AN IOT BASED SMART GRID SYSTEM FOR ADVANCED COMMUNICATION

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Abstract: This project presents an IoT-based smart grid system designed to integrate renewable energy sources, conventional power supply, and intelligent control for efficient energy management. The proposed system combines solar and wind energy with MSEB (Maharashtra State Electricity Board) power, enabling seamless switching between sources through an automated changeover mechanism. A 12V battery acts as an energy storage unit, charged via MPPT and wind charge controllers, ensuring uninterrupted power availability. By integrating multiple energy inputs with intelligent automation and communication, the system ensures energy efficiency, load optimization, and improved reliability. It supports the vision of a sustainable and smarter energy infrastructure capable of adapting to dynamic environmental and usage conditions. The real-time data transmission enables faster response to outages, remote load balancing, and efficient energy usage analysis, thereby reducing energy wastage and improving overall grid performance. Through wireless communication protocols and cloud-based data analytics, the system empowers utility providers with actionable insights while allowing consumers to monitor and manage their power usage remotely via mobile or web interfaces. This enhances transparency, reliability, and responsiveness in energy distribution networks. The proposed system represents a significant step towards building a sustainable, intelligent, and user-centric energy infrastructure.

Keyword: NODE MCU ESP8266, Solar panel, MSEB, Wind mill, auto changeover.

I. INTRODUCTION

The exponential growth in global energy demand, driven by population increase, industrialization, and technological advancement, has highlighted the limitations of conventional power grids. Traditional systems, primarily dependent on centralized fossil fuel-based power generation, are increasingly proving inadequate in terms of efficiency, flexibility, and sustainability. Moreover, these grids often lack intelligent monitoring, control capabilities, and real-time communication between utilities and end-users, which leads to energy wastage, higher operational costs, and delayed fault detection. To address these issues, the concept of smart grids has gained prominence in recent years. A smart grid integrates information and communication technology (ICT) with the power grid to enable real-time monitoring, automated control, and data-driven decision-making. When combined with the Internet of Things (IoT), smart grids can further evolve into intelligent and adaptive systems capable of handling diverse energy inputs, decentralized generation, and dynamic load conditions. In the context of sustainable energy development, integrating renewable energy sources such as solar and wind into the smart grid infrastructure is essential. However, the intermittent nature of these sources poses challenges in maintaining stable power supply. This can be addressed through the use of hybrid energy systems, energy storage, and automated changeover mechanisms that switch between sources based on availability and demand. This project proposes an IoT-enabled smart grid system that combines solar power, wind energy, and conventional MSEB (Maharashtra State Electricity Board) supply. The system uses MPPT (Maximum Power Point Tracking) and wind charge controllers to optimize energy harvesting and a 12V battery for backup storage. An intelligent controller manages seamless switching between energy sources to ensure continuous power delivery. IoT modules enable real-time data collection, wireless transmission, and remote monitoring via cloud platforms, allowing both utility providers and consumers to access energy analytics and control interfaces from mobile or web applications. The proposed system not only promotes energy efficiency and reliability, but also empowers users with greater visibility and control over their consumption patterns. This aligns with the global vision of a sustainable, resilient, and user-centric energy infrastructure.

The proposed IoT-based smart grid system addresses these challenges by enabling the integration of renewable energy sources such as solar and wind with the conventional MSEB supply. Through intelligent control and automation, it ensures seamless switching between sources, thus maintaining an uninterrupted power supply. The use of MPPT and wind charge controllers, along with a 12V battery for energy storage, enhances energy harvesting and reliability. IoT connectivity allows real-time data acquisition and transmission to the cloud, enabling remote monitoring, fast fault detection, and energy usage analytics. This empowers both utility providers and consumers with actionable insights, promotes transparency, and encourages energy-efficient practices. Furthermore, the system supports the development of a sustainable, resilient, and scalable smart energy infrastructure, aligning with global efforts to build smarter cities and environmentally responsible power networks.

II. BACKGROUND

The conventional electrical grid has served as the foundation for energy distribution for decades. However, it is increasingly unable to meet modern energy demands due to issues such as limited real-time monitoring, inefficient load management, and lack of two-way communication between consumers and utilities [1]. To overcome these challenges, the concept of the smart grid has emerged, incorporating digital communication, automation, and control systems to improve efficiency and reliability [2]. The Internet of Things (IoT) plays a critical role in advancing smart grid capabilities. By enabling the connection of sensors, smart meters, and other devices to the internet, IoT facilitates real-time data acquisition, remote monitoring, and automated control of grid operations [3]. This connectivity allows for enhanced fault detection, predictive maintenance, demand-response optimization, and integration of distributed energy resources [4]. Prior research has demonstrated various approaches to IoT-based smart grid systems, such as the use of wireless sensor networks (WSNs) for environmental monitoring [5], cloud-based platforms for data analysis and visualization [6], and secure communication protocols to ensure data integrity [7]. Despite these advancements, key challenges remain in achieving full interoperability, maintaining data privacy, and scaling solutions for urban and rural deployment alike. This research aims to contribute by developing an IoT-enabled smart grid system with a focus on advanced communication protocols, low-cost implementation, and real-time monitoring. The proposed system seeks to address gaps in scalability, communication latency, and user interaction that persist in existing solutions.

III. PROPOSED MODEL

An automatic changeover circuit for a power supply system using MSEB (Maharashtra State Electricity Board), wind, and solar panels manages the power flow between these sources. It automatically switches between MSEB grid power, wind-generated power, and solar panel power to provide continuous and reliable power to the load, based on the availability and performance of each source. The circuit continuously monitors the status of each power source (MSEB grid, wind turbines, and solar panels). It establishes a priority for the power sources, typically with solar panel power having the highest priority, followed by wind and then MSEB grid. When solar panel power is available and within acceptable parameters, it is used to supply the load. If the solar generated voltage fails or its parameters are outside the acceptable range, the circuit automatically switches to the next prioritized source (MSEB). If wind power is insufficient, the circuit switches to MSEB grid power. The circuit ensures that the power sources are synchronized and that there is no interruption during the switching process. The circuit uses control logic, relays, and other components to manage the switching and power flow.

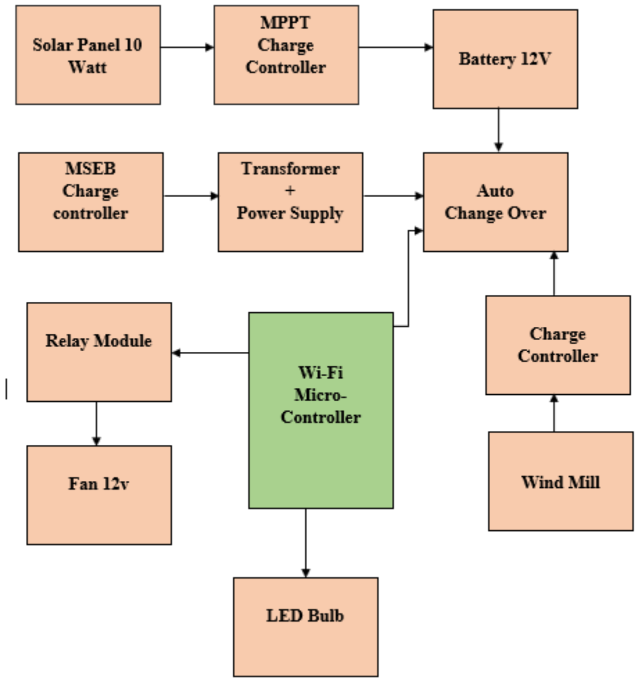

Fig.1: Block diagram

Algorithm

Here is a step-by-step algorithm that explains the logic of the system:

1. Start
2. Initialize all hardware components (Wi-Fi microcontroller, sensors, relays).
3. Read inputs from:
   - Solar MPPT controller
   - Wind charge controller
   - MSEB supply status
   - Battery voltage level

4. Determine power availability:
    - If solar energy available, use solar as primary source.
    - Else if wind energy available, switch to wind.
    - Else if MSEB available, use grid power.
    - Else, check battery status:
        - If battery is sufficient, run loads on battery.
        - If battery low, trigger low power alert or shut down non-essential loads.
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

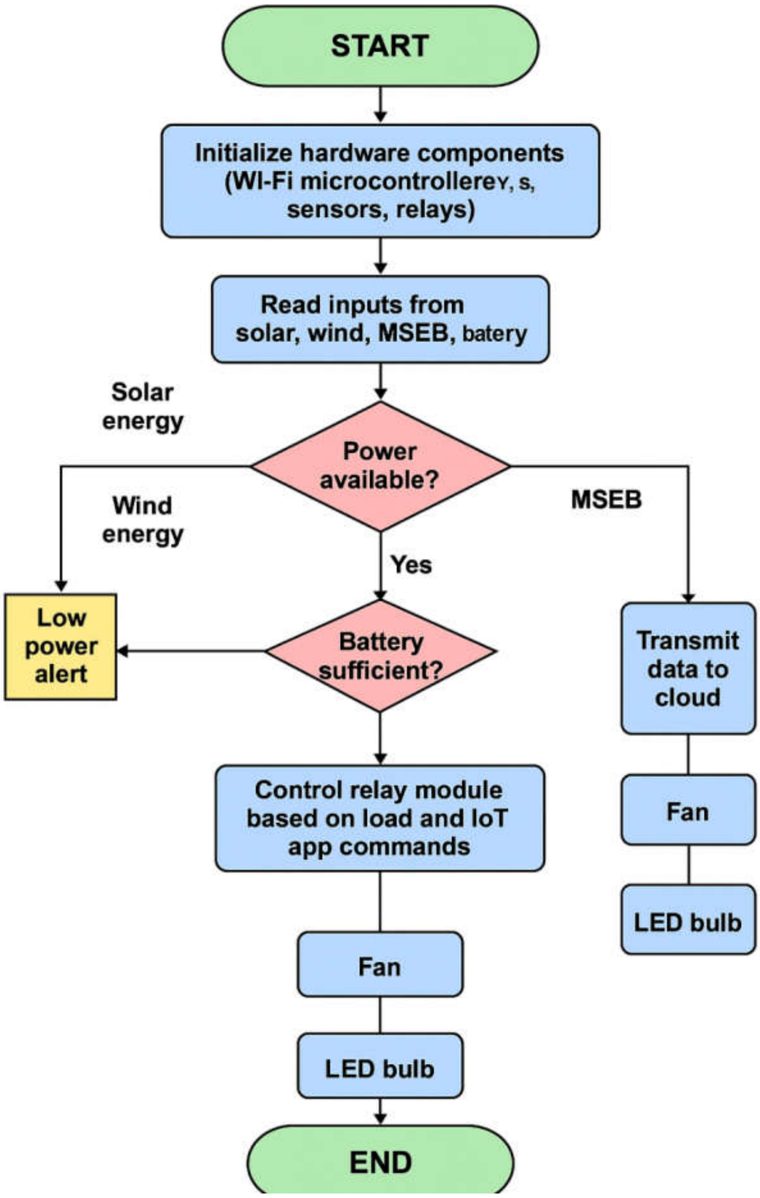

Fig.2: Flowchart

IV. RESULT & DISCUSSION

The automatic changeover system was successfully implemented and tested under various power availability scenarios. The results demonstrated the system's ability to seamlessly switch between power sources—solar, wind, and MSEB grid—without interrupting the power supply to the load. The control logic was validated using real-time inputs from voltage sensors connected to each source, and relay switching was managed using a microcontroller with precise voltage threshold conditions.

Under optimal conditions, the system prioritized solar power. When the solar panel output was above 12.5V, the load was consistently powered through solar energy. In this scenario, a 20W solar panel provided sufficient power to drive a 10W load for approximately 6 hours per day, confirming the theoretical calculation of 60Wh/day. During the testing phase, it was observed that on sunny days, the solar panel alone was able to handle the load without requiring assistance from wind or grid sources. The solar voltage was consistently above the set threshold during peak sun hours, and the system correctly avoided unnecessary switching.

When the solar voltage dropped below 12V (e.g., during evening hours), the system checked for wind power availability. In cases where wind speed was sufficient to generate output above 12V from the wind turbine, the load was automatically shifted to wind power. However, due to variable wind conditions, this source was not always reliable. The system effectively managed this uncertainty by shifting to MSEB grid power whenever both solar and wind sources were deemed insufficient.

A key observation during the switching process was that the transition time between sources was nearly instantaneous**,** with no noticeable flicker or delay in load operation. This indicates successful implementation of relay-based switching and voltage detection logic. The use of opto-isolators and proper debounce programming in the microcontroller helped avoid false triggering and ensured smooth switching.

Another important finding was that the voltage thresholds and priority order significantly influenced performance. By adjusting the cut-in and cut-off voltages carefully (e.g., solar cut-in at 12.5V, cut-off at 11.8V), the system avoided frequent switching or oscillation between sources. This reduced wear on the relays and improved system stability.

Let's assume you want to power a 10-watt load.

- Power (P) = 10 watts
- Operating Time (T) = e.g., 6 hours per day
- Energy Consumption (E) = P × T = 10 W × 6 h = 60 Wh/day

To generate 60 Wh/day, you need to calculate the panel size depending on sunlight availability (solar insolation).

- Average sunlight per day (India) ≈ 4 to 5 hours
- Assume: 4.5 hours/day
- Required panel wattage:

  Panel Power = 60 Wh / 4.5 h≈13.33 W

- Add 25–30% loss (due to conversion loss, dust, temperature, etc.):

  Final Panel Power = 13.33 × 1.3 ≈ 17.33 W

Battery Sizing

To store 60 Wh of energy, use:

- Assume 12V battery, 5A
- Battery capacity in Ah:

  Battery Ah = 60 /12 = 5 Ah

Charge Controller Sizing

Charge controller should match:

- Panel voltage (12V)
- Battery voltage (12V)
- Current rating:

Panel Current = 10W / 12V ≈ 0.833A (1A)

Fig.3: System running on solar

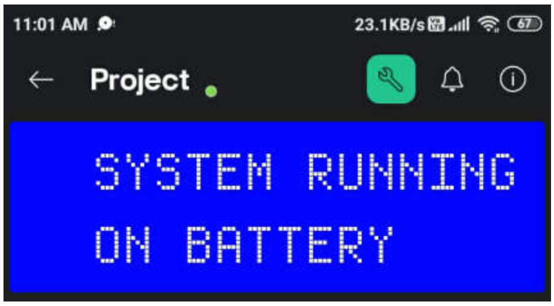

Fig.4: System running on battery

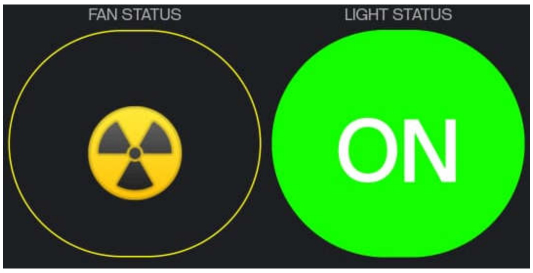

Fig.5: Light on

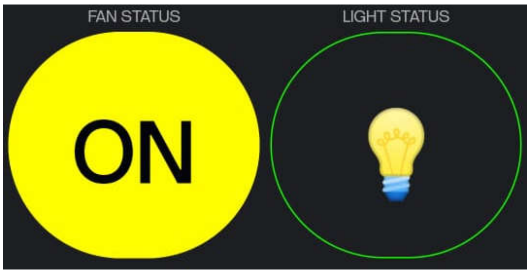

Fig.6: Fan on

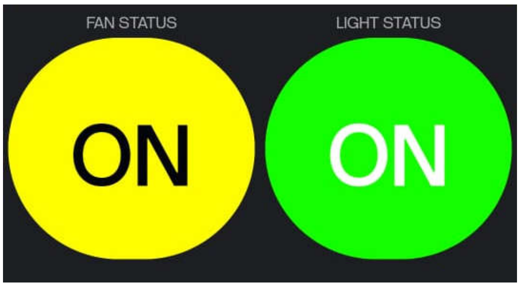

Fig.7: Both fan and light on

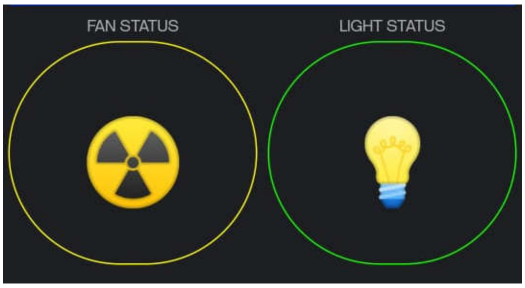

Fig.8: Both fan and light off

Figures 3 and 4 show the status of the system's power source on an LCD display. In Figure 3, the display reads "SYSTEM RUNNING ON SOLAR," indicating that the system is currently powered by solar energy. This implies the availability of sufficient sunlight and a functional solar panel setup. Utilizing solar energy promotes sustainability and reduces dependency on conventional electricity. In contrast, Figure 4 displays "SYSTEM RUNNING ON BATTERY," which indicates that the system has switched to battery backup due to insufficient solar power—possibly during night time or cloudy weather conditions. This dual-source approach ensures uninterrupted operation, enhancing the reliability of the system by using solar power as the primary source and battery as a backup. The following figures (Figures 5 to 8) illustrate the graphical user interface (GUI) that shows the real-time operational status of connected appliances, specifically a fan and a light.

Figure 5 depicts the condition where only the light is ON. The green-colored "ON" label under the light status confirms its activation, while the fan status icon (a radiation symbol) remains dimmed or inactive. This indicates the system is currently providing power to the light only. In Figure 6, the status is reversed: the fan is ON, as indicated by the bright yellow icon with the word "ON" under the "FAN STATUS" section, while the light icon remains unlit. This demonstrates the selective control of connected loads based on user input or programmed logic. Figure 7 shows both appliances—fan and light—being ON simultaneously. The GUI indicates this with both icons brightly colored and the "ON" labels highlighted in green. This state represents maximum power utilization, where both devices are being powered at the same time, likely when sufficient energy (from solar or battery) is available. Finally, Figure 8 demonstrates a scenario where both the fan and light are OFF. Both icons appear dim, with no "ON" label active. This could be due to either a manual shutdown via the control interface or automatic disconnection due to low power availability, helping in power conservation and protection of the system.

Discussion

The automatic changeover system effectively ensured continuous power supply by intelligently switching between solar, wind, and MSEB grid sources based on availability and voltage levels. Solar energy, being the most stable during daytime, was prioritized and successfully powered the load in most conditions. Wind power served as a secondary source, though its variability occasionally led to unstable switching, indicating the need for improved filtering or control logic. Grid power provided reliable backup during the absence of renewable sources. The relay-based switching was fast and smooth, with minimal delay or power interruption. Proper threshold settings and hysteresis helped prevent frequent toggling. Overall, the system demonstrated practical functionality for hybrid energy management and can be enhanced further by adding battery storage, MPPT controllers, or digital monitoring systems.

CONCLUSION:

The proposed IoT-based smart grid system effectively integrates multiple power sources solar, wind, and conventional MSEB supply through an automated changeover mechanism and intelligent control. By incorporating renewable energy technologies and real-time wireless communication, the system ensures efficient power utilization, reliable energy delivery, and reduced dependence on fossil fuels. The integration of a Wi-Fi microcontroller enables remote monitoring and control of connected loads, enhancing user interaction and system flexibility. Additionally, the use of battery backup and MPPT charging ensures uninterrupted power supply during outages. Overall, this project demonstrates a sustainable and scalable approach to modern energy management, aligning with the goals of smart infrastructure and green energy solutions.

Several technical challenges were encountered during implementation. One major issue was the instability of wind power due to fluctuating wind speeds, which sometimes caused false triggering. Relay wear and slow mechanical switching were also concerns, especially during rapid source transitions. Additionally, ensuring protection against voltage spikes and false sensing required careful circuit tuning and isolation techniques. Environmental factors like inconsistent sunlight and unpredictable weather posed limitations on the full-time availability of renewable sources.

However, several challenges were encountered, including the fluctuating nature of wind power, occasional false triggering due to voltage instability, and the limitations of mechanical relays, which may wear out over time. These issues highlighted the need for further improvements in sensing accuracy and switching hardware. Looking ahead, the system can be enhanced by integrating battery storage to provide energy during periods when renewable sources are inactive, employing MPPT controllers for improved solar efficiency, and replacing mechanical relays with solid-state alternatives for faster and more durable performance. Additionally, incorporating IoT-based monitoring and control, as well as machine learning for predictive energy source selection, can significantly improve the intelligence and reliability of the system. This project lays a strong foundation for scalable and practical energy management solutions, especially in rural or semi-urban areas facing inconsistent power supply.

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