

# Smart Solar Community Microgrid System for Energy Sharing and Real-Time Monitoring


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**ABSTRACT:** The Smart Solar Community Microgrid project presents an efficient and sustainable approach to decentralized energy management using renewable resources. In this system, two independent residential units (houses) are powered by solar panels integrated with battery storage and connected to a common microgrid line. Each unit is equipped with an ESP32 microcontroller, INA219 current sensor, and voltage sensor to accurately measure real-time solar energy generation and energy consumption. The system also includes an LCD display for local monitoring and a DC motor acting as a controllable load. The generated energy is first utilized locally, and any excess energy is stored in shared grid batteries, enabling optimal energy utilization and reducing dependency on conventional power sources.

Furthermore, the system incorporates IoT capabilities using the ThingSpeak platform to transmit and visualize energy data remotely. The collected data includes generated power, consumed energy, and stored surplus energy for each house, enabling precise energy tracking and billing calculations. This ensures fair energy distribution and cost estimation among users in the microgrid. The integration of smart sensing, wireless communication, and cloud analytics makes the system highly efficient, scalable, and suitable for modern smart communities aiming for energy sustainability and intelligent power management.

**KEYWORDS:** Smart Solar Microgrid, Renewable Energy, Energy Sharing, IOT Monitoring, ESP32, Smart Billing, Real-Time Monitoring, Energy Management.

## 1. INTRODUCTION

The increasing demand for electrical energy and the depletion of conventional fossil fuel resources have driven the need for sustainable and renewable energy solutions. Among various alternatives, solar energy has emerged as a reliable, eco-friendly, and abundant source. In parallel, microgrid technology has gained importance as an efficient approach to integrate distributed energy resources such as solar panels and battery storage systems. A microgrid is a localized

energy system that can operate independently or in coordination with the main grid, improving energy efficiency, reliability, and resilience.

The Smart Solar Community Microgrid system is designed to address challenges in energy generation, distribution, and monitoring at a community level. The system consists of two residential units connected through a common microgrid line, enabling efficient energy sharing. Each unit is equipped with an ESP32 microcontroller, along with sensors such as the INA219 current sensor and a voltage sensor, to measure real-time electrical parameters including voltage, current, and power. An LCD display provides instant local feedback, while a DC motor is used as a controllable load to simulate energy consumption.

In this system, solar energy generated by each house is primarily used for local consumption. Any excess energy is stored in a shared battery system and can be utilized by either household when required. This approach minimizes energy wastage and reduces dependency on conventional power sources. Additionally, the system incorporates a smart billing mechanism that considers both energy generation and consumption, ensuring fair and transparent cost distribution.

The integration of IoT technology using the ThingSpeak platform enables real-time data transmission and remote monitoring. Users can analyze energy usage patterns through cloud-based visualization. Overall, the system provides an efficient, scalable, and sustainable solution for modern energy management in smart communities.

**Table 1.1: Literature survey of some of the existing work :**

S. No	Author(s)	Description of Work	Methodology / Focus	Key Finding(s)
1	Z. P. Muqorrobin et al.	ESP32-based solar power monitoring using INA219	Real-time voltage and current sensing with embedded system	Accurate and low-cost solar monitoring system
2	R. I. Putri et al.	IoT-based monitoring of PV systems	Cloud-based real-time data acquisition and visualization	Improves remote accessibility and system efficiency
3	Z. F. Raham et al.	Smart solar monitoring using Grafana	IoT dashboards for data visualization	Enhanced user interaction and monitoring clarity
4	V. M. S. Perumal et al.	Solar energy forecasting using LSTM	AI-based prediction with IoT monitoring	Improves energy prediction accuracy

5	J. S. Jadhav et al.	AI-based microgrid energy management	Machine learning for smart energy decisions	Optimizes energy distribution in microgrids
6	A. W. Hasanah et al.	Battery monitoring using ESP32 and INA219	IoT-based battery and load control system	Improves battery efficiency and lifespan
7	S. S. Reddy et al.	Solar microgrid for rural electrification	Design of decentralized solar systems	Enhances energy access in remote areas
8	M. H. Ali et al.	IoT-based smart microgrid management	Real-time monitoring and control strategies	Improves system efficiency and reliability
9	K. Sharma et al.	Real-time energy monitoring using ESP32	Cloud-integrated embedded monitoring system	Enables efficient data tracking and analysis
10	L. Zhang et al.	Distributed energy sharing in microgrids	Review of community-based energy sharing models	Improves energy utilization and load balancing
11	P. K. Singh et al.	IoT-based smart metering and billing	Automated billing using real-time data	Ensures transparency and accurate billing
12	N. Kumar et al.	Low-cost solar monitoring system	Embedded system design for energy tracking	Cost-effective solution for small-scale systems

## II. PROBLEM STATEMENT

The increasing demand for electrical energy and the depletion of conventional fossil fuel resources have driven the need for sustainable and renewable energy solutions. Among various alternatives, solar energy has emerged as a reliable, eco-friendly, and abundant source. In parallel, microgrid technology has gained importance as an efficient approach to integrate distributed energy resources such as solar panels and battery storage systems. A microgrid is a localized energy system that can operate independently or in coordination with the main grid, improving energy efficiency, reliability, and resilience.

The Smart Solar Community Microgrid system is designed to address challenges in energy generation, distribution, and monitoring at a community level. The system consists of two residential units connected through a common microgrid line, enabling efficient energy sharing. Each unit is equipped with an ESP32 microcontroller, along with sensors such as the INA219 current sensor and a voltage sensor, to measure real-time electrical parameters including voltage, current, and power. An LCD display provides instant local feedback, while a DC motor is used as a controllable load to simulate energy consumption.

In this system, solar energy generated by each house is primarily used for local consumption. Any excess energy is stored in a shared battery system and can be utilized by either household when required. This approach minimizes energy wastage and reduces dependency on conventional power sources. Additionally, the system incorporates a smart billing mechanism that considers both energy generation and consumption, ensuring fair and transparent cost distribution.

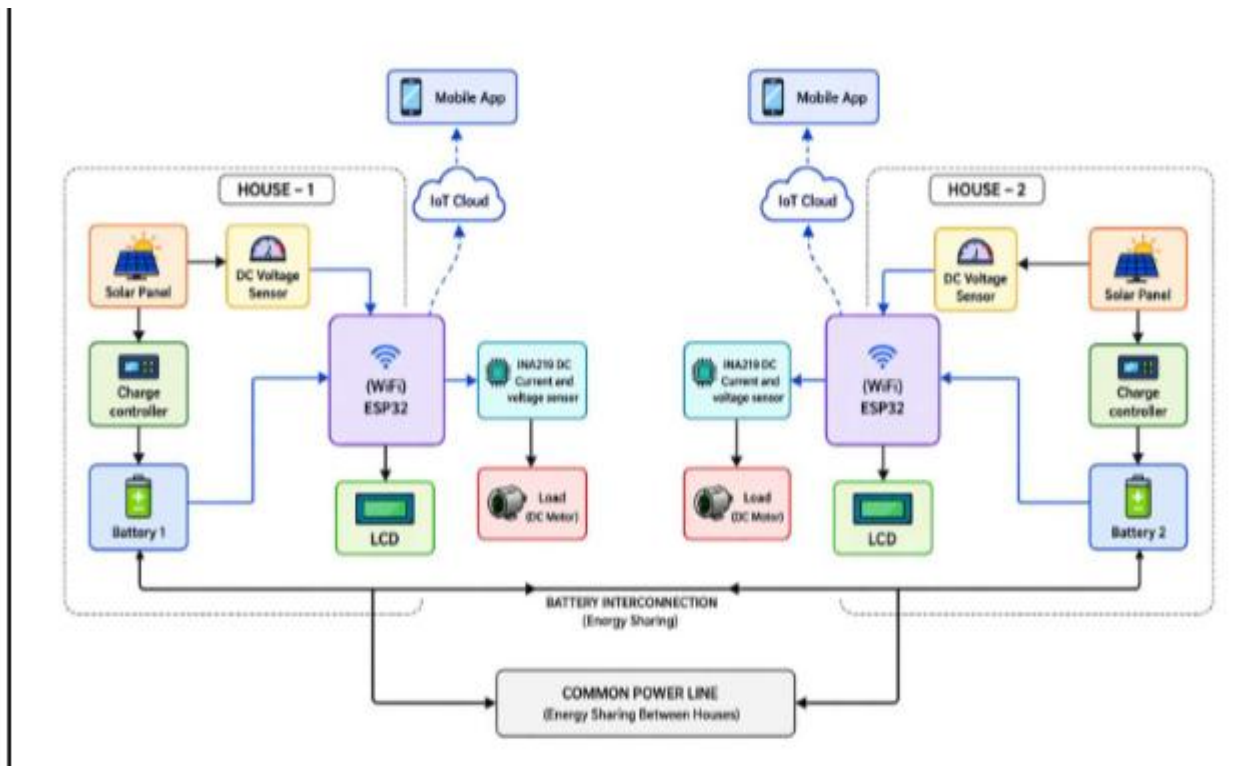
The integration of IoT technology using the ThingSpeak platform enables real-time data transmission and remote monitoring. Users can analyze energy usage patterns through cloud-based visualization. Overall, the system provides an efficient, scalable, and sustainable solution for modern energy management in smart communities.

## III. METHODOLOGY

The Smart Solar Community Microgrid system is based on the methodology that comprises incorporating hardware elements, data collection by sensors, real-time processing, IoT communication, and energy management plans to guarantee the efficient work. This system is structured to have two similar units that represent households to be connected by a shared microgrid to share energy. The units will consist of a solar panel, battery storage, sensors, load, and an ESP32 microcontroller.

To obtain the data, an INA219 sensor is used to measure the current and compute the power, and a voltage sensor is used to monitor the supply voltage. These sensors feed constantly real-time data to the ESP32 which interprets the information periodically. The system computes the energy generated and used to ascertain excess or shortage conditions in every unit.

According to the analysis, the energy management strategy makes sure that, when there is surplus energy, it can be stored in common batteries, whereas when there is a deficit energy, it can be provided by the battery or microgrid. This ensures a flow of energy is balanced, and wastage is reduced. The IoT price is realized by means of a Wi-Fi connection, which allows transmitting the data to the ThingSpeak platform to monitor and visualize it remotely. Also, there is a billing system that determines the net energy consumption and energy cost, which makes the energy distribution among users to be accurate and transparent.



**Fig. 3.1: Block Diagram Of The System**

The Fig. 3.1 shows a smart solar micro grid where two houses are interconnected by a shared power line to share energy. The houses are fitted with a solar panel, a charge controller, battery, sensors, ESP32, LCD, and a load. The voltage and current are measured by sensors and sent to the ESP32 which processes and sends the data to the IoT cloud using Wi-Fi. The local use of energy is made, and there is a sharing of excess energy in interconnected batteries. The system allows real-time monitoring through mobile applications and efficient distribution of the energy as it is distributed, minimizes waste, and equal distribution of power between the two houses.

#### IV. SYSTEM DESIGN AND IMPLEMENTATION

The circuit diagram represents a smart solar community microgrid system that connects the grid, solar panel, and batteries with intelligent control using an ESP32 microcontroller.

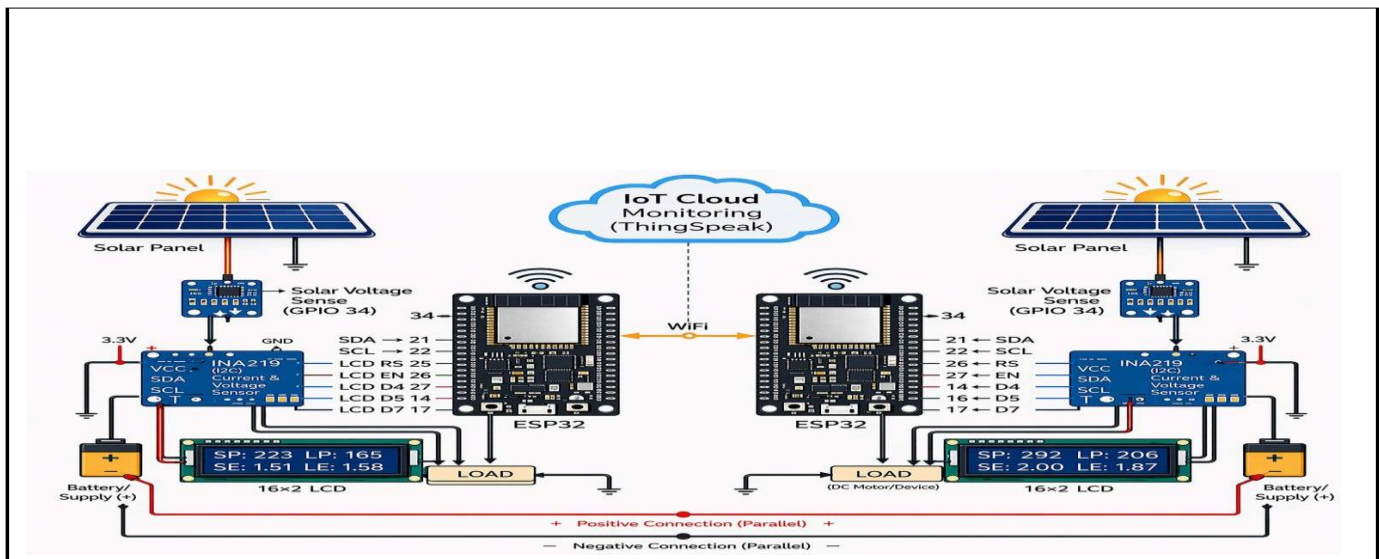
##### A. HARDWARE INTERFACING:

The Smart Solar Community Microgrid system has a hardware interfacing that guarantees effective communications and coordination of all parts. In the center of the system is the ESP32 microcontroller that serves as the central point of interaction with sensors and display modules and other hardware components. The solar panel is attached as the main source of energy, which provides the DC power to the system. This power is controlled and is directly consumed by the load or is stored in the lithium-ion battery. The battery is connected in a manner that it can both accept excess energy and provide power where there is low production of solar energy to ensure that there is no interruption of operation.

The sensor is connected to the ESP32 via the I2C communication protocol with the SDA (data line) and SCL (clock line) of the sensor board connected to the relevant GPIO pins of the ESP32. The sensor is connected in series between the power source and the load and therefore, it is able to measure the current flowing and the voltage on the bus. This information is constantly transmitted to the ESP32 to be processed. In a similar manner, the voltage sensor is then connected to an analog input pin of the ESP32, where it limits high voltages to a safe and measurable range. The ESP32 measures this analog signal and starts to interpret the signal in digital values to continue with the calculations.

The power supply is connected to the DC motor which is used as a load via the measurement circuit such that the energy consumed by the motor can be measured. The motor will run on DC voltage either provided by the solar panel or battery, whichever is available. The ESP32 connects to the LCD display via the digital GPIO pins or I2C module, allowing it to accept processed data like the voltage, current and power values. This enables monitoring of system parameters in real time.

Also, the DC-DC boost converter is connected between the battery and the system components. It boosts the battery voltage to a constant position needed to power the ESP32, sensors and display. This makes sure there is consistent performance even in the case of battery voltage variations. It also connects the ESP32 with the Wi-Fi network, allowing communication with the ThingSpeak cloud platform in order to remotely monitor. All pieces therefore come together with due electrical and communication interfaces which enable effective data transfer, energy control as well as the dependability of the micro grid system.



**Fig. 4.1: Schematic Diagram.**

This Fig. 4.1 illustration shows a Smart Solar Community Microgrid network consisting of two autonomous houses, which are linked directly by a common energy grid. The houses each have a solar panel to produce electrical power, which is read with the help of a voltage sensor attached to the ESP32 microcontroller. The sensor to measure current and calculate the power consumption is an INA219 sensor. This real-time data is processed through the ESP32 and key parameters like solar power (SP), load power (LP) and energy values are shown on a 16×2 LCD.

Both ESP32 modules can be linked using Wi-Fi and send data to the ThingSpeak IoT cloud to monitor and visualize it remotely. Each unit is then simulated with a DC load to mimic energy usage. The power lines of the batteries in both houses are in parallel so that the power may be shared. The surplus energy in one house will be able to serve the other in

times of need. The system is efficient in energy consumption, power distribution is balanced and promotes smart energy management.

## B. SYSTEM FLOWCHART :

The flowchart demonstrates how a Smart Solar Community Microgrid system works, presenting a way of how energy is produced, measured, controlled, and used effectively.

It starts with the Solar panel converting photovoltaic energy into electricity. Sensors like INA219 or ACS712 that record real time values of voltage and current are then used to measure this energy. These sensor readings are sent to the ESP32 microcontroller, which acts as the central processing unit of the system. The ESP32 analyses the data and computes such essential parameters as power ( $P = V \times I$ ) and energy ( $E = P \times t$ ).

Next, the system compares the generated energy with the consumed energy. In case the energy produced exceeds the consumption, the surplus energy is stored in the battery. On the other hand, if the consumption exceeds generation, the required energy is drawn from the battery. This step in decision making will allow effective use of energy and avoid wastage.

Once the energy flow has been controlled, the system will update the energy status of the two houses connected in the microgrid. It subsequently shows real time data in terms of voltage, current, power and energy on the LCD to be locally monitored. At the same time, this data is sent to the Wi-Fi-powered ESP32 to the ThingSpeak cloud platform, where it can be accessed remotely and visualized with IoT dashboards.

Lastly, net energy usage is calculated by deducting the energy consumed by the generated energy. On the basis of this value, users are billed fairly and transparently. The cycle is then repeated and this ensures the loop remains constantly monitored and intelligent energy management.

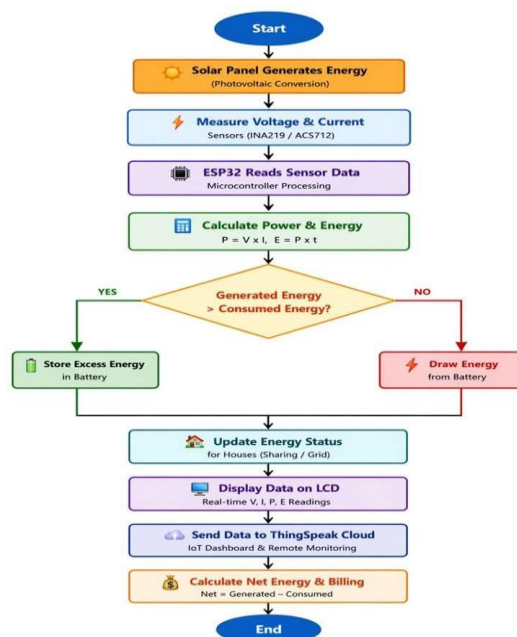


Fig. 4.2: Workflow Diagram

## V. RESULTS AND DISCUSSION:

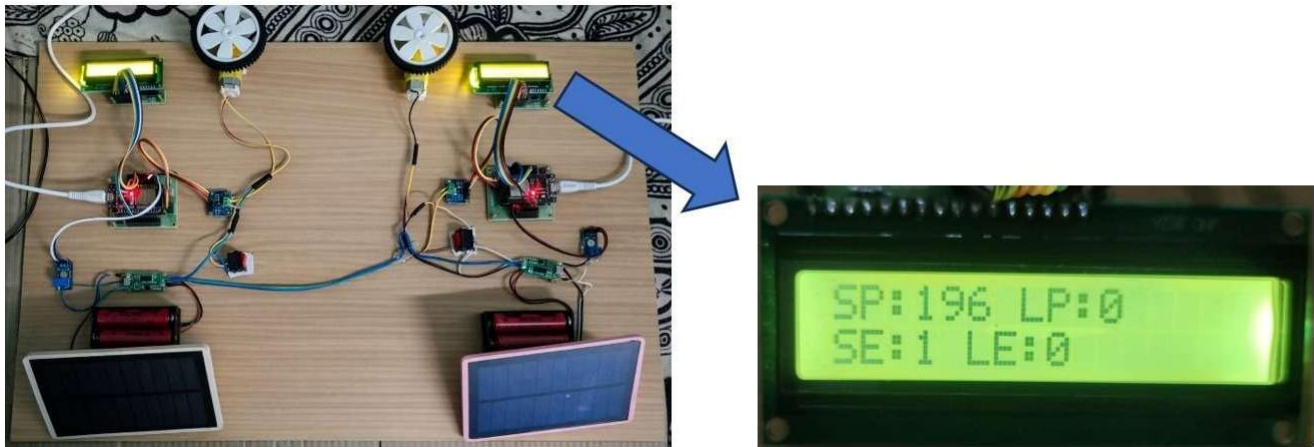
### 5.1 System Implementation Results:

The Smart Solar Community Microgrid system was effectively deployed and experimented in various operating conditions to assess its performance in energy generation, consumption, storage, sharing and IoT based monitoring. The system is made up of two houses linked together with a shared microgrid line, where they have solarpanels, sensors, ESP32 and load.

#### 5.1.1 Solar Energy Generation:

The solar panels in both houses produced electrical energy based on the intensity of light. It was noted that with increased light conditions, voltage and current output were higher leading to increased power generation. INA219 sensor was able to measure current and power accurately, and the voltage sensor gave stable voltage readings.

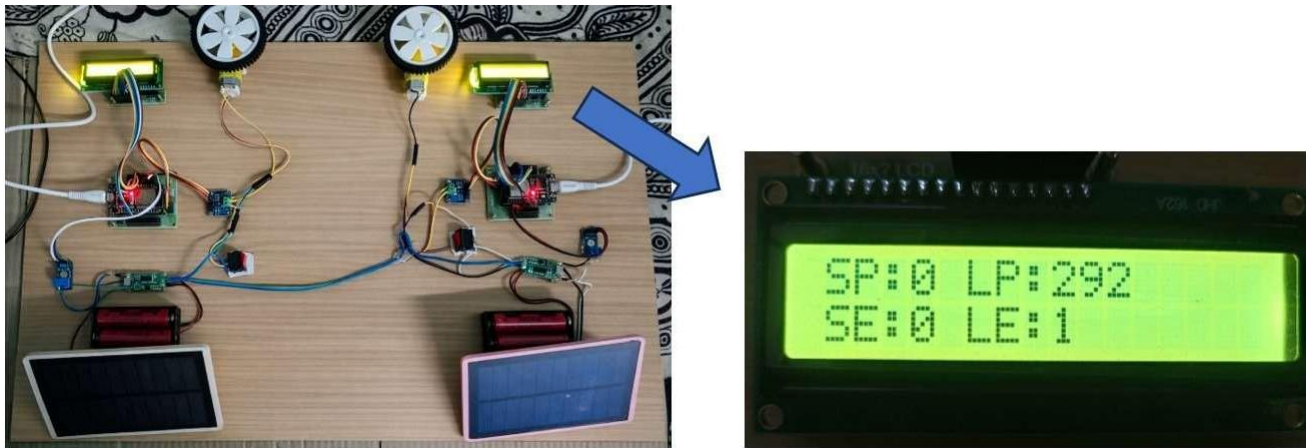
**Fig 5.1: Solar panel output voltage and current measurement setup**



The Fig. 5.1 shows a practical setup of a smart solar microgrid system with two independent units (houses). Each unit includes a solar panel, battery, ESP32, sensors, LCD, and a DC motor as load. The system monitors energy generation and consumption in real time. The LCD display shows parameters like solar power (SP) is the solar power generated and (SE) is solar energy consumption.

#### 5.1.2 Load Consumption Analysis:

The DC motor that served as a load was constant electrical energy consumer whenever it was operating on the system. The system was able to measure real time energy consumption with the sensing modules connected. It was noted that the current pulled by the motor went up proportionately with increasing load as expected of an electrical system. The results of the readings made by the INA219 were correct and consistent, which confirms the correct work of the sensor. The findings indicate that the system can be effective in tracking changes in the load conditions and can be relied on to monitor energy consumption in the smart solar microgrid system



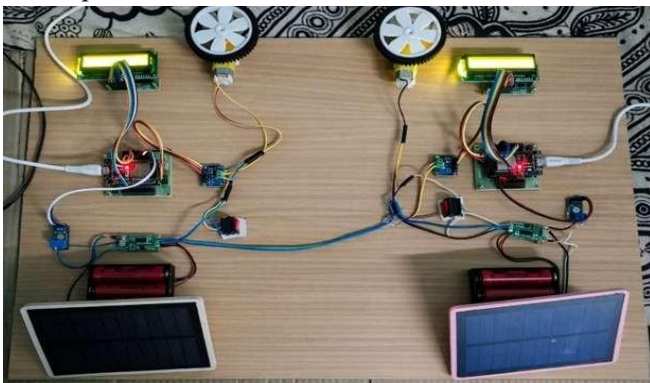
**Fig 5.2: Load (DC Motor) Energy Consumption Measurement**

The Fig. 5.2 shows a practical setup of a smart solar microgrid system with two independent units (houses). Each unit includes a solar panel, battery, ESP32, sensors, LCD, and a DC motor as load. The system monitors energy generation and consumption in real time. The LCD display shows parameters like LP is Load power consumption and LE is Load Energy Used.

### 5.1.3 Energy Sharing Between Houses:

Among the most significant outcomes of the system, it is possible to mention the effective energy sharing of the two houses that were interconnected with the help of the microgrid. In the cases of excess solar energy produced on one house, it was effectively passed to the common microgrid line and stored in the common battery. This accumulated energy was later released to be used by the second house when the solar generation of the house was inadequate. The smooth interaction of energy between the two units shows how the system can be effective in handling distributed energy resources.

This outcome is a clear reflection of a realistic application of a smart microgrid, in which there is a balance between the energy demand and supply in a small community. It minimizes wastage of energy, enhances the use of renewable energy and continuous power supply. In general, the system improves reliability, efficiency, and sustainability, and is a good choice to incorporate in future energy management systems in residential setting and smart grid development.

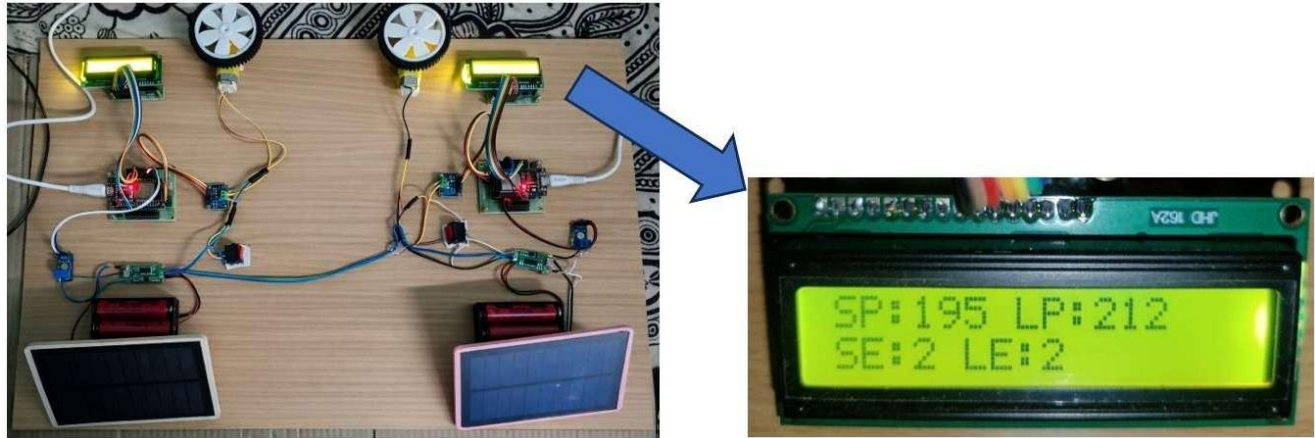


**Fig 5.3: Energy Sharing Between Houses Via Common Microgrid**

### 5.1.4 Real-Time Data Display:

The picture depicts a realistic installation of a smart solar microgrid system with two autonomous units (houses). A solar panel, battery, ESP32, sensors, LCD and DC motor are load in each unit. The system checks the energy generation and consumption in real-time. The LCD display presents parameters such as solar power (SP), load power (LP), solar energy (SE) and load energy (LE) indicating effective energy monitoring and sharing.

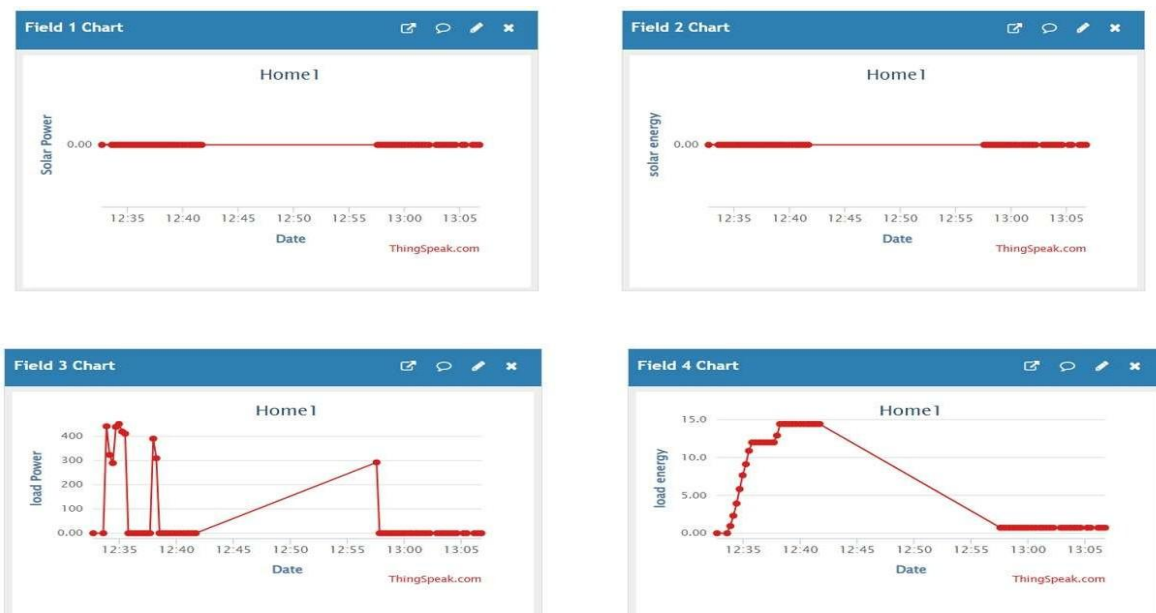
Fig 5.4: LCD Display Shows Real-Time Monitoring



### 5.1.5 IOT Monitoring Using ThingSpeak:

The ESP32 was able to send the data to ThingSpeak cloud platform. Data was represented graphically as a series of curves depicting changes in voltage, current and power with time. The users could remotely monitor the performance of the system via mobile or web applications.

The IoT integration was found to be dependable and with small delay in transmitting the data.



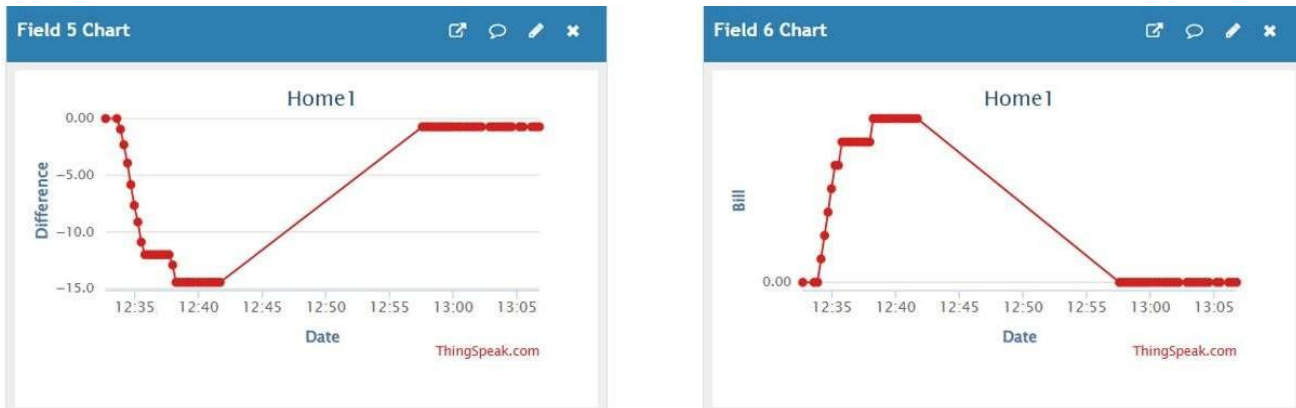


Fig. 5.5: ThingSpeak Dashboard Showing Energy data Graphs

### 5.1.6 Billing Calculations And Results:

The system was able to calculate the energy generation and consumption in each house. Net energy usage was calculated based on these values and hence fair billing. Homes that produced more energy received lower billing whereas those that produced more energy received more charges.

This validates the effectiveness of the smart billing mechanism.  $\text{Net Energy} = \text{Load Energy} - \text{Solar Energy}$ .

$\text{Bill} = \text{Net Energy} \times \text{Tariff rate}$ .

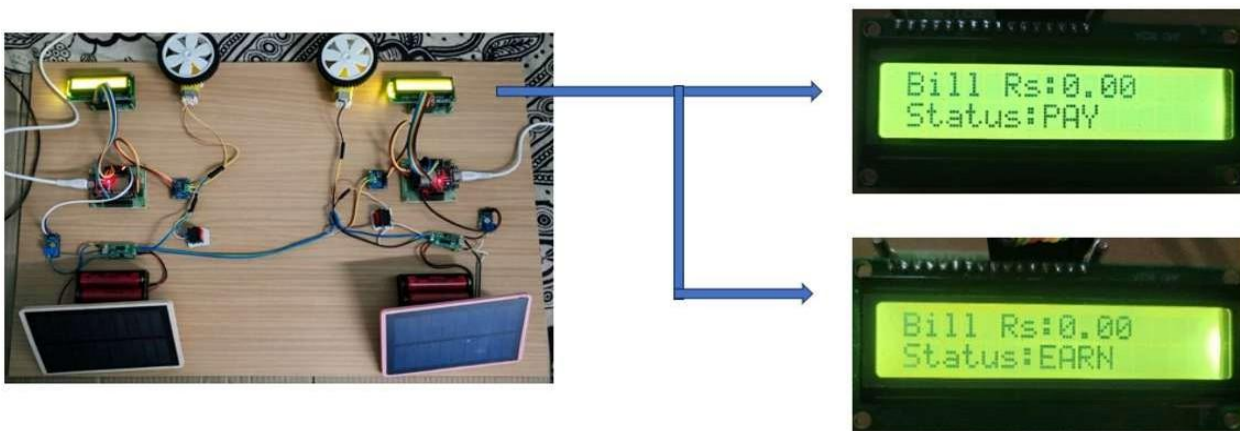


Fig 5.6 Energy Consumption and Billing Calculation Output

### 5.1.7 Overall System Performance:

The entire system worked well in that there was proper sensor readings, constant communication and proper management of energy. The combination of the principles of renewable energy, IoT, and microgrids led to:

- \* Reduced energy wastage
- \* Efficient energy sharing
- \* Improved monitoring and control

\* Transparent billing system

## 5.2 Discussion

The experimental outcomes prove that the proposed Smart Solar Community Microgrid system is a decentralized energy management system that is reliable and efficient. The ESP32 and the IoT technology allow real-time monitoring, data acquisition, and accessibility remotely, which makes the system very user-friendly and can be scaled to various applications of real-world use. The combination of sensors and communication technology guarantees proper measurement of electrical parameters and performance monitoring of the system at all times.

Among the most important results of the system is the successful energy sharing among several households. The energy sharing option greatly enhances the use of renewable energy as it shares the surplus power in one home with other members of the community. This minimizes the amount of energy waste and makes sure that the resources at hand are utilized in an efficient manner. The existence of a common battery storage facility also improves the performance of the systems as it stores any excess energy and delivers it during periods of low solar production or in non-solar areas.

The battery storage is crucial where there is continuity in the power supply and solving the intermittency of solar energy. It guarantees users a constant and continuous source of energy even when there is cloudy weather or at night. Also, a fair and transparent mechanism of smart billing adopted in the system is a measure that will help to calculate energy consumption on real consumption and contribution. This motivates the users to be actively involved in the renewable energy production and embrace energy-saving measures.

The system, although effective, has a number of aspects that can be improved and developed. The scalability can be improved by expanding the microgrid to more houses and benefit of energy sharing. Ensuring the use of advanced energy forecasting methods based on data analytics or predictive algorithms can enhance energy management and maximize resources use. Combining the use of mobile applications as a control system can offer a better access control and monitoring to users.

Moreover, large-scale applications can enhance reliability of systems by using larger capacity batteries and other renewable sources of energy. All in all, the suggested system has a high potential of further improvement and real-life implementation in smart communities to help in efficient, sustainable, and intelligent energy management solutions.

## VI. CONCLUSION:

The Smart Solar Community Microgrid system effectively proves the effective and sustainable model of decentralized energy production, control, and distribution based on renewable sources. The system successfully monitors real-time energy production and consumption of several households by incorporating the solar panels, battery storage, ESP32 microcontrollers, and sensing devices like INA219 and voltage sensors. The use of a shared microgrid makes the utilization of energy efficient as the surplus of energy produced in one house can be stored and utilized by another hence, eliminating the waste of energy.

Introduction of IoT through the ThingSpeak platform enriches the system by allowing remote monitoring, data visualization and high awareness by the user. The LCD display allows users to see immediate local feedback, and an integration with clouds enables them to monitor their energy consumption trends over time. Also, the smart billing system will be used to ensure a fair and transparent energy consumption according to the actual use and contribution, which will promote the use of renewable energy sources.

In general, this project demonstrates how the use of renewable energy systems in conjunction with the IoT and embedded technologies can produce intelligent and scalable energy solutions. The system is affordable, robust, and applicable in real life like smart communities, rural electrification and microgrid-based power systems. Additional improvements can be made in future by incorporating sophisticated analytics, mobile apps, and support of bigger networks, which will enhance efficiency and flexibility. The work is in the direction of a cleaner, smarter and more sustainable energy future.

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