A Novel Approach for Automatic Switching of Power System using IoT Based Renewable Energy Sources

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Abstract:-The increasing integration of renewable energy sources into modern power systems presents both opportunities and challenges, particularly in terms of reliability, efficiency, and real-time energy management. This paper proposes a novel IoT-based architecture for the automatic switching of power sources, leveraging cloud-derived weather data to optimize the distribution of renewable energy without relying on physical weather sensors. The system employs a microcontroller-based energy management unit that dynamically allocates power between critical and non-critical loads based on real-time environmental conditions and generation capacity. By prioritizing essential loads during periods of low renewable availability and redirecting surplus energy to secondary loads when conditions permit, the proposed framework enhances overall system resilience, reduces energy waste, and improves load balancing. The use of IoT technology not only simplifies the hardware architecture but also enables scalable and remote energy control, making it suitable for smart grid and off-grid applications alike. Experimental validation demonstrates the system's effectiveness in real-time energy optimization and its potential to contribute to sustainable and autonomous energy infrastructure.

Keywords: *Renewable Energy, Solar Power, Wind Power, IoT, Automatic Power Switching, Grid Integration, Smart Grid, Power Management, Energy Efficiency.*

1. Introduction

The increasing global energy demand, coupled with the urgent need to mitigate greenhouse gas emissions, has accelerated the shift toward renewable energy sources (RES) such as solar, wind, hydro, and biomass. However, the intermittent and decentralized nature of these sources presents significant challenges for their seamless integration into existing power grids [1][2]. Traditional grid infrastructure, designed for centralized energy production, struggles with balancing supply and demand in real-time when faced with the variable output of renewables [3]. The emergence of the Internet of Things (IoT) offers promising solutions to these challenges. IoT-enabled systems can monitor, control, and optimize energy flow in smart grids through real-time data acquisition, communication, and processing [4][5]. By leveraging sensors, smart meters, actuators, and cloud-based analytics, IoT facilitates improved load forecasting, demand response, and distributed energy resource (DER) management [6][7]. These capabilities are vital for enhancing the stability, efficiency, and reliability of power grids that incorporate renewable sources.

Moreover, the integration of IoT with renewable energy technologies contributes to the development of intelligent energy management systems (EMS), enabling predictive maintenance, fault detection, and decentralized energy trading [8][9]. These advancements align with the vision of smart grids, which aim to be more responsive, automated, and resilient [10]. Despite the potential benefits, several challenges persist, including cybersecurity risks, data privacy concerns, communication latency, and interoperability among heterogeneous devices [11][12]. Additionally, the deployment of IoT in energy systems requires robust communication protocols, edge computing capabilities, and scalable architectures [13][14]. Addressing these issues is crucial for realizing a fully integrated, IoT-driven, renewable-based smart grid.

Automatic power switching for solar and wind integration using IoT is an advanced approach that enables seamless, intelligent, and efficient management of multiple energy sources. By leveraging IoT technologies, these systems can monitor, control, and switch between solar, wind, grid, and backup sources based on real-time data, ensuring uninterrupted power supply and optimal energy utilization. IoT-based ATS system improves switching speed and affordability, the notable drawback is the potential for significant lag during source transitions, especially in adverse conditions, as well as concerns related to cloud platform security and costs [15][16].Despite its potential, the deployment of IoT-based automatic switching systems faces several barriers, including cybersecurity risks, interoperability issues, and high initial investment costs [11] [12].Additionally, the deployment of IoT in energy systems requires robust communication protocols, edge computing capabilities, and scalable architectures [13][14]. Addressing these issues is crucial for realizing a fully integrated, IoT-driven, renewable-based smart grid.IoT-based energy management systems (EMS) deploy smart meters, sensors, actuators, and edge computing devices to control distributed energy resources (DERs) and enable automatic power switching based on system states [17]. However, in the absence of predictive capabilities, such systems often rely on reactive switching, which may not be optimal under rapidly changing weather conditions.Weather forecasting emerges as a critical enabler in this context, enhancing the effectiveness of automatic power switching in IoT-based renewable systems. Accurate short-term and medium-term weather forecasts can predict fluctuations in solar irradiance, wind speed, and temperature key variables that influence renewable generation output [18][19]. By integrating weather forecast data into IoT-based EMS, it becomes possible to transition from reactive to predictive control, improving the timing and efficiency of source switching [20].

This paper proposes a sensor-less, IoT-enabled weather-based energy management system for the automatic switching of power sources in response to dynamic load demands. The system leverages IoT platforms to acquire real-time weather data from cloud-based services, thereby eliminating the need for physical weather sensors and reducing system complexity and cost. A microcontroller-driven control unit processes this data to intelligently manage the distribution of renewable energy across prioritized load categories. During periods of limited renewable generation, the system ensures uninterrupted supply to critical loads, while surplus energy- when available -is dynamically allocated to non-critical loads, enhancing overall energy efficiency and operational reliability.

2. System Design and Methodology

The block diagram of the proposed system, as shown in Figure 1, consists of multiple input sources—solar, wind, and battery—along with switching circuits, a DC-DC converter, a three-phase inverter, PWM signal generators, a Raspberry Pi microcontroller, and IoT-connected devices. The solar and wind modules serve as the primary renewable energy sources, while the battery functions as a backup energy storage unit to ensure continuity of supply during low-generation periods. Switching circuits are used to manage the automatic selection and transition between different energy sources based on real-time availability and load demand. The DC-DC converter regulates and stabilizes the voltage output from the sources before feeding it into the inverter. The three-phase inverter converts the regulated DC voltage into AC power suitable for grid or load consumption. Pulse Width Modulation (PWM) signals are used to control the inverter switching operation for efficient energy conversion. A Raspberry Pi microcontroller acts as the central control unit, processing sensor data, executing control logic, and communicating with cloud servers. IoT-connected devices enable real-time monitoring, remote control, and data logging of system parameters through internet-based interfaces

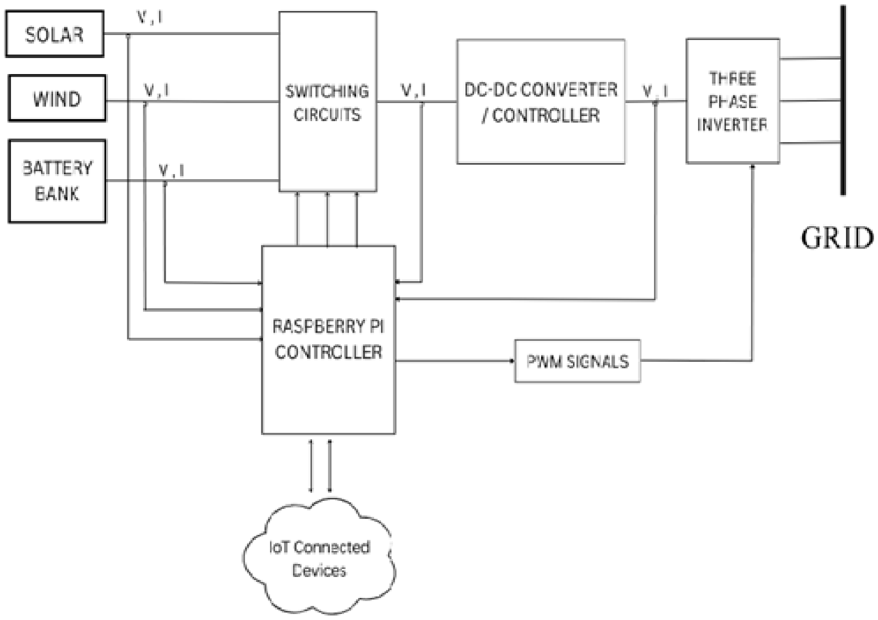

Figure 1.Block Diagram of the Proposed System

Instead of relying on physical weather sensors (such as pyranometers for solar radiation or anemometers for wind speed), the system retrieves real-time weather data from online services such as OpenWeatherMap, NOAA, or local meteorological APIs. This data includes parameters such as solar irradiance, temperature, wind speed, cloud cover, and rainfall probability, which are used to predict the generation capacity of renewable energy sources (RES). A Raspberry Pi microcontroller continuously fetches and processes this weather data. It analyzes weather forecasts, power availability, and load demand to determine the optimal energy source for supplying power. Users can monitor and control the system through a mobile application that provides real-time updates on power status, energy consumption, and weather forecasts. This enhances user engagement and enables manual overrides when necessary.

2.1 System Control Strategy

Based on the collected data, the proposed system employs intelligent algorithms to determine the most efficient power source at any given time, ensuring continuous power supply while optimizing cost and energy efficiency.

1. When weather conditions predict high solar irradiance or wind speed, renewable energy sources (RES) are prioritized to maximize green energy utilization.

2. If RES generation is insufficient due to factors such as cloudy weather, nighttime, or low wind speed, the system switches to grid power to maintain supply reliability.

3. Battery storage, when available, is dedicated to supplying critical loads, ensuring uninterrupted power to essential services.

4. Upon detection of overloads or faults, the system isolates faulty sources and reconfigures power flow accordingly to prevent cascading failures.

Relays and solid-state relays (SSRs) facilitate automatic load transfer between the grid and RES according to the switching logic implemented by the control algorithms. The system continuously calculates total power generation against demand to manage load distribution effectively:

1. If generated power exceeds load demand, all loads are powered exclusively by RES, maximizing renewable penetration.

2. When generation equals demand, essential loads such as hospitals and telecom towers receive priority power supply, while non-essential loads, like street lighting, are energized only if surplus renewable energy is available.

3. In scenarios where demand surpasses available power, the system executes load shedding protocols to maintain grid stability and prevent outages.

This hierarchical and predictive control strategy ensures optimal use of renewable resources while maintaining reliability and resilience in the IoT-enabled smart grid environment.

3. Hardware implementaion

The IoT-based load management system illustrated in this project embodies a smart, adaptive, and highly integrated approach to managing renewable energy sources in combination with energy storage and load prioritization. The core of the system relies on hybrid energy generation using both solar and wind sources, which are converted into usable electrical energy through dedicated photovoltaic (PV) panels and a BLDC-based wind turbine generator. These energy inputs are processed through respective charge controllers that regulate voltage and current to ensure safe charging of lithium-ion batteries, preventing overcharging and deep discharge while maintaining energy storage efficiency.Once stabilized, the energy is stored in a battery bank and routed either directly to the loads or through a DC-AC inverter for powering conventional AC appliances. The inverter ensures compatibility with household and commercial devices by converting 12V/24V DC to a usable 220V AC output. The system also includes DC-DC converters to maintain optimal voltage levels across various components and subsystems.

At the core of the energy management architecture is the Raspberry Pi Pico WRP2040, a compact microcontroller with integrated Wi-Fi that serves as the central control unit. The Pico W interfaces with current sensors (ACS712) and voltage sensing circuits to monitor real-time power flow from different sources and to connected loads. These analog signals are digitized using ADS1115 16-bit analog-to-digital converter (ADC) modules and sent to the microcontroller for processing. The Pico W analyzes this data and makes control decisions based on preprogrammed algorithms and weather forecast data acquired via IoT.

Weather forecasts are retrieved from online APIs, such as OpenWeatherMap or NOAA, eliminating the need for physical weather sensors while providing accurate predictive inputs. Based on the availability of solar and wind energy, along with the battery's state of charge, the system selects the most appropriate power source at any given time. When renewable energy availability is high, it is prioritized for directly powering the system or charging the batteries. During periods of low generation, the system intelligently switches to stored battery power or, if necessary, grid power. This intelligent source selection ensures optimal utilization of renewable energy while minimizing dependency on conventional power grids.Load management is executed via 2-channel and 4-channel relay modules, which control the distribution of power to various connected devices. These relays are controlled by the Raspberry Pi Pico W and are programmed to respond dynamically to variations in energy generation and load demand. The system categorizes loads into essential and non-essential types. Essential loads—such as communication systems or medical equipment—receive uninterrupted power supply, while non-essential loads—such as lighting or secondary appliances—are only powered when excess energy is available. In case of a power shortfall, the system automatically performs load shedding to maintain overall stability without requiring user intervention.

The relay-based switching mechanism also facilitates fault isolation. If an overload or fault is detected in one of the energy sources, the system isolates the faulty input and redirects power from an alternative source, thereby improving safety and ensuring operational continuity. All switching operations are seamless and do not interrupt the supply to critical loads.IoT integration enhances the system's intelligence and responsiveness. Using the Blynk platform or similar IoT dashboards, users can monitor real-time system parameters, including power generation, load status, battery level, and waveform data. The platform also enables remote control and analytics, allowing users to adjust system behavior based on forecasted usage patterns, environmental conditions, or operational needs.The Circuit diagram and Hardware implementation for the proposed system is shown in Figure 2.a and Figure 2.b.

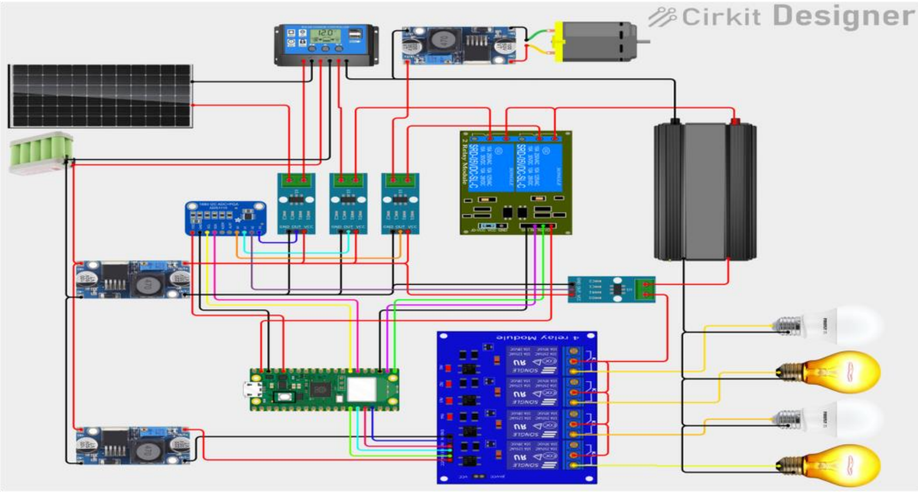

Figure 2.a.Circuit Diagram for Hardware Implementation

Figure 2.b.Connection diagram for Hardware Implementation

4. Results and Discussion

IoT-based load management system demonstrate the convergence of embedded control, renewable energy integration, and cloud-based intelligence. It offers a scalable, resilient, and highly efficient solution for optimizing energy usage in residential, commercial, and remote applications. By balancing supply and demand, prioritizing critical loads, and enabling remote visibility and control, the system reduces energy waste, enhances reliability, and promotes sustainable energy usage .In the proposed system, weather data is obtained via an API from the OpenWeatherMap cloud platform, which provides current and forecasted weather reports in JSON format. The microcontroller processes this data to support renewable energy generation predictions. An IoT-based monitoring and control dashboard is implemented using the Blynk cloud platform, as illustrated in Figure 3.

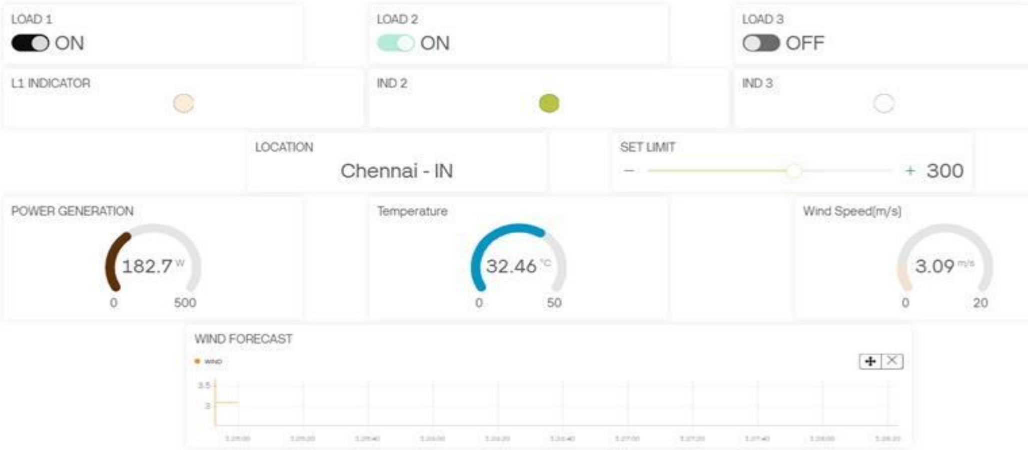

Figure 3.Blynk -Dashboard for monitoring and control

The Weather data can be obtained from Open Weather Map platform and it is shown in the Figure 4.

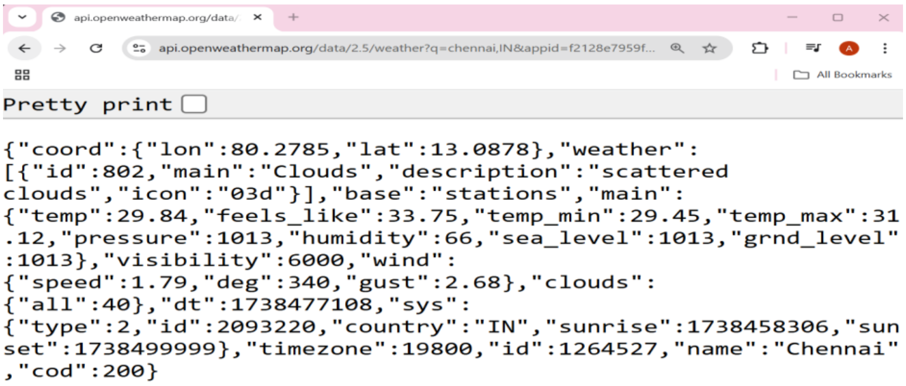

Figure 4.Weather data from OpenWeatherMap

The data collected over various daytime intervals demonstrates the interplay between solar irradiance, wind speed, and the resulting power generated from renewable energy sources (RES). The observed values are summarized in Table 1.

Timings	Solar Irradiance (Wb/m^2)	Wind Speed (m/s)	Power Generated From RES (W)
09.00 AM - 11.00AM	850	5	75 - 100
11.00 AM - 02.00 PM	1000	4	100 - 300
02.00 PM - 04.00 PM	900	5	200-350
04.00 PM - 06.00 PM	750	5	200

Table 1.Power Generation of RES

To better understand these variations, here's a graph shown in Figure 5 illustrating the relationship between time, solar irradiance, wind speed, and power output:

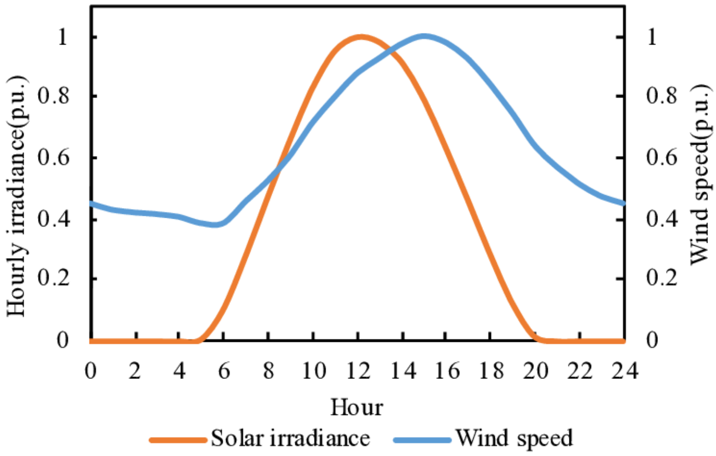

Figure 5.Graph Power Generation of RES

Here's a concise summary of the key insights derived from the graph:

1. **Solar Irradiance**peaked at **1000 Wb/m²** between **11:00 AM and 02:00 PM**, aligning with midday when the sun is at its highest point.
2. **Wind Speed**remained relatively constant at **5 m/s**, with a slight decrease to **4 m/s** during the midday period.
3. **Power Generation**from renewable energy sources varied, with the highest output observed between **02:00 PM and 04:00 PM**, reaching up to **350 W**.
4. **Evening Period**(04:00 PM – 06:00 PM) saw a decline in solar irradiance to **750 Wb/m²**, resulting in a reduced power output of **200 W**.
5. **Consistent Wind Speeds**throughout the day contributed to a stable power generation, especially during periods of lower solar irradiance.

Table 2. Highlight the importance of load management in optimizing the use of available RES power, ensuring that loads are connected based on the power generated to maintain system stability and efficiency

SET LIMIT = 500 W			
POWER GENERATED FROM RES (W)	LOAD 1 (75W)	LOAD 2 (100W)	LOAD 3 (150W)
< 50W	Disconnected with RES		
50 - 100	ON	OFF	OFF
100-150	ON	OFF	OFF
150-200	ON	ON	OFF
200-250	ON	ON	OFF
250-300	ON	ON	OFF
300-350	ON	ON	ON

Table 2.Switching of the loads with power generation

Load Management Insights

1. Power Generation Below 50W: When RES output is less than 50W, all loads (75W, 100W, and 150W) are disconnected, indicating insufficient power to meet any load requirements.

2. 50W to 100W Output: With power generation in this range, only Load 1 (75W) is connected, while Loads 2 (100W) and 3 (150W) are disconnected, suggesting that the available power is just enough to support the smallest load.

3. 100W to 150W Output: In this scenario, Load 1 remains connected, but Load 2 is disconnected, while Load 3 is still unsupported, reflecting a prioritization of loads based on power availability.

4. 150W to 200W Output: Both Load 1 and Load 2 are connected, but Load 3 is disconnected, indicating that the system can support two loads simultaneously.

5. 200W to 350W Output: Power generation in this range supports all three loads, demonstrating the system's capacity to handle the maximum load capacity efficiently

5. Conclusion

The integration of solar and wind energy with IoT technology offers a promising approach to achieving sustainable, efficient, and intelligent energy consumption. The proposed sensorless, IoT-based weather forecasting system facilitates intelligent load switching between the grid and renewable energy sources without relying on physical environmental sensors. By leveraging predictive weather analytics, the system enhances energy efficiency, ensures operational reliability, and reduces dependence on the conventional power grid, while maximizing the utilization of available renewable resources.

Moreover, the flexibility and scalability inherent to IoT-based systems enable seamless integration with existing energy infrastructures, thereby supporting the transition toward a more decentralized and resilient energy grid. As advancements in renewable energy technologies and IoT platforms continue to accelerate, the adoption of such integrated solutions has the potential to transform the generation, distribution, and consumption of energy—paving the way for a greener, smarter, and more sustainable energy future.

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