IoT Based Smart Grid to Remotely Monitor and Control Renewable Energy Source

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Abstract: The integration of the Internet of Things (IoT) with smart grid systems provides an intelligent platform for renewable energy monitoring, fault detection, and reliable power management. In this paper, we present an IoT-enabled smart grid framework that integrates a solar panel system with the Maharashtra State Electricity Board (MSEB) supply using an automatic changeover mechanism. The proposed system ensures uninterrupted power by automatically switching between solar energy and grid supply based on availability and demand. IoT-based sensors and controllers are employed for real-time data acquisition, load management, and transmission line fault detection, enabling efficient and secure operation. The system also incorporates advanced metering for accurate monitoring of energy generation and consumption, along with remote control and decision-making capabilities. Experimental validation demonstrates reliable changeover operation, effective renewable energy utilization, and timely fault detection, proving the potential of the proposed IoT-based smart grid for sustainable and resilient power distribution.

Keywords: Internet of Things (IoT), Smart Grid, Renewable Energy, Solar Energy, Energy Management System (EMS), Edge Computing, Communication Protocols (MQTT), Remote Monitoring, Real-time Control.

1. INTRODUCTION

The increasing demand for electricity, coupled with the depletion of fossil fuel reserves, has necessitated the integration of renewable energy sources into modern power systems. Among various renewable sources, solar energy has emerged as one of the most promising and sustainable alternatives due to its abundance, low environmental impact, and ease of deployment. However, the intermittent nature of solar power creates challenges in ensuring continuous and reliable electricity supply, especially in regions with fluctuating weather conditions. To overcome these challenges, hybrid systems that combine renewable sources with conventional grid supply have become essential.The smart grid concept, empowered by the Internet of Things (IoT), has transformed the operation and management of power systems. IoT-enabled smart grids allow real-time data acquisition, remote operation, demand-side management, and intelligent decision-making, thereby enhancing efficiency, reliability, and sustainability. Recent advancements have focused on IoT-based renewable energy monitoring, advanced metering infrastructures, and demand response strategies. In addition, transmission line fault detection plays a critical role in maintaining the resilience of power distribution networks, while the integration of smart charging stations addresses the growing need for electric vehicle (EV) charging and battery storage management.

In this paper, we present an IoT-enabled smart grid framework that integrates solar panels with the Maharashtra State Electricity Board (MSEB) supply through an automatic changeover mechanism. The system ensures uninterrupted power supply by intelligently switching between solar energy and grid supply depending on availability and load demand. To enhance reliability, transmission line fault detection and diagnosis are incorporated for real-time monitoring and timely fault isolation. Furthermore, the framework supports a wired charging station for electric vehicles and battery storage units, enabling efficient utilization of renewable energy and reducing dependence on conventional grid supply. IoT-based sensors and controllers provide continuous monitoring of generation, consumption, and fault conditions, while experimental validation demonstrates the effectiveness of the proposed system in achieving seamless power changeover, reliable fault detection, and sustainable energy distribution.

2. LITERATURE SURVEY

The integration of IoT with smart grid systems has attracted significant attention in recent years. Several researchers have focused on renewable energy monitoring, load management, and fault detection to enhance grid efficiency and reliability.

IoT-based solar energy monitoring systems have been widely explored. For instance, [1] developed a real-time monitoring framework for photovoltaic (PV) systems using IoT sensors and cloud platforms to optimize power generation. Similarly, [2] proposed a hybrid solar–grid energy system with automatic load switching, demonstrating improved energy utilization and reduced dependency on conventional power sources.

In the area of smart metering and load management, [3] presented an advanced metering infrastructure (AMI) integrated with IoT that provides real-time consumption data and supports demand response strategies. This work highlighted the potential of IoT in enabling consumers to make informed energy usage decisions while assisting utilities in load balancing.

Transmission line fault detection has also been an area of focus. Researchers in [4] introduced an IoT-enabled fault detection and classification method for distribution lines, where real-time sensor data was used to quickly identify short circuits and line interruptions. Another work [5] developed a cloud-based fault detection model capable of isolating faults to minimize downtime and enhance grid resilience.

With the growing popularity of electric vehicles (EVs), charging station integration into smart grids has been studied extensively. In [6], an IoT-based EV charging management system was proposed to optimize charging schedules and reduce peak demand on the grid. Likewise, [7] demonstrated a wired charging station controlled by IoT, ensuring efficient charging and monitoring of EVs while supporting renewable integration.

3. METHODOLOGY

3.1 Proposed Method

The proposed method uses an IoT-enabled solar monitoring system where a solar panel generates energy and an IoT device records and transmits the data to the IoT cloud. The mobile app connected to the cloud displays real-time system status and allows users to monitor solar power usage and remotely control connected loads. This ensures efficient utilization and smart management of renewable energy.

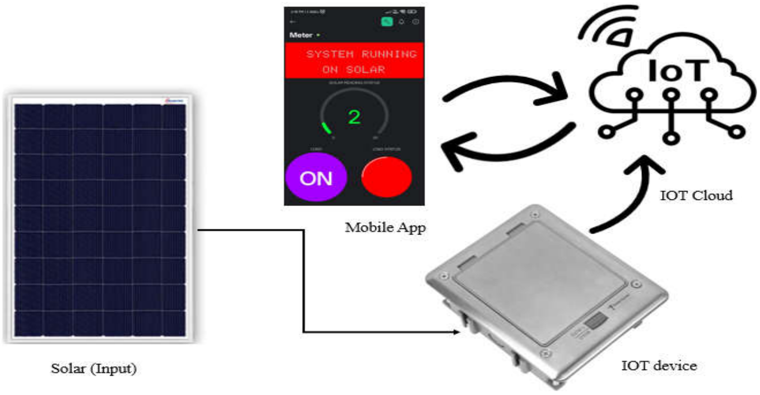

Fig.1: Proposed method

The proposed IoT-enabled smart grid system consists of three stages: Power Supply Stage, Control & Processing Stage, and Cloud Control Stage.

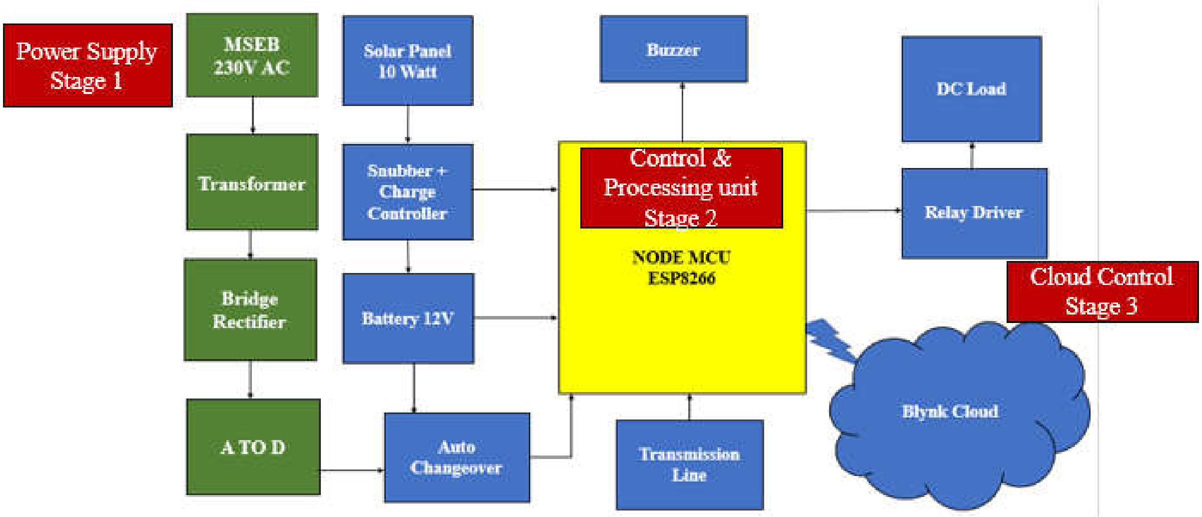

Fig.2: Block diagram

Stage 1: Power Supply – The 230V AC supply from MSEB is stepped down through a transformer, rectified using a bridge rectifier, and converted into regulated DC power. Alongside, a 10W solar panel generates DC electricity, which passes through a snubber and charge controller to safely charge a 12V battery. An auto-changeover unit ensures that the load receives uninterrupted power by switching between solar energy and the MSEB supply depending on availability.

Stage 2: Control & Processing – The NodeMCU ESP8266 microcontroller acts as the central unit, receiving regulated power and monitoring system parameters. It manages the auto-changeover operation, battery charging, and fault detection. A relay driver is used to control the DC load and wired charging station, ensuring efficient utilization of both renewable and grid power.

Stage 3: Cloud Control – The NodeMCU is Wi-Fi enabled and connected to the Blynk Cloud platform. This allows real-time monitoring of solar power generation, battery status, and load conditions. Through the Blynk mobile application, users can remotely switch loads on or off, observe system performance, and ensure reliable and user-friendly energy management.

3.2 Algorithm

1. Start
2. Initialize all hardware components (Wi-Fi microcontroller, relays).
3. Read inputs from:
   - Solar MPPT controller
   - MSEB supply status
4. Determine power availability:
   - If solar energy available, use solar as primary source.
   - Else MSEB available, use grid power.
5. Control relay module based on:
   - Load requirement
   - User commands from IoT app
   - Power source priority
6. Transmit data to cloud (Blynk).
7. Monitor user input from IoT dashboard (ON/OFF commands).
8. Adjust outputs accordingly (turn ON/OFF bulb).
9. Repeat monitoring cycle every few seconds.
10. End

3.3 Project flow

The flowchart illustrates the working process of a solar energy monitoring and management system integrated with IoT and the Blynk cloud. The operation begins with the initialization step, followed by connecting the system to Wi-Fi and establishing a connection with the Blynk cloud platform. Once connected, the system continuously reads solar data, such as voltage and current, and transmits it to the cloud for monitoring. After data transmission, the system checks for any transmission faults. If a fault is detected, an alert is generated by activating a buzzer and sending a notification to the user. If no fault occurs, the system evaluates the solar power output. When the solar output is greater than or equal to the required threshold, the load is supplied directly from the solar system. Otherwise, the load is supplied from the MSEB (Maharashtra State Electricity Board) grid to ensure uninterrupted power. This cycle repeats continuously, enabling reliable monitoring, fault detection, and efficient power management.

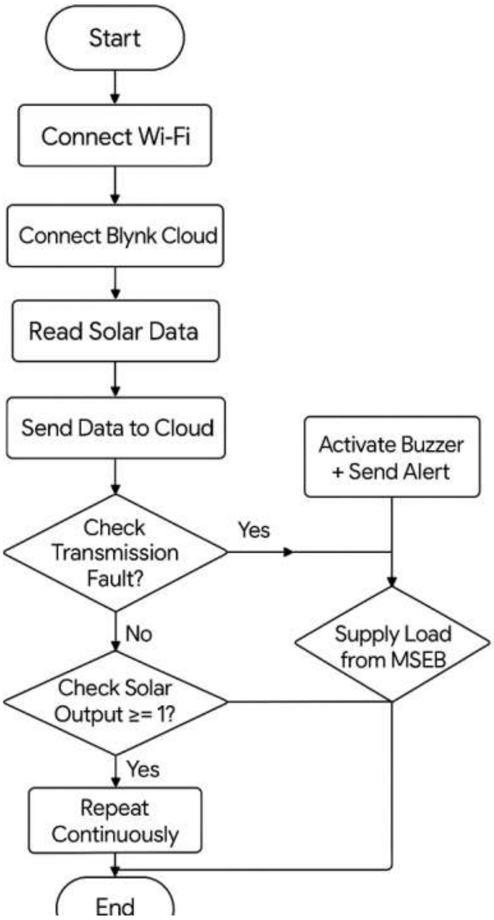

Fig.4: Flowchart

Fig.5: System running on MSEB

The figure represents a smart solar energy monitoring system interface that displays real-time operational status of a load powered by MSEB. At the top, the screen is labeled "Meter" with a green indicator dot, showing that the system is active and connected. A large red display panel in the center shows the message: "SYSTEM RUNNING ON MSEB". This indicates that the connected load is currently OFF and System running on MSEB because solar is not generated enough voltage.

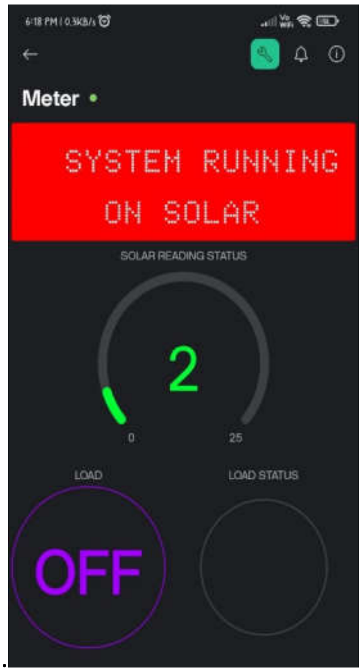

Fig.6: System running on Solar

The figure represents a smart solar energy monitoring system interface that displays real-time operational status of a load powered by solar energy. A large red display panel in the center shows the message: "SYSTEM RUNNING ON SOLAR". This indicates that the connected load is currently being powered by solar energy instead of the grid. A circular gauge labeled "SOLAR READING STATUS" shows the current solar reading. The value displayed is 2 (out of 25), which represents the measured solar input, possibly in terms of voltage. Load Button (Purple, marked "OFF"): Indicates that the connected load is currently switched OFF. Load Status Indicator (Only Circle): Shows the operational status of the load. The no color might signify an alert/diactive state, or simply indicate that the system is in operation.

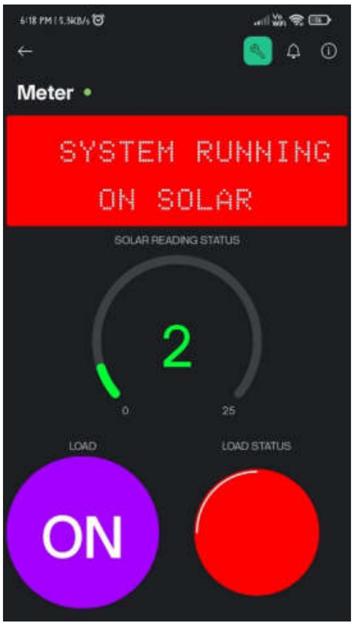

Fig.7: Active load

The figure represents a smart solar energy monitoring system interface that displays real-time operational status of a load powered by solar energy. A large red display panel in the center shows the message: "SYSTEM RUNNING ON SOLAR". This indicates that the connected load is currently being powered by solar energy instead of the grid. A circular gauge labeled "SOLAR READING STATUS" shows the current solar reading. The value displayed is 2 (out of 25), which represents the measured solar input, possibly in terms of voltage**.** Load Button (Purple, marked "ON")**:** Indicates that the connected load is currently switched ON**.** Load Status Indicator (Red Circle)**:** Shows the operational status of the load. The red color might signify an alert/active state, or simply indicate that the system is in operation.

The image shows a prototype model of a solar-powered smart energy monitoring and load control system. The setup integrates a photovoltaic (PV) solar panel, control circuits, and an electrical load for testing purposes. The solar panel generates DC power from sunlight, which is connected via wires to the control circuit for regulation and monitoring. Multiple PCB boards are used for different functions: a Voltage Regulation Circuit ensures a stable voltage supply, a Microcontroller/ESP Module Board (green PCB on the right) handles data acquisition, processing, and communication with the IoT dashboard, and a Relay Driver Circuit switches the load (lamp or appliance) ON and OFF as per control signals. Indicator LED Boards provide visual feedback of system status such as ON/OFF, charging, or fault conditions.

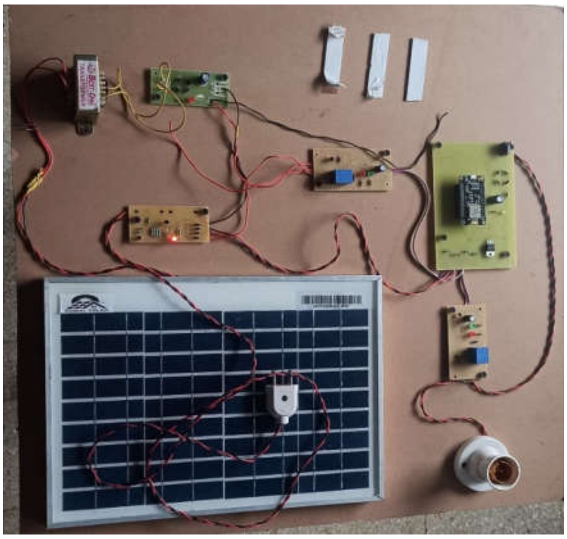

Fig.8: Final project

A transformer is connected for stepping down AC supply during hybrid/grid-solar operation or for charging support. The electrical load (bulb holder) is powered either by solar energy or by the grid when solar is insufficient. System wiring (red and black cables) connects all modules, transferring solar power, regulated output, and control signals. The microcontroller monitors solar performance and operational parameters, while the relay driver ensures automatic load control. In case of a transmission line fault, a buzzer is activated to provide an audible alert, ensuring immediate fault detection. LEDs further indicate real-time solar input, system mode, and load status, enabling reliable monitoring and control of the hybrid solar system.

Sr. No.	Solar Voltage (V)	Solar Current (A)	Power Output (W)	Load Status (App Controlled)	Auto Changeover	System Action
1	12.2	0.65	7.9	ON	Not required	Load powered from solar
2	11.8	0.55	6.5	OFF	Not required	Load powered from solar
3	10.5	0.35	3.7	ON	Not required	Load manually OFF by app
4	0	0	0	OFF	YES → Transformer	Load shifted to transformer backup
5	12.3	0.75	9.2	ON	Not required	Peak solar → load fully powered from solar

4. CONCLUSION

The developed prototype successfully demonstrates a solar-powered smart energy monitoring and load control system with integrated IoT-based supervision. A 10 W, photovoltaic panel was used as the primary energy source, with a transformer providing backup through auto changeover when solar power was insufficient. The system allows the load to be controlled via a mobile application, ensuring user flexibility. A relay driver circuit ensures automatic switching between solar and transformer supply, while indicator LEDs provide clear system status. Additionally, the system incorporates a transmission line fault detection mechanism, where the load is disconnected and a buzzer is activated to provide immediate fault alert. The experimental results confirm reliable operation of solar monitoring, efficient load management, seamless auto changeover, and robust fault indication. Overall, the prototype validates the feasibility of combining renewable energy utilization, IoT monitoring, automated control, and safety features in a compact and cost-effective system.

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