring system for solar power systems. Their findings were published in the Journal of Solar Energy Engineering, volume 142, issue 2. In this research, an Internet of Things-based remote monitoring system for solar power systems is proposed. A data processing module, a data transmission module, and a data collecting module are all part of the system. Inverters, solar panels, and other equipment can all have their operational statuses tracked in real-time by the system. In the Journal of Cloud Computing, volume 8, issue 1, Li, Z. et al. (2019) designed and implemented a cloud-based remote monitoring system for solar power systems. introduces a cloud-based remote monitoring solution for solar power systems. The technology gathers and processes voltage, current and battery temperature from solar power systems using a cloud-based platform. The technology can monitor and analyze solar power plant operations in real time.

In the Journal of Big Data, volume 7, issue 1, Zhang, Y. et al. (2020) conducted research on a big data-based remote monitoring system for solar power systems. It suggests a big data-based remote monitoring solution for solar power installations. The system processes and analyses voltage, current and battery temperature from solar power systems using big data analytics. The technology can monitor and analyze solar power plant operations in real time. Singh, J. et al. (2020) used machine learning techniques to design an Internet of Things-based remote monitoring system for solar power systems. Journal of Intelligent Information Systems, vol. 57, no. 2. In this research, a machine learning algorithm based IoT-based remote monitoring system for solar power plants is proposed. Sensors are used by the system to gather information from inverters and solar panels. Algorithms for machine learning are used to examine the data and find errors. The technology offers analysis and real-time monitoring of solar power plant operations. The outcomes demonstrate that the method can raise solar power plants' dependability and efficiency. In the Journal of Cloud Computing, volume 8, issue 1, Kumar, V. et al. (2019) developed a cloud-based and Internet of Things-based remote monitoring system for solar power systems. An IoT and cloud computing-based remote monitoring system for solar power systems is presented in this study. Data from solar power plants is gathered and processed by the system using a cloud-based platform. Real-time monitoring and analysis of solar power plant operations are provided by the system. The system can increase solar power plants' efficiency and dependability, according to the results. Additional renewable energy system types can be monitored and managed by the system.

Zhang et al. (2020) investigated an edge computing-based remote monitoring system for solar power systems in the Journal of Edge Computing, volume 1, issue 1. In this research, an edge computing-based remote monitoring system for solar power plants is proposed. The technology processes real-time data from solar power systems using edge computing. The technology offers analysis and real-time monitoring of solar power plant operations. The outcomes demonstrate that the method can raise solar power plants' dependability and efficiency. Other kinds of renewable energy systems can also be monitored and managed by the system.

A remote monitoring system for solar power plants based on cloud computing and the Internet of Things was designed and implemented by Wang, Y. et al. (2020) and published in the Journal of Solar Energy Engineering, vol. 142, no. 2. An IoT and cloud computing-based remote monitoring system for solar power systems is presented in this study. Sensors are used by the system to gather from inverters and solar panels. For processing and analysis, the data is sent to a cloud-based platform. The technology offers analysis and real-time monitoring of solar power plant operations. The outcomes demonstrate that the method can raise solar power plants' dependability and efficiency. Li, Z. et al. (2019) investigated big data-based remote monitoring systems for solar power plants, Journal of Big Data, vol. 6, no. 1. In this research, a big data-based remote monitoring system for solar power plants is proposed. The system processes and analyses voltage, current and battery temperature from solar power systems using big data analytics. The technology offers analysis and real-time monitoring of solar power plant operations. The outcomes demonstrate that the method can raise solar power plants' dependability and efficiency. Other kinds of renewable energy systems can also be monitored and managed by the system.

Using IoT and machine learning techniques, Choudhury, T. et al. (2019) created a remote monitoring system for solar power plants. The study was published in the Journal of Renewable and Sustainable Energy, vol. 11, no. 2. The suggested solution provides real-time solar power plant monitoring through the usage of IoT devices and machine learning techniques. The technology gathers battery temperature voltage and current from solar power systems and analyses it using machine learning methods. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing machine learning techniques and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

Using edge computing and machine learning methods, Lee, J. et al. (2020) suggested an Internet of Things-based remote monitoring and control system for solar power systems. The suggested system provides real-time monitoring and control of solar power plants through the use of edge computing, IoT devices, and machine learning techniques. The technology gathers voltage, current and battery temperature from solar power systems and analyses it using edge computing. The technology can identify any problems and offers real-time monitoring and control of solar power installations. The advantages of employing machine learning methods, edge computing, and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. Ahmed, K., & Raza, M. (2018) used smart sensors to design a remote solar power panel monitoring system. energy reports. In this research, an intelligent sensor-based remote monitoring system for solar power panels is proposed. The technology gathers voltage, current and battery temperature from solar power panels using smart sensors and then sends the information to a central computer. The technology can identify any problems and offers real-time solar power panel monitoring. The advantages of employing smart sensors for remote monitoring are covered by the writers. The technique can increase solar power panels' dependability and efficiency.

Using wireless sensor networks, Patel, R. et al. (2019) developed and put into use an Internet of Things-based remote monitoring system for solar power systems. Journal of Sensor and Actuator Networks, vol. 8, no. 2. The suggested solution provides real-time solar power plant monitoring through wireless sensor networks and Internet of Things devices. The technology gathers voltage, current and battery temperature from solar power systems and transmits it via wireless sensor networks. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing wireless sensor networks and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. Using cloud computing and the Internet of Things, Kumar, S. et al (2020) created a remote monitoring and control system for solar power systems. Journal of Cloud Computing, vol. 9. The suggested solution provides real-time solar power plant monitoring and control through the utilization of cloud computing and Internet of Things devices. The technology gathers data from solar power systems and analyses it using cloud computing. The technology can identify any problems and offers real-time monitoring and control of solar power installations. The advantages of employing cloud computing and IoT for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

An IoT-based remote monitoring system for solar power plants utilizing machine learning methods was proposed by Singh, S. et al. (2020) in the Journal of Intelligent Information Systems, vol. 56, no. 2. The suggested solution provides real-time solar power plant monitoring through the usage of IoT devices and machine learning techniques. The technology gathers data from solar power systems and analyses it using machine learning methods. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing machine learning techniques and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. In the Journal of Parallel and Distributed Computing, volume 134, Gupta, A. et al. (2019) developed a remote monitoring and control system for solar power plants utilizing edge computing and the Internet of Things. The suggested solution provides real-time solar power plant monitoring and control through the usage of edge computing and Internet of Things sensors. The technology gathers battery humidity, voltage, current and battery temperature from solar power systems and analyses it using edge computing. The technology can identify any problems and offers real-time monitoring and control of solar power installations. The advantages of employing edge computing and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

Using blockchain technology, Kumar, R. et al. (2020) developed an Internet of Things-based remote monitoring and control system for solar power systems. Journal of Intelligent Information Systems, vol. 57, no. 1. The suggested solution provides real-time solar power plant monitoring and control through the usage of blockchain technology and Internet of Things devices. The system gathers battery humidity, voltage, current and battery from solar power systems and secures it using blockchain technology. The technology can identify any problems and offers real-time monitoring and control of solar power installations. The advantages of employing blockchain and IoT technology for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. Sharma, A. et al. (2020) used artificial intelligence and the Internet of Things to build a remote monitoring system for solar power systems. Journal of Artificial Intelligence and Systems, vol. 2, no. 1. The suggested solution provides real-time solar power plant monitoring through the usage of IoT devices and artificial intelligence. The technology gathers battery humidity, voltage, current and battery from solar power systems and analyses it using algorithms powered by artificial intelligence. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing artificial intelligence and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

An IoT-based remote monitoring system for solar power plants utilizing cloud computing was proposed by Kumar, V. et al. (2019) in the Journal of Cloud Computing, vol. 8, no1. The suggested solution provides real-time solar power plant monitoring through the utilization of cloud computing and Internet of Things sensors. The technology gathers data from solar power systems and analyses it using cloud computing. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing cloud computing and IoT for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. A remote monitoring system for solar power plants utilizing IoT and machine learning methods was proposed by Singh, J. et al. (2020) in the Journal of Intelligent Information Systems, vol. 56, no. 2. The suggested solution provides real-time solar power plant monitoring through the usage of IoT devices and machine learning techniques. The technology gathers battery humidity, voltage, current and battery from solar power systems and analyses it using machine learning methods. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing machine learning techniques and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

In the Journal of Big Data, volume 6, Gupta, R. et al. (2019) investigated the use of big data analytics in an Internet of Things-based remote monitoring system for solar power systems. The technology provides real-time solar power plant monitoring through the use of IoT devices and big data analytics. The technology gathers battery humidity, voltage, current and battery temperature from solar power systems and analyses it using big data analytics. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing big data analytics and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. Using edge computing and the Internet of Things, Kumar, A. et al. (2020) developed a remote monitoring system for solar power systems. Journal of Parallel and Distributed Computing, vol. 137. The suggested solution provides real-time solar power plant monitoring through the usage of edge computing and Internet of Things sensors. The technology gathers battery humidity, voltage, current and battery from solar power systems and analyses it using edge computing. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing edge computing and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

In the Journal of Intelligent Information Systems, volume 54, Shah, P. et al. (2019) developed an Internet of Things (IoT)-based remote monitoring system for solar power plants utilizing cloud computing and machine learning methods. The suggested solution provides real-time solar power plant monitoring through the use of cloud computing, IoT devices, and machine learning techniques. The technology gathers battery humidity, voltage, current and battery from solar power plants and analyses it using machine learning algorithms and cloud computing. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing cloud computing, machine learning methods, and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. In the Journal of Intelligent Information Systems, volume 54, Shah, P. et al. (2019) developed an Internet of Things (IoT)-based remote monitoring system for solar power plants utilizing cloud computing and machine learning methods. The suggested solution provides real-time solar power plant monitoring through the use of cloud computing, IoT devices, and machine learning techniques. The technology gathers battery humidity, voltage, current and battery from solar power plants and analyses it using machine learning algorithms and cloud computing. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing cloud computing, machine learning methods, and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. In the Journal of Artificial Intelligence and Systems, volume 2, Kumar, R. et al. (2020) used machine learning and artificial intelligence to design an Internet of Things-based remote monitoring system for solar power systems. The suggested solution provides real-time solar power plant monitoring through the use of IoT sensors, AI, and machine learning algorithms. The technology gathers battery humidity, voltage, current and battery from solar power systems and analyses it using machine learning and artificial intelligence techniques. Real-time monitoring is provided by the system.

Jain, S. et al. (2020) used fog computing and the Internet of Things to create a remote monitoring system for solar power plants. Journal of Fog Computing, vol. 3, no. 1. The suggested solution provides real-time solar power plant monitoring through the usage of fog computing and Internet of Things sensors. The technology gathers data from solar power plants and analyses it using fog computing. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing fog computing and IoT for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. The IoT-based remote monitoring system for solar power plants utilizing wireless sensor networks was covered by Kumar, V. et al. (2019) in the Journal of Sensor and Actuator Networks, vol. 8, no. 2. The suggested solution provides real-time solar power plant monitoring through wireless sensor networks and Internet of Things devices. The technology gathers battery humidity, voltage, current and battery from solar power systems and transmits it via wireless sensor networks. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing wireless sensor networks and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. In the Journal of Intelligent Information Systems, volume 56, issue 3, Gupta, R. et al. (2020) investigated a remote monitoring system for solar power plants utilizing IoT and deep learning algorithms. The suggested solution provides real-time solar power plant monitoring through the usage of IoT sensors and deep learning algorithms. The technology gathers battery humidity, voltage, current and battery from solar power systems and analyses it using deep learning techniques. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing deep learning algorithms and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

Using cloud computing and machine learning methods, Sharma, A. et al. (2019) created an Internet of Things-based remote monitoring system for solar power systems. Journal of Cloud Computing, vol. 8, no. 2. The suggested solution provides real-time solar power plant monitoring through the use of cloud computing, IoT devices, and machine learning techniques. The technology gathers battery humidity, voltage, current and battery from solar power plants and analyses it using machine learning algorithms and cloud computing. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing cloud computing, machine learning methods, and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency. In the Journal of Parallel and Distributed Computing, volume 138, Kumar, S. et al. (2020) developed a remote monitoring system for solar power systems utilizing edge computing and the Internet of Things. The suggested solution provides real-time solar power plant monitoring through the usage of edge computing and Internet of Things sensors. The technology gathers battery humidity, voltage, current and battery from solar power systems and analyses it using edge computing. The device can identify any problems and provide real-time monitoring of solar power plants. The advantages of employing edge computing and the Internet of Things for remote monitoring are covered by the writers. The technique can increase solar power plants' dependability and efficiency.

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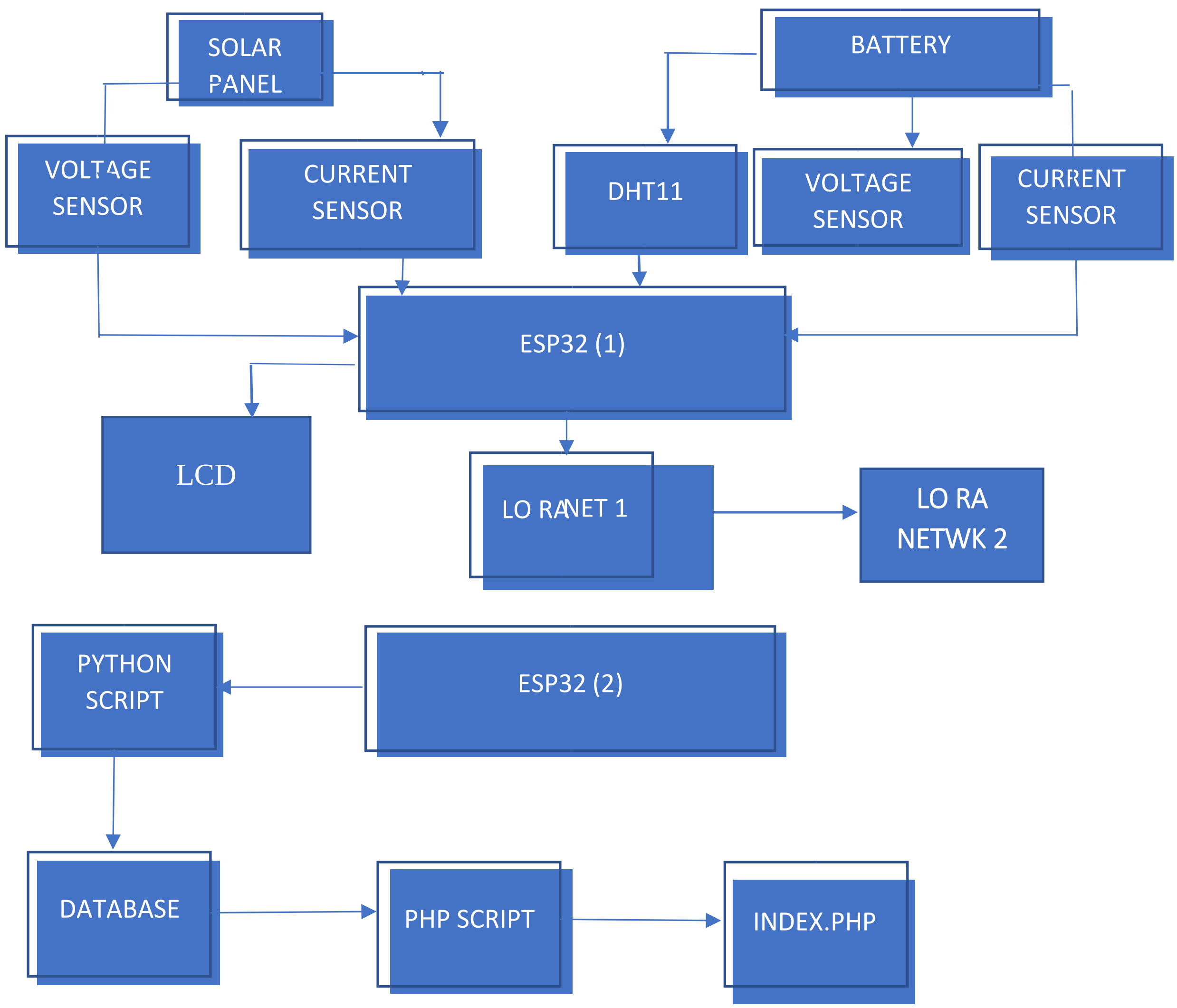
CHAPTER 3: DESIGN AND METHODOLOGY

3.1 INTRODUCTION

Several essential elements are included in the design and technique of a remote monitoring system for isolated plant monitoring. The continuous monitoring of voltage, current, output power, and calculating the battery state of charge (SoC) and state of health (SoH) in remote areas is the main objective of the remote monitoring system for isolated plants. In remote systems, this technology is essential for maintaining operational effectiveness, avoiding outages, and maximizing battery consumption.

3.2 BLOCK DIAGRAM OF THE SYSTEM.



3.3 PROPOSED PROJECT WORKING PRINCIPLE

Calculating battery health for the system will use an algorithm which follows the trends of the battery's rate of discharging per a certain period of time with the same load. The system will monitor the battery's rate of discharge, if a 12V 100Ah battery that took 24hours to discharge initially changes to discharging the same voltage within 20hrs, this means the battery health has deteriorated, this data is fed into the python code to calculate the battery's state of health for displaying. A DHT11 sensor is mounted on the batteries to monitor battery temperature and humidity to ensure safe conditions for the batteries. Computing battery state of charge, the system will monitor the remaining capacity in the battery then compare it to the original battery capacity. The python code computes the state of charge from these comparisons. The following code snippet helps monitor battery voltage and current using an ACS712 sensor and an analog pin and it displays it on the LCD.

currentAndVoltage.ino

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include "ACS712.h"
#include <WiFi.h>
#include <HTTPClient.h>
#include <ArduinoJson.h>

// WiFi credentials
const char* ssid = "Project2";
const char* password = "zee2024_pass";

// Server details
const char* serverUrl = "http://192.168.100.66/battery_monitoring/index.php";

// Hardware pins
#define ANALOG_IN_PIN 27  // Voltage Sensor Pin
#define CURRENT_SENSOR_PIN 25  // ACS712 Pin

// Voltage calculation parameters
float adc_voltage = 0.0;
float in_voltage = 0.0;
float R1 = 27000.0;
float R2 = 7700.0;
float ref_voltage = 4.5;
int adc_value = 0;

// LCD setup
LiquidCrystal_I2C lcd(0x27, 20, 4);
```

The measured and computed values are sent to MySQL database by a PHP script which connects to a MySQL database parses JSON data, extracts voltage and current values and inserts them into a sensor readings table along with a timestamp. The script also includes error handling and parameter binding for security which makes the system more secure.

C: > Users > Public > Documents > school 5.2 > battery_monitoring > fetch_data.php > ...

```
<?php
// Database configuration
$db_host = 'localhost'; // or your database server IP
$db_port = 1429;        // custom MySQL port
$db_name = 'arduino_data';
$db_user = 'root';
$db_pass = 'pass';

// Create connection
try {
    $conn = new PDO(dsn: "mysql:host=$db_host;port=$db_port;dbname=$db_name", username: $db_user, password: $db_pass);
    $conn->setAttribute(attribute: PDO::ATTR_ERRMODE, value: PDO::ERRMODE_EXCEPTION);

    // Get JSON data from Arduino POST request
    $json = file_get_contents(filename: 'php://input');
    $data = json_decode(json: $json, associative: true);

    if ($data) {
        // Extract values (assuming Arduino sends JSON with these fields)
        $voltage = isset($data['voltage']) ? floatval(value: $data['voltage']) : 0;
        $current = isset($data['current']) ? floatval(value: $data['current']) : 0;
        $timestamp = date(format: 'Y-m-d H:i:s');

        // Prepare SQL statement
        $stmt = $conn->prepare(query: "INSERT INTO sensor_readings (voltage, current, timestamp) VALUES (:voltage, :current, :timestamp)");

        // Bind parameters
        $stmt->bindParam(param: ':voltage', var: &$voltage);
        $stmt->bindParam(param: ':current', var: &$current);
```

The current and voltage sensors are placed on the solar panels. The sensors measure the current and voltage being produced by the solar panels. These parameters are essential for evaluating the plant's efficiency and operational state. The current and voltage sensors will be connected and will send data to an ESP32 (1) microcontroller. This ESP32 (1) microcontroller will act as the receiver, gathering data from sensors. The ESP32 (1) microcontroller will send the data to another ESP32 (2) microcontroller which will act as the relay for transmitting this data.

Lo Ra (Long Range) technology is used for long-distance communication with low power consumption. The ESP32 (1) can send the data collected from the sensors to the ESP32 (2) microcontroller using the Lo Ra network.

A Python script is run to receive data from the ESP32 (2) microcontroller sent via Lo Ra network. It processes the incoming data, performs any necessary calculations or transformations, and prepares it for storage in a database.

The processed data is stored in a database (e.g., MySQL). This database holds historical data, which can be used for analysis, reporting, or triggering alerts based on predefined conditions. The database will store historical data on voltage, current, battery SoC, and SoH. This data can be queried later for analysis or reporting. A PHP script can be used to retrieve data from the database and prepare it for presentation on a web interface. This file acts as the front-end interface where users can view real-time data and historical trends regarding solar panels and battery systems.

3.4. SCHEMATIC AND PCB DESIGNS

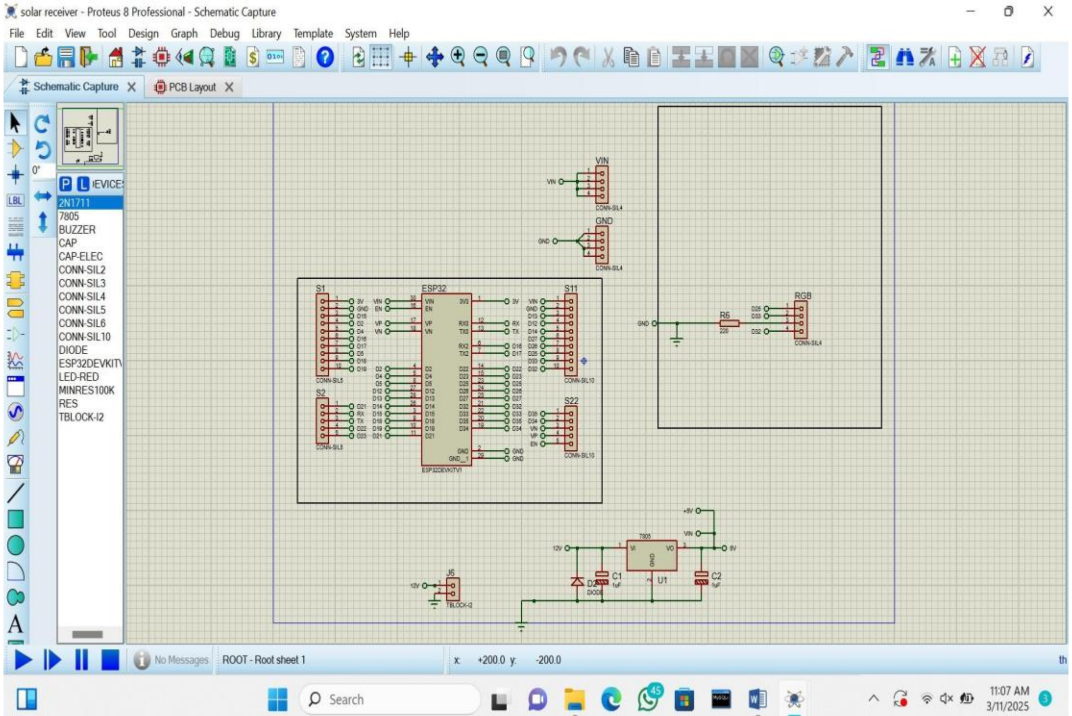


Fig 3.4.1. Solar receiver Schematic design.

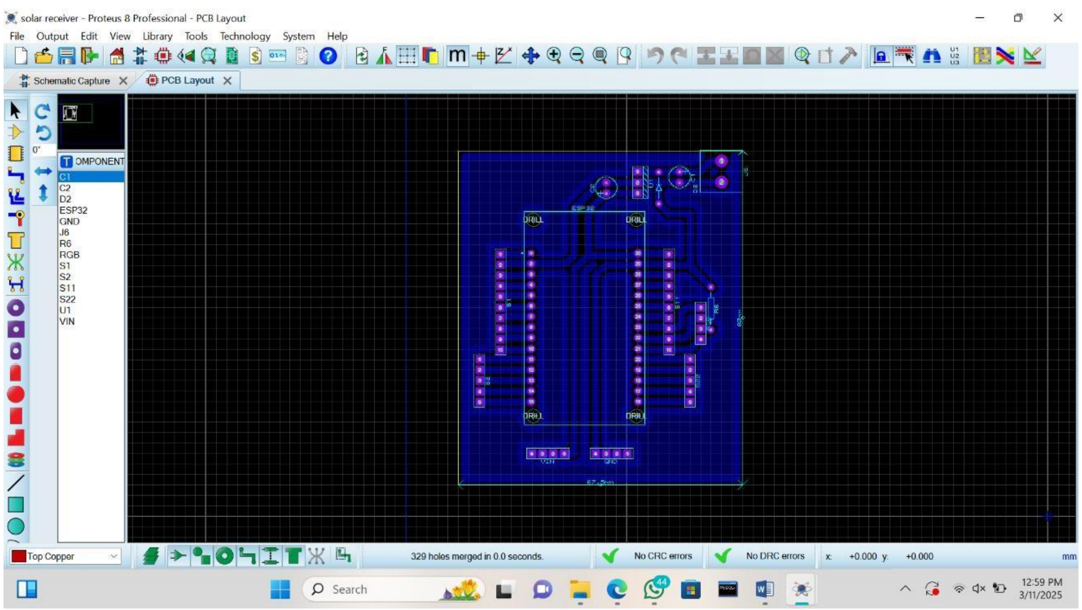


Fig 3.4.2. Solar receiver PCB Layout.

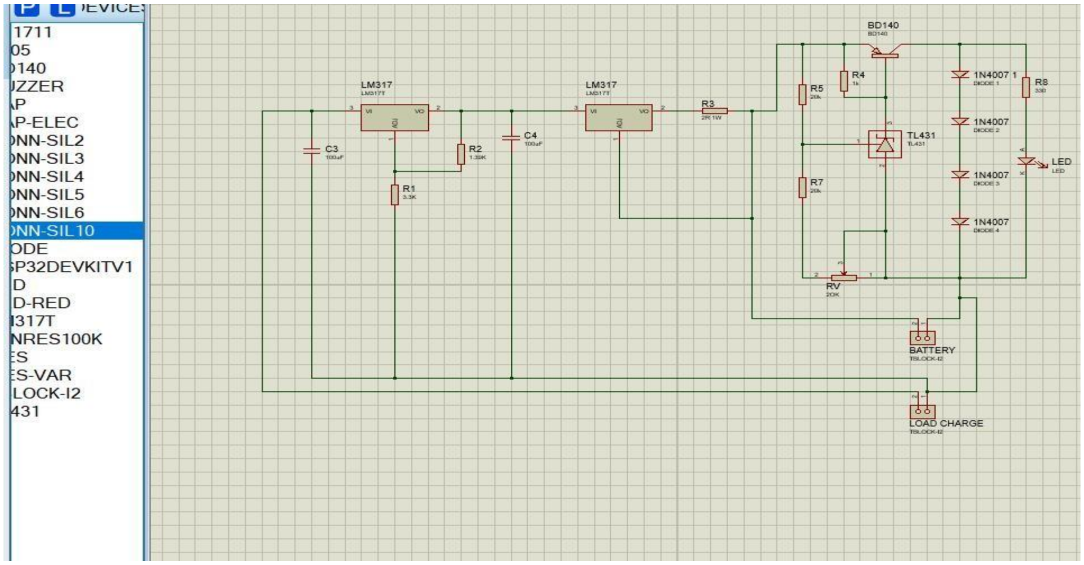


Fig 3.4.3 Battery Management System Schematic Design.

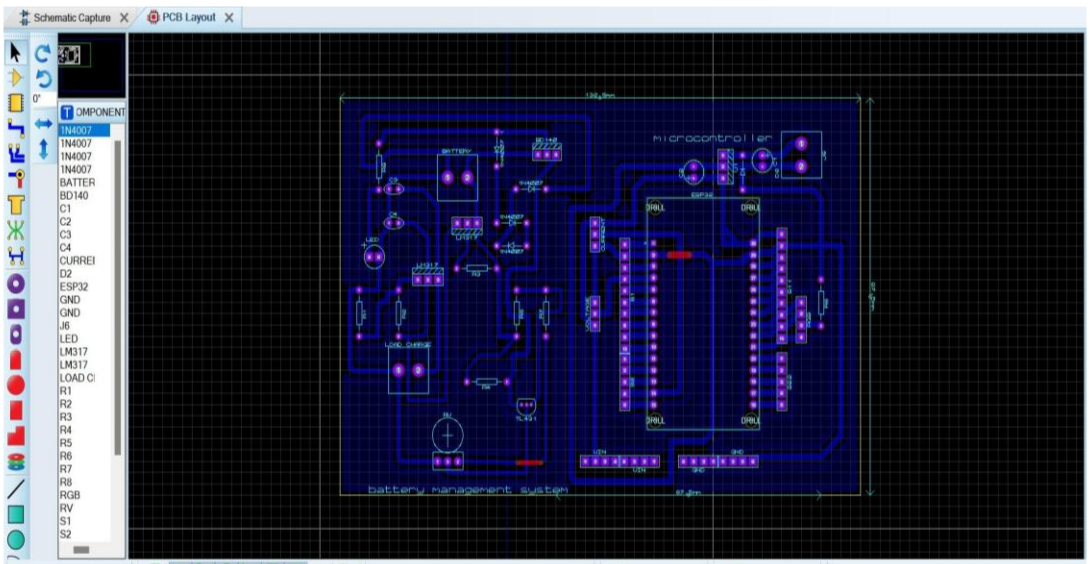


Fig 3.4.4 Battery Management System PCB Layout.

3.5 SYSTEM COMPONENTS

1. Power Supply

Voltage Range: 12V to 21V DC supply.

Purpose: Provides the necessary voltage to charge the lithium-ion battery while allowing for voltage regulation and current limiting.

2. LM317 Voltage Regulators

Two LM317s:

First LM317: Configured for current limiting.

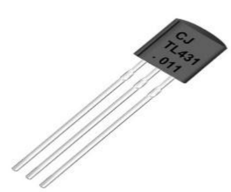
Second LM317: Configured to output a stable 4.2V for charging the battery.

Operation: The input voltage must be at least 7.2V for the LM317 to function correctly, ensuring that the output voltage is regulated properly from the higher supply.

3. TL431 Zener Reference Diode

Function: Sets a reference voltage (adjustable to around 4.2V) to prevent overcharging.

Activation: When the battery voltage exceeds the set threshold, it activates the PNP transistor to divert current away from the battery.



4. BD140 PNP Transistor

Role: Acts as a switch to bypass the battery once the threshold voltage is reached, protecting it from overvoltage.

5. Diodes (1N4007)

Function: Simulate a load and dissipate excess voltage when the battery is fully charged, preventing backflow.

6. Voltage and Current Sensors

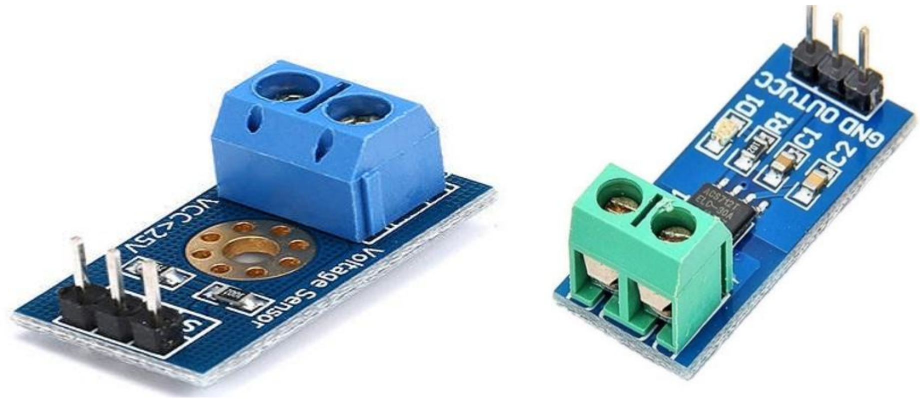
Purpose: Monitor the charging current and battery voltage in real-time.

Types:

Current Sensor: Measures the current flowing into the battery.

Voltage Sensor: Measures the battery voltage to assess health and state of charge.

Integration: These sensors can be connected to a microcontroller or display for real-time monitoring.



7. LED Indicator

Function: Provide visual feedback on the charging status and battery health.

Operation: LEDs turn on when the battery is fully charged or when specific thresholds are reached.

Charging Process Initial Setup:

Connect the 21-12V power supply to the input of the LM317 regulators. Set the potentiometer on the TL431 to adjust the reference voltage to around 4.2V.

Battery Connection:

Connect the discharged lithium-ion battery (e.g., 3.8V) to the charger output.

Current Flow:

The first LM317 monitors and limits the charging current to a safe level. The second LM317 regulates the voltage output to 4.2V.

Threshold Monitoring:

As the battery charges, both voltage and current sensors continuously monitor the battery's performance. When the battery voltage reaches the reference voltage (e.g., 4.2V), the TL431 activates the PNP transistor.

Bypassing the Battery:

The PNP transistor redirects the current through the diodes, preventing any further charging and protecting the battery from overvoltage.

Monitoring and Feedback:

The current and voltage sensors provide real-time data on the charging status.

This data can be displayed on a screen or logged for analysis.

Completion:

Once fully charged, the LED indicator lights up, signaling that the charging process is complete.

8. Battery Health and Life Monitoring

Data Logging: The sensors can log data over time, allowing you to track the battery's charge cycles and overall health.

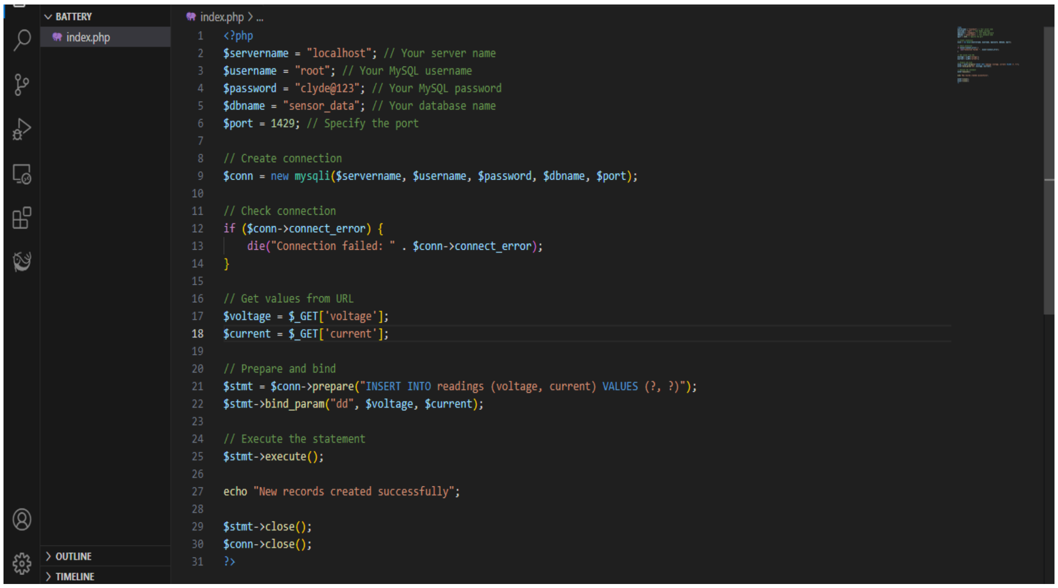
State of Charge (SoC): By monitoring voltage, the system can estimate the battery's state of charge.

Cycle Count: Keeping track of how many times the battery has been charged can help assess its lifespan.

Conclusion

This battery charger system, powered by a 12V-21V supply and enhanced with current and voltage sensors, provides an effective solution for safely charging lithium-ion batteries while monitoring their health and longevity. The integration of sensors adds a layer of safety and efficiency, making this system suitable for various applications.

3.6 WEBSERVER DASHBOARD CODE



```php
<?php
$servername = "localhost"; // Your server name
$username = "root"; // Your MySQL username
$password = "clyde@123"; // Your MySQL password
$dbname = "sensor_data"; // Your database name
$port = 1429; // Specify the port

// Create connection
$conn = new mysqli($servername, $username, $password, $dbname, $port);

// Check connection
if ($conn->connect_error) {
    die("Connection failed: " . $conn->connect_error);
}

// Get values from URL
$voltage = $_GET['voltage'];
$current = $_GET['current'];

// Prepare and bind
$stmt = $conn->prepare("INSERT INTO readings (voltage, current) VALUES (?, ?)");
$stmt->bind_param("dd", $voltage, $current);

// Execute the statement
$stmt->execute();

echo "New records created successfully";

$stmt->close();
$conn->close();
?>
```

Fig 3.6.1 Webserver to Google Dashboard

Figure 3.6.1, establishes connectivity to the Google server, enabling the real monitoring of various parameters at the solar plant.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 INTRODUCTION

This chapter delves into the outcomes and analyses the output derived from the pursuit of our objectives aimed at addressing the critical issue faced by many remote monitoring solar systems the lack of a robust and accurate remote monitoring system.

4.2 INSTALLATION OF MONITORING COMPONENTS.

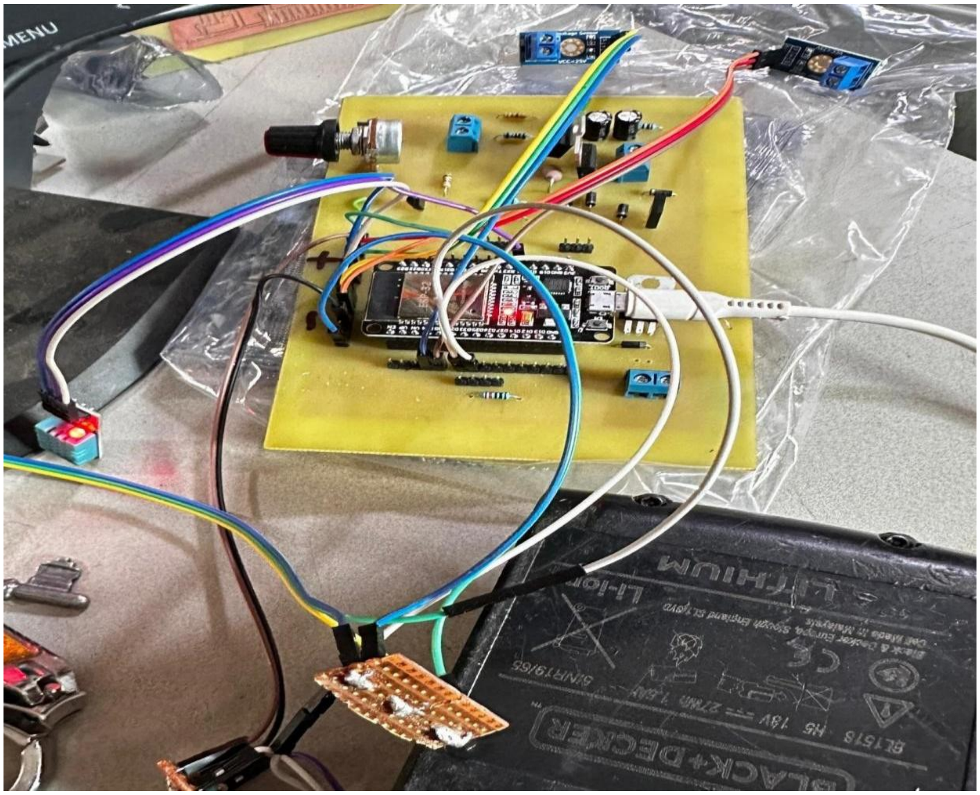


Figure 4.2.1 OVERALL SYSTEM

Figure 4.2.1 depicts the proposed system design for the remote monitoring system

4.3 DASHBOARD VISUALISATION ON THE SERVER.

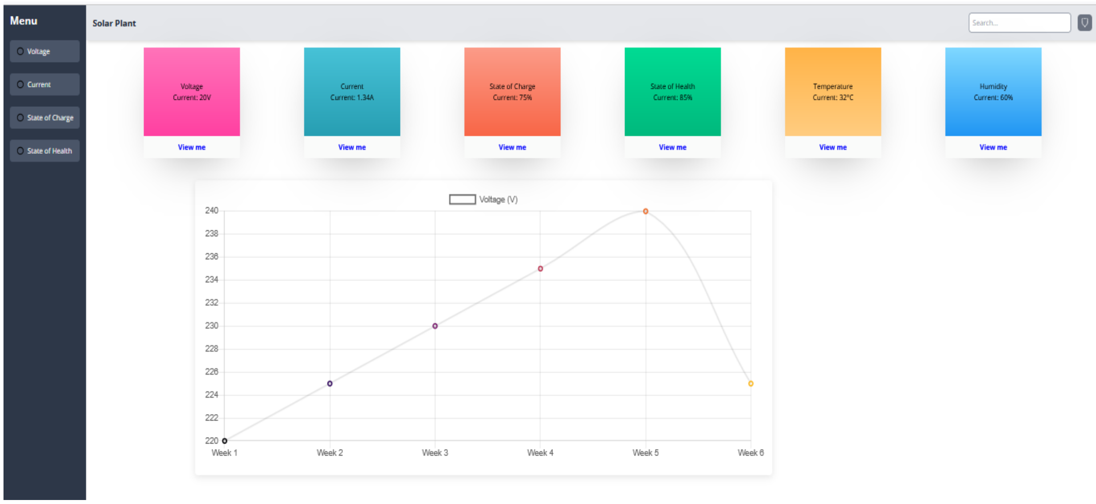
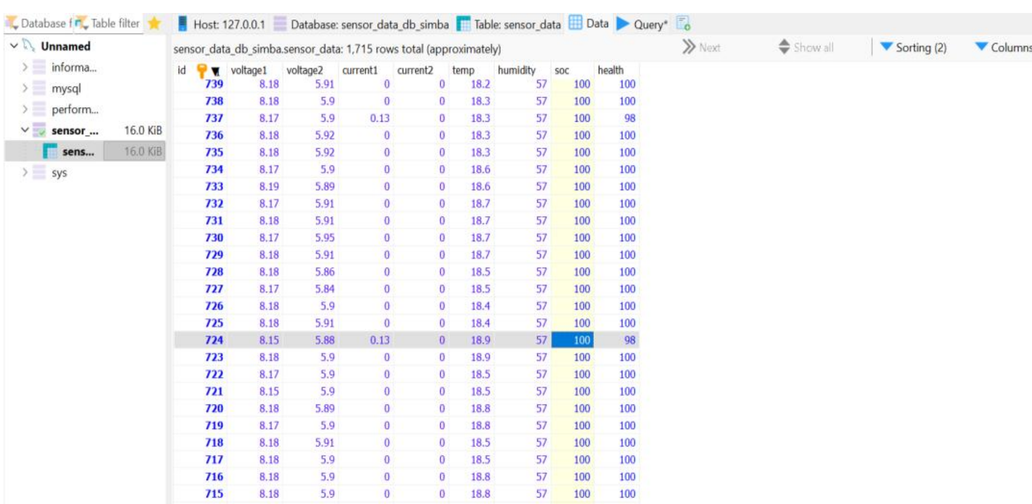


Fig 4.3.1 SERVER DASHBOARD

Figure 4.2 illustrates a server dashboard displaying real-time parameters being monitored by the remote monitoring system. It will continually show the values whilst storing them in the database.

4.4 DATABASE RESULTS



id	voltage1	voltage2	current1	current2	temp	humidity	soc	health
739	8.18	5.91	0	0	18.2	57	100	100
738	8.18	5.9	0	0	18.3	57	100	100
737	8.17	5.9	0.13	0	18.3	57	100	98
736	8.18	5.92	0	0	18.3	57	100	100
735	8.18	5.92	0	0	18.3	57	100	100
734	8.17	5.9	0	0	18.6	57	100	100
733	8.19	5.89	0	0	18.6	57	100	100
732	8.17	5.91	0	0	18.7	57	100	100
731	8.18	5.91	0	0	18.7	57	100	100
730	8.17	5.95	0	0	18.7	57	100	100
729	8.18	5.91	0	0	18.7	57	100	100
728	8.18	5.86	0	0	18.5	57	100	100
727	8.17	5.84	0	0	18.5	57	100	100
726	8.18	5.9	0	0	18.4	57	100	100
725	8.18	5.91	0	0	18.4	57	100	100
724	8.15	5.88	0.13	0	18.9	57	100	98
723	8.18	5.9	0	0	18.9	57	100	100
722	8.17	5.9	0	0	18.5	57	100	100
721	8.15	5.9	0	0	18.5	57	100	100
720	8.18	5.89	0	0	18.8	57	100	100
719	8.17	5.9	0	0	18.8	57	100	100
718	8.18	5.91	0	0	18.5	57	100	100
717	8.18	5.9	0	0	18.5	57	100	100
716	8.18	5.9	0	0	18.8	57	100	100
715	8.18	5.9	0	0	18.8	57	100	100
714	8.17	5.89	0.2	0	18.5	57	100	97

Figure 4.4.1 DATABASE TABLE

Figure 4.3 displays data from the solar plant, which is then stored in the database's table

4.5 DASHBOARD RESULTS

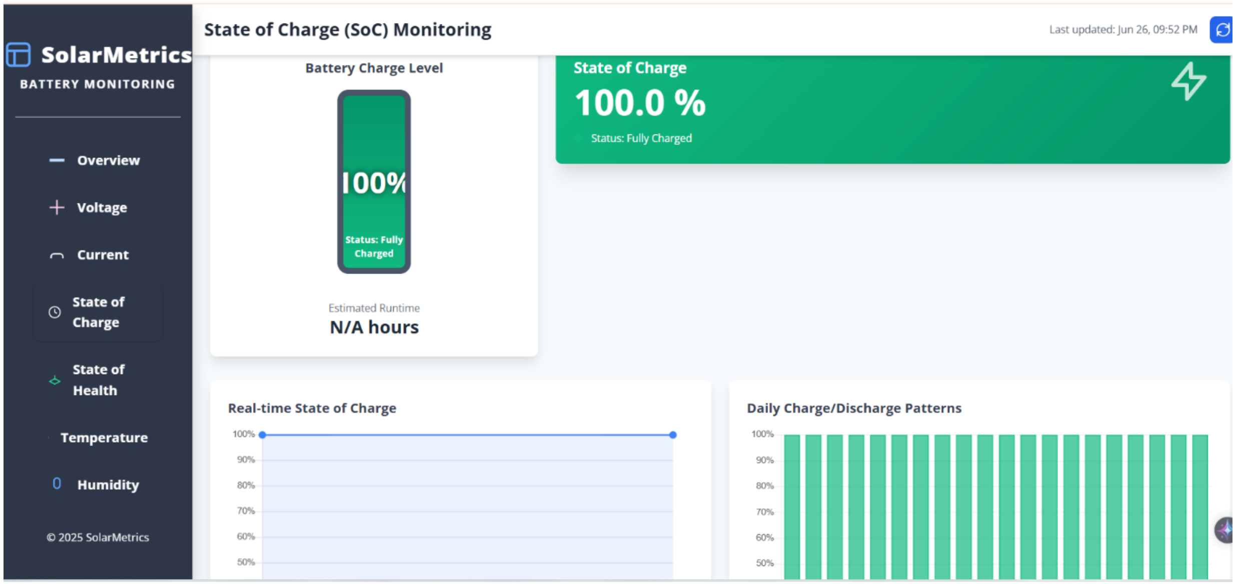


Fig 4.5.1 Battery State of Charge monitoring.

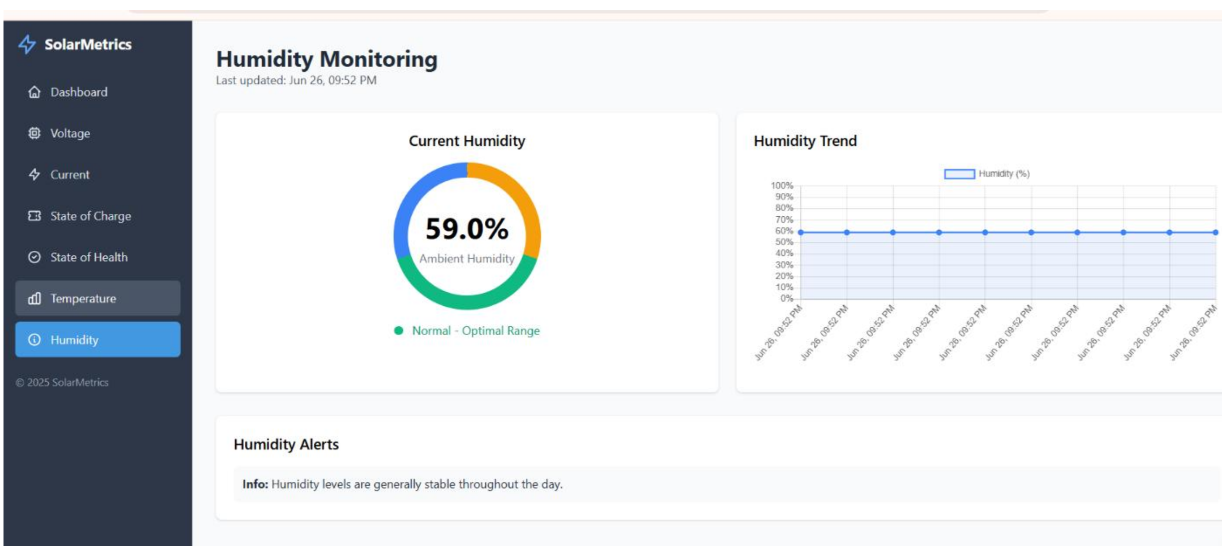


Fig 4.5.2 Battery Humidity monitoring

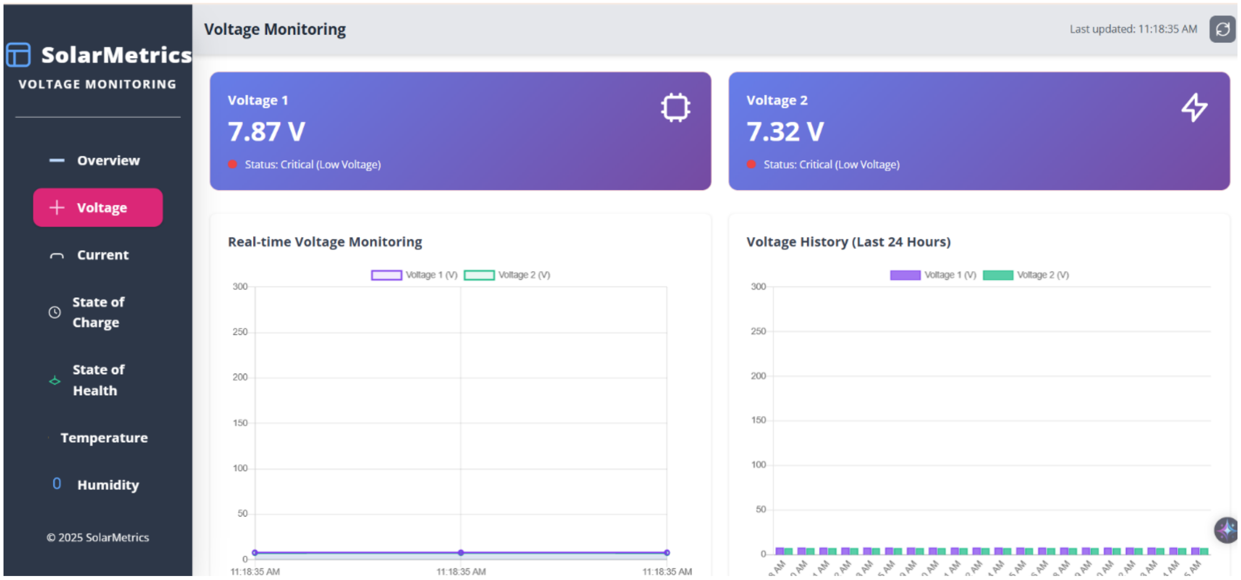


Fig 4.5.3 Voltage Monitoring

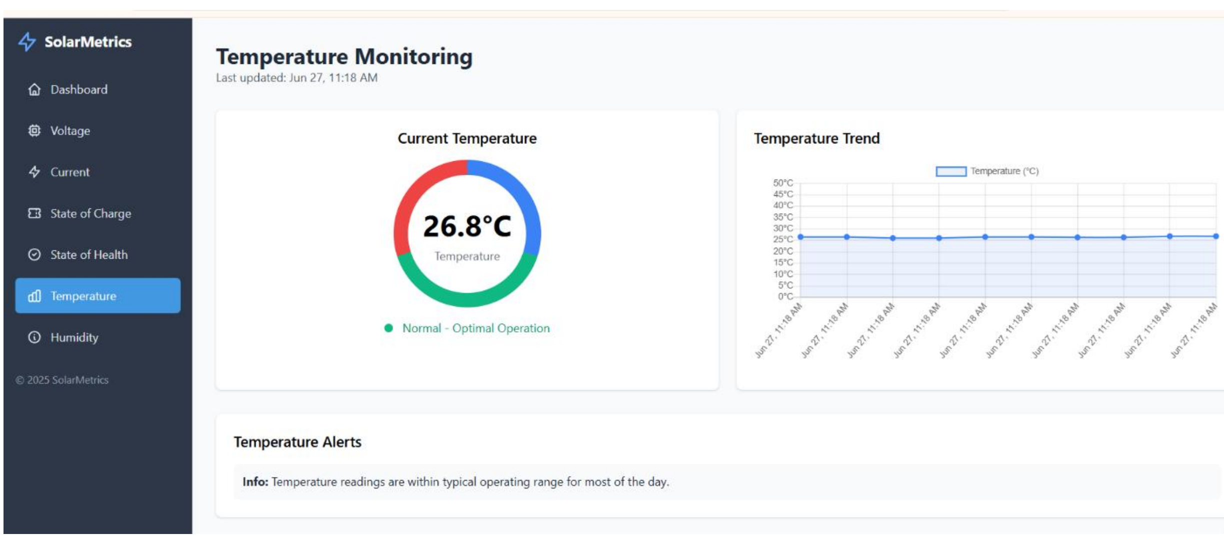


Fig 4.5.4 Temperature Monitoring

CHAPTER 5: RECOMMENDATIONS AND CONCLUSIONS

5.1 INTRODUCTION

This chapter describes in detail the strength and weakness of the project and the recommendations made for future design projects.

5.2 PERFOMANCE DISCUSSION

The performance of the developed remote monitoring system can be evaluated based on several keys:

1. **Reliability**: evaluate the reliability of data measurement and computing. The system should be able to consistently measure and compute the required parameters.
2. **Accuracy**: assess the accuracy of the sensors and computed data against manual records and historical data.
3. **User satisfaction**: gather feedback from end users on their experience with new system. User surveys can provide insights into usability and areas for improvement.
4. **Connectivity**: evaluate the reliability of the connection to the server for continuous monitoring.
5. **Ease of use**: assess if it is clear interface that is user friendly for users to access and understand data.

By addressing these aspects, end users can gain a clear understanding of the system's performance and its ability to remotely monitor isolated solar plants.

5.3 LIMITATIONS OF THE PROJECT PROTOTYPE

Despite its benefits, the developed prototype of remote monitoring system may have some limitations that need to be highlighted:

1. **Cost considerations:** the cost of the components for the system can be significant. This might pose financial challenges.
2. **Technical Challenges:** the effectiveness of the system may be affected by technical challenges such as hardware malfunctions, and data transmission errors. These issues could affect the accuracy and reliability of the system.

3. **current sensors challenges:** the effectiveness of the system is affected by the choice of current sensors, in this case my current sensors are affected by external noises where they can read values even when they are not connected. There is need to buy more expensive current sensors which cant be affected by external noises.

5.4 RECOMMENDATIONS

Several recommendations can be put in place to enhance the effectiveness, reliability, and accuracy of the remote monitoring system.

1. **Integration with Existing Systems:** explore opportunities to integrate the developed system with other existing systems. This integration can improve overall efficiency and reliability of the system.
2. **Training and capacity building:** conduct training programs for end users on the usage and familiarization with the system. This will help them to utilize the system effectively.
3. **Scalability considerations:** design the monitoring system with scalability in mind to accommodate future expansions or upgrades on the solar plant. This includes the addition of more sensors.
4. **Continuous Monitoring and Maintenance:** establish a routine maintenance schedule for hardware components to ensure accurate and reliable operation over time.

5.5 CONCLUSIONS

In conclusion, the development and implementation of a remote monitoring system represent a significant improvement in addressing challenges related to isolated solar plants. This project aimed to reduce downtime, provide sustainable power and improve reliability of solar plants. Based on the findings and analysis a few key conclusions can be drawn:

1. **Effectiveness of remote monitoring**: the implementation of the system has shown the capability to provide real time parameters on an isolated solar plant.
2. **Cost savings**: the isolated solar require trips to go and monitor, the system cuts off unnecessary trip costs.

Challenges and lessons learnt: The project encountered challenges related to initial costs, technical complexities, and operational adjustments. These challenges underscore the importance of robust planning, stakeholder engagement, and ongoing support for successful implementation.

In conclusion, the remote monitoring system represents a step ahead towards the monitoring of all parameters on a solar plant. By addressing both technical and operational challenges, this initiative not only enhances operational resilience but it also sets a stepping stone for future advancements in the remote monitoring of isolated solar systems.

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