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A Switching System Between Solar PV and Grid Power Supply

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Abstract: Many off-grid villages in Sarawak, Malaysia, previously relied on installed solar photovoltaic (PV) panels for electricity. However, with the recent expansion of the local electric utility grid, achieving 99.2% statewide electricity coverage, these solar PV systems are largely unused. This research addresses this underutilization by developing a solar-grid switching system that enables rural villagers to effectively integrate their existing solar PV panels with the grid supply. The system automatically switches to solar PV power when sufficient energy is generated, thereby reducing electricity bills for households and contributing to a lower carbon footprint for the grid. The developed system utilizes microcontrollers to continuously monitor battery voltage. Based on the measured voltage, the microcontroller triggers contactors to switch between the solar PV and grid power sources, ensuring a stable supply to the load. Voltage data is also transmitted to a server via a Wi-Fi-capable microcontroller for remote monitoring.

Keywords: Solar PV, grid, power switching system.

INTRODUCTION

Sarawak Energy Berhad (SEB), the local electric utility (LEA) in Sarawak, Malaysia, has successfully expanded its electricity coverage, reaching 99.2% penetration across the state (Jong, F. C., & Ahmed, M. M. 2024). This rapid grid expansion over the past few years has significantly altered the power landscape in rural areas. Just a decade ago, many remote villages, inaccessible by conventional grid lines, were electrified through solar photovoltaic (PV) systems, backed by a substantial Federal government investment of USD$115 million (Ten, M. 2015). However, with the grid now reaching most of these villages, a significant number of these previously installed solar PV panels are currently unused.

This underutilization represents a missed opportunity to leverage existing renewable energy infrastructure. Integrating these idle PV systems with the newly available grid supply could offer substantial benefits. Villagers could reduce their reliance on grid power, leading to lower electricity bills, while simultaneously contributing to the reduction of climate change-inducing emissions by the LEA.

This research aims to address this challenge by developing a cost-effective, automated solar-grid switching system. The proposed system enables seamless transition between solar PV power and grid power, prioritizing solar energy when available. The system's design focuses on practicality and affordability, utilizing readily available microcontroller technology to ensure its applicability in rural settings.

LITREATURE REVIEW

The integration of hybrid power sources has been a significant area of research and development globally, particularly in countries like Germany, which have heavily invested in renewable energy technologies (Kneiske, T. M. 2023; Kühn, U). Following events such as the Fukushima disaster, Germany embarked on a transition towards "renewables," primarily focusing on PV panels and wind turbines, coupled with the phased retirement of nuclear power plants (Kühn, U). This trend was also observed in regions like California, USA, and Australia (Haegel, N. M., & Kurtz, S. R 2023; Rey-Costa, E. *et al.,* 2023)

However, the intermittency inherent in solar PV and wind power poses significant challenges to grid stability and can lead to higher household electricity bills, as experienced in Germany, California, and Australia (Stute, J. *et al.,* 2024; Seyedrezaei, M. *et al.,* 2024; McCarthy, B. 2024)Sudden drops in renewable energy generation, for instance, due to cloud cover over large PV installations, can cause supply-demand imbalances, potentially leading to grid instability or blackouts (Karunakaran, P. *et al.,* 2022; Ertem, M. 2024). Grid operators typically maintain "spinning reserves"—excess capacity from conventional power plants—to quickly respond to such fluctuations and prevent grid disruptions (Karunakaran, P. 2024). This necessity of maintaining readily available backup power often contributes to the overall cost of electricity from intermittent renewable sources.

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The need for stable and reliable power delivery when integrating intermittent renewables has spurred innovations in power management systems. For instance, integrated battery storage solutions, such as Tesla's Powerwall, alongside electric vehicle batteries, have been proposed to help stabilize grids by providing immediate power backup during generation dips (Beckman, C. A. P. *et al.,* 2024).

While sophisticated hybrid power management systems exist (Kneiske, T. M. 2023), the focus of this research is to develop a cost-effective solution specifically for utilizing existing, often neglected, solar PV installations in rural Sarawak. This project leverages the simplicity and widespread availability of Arduino microcontrollers, which are favored globally for their accessibility and economic viability in educational and hobbyist applications (De Groff, D. 2024).

The Arduino platform offers various microcontrollers suitable for control applications. The Arduino UNO is a popular choice for its ease of use and 5V output pins, which are compatible with standard relays. For remote monitoring capabilities, the Arduino ESP8266 is a suitable alternative due to its integrated Wi-Fi module and general-purpose input/output (GPIO) pins. While the ESP8266 offers a powerful 32-bit architecture and Wi-Fi connectivity, its 3.3V output pins require careful consideration when interfacing with 5V-triggered devices like many standard relays (De Groff, D. 2024). This research explores a dual-microcontroller approach to overcome these limitations and provide a practical, monitorable solution for rural electrification.

METHODOLOGY AND RESULTS

System Design

The developed solar-grid switching system is designed to automatically select between solar PV and grid power based on the charge level of the solar battery. The overall system architecture is illustrated in Fig. 1 (Block Diagram), Fig. 2 (Single Line Diagram), and Fig. 3 (Wiring Schematic).

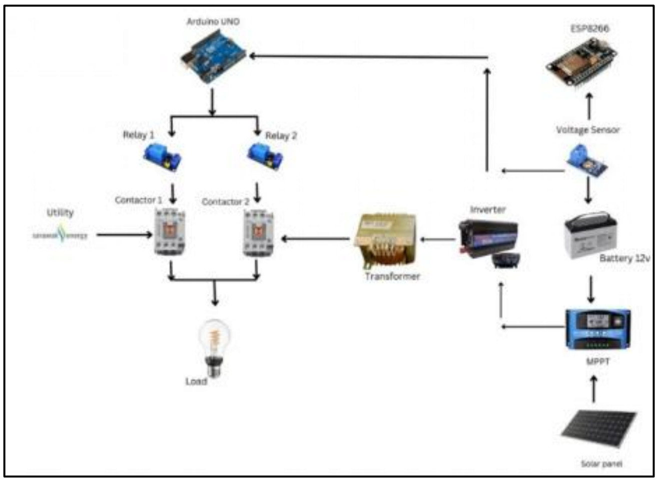

Fig. 1: The block diagram of the PV-grid switching System

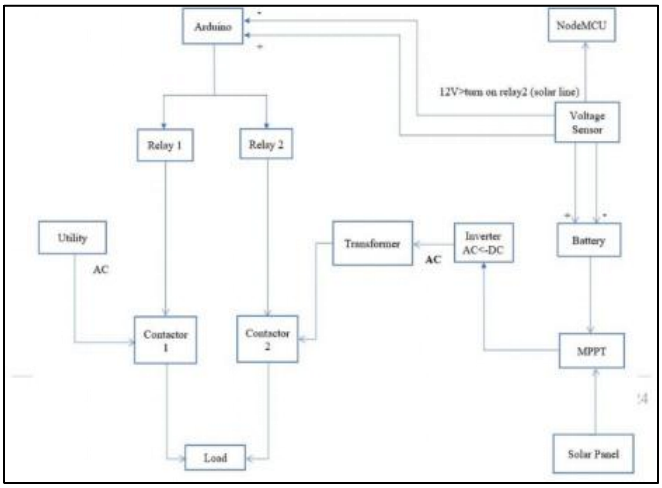

Fig. 2: Single Line diagram

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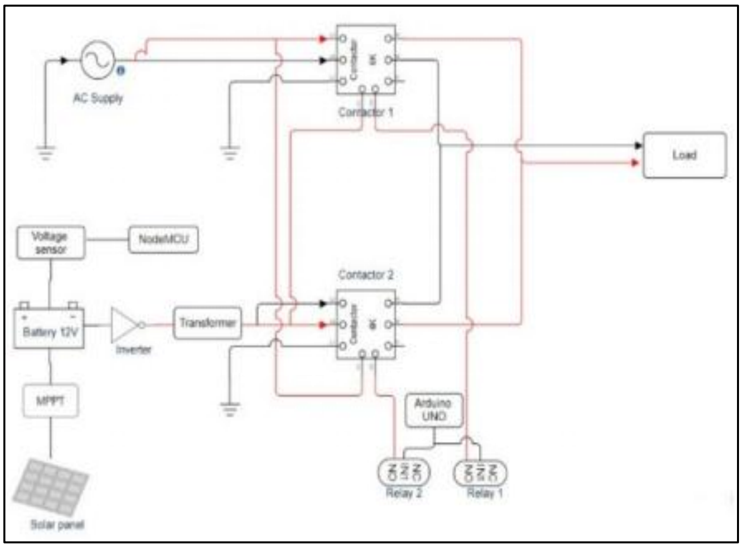

Fig. 3: The Schematic for the whole system

Key Components:
Solar PV Panels: The existing panels in the rural villages serve as the primary power source. Maximum Power Point Tracking (MPPT) Charger: An MPPT unit (Figure omitted, but described) is crucial for maximizing power extraction from the PV panels. It continuously adjusts the operating point of the PV panel to ensure maximum power transfer to the battery, accounting for variations in sunlight intensity, temperature, and shading (Podder, A. K. *et al.,* 2019). The MPPT's power rating must match that of the PV panel.

Battery: A 12V battery stores the energy generated by the PV panels. Its terminal voltage (V_T) is the primary parameter for switching decisions.

Inverter: Converts the DC power from the battery into AC power suitable for household loads. For this project, a 220V (Chinese standard) inverter was used.

Autotransformer: Since the inverter output is 220V and the Malaysian standard consumer voltage is 240V, an autotransformer is used to step up the voltage. An autotransformer, having a single coil with taps, offers high efficiency for voltage ratios close to unity [Equation and derivation omitted, but the concept of V_1/V_2=N_1/N_2 and the specific tap point for 220V/240V conversion are relevant]. A custom-wound autotransformer was procured to achieve the precise 220V to 240V step-up (91.67% tap for the 220V input from the 240V winding).

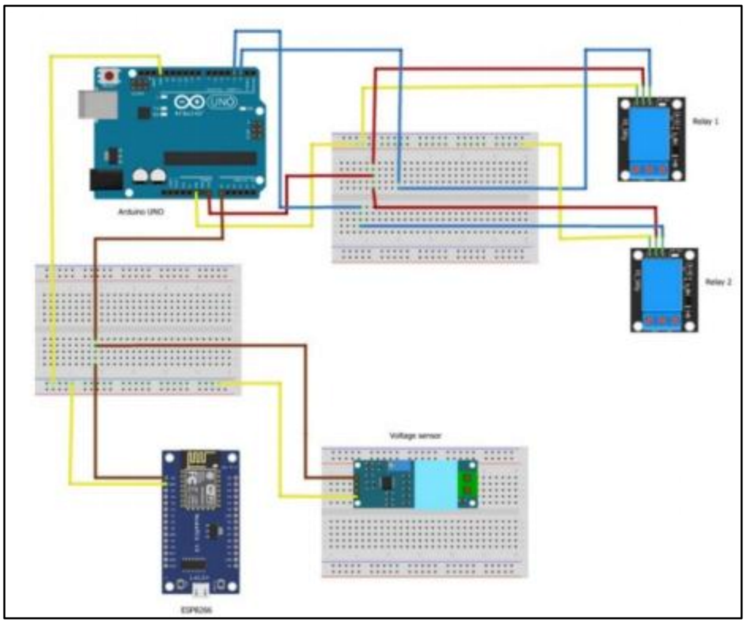

Fig. 4: Breadboard testing

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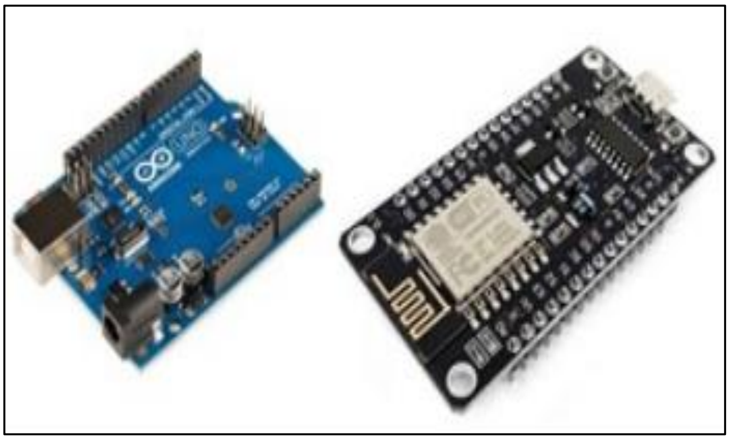

Fig. 5: The two microcontrollers used Arduino UNO (left) and Arduino ESP8266 (right)

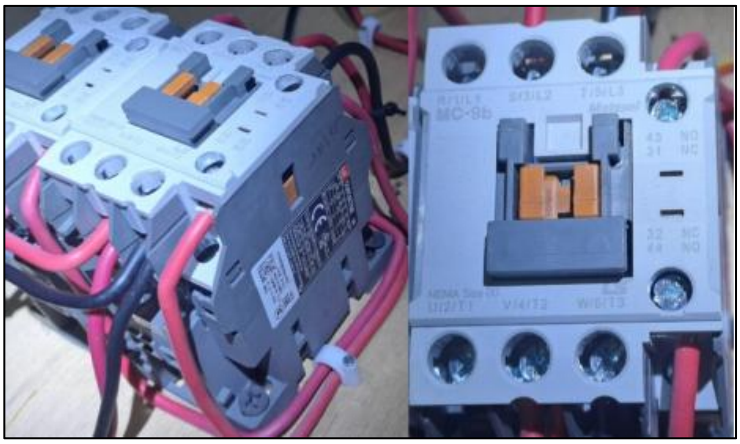

Fig. 6: The contactors used

Contactors (LS Electric): These are high-power electrical switches (see Fig. 6) controlled by relays to connect either the solar PV (via inverter) or the grid supply to the load. Contactors use coils that, when energized (with AC in this case), create a magnetic field to close the contacts. A "shading ring" (Fig. 9) is incorporated in AC-energized contactors to reduce noise from the alternating magnetic field.

Fig. 7: The relays used

Relays (Arduino-compatible): Low-power switches (see Fig. 7) triggered by the microcontrollers. These relays, designed for 5V input, control the 240V supply to the contactor coils. Voltage Sensor: Measures the battery's terminal voltage (see Fig. 8).

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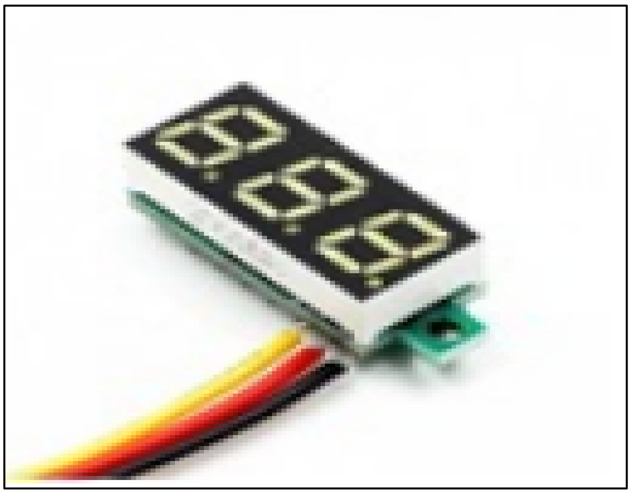

Fig. 8: The voltage sensor used

Microcontrollers:Arduino UNO (Fig. 5, left): Responsible for reading the battery voltage and controlling the switching logic via relays. Its 5V output pins are crucial for triggering the relays.

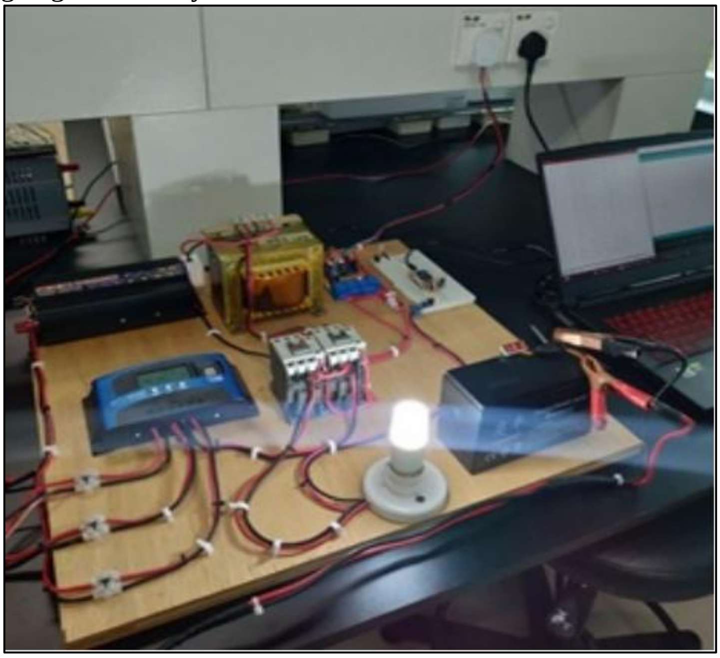

Fig. 9: The whole setup of the PV grid switching system

Arduino ESP8266 (Fig. 5, right): Equipped with a Wi-Fi module, this microcontroller monitors the battery voltage and transmits the data to a server (Blynk platform) for remote monitoring. Its 3.3V output pins make it unsuitable for direct control of the 5V relays, necessitating the use of a separate Arduino UNO for switching.

System Operation

The core operational logic is managed by the Arduino UNO. The voltage sensor (connected to analog pin A0) continuously measures the battery's terminal voltage.

Solar Mode: If the battery voltage is geq11V (indicating sufficient charge), the Arduino UNO activates Relay 2 (connected to digital pin 3). Relay 2, in turn, energizes Contactor 2, which connects the load to the solar PV supply (via the MPPT, battery, inverter, and autotransformer). Grid Mode: If the battery voltage drops below 11V (indicating low charge), the Arduino UNO deactivates Relay 2 and activates Relay 1 (connected to digital pin 2). Relay 1 then energizes Contactor 1, switching the load to the LEA's grid power supply.

The Arduino ESP8266 operates in parallel to provide remote monitoring. It also reads the battery voltage via a dedicated voltage sensor (connected to its analog pin A0). This data is then

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transmitted wirelessly to the Blynk cloud platform using its integrated Wi-Fi module. This allows users to view real-time battery voltage and system status through a mobile application.

Software Logic (Simplified)

Arduino UNO Code Snippet (Switching Logic):

```
const int sensorPin = A0;   // Voltage sensor
connected to A0
const int relay1Pin = 2;     // Relay 1 (Grid)
connected to pin 2
const int relay2Pin = 3;    // Relay 2 (Solar)
connected to pin 3
void setup() {
Serial.begin(115200);
pinMode(relay1Pin, OUTPUT);
pinMode(relay2Pin, OUTPUT);
digitalWrite(relay1Pin, HIGH); // Initially, switch
to Grid (safety default)
digitalWrite(relay2Pin, LOW);}
void loop() {
int sensorValue = analogRead(sensorPin);
float voltage = sensorValue * (4.137 / 1023.0) *
(12.0 / 2.0); // Convert sensor value to 12V range
// Switching Logic
if (voltage >= 11.00) {
digitalWrite(relay1Pin, LOW);  // Turn off Grid
relay
digitalWrite(relay2Pin, HIGH); // Turn on Solar
relay
Serial.println("Switching to Solar PV");}
else {
digitalWrite(relay1Pin, HIGH); // Turn on Grid
relay
digitalWrite(relay2Pin, LOW);  // Turn off Solar
relay
Serial.println("Switching to Grid Power");  }
delay(1000); // Check every second}
```

Arduino ESP8266 Code Snippet (Monitoring Logic):

Arduino

```
    #define BLYNK_PRINT Serial
    #include <ESP8266WiFi.h>
    #include <BlynkSimpleEsp8266.h>
char ssid[] = "UTS-Student";    // Replace with
your network credentials
char pass[] = "student1234";
char auth[] = "YOUR_BLYNK_AUTH_TOKEN";
// Replace with your Blynk Auth Token
const int sensorPin = A0;      // Voltage sensor
connected to A0
#define VIRTUAL_PIN V1         // Blynk virtual
pin for the gauge
void setup() {
Serial.begin(115200);
Blynk.begin(auth, ssid, pass, "blynk.cloud", 80);
Serial.println("ESP8266 Voltage Sensor
Initialized");}
void loop() {
int sensorValue = analogRead(sensorPin);
float voltage = sensorValue * (2.59 / 1023.0) *
(12.0 / 2.0); // Convert sensor value to 12V range
Blynk.virtualWrite(VIRTUAL_PIN, voltage); //
Send voltage to Blynk app
delay(1000); // Update every second
Blynk.run(); // Process Blynk events}
```

Experimental Setup and Results

The full system was assembled and tested as shown in Fig. 9. Breadboard testing (Fig. 4) was conducted to validate individual component functionality before final assembly. The system's performance was evaluated by monitoring the battery voltage and observing the switching behavior of the contactors. Table 2 is the observed system switching behavior.

Table 1: Observed system switching behavior

Time	Weather	Voltage Level (V)	Power Lines
2.30 pm	Rainy	11.79	Solar
2.40 pm	Rainy	11.79	Solar
2.50 pm	Rainy	11.68	Solar
3.00 pm	Rainy	11.62	Solar
3.10 pm	Rainy	11.56	Solar
3.20 pm	Rainy	11.42	Solar
3.30 pm	Rainy	11.26	Solar
3.40 pm	Rainy	10.83	Utility
3.50 pm	Partly Cloudy	11.68	Solar
4.00 pm	Partly Cloudy	11.85	Solar
4.10 pm	Partly Cloudy	11.89	Solar
4.20 pm	Partly Cloudy	11.91	Solar
4.30 pm	Partly Cloudy	11.91	Solar
4.40 pm	Partly Cloudy	11.93	Solar

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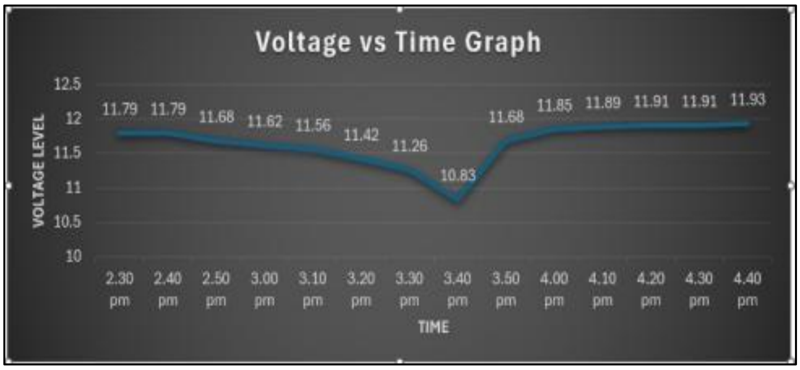

Fig. 10: The voltage versus time graph derived from the BLYNK application.

The remote monitoring via the Blynk application (Fig. 10) successfully displayed real-time battery voltage data, confirming the ESP8266's ability to transmit sensor readings over Wi-Fi. The switching logic implemented on the Arduino UNO reliably controlled the relays and subsequently the contactors, enabling the system to automatically transition between solar PV and grid power based on the battery's state of charge.

CONCLUSION

This research successfully developed and implemented an automated solar-grid switching system that enables rural villages in Sarawak, Malaysia, to effectively utilize their existing, previously unutilized, solar PV installations. By automatically switching the power source between solar PV and the main grid based on battery voltage, the system offers a practical solution for reducing household electricity bills and supporting the local electric utility's climate change mitigation goals.

The system's design, leveraging low-cost Arduino microcontrollers (UNO for control and ESP8266 for remote monitoring), demonstrates a viable and affordable approach for rural electrification challenges. The implementation of an autotransformer for seamless voltage conversion from the inverter to the local grid standard further highlights a cost-effective engineering solution. This system provides a clear pathway for maximizing the utility of existing renewable energy assets in regions experiencing grid expansion. The electric utility of Sarawak, Malaysia is named Sarawak Energy Berhad (SEB). Henceforth it will be referred to as the Local Electric Utility (LEA). The LEA managed to achieve 99.2 % penetration of electric coverage (Jong, F. C., & Ahmed, M. M. 2024). This was achieved in a few years. Just 10 years ago, there were many villages where the grid lines could not reach, and the Federal government allocated USD$115 million to electrify the rural villages with solar Photo Voltaic (PV) electric power (Ten, M. 2015). But since the LEA's lines have entered most of these villages, these PV panels are unused today. The system developed in this research is one way to utilize the unused PV panels to save electric bills for the villagers as well as reduce the carbon footprint of the LEA.

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