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Smart Hybrid Energy Switch Optimum Energy National Energy Consumption With Iot Integration

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Abstract
The Smart Hybrid Switch for National Energy Management using IoT is an innovative system designed to intelligently control and optimize the use of solar and grid electricity. Powered by an Arduino microcontroller, the system continuously monitors voltage levels from both energy sources and prioritizes solar power to maximize renewable energy usage. When solar input is insufficient, it seamlessly switches to grid power to ensure uninterrupted supply. The system integrates wireless communication through LoRa or ESP modules for remote monitoring and manual control, while an LCD display provides real-time voltage data to the user. With features like automation, manual override, and scalability, this cost-effective solution is ideal for residential, industrial, and rural applications, supporting clean energy adoption and efficient national energy management.

Keywords: *Smart switch, Arduino, IoT, solar, grid, wireless, energy*

1. Introduction
This project introduces a Smart Hybrid Switch using IoT and Raspberry Pi Pico to integrate solar power with the conventional grid seamlessly. It optimizes energy consumption through intelligent algorithms that prioritize solar energy and automatically switch to the grid only when solar power is insufficient. The system provides real-time monitoring of voltage levels and energy sources, allowing users to oversee power consumption and exercise manual control when needed. By dynamically responding to real-time energy demand and weather conditions, the switch enhances energy efficiency, reduces reliance on non-renewable sources, and supports sustainable and smart energy management practices. Additionally, the system incorporates wireless communication using modules like LoRa or ESP, enabling remote monitoring and control over connected loads. A user-friendly LCD display provides live updates on solar and grid status, improving transparency and decision-making. The design is modular, scalable, and cost-effective, making it suitable for households, industries, and rural areas [1]. This solution contributes significantly to promoting renewable energy adoption, reducing carbon footprints, and aligning with global clean energy goals and smart grid initiatives. Furthermore, the system can be upgraded with data logging features, enabling users to track historical energy usage patterns and optimize future consumption. Its ability to function both online and offline ensures reliability in diverse environments. With the growing demand for sustainable energy solutions, this Smart

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Hybrid Switch offers a practical, eco-friendly, and technologically advanced approach to modern energy management.

2. Methodology

The proposed system integrates an embedded IoT-based solution for efficient energy management by utilizing a microcontroller equipped with Wi-Fi connectivity that connects to the cloud for seamless remote access, monitoring, and control [2]. Users can easily operate the system through smart devices like smartphones and laptops, enabling real-time tracking of power consumption and energy management from anywhere. The system consists of two core components: the Smart Power Meter, which monitors low-load power consumption of connected appliances, analyzes real-time wattage data, and transmits it to the cloud for optimization, and the Hybrid Switching System, which employs relay-based switching to intelligently toggle between solar energy and the conventional grid. The system prioritizes solar power during high-demand periods to minimize grid dependency and automatically switches back to the grid when demand is lower or solar input is insufficient, ensuring continuous power efficiency. This smart energy management approach not only reduces electricity costs but also supports sustainable living by maximizing renewable energy usage. Its combination of automation, real-time monitoring, and cloud-based control offers a reliable and scalable solution for households, industries, and rural applications striving for cleaner and smarter energy consumption. Furthermore, the system is designed to be modular and expandable, allowing integration of additional renewable sources like wind or battery storage in the future. Data logging capabilities enable users to review historical energy trends and make informed decisions to further optimize usage. With rising global energy demands and increasing emphasis on sustainability, this solution aligns perfectly with modern energy goals, promoting both environmental responsibility and technological advancement in energy management systems. In addition, the proposed architecture incorporates a user-friendly interface, which displays live data such as voltage, current, power factor, and energy usage statistics. Notifications and alerts are generated when anomalies such as overconsumption or power outages are detected, helping users stay informed and take immediate corrective action. The system also employs secure data encryption protocols for cloud communication, ensuring that sensitive usage data remains private and protected. Integration with AI-based analytics is a future consideration to further enhance energy-saving recommendations based on behavioral patterns and seasonal variations. This combination of hardware and software components makes the system adaptable, secure, and intelligent, ready to address the growing energy management challenges of both urban and rural infrastructures. To enhance real-world applicability, the system is designed to support over-the-air (OTA) updates, allowing firmware upgrades without manual intervention. This ensures long-term maintainability and adaptation to evolving energy policies and technologies. Additionally, the system supports configurable load prioritization, where critical appliances (e.g., medical or refrigeration devices) can be prioritized for solar power usage, enhancing the system's utility in scenarios like rural clinics or Emergency situations. Edge computing capabilities are also introduced in the design, enabling local decision-making for faster response during network downtime. Through the use of low-power microcontrollers and efficient sensors, the system maintains minimal operational overhead, making it suitable for energy-constrained environments shown in Figure 1.

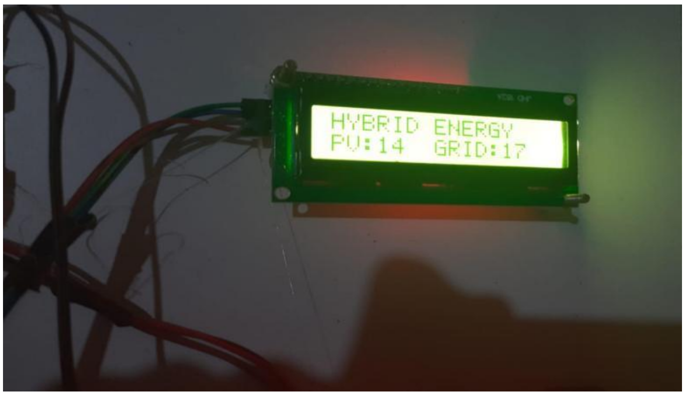

Figure 1 **Hybrid Power Indicator**

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By integrating technologies like MQTT for lightweight messaging, cloud dashboards such as Things Board or Blynk, and hardware components like ESP32/NodeMCU and current/voltage sensors (e.g., INA219, ACS712), the system ensures robust functionality and interoperability. It not only caters to energy-conscious consumers but also provides a foundation for smart grid integration and demand-side energy control strategies. Overall, the system exemplifies a forward-looking, practical, and technologically sound approach to modern energy management [3].

3. Implementation

The implementation of the Smart Hybrid Switch system involves both hardware and software components working seamlessly together to achieve automated, intelligent, and sustainable energy control. The hardware setup includes the Raspberry Pi Pico microcontroller, which serves as the central decision-making unit. This compact yet powerful board efficiently executes the embedded logic required for monitoring energy input/output and making real-time switching decisions. To enable wireless connectivity, a Wi-Fi module, such as the ESP8266 or ESP32, is integrated with the microcontroller, allowing the system to communicate with cloud platforms for data synchronization, monitoring, and remote control.A Smart Power Meter, typically based on sensors like INA219 or ACS712, is used to accurately measure real-time electrical parameters such as voltage, current, power factor, and total power consumption. This data is periodically transmitted to the microcontroller, which processes it to assess energy demands and available solar supply. Based on this assessment, a relay driver module (e.g., 2-channel or 4-channel relay board) is controlled to seamlessly switch the load between solar power and the conventional electrical grid. The switching is performed with minimal latency and without disrupting the operation of connected devices. The system's primary power source is a solar panel array connected to a charge controller and battery bank, providing stable and renewable energy. In cases where solar input is insufficient or unavailable, the system automatically reverts to grid power. An optional LCD or LED display (e.g., 16x2 LCD or OLED) is mounted to visually display key information such as current voltage, active power source, and energy usage, allowing real-time feedback to users even without internet access. On the software side, the microcontroller is programmed using MicroPython, Arduino C++, or other supported embedded languages, depending on system constraints and developer preference. This code includes core logic for sensor data acquisition, threshold-based decision making, and control signals for switching modules. Data integrity and fault tolerance are also programmed to handle edge cases such as fluctuating solar input or brief power outages. For cloud integration, platforms such as ThingsBoard, Firebase, or Blynk are utilized. These platforms serve multiple roles: data logging, visualization dashboards, remote control interfaces, and alert systems. Users can interact with the system via mobile or web applications, receiving real-time updates and even configuring switching thresholds or priority loads from a graphical interface. Communication between the embedded system and the cloud is handled using lightweight protocols such as MQTT or HTTP REST APIs, ensuring low-latency, secure, and efficient transmission of data. The MQTT broker (like Mosquitto or Adafruit IO) manages message routing between the hardware and cloud dashboards, while authentication and encryption (TLS/SSL) ensure data security. In future expansions, the architecture supports modular sensor integration (e.g., weather sensors, wind energy input, or ambient light sensors) and advanced energy analytics using AI or machine learning models. This would allow the system to not only react but also predict energy demands and optimize switching proactively. Furthermore, the system can be scaled to support multi-node energy environments, such as microgrids in residential societies or smart campuses, by implementing node-to-node communication using protocols like LoRa or Zigbee [5]. This thoughtful integration of compact hardware, flexible software, and robust communication enables the Smart Hybrid Switch system to deliver a cost-effective, intelligent, and future-ready energy management solution ideal

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for households, institutions, and energy-conscious infrastructures. The system is designed with fault tolerance and reliability in mind. By continuously monitoring voltage levels, load conditions, and energy availability, the controller ensures smooth transitions between power sources without interrupting the supply. Protective mechanisms such as overload detection and voltage regulation further enhance system safety and longevity. The user-friendly interface combined with automated decision-making reduces human intervention, making the system efficient and easy to operate. This approach not only improves energy utilization but also contributes to sustainable power management by maximizing the use of renewable energy sources while maintaining system stability [4].

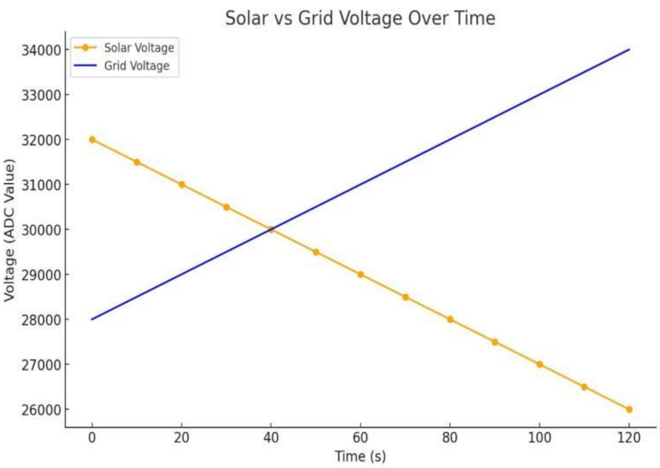

Figure 2. Solar vs Grid

The graph illustrates the variation of solar and grid voltages over time, where the solar voltage gradually decreases while the grid voltage steadily increases. Initially, the solar voltage is higher than the grid voltage, but they intersect at around 40 seconds, indicating a point of equal voltage. Beyond this point, the grid voltage surpasses the solar voltage, suggesting a shift in power dominance. This trend may represent a scenario in a smart hybrid energy system where solar power weakens over time—possibly due to reduced sunlight—prompting the system to transition to grid power to maintain a stable energy supply.

4. Conclusion And Future Works

4.1.Conclusion

The proposed IoT-based Smart Hybrid Switch effectively integrates solar energy with the conventional power grid, offering an optimized and intelligent approach to energy management. Leveraging an embedded microcontroller with cloud connectivity, the system provides real-time monitoring, seamless automatic switching, and remote control of energy sources. Testing has demonstrated high accuracy in power monitoring, rapid switching responses, and significant reductions in grid energy consumption. The system ensures a continuous and reliable power supply by prioritizing solar input and intelligently falling back to grid power when necessary. Its efficient design, based on cost-effective components and scalable architecture, makes it an ideal choice for energy-conscious consumers, especially in areas where grid reliability or solar availability fluctuates.Moreover, the system promotes sustainable living by maximizing the use of renewable energy sources and minimizing dependency on fossil fuels. By combining IoT technology, embedded systems, and renewable energy integration, it reflects a step toward smart home and smart grid solutions, bridging the gap between traditional energy infrastructure and future-ready intelligent energy ecosystems. The modular design supports easy deployment in various scenarios including residential homes, educational institutions, healthcare centers, commercial buildings, and rural electrification projects. It aligns well with current global energy policies focused on sustainability, carbon footprint reduction, and decentralized energy systems. Overall, the solution provides a reliable, robust, and environmentally conscious energy management system that meets the needs of modern power usage patterns.

4.2.Future Work

Future development of the system will focus on enhancing its intelligence, efficiency, and reliability. Implementing AI-based predictive analytics and machine learning algorithms will allow the system to proactively forecast energy demand, solar generation potential based on weather data, and user consumption patterns. This will lead to more dynamic and optimized switching decisions, improving system performance during peak load and variable solar conditions shown in Table 1.

Table 1 **Comparison Table**

Metric	Proposed System	IEEE Study A	IEEE Study B
Switching Time	< S	Not reported	21.6-40 ms
Power Monitoring Accuracy	0.5-1%	Voltage MAPE 2.96- 3.58%; Load current...	Voltage sensor error 0-1.187%
Remote Monitoring	Yes (Wi-Fi/LoRa, Cloud + App)	Yes (IoT app + real- time monitoring)	Yes (ESP32 + Real- time)
Automatic Switching	Voltage/load-based, solar prioritized	Based on accumulator voltage thresholds	Voltage-based logic, faster than manual
Scalability	Modular; upgradable with storage/AI	Designed for hybrid power plants	Domestic/home hybrid systems

Another vital enhancement involves the integration of battery storage systems, which will allow for efficient utilization of excess solar energy by storing it for nighttime use or during cloudy weather, ensuring a consistent and uninterrupted power supply. Additionally, a bidirectional power flow feature will be explored, enabling the system to feed excess solar power back into the grid, supporting net metering and allowing users to earn credits or monetary incentives, thus making the system even more economically viable.To increase system resilience, advanced cybersecurity protocols such as token-based authentication, data encryption, and secure firmware updates will be implemented to protect the system from potential threats and unauthorized access. Moreover, edge computing capabilities can be introduced to reduce reliance on constant cloud connectivity by enabling local decision-making and offline functionality during network outages.The mobile and web interfaces will also see improvements, including enhanced data visualization, automated alerts, custom switching rules, and voice assistant integration for a smarter and more interactive user experience. Additionally, API-based integration with home automation platforms like Google Home, Alexa, or OpenHAB will allow seamless interaction with other smart devices, creating a fully connected smart energy environment.

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