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Design and Development of an Intelligent Smart Solar Switching Tracking System used for Smart Energy Meter System Utilizing a Mobile App

Padmavathi M[1], Armaan Anil Narang[2], Lavanya P[3], Kshitij Arnav L. Gowda[4], Umashankara Raja R[5] and Pavithra G[6]
[1]Assistant Professor, Dept. of Electronics & Communication Engineering, Dayananda Sagar College of Engineering, Bangalore, Karnataka, India
Email: padma_1616@yahoo.co.in
[2-4]UG students, Dayananda Sagar College of Engineering, Bangalore, Karnataka, India
[5]Professor, Dept. of Physics, Sapthagiri NPS University, Bangalore, Karnataka
[6]Associate Professor, Dept. of Electronics & Communication Engineering, Dayananda Sagar College of Engineering, Bangalore, Karnataka, India

***Abstract*— The Smart Energy Meter System Using Mobile App is an advanced energy monitoring and management system designed to measure electricity consumption accurately and provide real-time information to users through a mobile application. The main objective of this project is to help consumers monitor their energy usage, reduce electricity wastage, and promote efficient energy management. The system consists of a smart energy meter integrated with a microcontroller, current and voltage sensors, and a wireless communication module. The energy consumption data collected by the meter is transmitted to a mobile application through the Internet. Users can view real-time energy usage, electricity cost, historical consumption records, and receive alerts for excessive power consumption. The mobile application provides a user-friendly interface for monitoring and controlling energy usage from anywhere. The proposed system improves transparency in electricity consumption and encourages users to adopt energy-saving practices. It also reduces the need for manual meter reading and enables efficient energy management for residential and commercial applications. The Hybrid Solar Smart Switching System is an intelligent energy management solution developed to optimize the utilization of solar energy while ensuring a continuous and reliable power supply. With the increasing demand for electricity and the growing need for sustainable energy resources, the system aims to reduce dependency on conventional grid electricity, lower energy costs, and promote the effective use of renewable energy. The primary objective of this project is to automatically manage and switch between available power sources based on real-time operating conditions, thereby improving energy efficiency and ensuring uninterrupted operation of connected electrical loads. The proposed system integrates multiple modern technologies, including solar photovoltaic (PV) energy generation, battery energy storage, embedded systems, Internet of Things (IoT), automation, and intelligent control mechanisms. Solar panels convert sunlight into electrical energy, which is utilized to power electrical loads and charge a backup battery system. An ESP32/Arduino microcontroller serves as the central processing unit of the system and continuously monitors various parameters such as solar panel output voltage, battery charge level, load demand, and grid power availability through connected sensors.**

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Based on the collected data, the controller makes intelligent decisions and operates relay modules to switch automatically between solar power and grid electricity.

***Index Terms*— Smart Energy Meter, Mobile Application, Energy Monitoring, IoT, Energy Management. Hybrid Solar System, Smart Switching, Renewable Energy, IoT Monitoring, Energy Management.**

I. Introduction Background of the Problem

Here, in this section, we do present a brief introductory note about the project work as follows.

A. Background of the Problem

Traditional electricity meters require manual reading and do not provide real-time information about energy consumption. Consumers often receive electricity bills without knowing how much energy they have used on a daily basis. This can lead to excessive energy consumption, billing errors, and difficulty in monitoring electricity usage [1].

B. Need for the Proposed System

With the increasing demand for electricity and the growth of smart technologies, there is a need for an efficient system that allows users to monitor and manage their energy consumption in real time. A Smart Energy Meter System using a Mobile App helps consumers track electricity usage, receive instant updates, and promote energy conservation [2].

C. Problem Statement

The existing energy metering system lacks real-time monitoring, remote accessibility, and efficient energy management features. Consumers are unable to monitor their electricity consumption continuously, resulting in energy wastage and unexpected electricity bills. Therefore, a smart and user-friendly solution is required to monitor energy usage through a mobile application [3].

II. Proposed Objectives

Five objectives are being proposed & they are implemented in this project work [4].

- To measure and monitor electricity consumption accurately.
- To display real-time energy usage through a mobile application.
- To provide remote access to energy consumption data.
- To help users reduce energy wastage and electricity costs.
- To improve energy management and awareness among consumers.

III. Scope, Outcomes and Significance of the Project Work

The project focuses on developing a smart energy meter integrated with a mobile application. The system can monitor energy consumption, display usage data, and provide alerts or notifications [9]. It can be used in homes, offices, educational institutions, and small industries for effective energy management. Some of the outcomes of the project are [5]

- Promotes efficient use of electrical energy.
- Reduces electricity wastage and unnecessary expenses.
- Provides convenience through remote monitoring.
- Supports sustainable development and smart energy management.
- Enhances consumer awareness regarding energy consumption.

Some of the expected outcomes are

- Real-time monitoring of electricity consumption.
- Easy access to energy usage data through a mobile app.
- Improved energy efficiency and reduced electricity bills.
- Accurate and reliable energy measurement.
- Increased awareness of energy conservation among users.

IV. Technology used in the Project Work

- Smart Energy Meter Sensor

- ➢ Microcontroller (ESP32/Arduino)
- ➢ Wi-Fi Communication Module
- ➢ Mobile Application (Android)
- ➢ IoT Technology
- ➢ Electricity Monitoring Sensors

V. PROCESS METHODOLOGY ADOPTED

- ➢ The energy meter sensor measures voltage, current, and power consumption.
- ➢ The ESP32/Arduino reads the sensor data.
- ➢ The collected data is processed and converted into energy units (kWh).
- ➢ Through Wi-Fi, the data is transmitted to the cloud server/mobile application.
- ➢ The mobile app displays real-time energy consumption.
- ➢ Users can monitor energy usage and receive alerts for excessive consumption
- ➢ The system is tested for accuracy, reliability, real time performance, and user friendliness to ensure effective energy monitoring.
- ➢ Install the system and perform periodic updates and maintenance.

VI. BLOCK-DIAGRAM AND FLOW-CHART

The Smart Energy Meter System as shown in the Fig. 1 receives 230V AC power, which is converted into 5V DC through the power supply unit to operate the circuit. The ACS712 current sensor and ZMPT101B voltage sensor measure the electrical parameters and send the data to the ESP32 microcontroller [8]. The ESP32 processes the data, calculates voltage, current, power, and energy consumption, and displays the values on a 16×2 LCD [7]. The LED indicator and buzzer provide status indication and alerts when necessary. Using its built-in Wi-Fi module, the ESP32 uploads the energy data to the Firebase cloud server, enabling users to monitor real-time electricity usage through a mobile application from anywhere. The proposed flow-chart for solving the problem is shown in the Fig. 2. The pictorial representation of the hardware developed along with the app design is shown in the Fig. 3 [7].

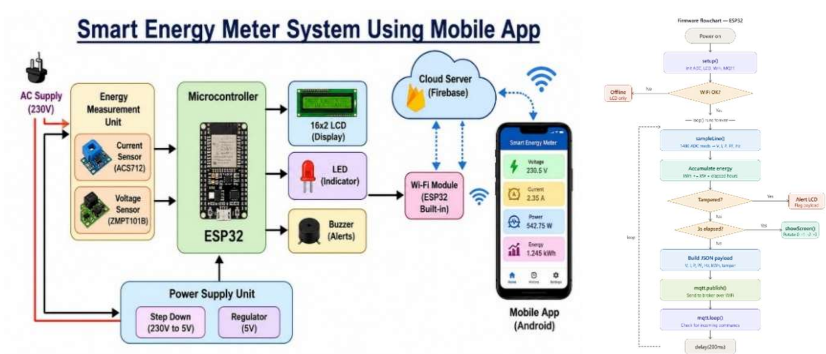

Fig. 1. Block-diagram of the Smart Energy Meter System using Mobile App

VII. ALGORITHM DEVELOPED

Step 1: Start the system.
Step 2: Initialize ESP32/Arduino and Wi-Fi connection.
Step 3: Read voltage and current values from the energy meter sensor.
Step 4: Calculate power and energy consumption.
Step 5: Store and process the measured data.
Step 6: Send the data to the cloud database/mobile application.
Step 7: Display real-time readings on the mobile app.
Step 8: Check if energy consumption exceeds the predefined limit.
Step 9: If the limit exceeds, send an alert notification to the user.
Step 10: Repeat monitoring continuously.
Step 11: Stop.

VIII. Snapshot and Results

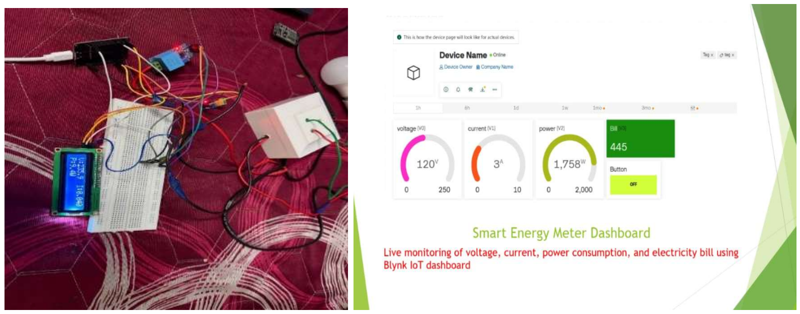

Fig. 2: Pictorial representation of the energy meter project work

IX. Priority based Energy Management Strategy

The system follows a priority-based energy management strategy in which solar energy is utilized as the primary power source whenever sufficient sunlight is available. Excess solar energy is stored in batteries for future use. During periods of low solar generation, cloudy weather, nighttime operation, or insufficient battery charge, the system automatically switches to grid electricity without interrupting the connected load [6]. This seamless switching mechanism ensures continuous power availability while maximizing the utilization of renewable energy resources. The Hybrid Solar Smart Switching System is designed to address the growing challenges of increasing electricity demand, rising energy costs, and the need for sustainable energy utilization. Conventional power systems rely heavily on grid electricity, which not only increases operational expenses but also contributes to environmental concerns [10].

X. System Design and Methodology Developed

The Hybrid Solar Smart Switching System is designed to provide an intelligent and reliable energy management solution by integrating solar energy, battery storage, grid electricity, and automated switching mechanisms. The system ensures continuous power supply to electrical loads while maximizing the utilization of renewable energy resources [8]. The design incorporates solar photovoltaic technology, embedded systems, IoT-based monitoring, and smart control algorithms to improve energy efficiency and reduce dependency on conventional power sources. The system continuously monitors solar power availability, battery charge level, and load demand. Based on these parameters, it automatically selects the most suitable power source. Solar energy is given the highest priority, followed by battery power and grid electricity. This methodology ensures efficient energy utilization while maintaining uninterrupted power supply as shown in the Fig. 3 [6].

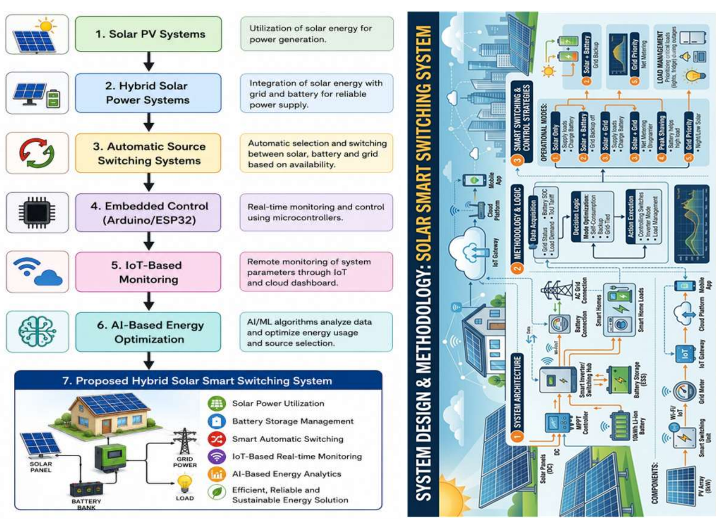

Fig. 3: Evolution of Technologies Leading to Proposed Hybrid Solar Smart Switching System / System Design and methodology

A. System Architecture

The architecture of the proposed system consists of a Solar Panel, Charge Controller, Battery Bank, ESP32 Microcontroller, Sensors, Relay Module, Grid Supply, IoT Monitoring Platform, and Electrical Load. The solar panel converts sunlight into electrical energy. The generated power is regulated through a charge controller before being supplied to the battery bank. The ESP32 controller continuously monitors system parameters through sensors and makes intelligent decisions regarding source selection. Relay modules are used to switch between solar power, battery power, and grid electricity based on operating conditions. Real-time data is transmitted to a cloud server and displayed on a web or mobile dashboard for remote monitoring.

The architecture enables seamless integration of renewable energy resources with conventional electricity sources, thereby ensuring reliable and efficient power management.

B. Block Diagram Description

The block diagram of the Hybrid Solar Smart Switching System illustrates the interaction between various hardware and software components. The solar panel acts as the primary energy source and supplies power to the battery through the charge controller. Sensors measure voltage, current, light intensity, and battery status. The ESP32 controller processes the collected information and controls the relay module accordingly. When solar power is available, the controller supplies power to the load through the solar system and charges the battery. During insufficient solar generation, the controller checks the battery condition and supplies power from the battery if adequate charge is available. If both solar and battery power are insufficient, the system automatically switches to grid electricity. All operational parameters are displayed on an LCD screen and uploaded to the IoT dashboard.

XI. Snapshots, Experimental Results and Discussions

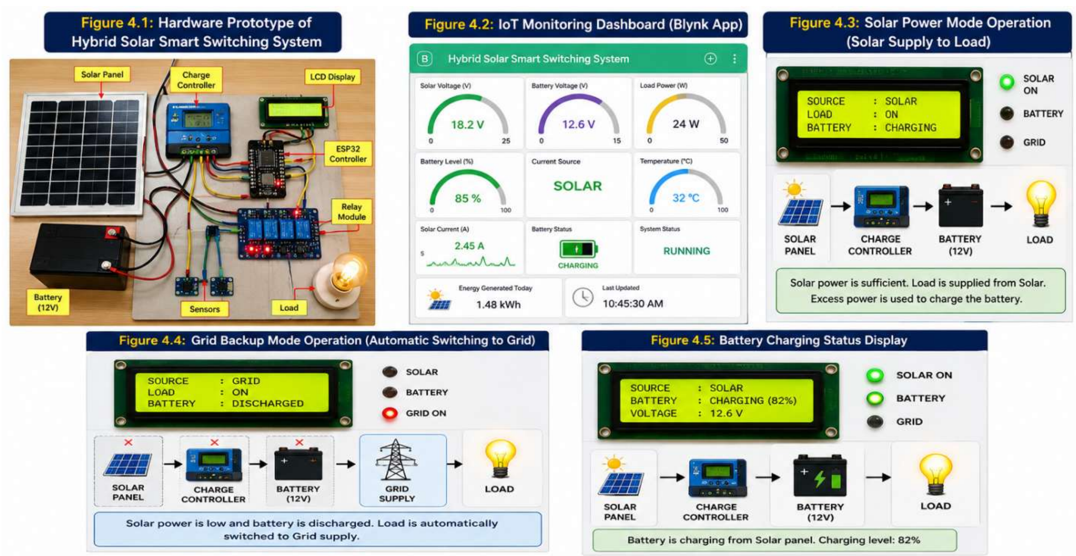

Table 4.1: Test Cases and Results

Test Case	Input Condition	Expected Output	Actual Output	Status
TC-1	High Solar Power Available	Load supplied from Solar	Solar Mode Activated	Pass
TC-2	Low Solar Power, Battery Charged	Load supplied from Battery	Battery Mode Activated	Pass
TC-3	Low Solar Power, Low Battery	Load supplied from Grid	Grid Mode Activated	Pass
TC-4	Battery Charging Condition	Battery Charging Enabled	Charging Successful	Pass
TC-5	IoT Monitoring	Dashboard Updated	Real-Time Data Displayed	Pass
TC-6	Automatic Switching	Seamless Source Transfer	Successful Switching	Pass

Table 4.2: Observation Table

Parameter	Measured Value	Parameter	Measured Value
Solar Panel Voltage	18 V	Switching Response Time	< 1 Second
Battery Voltage (Charged)	12.8 V	IoT Update Interval	5 Seconds
Battery Voltage (Low)	11.2 V	System Efficiency	Approximately 90%
Load Power Consumption	25 W	Operating Temperature	32 °C

Fig. 2: Experimental Results

XII. Working Methodology

The Hybrid Solar Smart Switching System operates through continuous monitoring and intelligent decision-making. During daytime, the solar panel generates electricity and supplies power to the load. Excess energy is stored in the battery bank. The ESP32 controller continuously evaluates solar generation and battery status.

When solar power decreases due to cloud cover or nighttime conditions, the controller automatically checks battery availability. If sufficient energy is stored, the battery supplies power to the load. In situations where both solar and battery energy are inadequate, the controller switches to grid electricity. This transition occurs automatically and ensures uninterrupted power supply. The IoT monitoring platform enables users to observe system performance remotely. Real-time information regarding power generation, battery status, energy consumption, and source selection is displayed on the dashboard. AI-based analytics can further optimize energy utilization by predicting future demand and recommending efficient power management strategies. Thus, the proposed methodology ensures maximum utilization of renewable energy, reduced electricity costs, enhanced reliability, and sustainable power management & the results of experiment is shown in Fig. 2 [9].

XIII. Conclusions and Future Scopes

The Hybrid Solar Smart Switching System was successfully designed and implemented to provide an intelligent, reliable, and energy-efficient power management solution. The system effectively integrates solar energy, battery storage, grid electricity, embedded control, and IoT-based monitoring into a single platform. The primary objective of maximizing renewable energy utilization while ensuring uninterrupted power supply was successfully achieved. The developed system continuously monitors solar power availability, battery charge level, and load requirements through sensors connected to the ESP32 microcontroller. Based on real-time operating conditions, the controller automatically switches between solar power, battery backup, and grid electricity. This intelligent switching mechanism ensures reliable operation and minimizes dependency on conventional power sources.

The Smart Energy Meter System Using Mobile App is an efficient and modern solution for monitoring electricity consumption. The system helps users track energy usage in real time through a mobile application, making it easier to manage power consumption and reduce electricity bills. By integrating sensors, a microcontroller, and wireless communication, the system provides accurate data, remote monitoring, and improved energy management. It also reduces manual meter reading and increases convenience for both consumers and electricity providers.

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