



Smart Energy Optimization System

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ABSTRACT

The Smart Energy Optimization System (SEOS) is an intelligent and advanced form of an automatic transfer switch. Its primary function is to ensure seamless transfer of load from one power supply source to the other. The SEOS is a combination of four modules viz; Intercommunication module, Interoperability module, Inverter Module and Charge controller module. These modules work concurrently to ensure to a high degree that energy being used is supplied from the most efficient sources. This study is aimed at designing and constructing a smart energy optimization system that optimizes the use of solar, grid, and diesel energy sources to meet load demands for domestic and industrial usage. Microcontrollers such as the ESP32, ATMEGA328, and EGS002 performed complex logical roles in the system alongside other components such as transformers, regulators, relays and sensors. The system was built in a modular design and tested in varying conditions. The smart energy optimization system is resilient, and demonstration showed that it efficiently alternated the power sources based on complex logical decisions encoded on the ESP32 microcontroller of interoperability module. The SEOS, via its intercommunication module communicates a cloud based IoT platform (Blynk) to facilitate its remote control by users. It is a feasible and effective way to save energy.

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INTRODUCTION

The global energy landscape is undergoing a transformative shift, driven by increasing demands for sustainability, cost-efficiency, and reliability. This transition is particularly significant in developing countries like Nigeria, where energy challenges are pervasive. Nigeria's energy sector is characterized by frequent power outages, high reliance on diesel generators, and underutilized renewable resources such as solar power. In Kwara State, the situation mirrors national trends, with institutions and industries grappling with unreliable grid power and escalating energy costs [1].

The energy sector in Nigeria predominantly relies on a mix of grid power, diesel generators, and, to a lesser extent, renewable sources. The national grid suffers from instability and frequent outages, which drive many

businesses and institutions to depend on diesel generators [2]. While diesel generators provide a temporary solution, they are costly and environmentally harmful due to their high fuel consumption and emissions [3]. Conversely, solar energy, despite Nigeria's significant solar potential, remains underutilized due to high initial costs and a lack of efficient integration systems [4].

The focus on enhancing energy efficiency and transitioning to renewable sources is essential for achieving sustainable energy systems, combating climate change, and ensuring energy security. Studies also highlight the correlation between increased energy efficiency and reduced environmental impact, emphasizing the importance of optimizing efficiency to minimize energy requirements and environmental effects,

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ultimately contributing to sustainable development and human well-being.

The central problem addressed by this research is the inefficiency and high cost associated with energy management in domestic and industrial environments. Despite the availability of various energy sources, including solar, grid power, and diesel generators, the current energy management practices are inadequate in meeting the demand for reliable and cost-effective energy. The grid power is unreliable, diesel generators are expensive and environmentally harmful, and solar energy is underutilized due to the lack of efficient integration systems. While there are various studies on energy efficiency and management, most are limited to theoretical models or specific applications without addressing the practical challenges faced by Nigerian institutions [4]. This research aims to bridge this gap by developing a practical, real-time energy management system using ESP32 technology in a modular design comprising of the Intercommunication module, Interoperability module, Inverter Module and Charge controller module, which can optimize the use of solar, grid, and diesel energy sources based on cost, availability and energy needs.

LITERATURE REVIEW

In recent years, the need for sustainable and cost-effective energy solutions has become increasingly urgent, particularly in developing countries like Nigeria, where energy demand often outstrips supply. Smart Energy Optimization Systems (SEOS) have emerged as a key solution to this challenge, offering the ability to optimize the use of multiple energy sources to meet load demand efficiently. In a study by [8], the integration of solar energy with conventional energy sources was found to significantly reduce energy costs and increase the reliability of power supply in industrial applications.

This finding was supported by [6], who highlight the potential of SEOS to improve energy efficiency in educational institutions, where energy demand is high and continuous power supply is essential for academic activities. Despite the clear benefits of SEOS, their adoption in Nigeria has

been slow due to several challenges, including the high initial cost of implementation and the lack of technical expertise. As noted by [5], the successful deployment of SEOS in Nigeria requires not only financial investment, but also capacity building to ensure that the necessary skills and knowledge are available to design, implement, and maintain these systems. Nonetheless, with the increasing availability of affordable technology and growing awareness of the benefits of energy efficiency, SEOS is expected to play an increasingly important role in Nigeria's energy landscape in the coming years.

[7], developed a smart grid-based energy management system that integrates renewable sources with grid power; utilizing real-time data for energy distribution optimization. Their approach resulted in improved energy efficiency and cost savings, though it was limited by the reliance on advanced grid infrastructure, which may not be available in less developed regions.

[9], developed a multi-energy system for commercial buildings, incorporating solar panels, battery storage, and grid power. Their system aimed to dynamically balance energy supply and demand, improving efficiency and reducing costs. However, the high investment required for storage technology limited accessibility for smaller entities. [10], proposed a framework integrating multiple renewable energy sources with grid power using a fuzzy logic controller. Their system improved energy management and cost savings, but faced challenges due to the complexity of fuzzy logic parameters and the need for extensive tuning.

[11], focused on a multi-energy source management system for industrial applications, combining solar, wind, and diesel generators. Their optimization algorithm effectively minimized costs and emissions, but the system's reliance on advanced optimization techniques limited practical implementation. [12], developed a hybrid energy system for urban areas, integrating solar, wind, and grid power. They used machine learning algorithms for demand prediction and energy optimization, showing improvements in efficiency and cost savings. However, the accuracy of

machine learning models was a challenge that affected system performance.

[13], examined a smart energy management system for rural communities, incorporating solar and diesel generators. Their system provided reliable power in areas with limited grid access, though high costs and maintenance requirements were significant limitations. [14], proposed an energy management system for commercial applications using real-time data to control solar and grid power. They achieved cost savings and improved reliability but faced challenges related to the need for advanced sensors and communication infrastructure.

[15], explored a hybrid system combining solar, wind, and battery storage for residential energy management. Their system demonstrated improvements in efficiency and cost reduction, but high battery storage costs and weather dependency were noted as limitations.

[16], investigated a multi-energy source system for electric vehicles, integrating solar and grid power with optimization algorithms for energy usage. Although, the system showed potential for cost savings and efficiency, its application was limited to specific use cases.

[17], focused on a smart energy management system for educational institutions, integrating solar, grid, and battery storage. Their approach improved energy efficiency and cost management, but was hindered by high implementation costs and system complexity.

[18], developed a multi-energy source management system for healthcare facilities, combining solar, wind, and diesel power. Their system improved reliability and cost savings, but faced challenges related to integrating diverse energy sources and infrastructure requirements.

[19], examined a hybrid energy system for data centers, integrating solar and grid power. Their focus on optimizing energy usage and reducing costs showed effective performance, but the need for sophisticated control systems and data analytics limited broader applicability.

[20], investigated a smart energy management system for residential buildings, integrating solar, grid, and battery storage. The system achieved cost savings and enhanced reliability, but high

battery storage costs and system complexity were significant drawbacks.

These studies collectively illustrate the advancements in multi-energy source management and highlight various approaches to optimizing energy use. Despite significant achievements, common limitations include high initial costs, complexity, dependence on advanced infrastructure, and weather forecasting challenges. Addressing these limitations remains a critical area for future research.

MATERIALS AND METHOD

Smart Energy Optimization system has been designed based on the idea of solving the repetitive task of alternating between energy sources. In a bid to achieve a safe, logical and seamless transition between sources, the existing solutions were studied and deficiencies were noted. The block diagram (Fig.1) was then established for the work. The circuit was then designed and simulated.

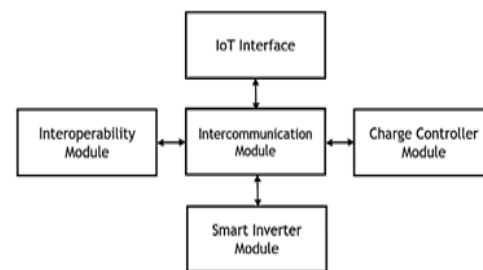


Fig.1: Block diagram of the Smart Energy Optimization System

Intercommunication Module

The Intercommunication Module shown in Fig. 2 is the communication routing module of the system. It manages the data exchange within and outside of the system. The intercommunication module embodies an ESP32 microcontroller unit in which its communication logic is encoded. This module is powered from a power bank module, which delivers 5V to the MCU and 6V to the LCD and which is connected to the MCU by an I2C connector board. This system utilizes a universal asynchronous receiver-transmitter (UART) to send and receive

information signal from other modules such as the interoperability module

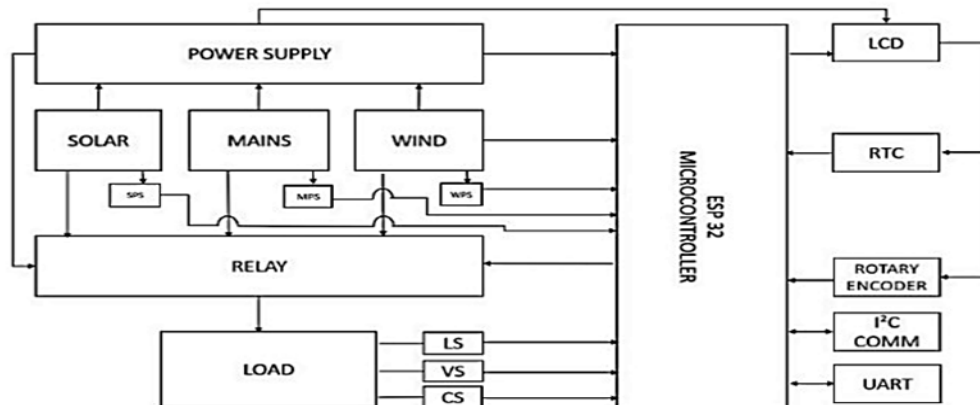


Fig 2: Block diagram of the Intercommunication module

The intercommunication module serves as the communication corridor of the SEOS; hence it holds more communication port than other modules as can be seen in Fig 3. The logical

operation is performed by ESP32 microcontroller, which doubles as a WIFI module for internet connectivity.

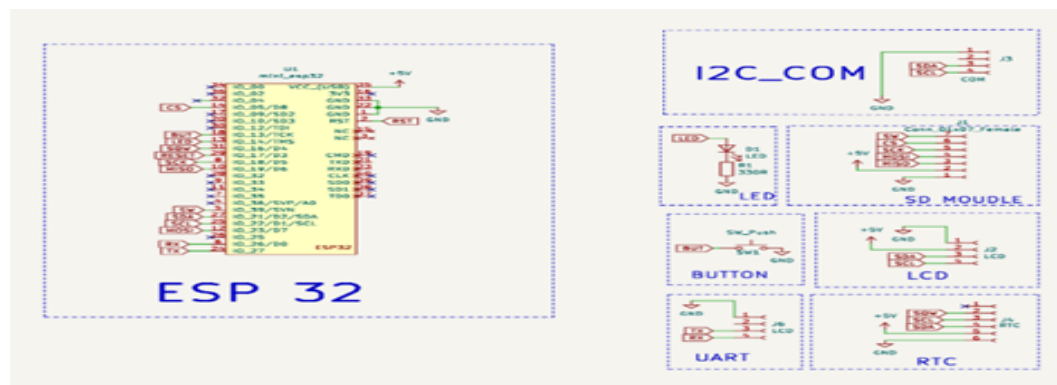


Fig 3: Circuit Diagram of the Intercommunication Module

INTEROPERABILITY MODULE

This serves as the main processing module of the smart energy optimization system. The interoperability module directly interfaces between the mains supply and the load. As shown in Fig 4, this module manages the various power supply sources (solar, grid and wind power supply).

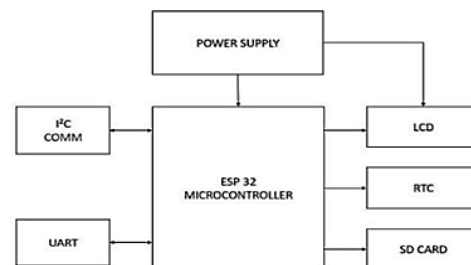


Fig 4: Block diagram of the Interoperability module.

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The interoperability module performs the SEOS core function which is power alternation. As shown in Fig 5, this module is fitted with majorly power conversion components such as the step-down transformer, relays, current sensors and input terminals.

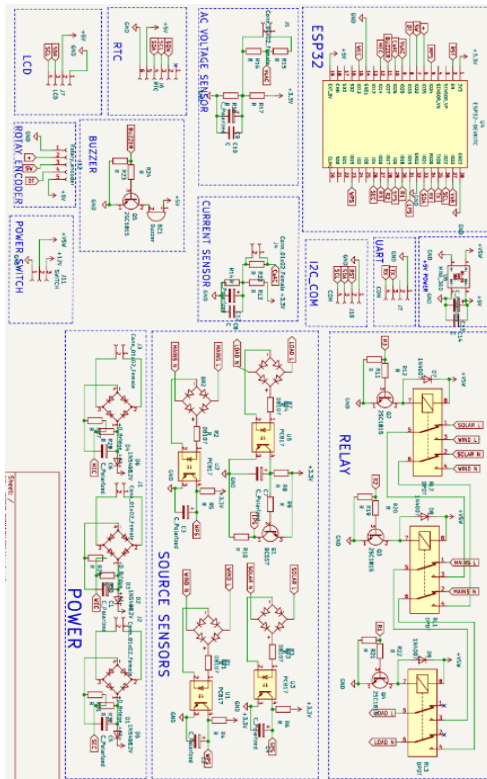


Fig. 5: Circuit Diagram of the Interoperability Module

Charge Controller Module

The charge controller module shown in Fig. 6, utilizes a MPPT (Maximum Power Point Tracking) solar charge controller, which tracks the peak output of the photovoltaic (PV) modules. The purpose of this type of charge controller is to maximize the power output from the cell and guarantees that batteries are charged to their fullest potential. By utilizing MPPT, the system will start functioning at maximum power point and produce its maximum power production by sensing the maximum radiation from the sun that falls into the PV modules.

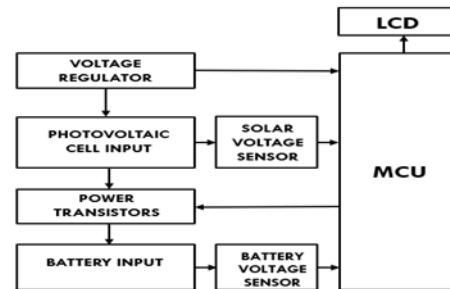


Fig 6: Block diagram of the charge controller module

The charge controller module monitors the charging and discharging capacity of the backup batteries for the renewable energy source. It also functions as a means of getting data on the battery such as battery level and solar panel output voltage. As shown in Fig 7, the charge controller module performs some level of power management with the aid of its MOSFET bank and the ATMEGA328p microchip

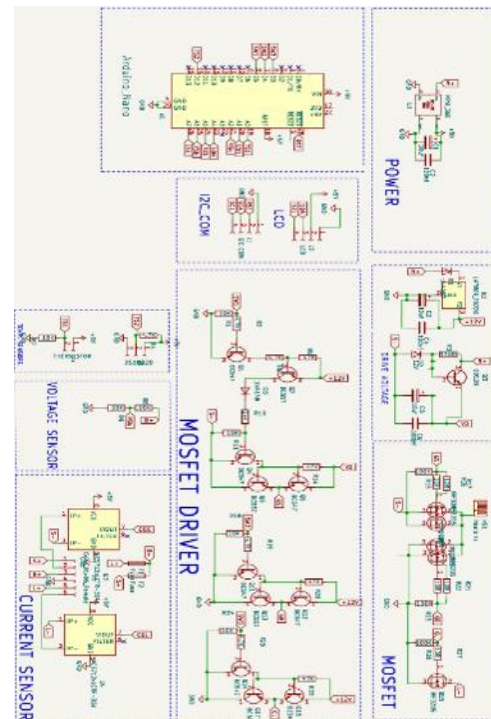


Fig 7: Circuit Diagram of the Charge Controller Module.

Smart Inverter Module

This module primarily performs the task of converting the DC supply from the batteries to AC output to power the loads. The smart inverter module shown in Fig 8, is directly applicable to the renewable energy sources (Solar and Wind power supply). The alternation of the supplied DC voltage is performed by H-bridge connected MOSFETs. The frequency of this alternation is determined by the EGS002 sign wave generator

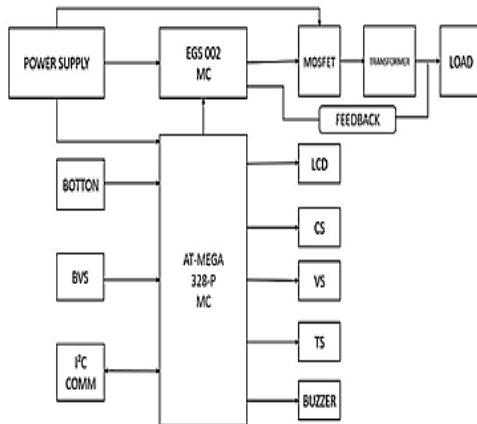


Fig 8: Block Diagram of Smart Inverter module.

The smart inverter circuit as shown in Fig 9, is governed by two microcontrollers, the EG002 and the ATMEGA328P. The EGS002 performs a single function of generating pure sine wave by sending timed switching signals to the H-bridge connected MOSFET bank. The ATMEGA328P performs multifunction of power, the indicators of the module, reading sensor inputs, signaling the EGS002 to start and end operation, writing the LCD through the I2C terminal chip and communicating other modules of the SEOS. The inverter is built to manage input voltage which it inverts to AC output hence it encompasses other components such as voltage sensor and current sensors.

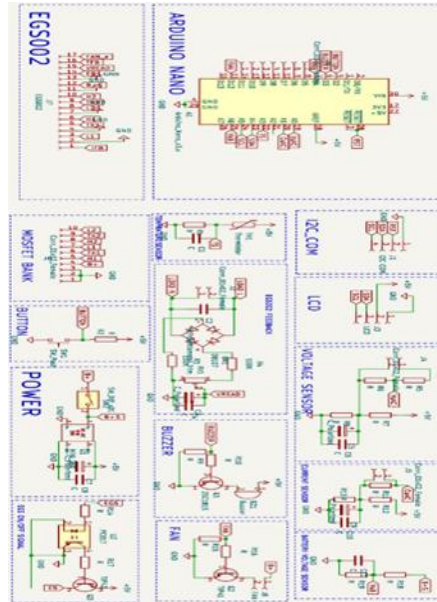


Fig 9: Circuit Diagram of the Smart Inverter Module.

Internet Of Things (IoT) Interface

This work integrated the hardware control with the Blynk IoT platform. Blynk is a versatile IoT platform designed to simplify the development and management of connected devices. Like most IoT platform, Blynk coordinates data transmission between mobile control and the other hardware device in a simple pattern as illustrated in Fig. 10. Blynk supports a wide range of hardware. For the purpose of this research, the ESP32 was integrated on the platform.

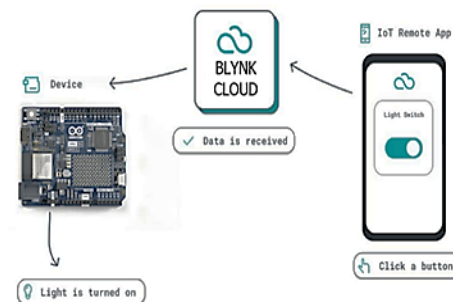


Fig. 10: Illustration of Hardware and Cloud Based Remote Control via Blynk Cloud.

The transmission of data to the cloud interface is made possible by the internet connectivity of the ESP32 microcontroller. The required data is sent, and the appropriate response is received from the cloud database via API (Application Programming Interface) calls. These calls are triggered by certain looped program running on the ESP32 microcontroller. Fig 11 shows the monitoring interfaces of the SEOS, where Fig 11A is the Blynk central dashboard with buttons that open another interface for the interoperability module, solar charge controller module and the smart inverter module. Fig 11B is the control interface for the interoperability module. It displays the status of the module including the active power supply source, system up-time, load connected and other parameters. Fig 11C shows the smart inverter dashboard. The smart inverter dashboard displays the current status of the system, up-time, load output readings and other parameters.

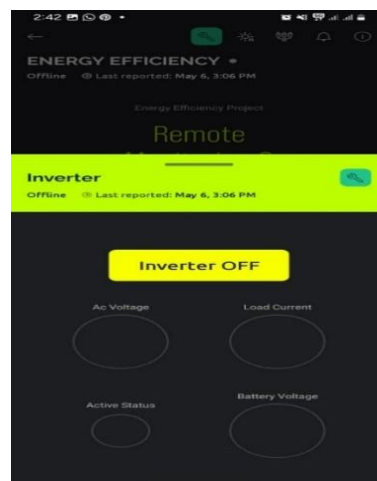


Fig 11C

CONSTRUCTION

After simulation of the designed work, it was followed by construction to ascertain the real-life performance of the system Fig. 12a-d show the pictorial views of the constructed work.



Fig 11A

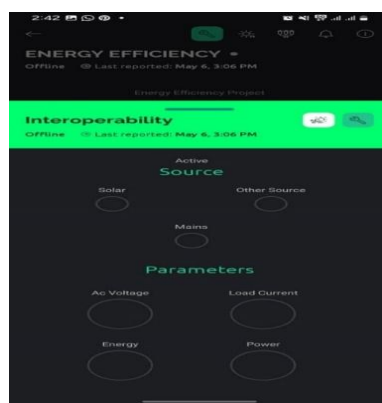


Fig 11B



Interoperability Module



Intercommunication Module

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Smart Inverter Module

TEST, RESULT AND DISCUSSION.

Testing is a critical phase in the development of the Smart Energy Optimization System (SEOS) for domestic applications. It involves evaluating the functionality, reliability, and performance of the SEOS prototype in simulated domestic settings. Here, we discuss the testing procedures and the results obtained during the testing phase.

TESTING PROCEDURES

The following procedures were adopted in testing the capabilities of the SEOS.

1. Power alternation test: The SEOS was tested to ensure that it could effectively transit between one power source to another, when actively connected source has no supply and another source has power supply. Two supplies were powered with standard (240V) and low voltage (190V), simultaneously.
2. Energy Monitoring Testing: The current and voltage sensors in the SEOS (in the interoperability module) were tested to accurately measure energy consumption for each load. The system displayed real-time energy usage data on the user interface.
3. Temperature Sensor Testing: The temperature sensors (ds18b20) were tested for accuracy in measuring ambient temperature and light levels, respectively.
4. IoT Communication Testing: The SEOS was tested to ensure seamless communication with the IoT server hosted

at Blynk. Data was transmitted to the server, and remote-control commands from the server, were successfully executed.

5. User Interface Testing: The web-based user interface was tested for user-friendliness, responsiveness, and accuracy in displaying real-time data, and allowing users to control loads.
6. Alarm System Testing: The alarm system was tested for its effectiveness in alerting users of potential issues.

RESULTS

The following results were recorded from the test performed:

1. Load Control: Load control testing was successful, allowing users to remotely control the source of their power supply. The system connected load to the higher voltage (240V) in the case of simultaneous supply.
2. Energy Monitoring: The current and voltage sensors accurately measured energy consumption for each load, this is recorded on the SD card log and used to logically decide peak load hours.
3. Temperature sensor: The temperature sensor provided accurate readings, enabling the SEOS to make informed decisions about load control based on environmental conditions.
4. IoT Communication: IoT communication testing, demonstrated that the SEOS could establish and maintain a connection with the IoT server. Data transmission and remote-control commands were successful.
5. User Interface: The web-based user interface proved to be user-friendly and responsive. Users could access real-time data, set load schedules, and control appliances with ease.
6. Alarm System: The alarm system functioned as intended, alerting users with an audible alarm when pre-set energy consumption thresholds were exceeded,

and when the load was transferred to a new source.

Table1 summarizes the result of the test carried out on determining factor precedence for power alternation using Grid, Wind, and Solar power as the input power sources. The factors considered include:

1. Grid power availability,
2. Solar power availability,
3. Wind power availability,
4. Backup battery capacity,
5. Peak load period,
6. Off-peak periods,
7. Sun availability

8. Wind speed.

From the table, it can be deduced that;

(i) As long as there is a supply at the input, the load must be powered

1. (ii) The grid power supply is most suitable for peak periods
2. (iii) The solar power is the next supply of choice for peak period
3. (iv) The solar is suitable for off-peak period regardless of grid availability
4. (v) The wind and solar supply are alternated with respect to high sun availability or high wind speed

Table 1: Representation of Test Scenarios and the Logical Decisions of the Interoperability Module

S/N	Factors								Active Source	Reason
	A	B	C	D	E	F	G	H		
1	0	0	0	0	0	0	0	0	None	No power supply
2	1	1	1	1	1	0	1	1	Grid	Grid power most efficient for peak periods
3	0	1	1	1	1	0	1	0	Solar	Due to high sun availability solar power is next suitable for peak periods
4	0	1	1	1	1	0	0	1	Wind	Due to high wind speed, the wind power source is made active
5	1	1	1	1	0	1	1	1	Solar	Due to off peak period, the solar power is utilized to safe cost, while efficiently powering the load
6	1	1	1	0	0	1	0	0	Grid	Due to low wind speed and sun unavailability, the grid power is used even in off-peak periods
7	0	0	1	0	1	0	0	1	Wind	Wind power will be made available regardless of its weak output since no other alternative is available

CONCLUSION

The results of this study have shown that the smart energy optimization system is a feasible and effective way to save energy. The system is easy to use, and can be easily installed in homes and businesses. The system is also affordable thus, making it a good choice for people on a budget.

The system was able to reduce the power consumption of a typical household by up to 20%. This is a significant amount of savings, and it can have a positive impact on the environment and the economy. The system was able to control the loads in a way that maximized energy savings. This was done by using the sensors to measure the power consumption of the

loads, and by using the microcontroller to control the loads accordingly.

The system was able to communicate with the IoT server reliably and securely. This allowed the user to monitor the system data and control the system remotely. The user interface was easy to use and allowed the user to control the system easily. This made it a good choice for people who are not familiar with technology.

RECOMMENDATIONS

The current system design will require significant adjustment and tear-down of the interoperability module if two more power sources are to be connected to the Smart Energy Optimization System. It is therefore recommended that the interoperability module be further

subdivided into the power supply module and the interoperability module itself such that, further addition of power source input (e.g. household generators, biomass power supply, thermal power supply) will only require adjusting the power supply module, while the interoperability module remains functional, leading to minimal operational downtime of the system. Also, more functionalities of the system can be made available to be controlled via the IoT interface. This includes all the menu levels of the interoperability module that can be navigated using the rotary encoder.

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