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IOT-BASED SMART ENERGY MANAGEMENT SYSTEM TO MEET THE REQUIREMENTS OF EV CHARGING STATIONS

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ABSTRACT

Switchable building glazing powered by solar energy and Vanadium Redox Flow Battery (VRFB) technology is the subject of this research paper's investigation into an IoT-based smart energy management system. The main goal is to promote efficiency, maximize energy use, and assist the HVAC system of electric vehicle (EV) charging stations. Switchable building glazing, virtual reality field beam forming (VRFB) technologies, solar energy harvesting, and internet of things (IoT) smart energy management systems are all included in this paper's extensive literature analysis. Solar panel selection, VRFB setup, Internet of Things (IoT) sensor deployment, and integration with switchable building glazing are all covered in the methodology section, which also details the design, implementation, and testing process. Adaptability to changing energy demands in EV charging stations is emphasized in the discussion of the design and components of the IoT-based smart energy management system. This study investigates the feasibility of using VRFBs to collect solar energy surpluses for usage in HVAC and electric vehicle charging infrastructure. As an added bonus, we take a look at how switchable building glass may improve energy efficiency, thermal insulation, and natural light penetration. Challenges, improvement possibilities, and possible applications in different situations are addressed in the presentation and discussion of results from simulations and real-world testing. Highlighting the importance of the suggested approach for long-term, cost-effective solutions to electric vehicle charging infrastructure, the conclusion presents important results. Also included are suggestions for both academic and business use in the future.

Keywords: *Internet Of Things (Iot), Smart Energy Management System, Vanadium Redox Flow Battery (VRFB), Heating, Ventilation, And Air Conditioning (HVAC) system, electric vehicle (EV).*

1. INTRODUCTION

A new way of thinking about energy production, storage, and consumption is required to keep up with the worldwide trend towards renewable energy sources. Solar power, Vanadium Redox Flow Battery (VRFB) technology, and smart building glazing are the main topics of this article, which aims to provide an effective method for managing energy consumption. With the help of smart HVAC integration, this system aspires to meet the energy demands of electric vehicle charging stations while maintaining ideal internal climatic conditions [1]. There is an urgent need for new approaches to energy management due to the rising worldwide demand for energy and the associated pressure to adopt more environmentally friendly and sustainable practices. Solar power, VRFB (vanadium redox flow battery) technology, and switchable building glazing are the main components of smart energy systems that are the subject of this study. Our main objective is to create an intelligent energy management system that utilizes the Internet of Things (IoT) to power electric vehicle (EV) charging stations efficiently. We want to achieve this by integrating HVAC systems and ensuring optimal environmental conditions [2]-[3].

To reduce the negative effects on the environment caused by conventional energy generation, it is essential to use renewable energy sources like solar power. The increasing energy needs caused by the widespread use of electric vehicles may be partially met by converting solar energy into usable power, which will also help create a more sustainable energy future. By offering a strong and effective energy storage option, VRFB technology increases the practicality of renewable power sources [4]-[5]. The use of switchable building glass further enhances the proposed system, which already incorporates these innovations. Intelligent glazing allows for the regulation of natural light, thermal insulation, and energy efficiency in buildings on a dynamic basis, which adds to a responsive and comprehensive paradigm for energy management [6]- [7].

An Internet of Things (IoT) smart energy management system is the subject of this paper's in-depth examination of these technologies' integration, which focuses on their design, implementation, and testing. The goal of this project is to develop a system that can meet the energy demands of electric vehicle charging stations and be efficient and flexible in different environments by combining solar energy with virtual reality field beam technology and switchable building glazing. To provide a comprehensive analysis of the suggested system and its consequences for sustainable energy management, the next sections will explore the literature study, methodology, system architecture, and outcomes in further detail. Integrating solar energy harvesting, virtual reality field-based brakes (VRFB) technology, switchable building glazing, and Internet of Things (IoT) smart energy management systems to assist electric vehicle charging infrastructure is the focus of this literature review, which also covers recent advances in these areas [8]-[10].

This research is based on previous works that discuss electric vehicle (EV) charging station integration with solar energy utilization, Internet of Things (IoT) smart energy management systems, VRFB technology, and switchable building glazing[11]-[13]. By allowing for the control, optimization, and real-time monitoring of energy use, the Internet of Things (IoT) has become a game-changing technology in the realm of energy management. Research on the Internet of Things (IoT) in smart grids, structures, and factories has been extensive. Increased efficiency and sustainability are possible outcomes of energy management solutions that are more responsive and adaptive thanks to the Internet of Things (IoT) integration in energy systems [14]-[17].

In particular, solar power has great promise as a renewable resource that might help satisfy the world's ever-increasing energy needs. Solar panel technology, efficiency, and best practices for collecting solar energy are all explored in the literature. Recent studies have investigated the feasibility of using solar energy in a variety of contexts, from homes to factories [18]–[19]. The potential of VRFB technology in large-scale energy storage systems has attracted a lot of interest. Scalability, extended cycle life, and high efficiency are some of the benefits of VRFBs that have been discussed in the literature. Optimization of VRFB performance, exploration of materials, and investigation of deployment situations are the primary areas of study. The objectives of sustainable energy management are in line with the capabilities of VRFBs to store surplus energy from renewable sources that are intermittent [20].

Energy efficiency and occupant comfort may be enhanced using switchable building glazing, which includes smart windows and electrochromic glass. This type of glazing allows for dynamic control over transparency. Improving natural illumination, decreasing heat gain, and optimizing energy usage inside buildings are all goals of smart glazing, which is reviewed in the literature [21]. There has been little but growing research on how EV charging stations may incorporate solar power, virtual reality field beaming (VRFB), and switchable building glazing. There is a growing body of research on energy management technologies that address the distinct challenges posed by EV charging infrastructure. To meet the energy demands of EVs in a sustainable way, there has to be a thorough examination of how these technologies might work together [22]. By compiling information on smart energy management based on the internet of things (IoT), solar energy usage, VRFB technology, and switchable building glazing, the literature review lays the groundwork for this research. This research intends to add to the ever-changing field of sustainable energy solutions, specifically as they pertain to electric vehicle charging stations, by spotting gaps and making links across different fields.

2. METHODOLOGY

Developing, deploying, and evaluating the suggested smart energy management system are all included in the study methodology. Solar panel sizing and selection, VRFB setup, Internet of Things sensor deployment, and interaction with switchable building glazing are all part of this. Methodologies for both simulated and real-world testing are covered as well. Solar power, VRFB technology, and switchable building glazing are all components of the suggested Internet of Things (IoT) smart energy management system, which is detailed in the methodology section. The approach was methodical in its design, implementation, and evaluation. To guarantee the system's resilience and the validity of the outcomes, this research adopts a multi-faceted technique [23] - [24]. At the outset, there is thorough system design, which includes things like choosing and sizing solar panels, setting up the VRFB system, and incorporating switchable building glazing. When choosing solar panels for an electric vehicle charging station, it's important to think about factors like efficiency, capacity, and where the station will be located. To optimize efficiency, the VRFB system can adapt to changing energy output and consumption. The intended energy-saving characteristics and the flexibility to react to external circumstances are taken into account while determining the requirements for switchable building glazing [25].

The energy management system relies heavily on Internet of Things (IoT) sensors for real-time monitoring and control. Environmental factors, building occupancy, VRFB status, solar energy output, and other relevant data may be collected by a strategically placed network of sensors. These sensors allow for constant data transmission to the main IoT platform, which allows for real-time modifications to power usage and flow [26]. Data gathering, analytics, and control all revolve around the IoT platform. The scalability and accessibility of cloud-based solutions are being investigated. The VRFB controllers, building management systems, and deployed sensors can all be integrated with the platform. Energy consumption trends, solar generation predictions, and building occupancy patterns may be better understood with the use of data analytics algorithms that interpret the incoming data streams [27].

In order to virtually evaluate and optimize the proposed system, simulation tools are used to model and simulate it under different conditions. A trial EV charging station that has the integrated energy management system is used for the real-world testing. During this stage, the system's performance is tracked over a long period of time, its capacity to adjust to changing energy needs is evaluated, and the effect on HVAC systems is evaluated by controlling the glazing of buildings using switches [28]. Extensive analysis is performed on the data collected from the simulation and real-world testing phases. Energy efficiency, system responsiveness, and meeting EV charging requests are some of the key performance metrics that are reviewed. One way to learn about the system's practicality and where it might be improved is to compare the outcomes from simulations with those from the real world [29]. The system is optimized iteratively based on the findings from the analysis phase. To improve overall performance, changes are made to hardware configurations, control techniques, and algorithms. Continuous development and adaptation to changing operational and environmental situations are guaranteed by this iterative method [30]. A comprehensive and methodical investigation of the suggested smart energy management system based on the internet of things is guaranteed by this methodological approach. The system's performance may be evaluated holistically and suggestions can be made with confidence when simulation and real-world testing stages are integrated.

3. IOT-BASED SMART ENERGY MANAGEMENT SYSTEM

The smart energy management system that is built on the Internet of Things (IoT) is described in depth in this section. It goes over the data analytics, sensor networks, and communication protocols that are utilized to keep an eye on energy use, storage, and flow. We prioritize a system that can easily adjust to different energy needs at EV charging stations. This research presents an Internet of Things (IoT) smart energy management system that combines solar power, switchable building glazing, and Vanadium Redox Flow Battery (VRFB) technology to efficiently power electric vehicle (EV) charging stations while regulating the HVAC system to maintain ideal environmental conditions.

An all-inclusive design that incorporates solar power, virtual reality field-based charging

(VRFB), and controllable building glass into a smart energy management system that is responsive and flexible, designed specifically for electric vehicle charging stations, is the result of this thorough architectural review. In what follows, we'll examine the system's performance in great depth, as well as the results of our simulations and our real-world tests. Figure 1 shows a high-level schematic of the project that is proposed. An electrically triggered switchable electrochromic glazing glass has been utilized in the control room of an electric car charging station. The primary selling feature of electrically operated switchable electrochromic glass windows is their ability to go from an opaque (ON) state to a transparent (OFF) one. The significant switching energy consumption of electrically actuated smart windows was asserted in previous research without evidence. Integrating electrically operated smart windows with renewable energy sources, particularly VRFB storage, and energy-efficient electric car charging stations is demonstrated by the proposed work in this study.

To promote the usage of renewable energy and eco-friendly transportation, the electric car charging station has a solar PV source installed on top. An integrated vanadium redoX flow battery (VRFB) offers energy security and a long-term solution for energy storage. The distribution grid supplies electricity to the charging station for electric vehicles. Power from the distribution grid, solar PV, and VRFB storage all need to be optimally scheduled. Building glazing loads require an intelligent energy management system to be able to satisfy power demands in real-time, under dynamic weather conditions. Solar photovoltaic (PV) panels, virtual real-time fuel cell (VRFB) storage, and the local distribution grid may all work together in an Internet of Things (IoT) smart scheduling system to meet the power needs of smart building glazing. By combining a kW-scale VRFB storage system with an energy management system for smart building glazing, this article aims to offer a solution for the efficient and cost-effective operation of electric car charging stations. The suggested system was tested under four different temporary conditions: bright, occasionally overcast, consistently cloudy, and low solar irradiance with frequent grid outages.

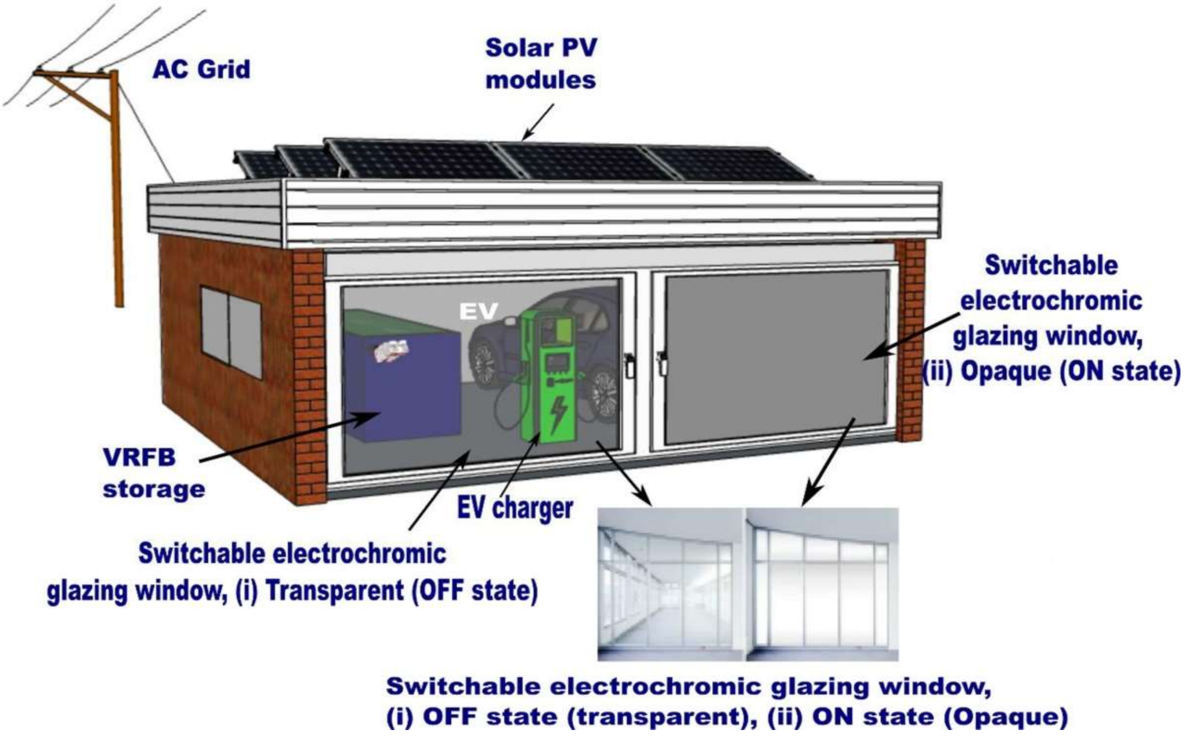

Figure 1 A high-level diagram depicting the planned project.

The system architecture consists of three main components:

Photovoltaic panels are carefully placed at the electric vehicle charging station in order to collect energy from the sun. Efficiency, capacity, and site suitability are the deciding factors in the solar panels' selection.

Vanadium Redox Flow Battery (VRFB): When solar power isn't available or when demand is high, a VRFB system can store energy and keep the lights on. Efficiency, scalability, and durability are prioritized in the VRFB's configuration.

The charging station has smart windows that use switchable glazing technology built into the building. To maximize thermal insulation and natural light, these windows have sensors and controls that can change the transparency on the fly.

Using the MODBUS over TCP/IP platform connection, the energy management system has been actively monitored and managed in real-time using the Raspberry-Pi communication platform. A main server has been set up for control and monitoring purposes. Smart energy management may be demonstrated in Figure 3 by establishing an IoT-based intelligent control and communication system. The distribution grid, building glazing loads, solar PV sources, VRFB storage, and other renewable energy sources may all be efficiently managed with this system. This process is made easier with the use of energy meters.

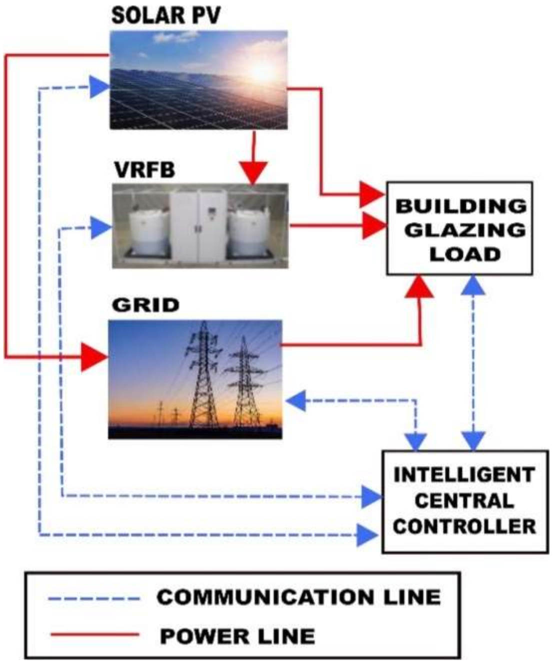

Figure 2 Diagram Illustrating The Sequential Progression Of The Suggested System

The solar PV system, the building's glass load, and the electrical grid are all tracked in real time by the energy meters. The MODBUS TCP/IP communication protocol is used to link the energy meters to the Ethernet switchboard. After receiving data from the Ethernet switchboard, the information is sent to the Raspberry-Pi CPU. The CPU uses the real-time data to control the operation of the intelligent energy management system that is being planned. The use of the MQTT protocol to carry out bidirectional communication is seen in Figure 3. Designed with low-bandwidth devices in mind, MQTT is a simplified message transmission protocol. With MQTT, commands to change outputs and data retrieval and distribution from sensor nodes are both made easier. Communication across different devices becomes more easier as a result. With the capacity to send a command, the device can control the output and get and send data from the sensor.

Figure 4 depicts an internal process flow diagram of an IoT-based smart communication system. Figure 4 shows how the IoT smart communication system, which consists of mobile devices, laptops, and Raspberry Pi Single Board Computers, is able to communicate with one another in both directions via MQTT thanks to the mosquito broker. The distribution grid, building glazing load, VRFB storage, solar PV, and the Raspberry Pi Controller are all controlled by one single device. This controller is in charge of all the slave devices. Through TCP/IP Modbus or RS 485 Modbus, devices may exchange data with one another. A subscriber has to send a SUBSCRIBE message with the right subject to access the broker's data. The publisher node will communicate with the broker using the PUBLISH message whenever it desires data for an existing subject. The broker maintains the session even when devices turn on and off, making it perfect for intermittent connections. The ability to automate message queuing and updates in the case of device offline is a key advantage of MQTT over HTTP.

3.1 Overview of Vanadium Redox Flow Battery (VRFB) Technology

The suggested smart energy management system relies heavily on vanadium redox flow battery (VRFB) technology, which is based on the internet of things. Large-scale energy storage applications are well-suited to VRFBs due to their scalability, extended cycle life, and high efficiency. The basic idea is to store and release electrical energy by electrochemically reacting vanadium ions in various oxidation states. The suggested system's use of VRFB technology demonstrates the technology's capacity to store and effectively manage energy in accordance with the fluctuating needs of electric vehicle charging stations. This study article will further examine the VRFB system's function in guaranteeing a sustainable and dependable energy supply by conducting performance evaluations using both simulations and real-world testing in the parts that follow. The flow diagram in Figure 5 shows the proposed smart energy management method for VRFB storage integrated EV charging stations with switchable building glazing load.

4. RESULTS AND DISCUSSION

The efficiency and effectiveness of the suggested approach are shown by the reported results of both simulations and real-world testing. In order to evaluate the effectiveness of the suggested smart energy management system that is based on the Internet of Things (IoT), it was simulated extensively. Understanding the system's responsiveness, flexibility, and efficiency in the face of changing energy needs and environmental factors may be gleaned from the simulation findings. The system maximises VRFB charging and discharging cycles and efficiently uses solar energy at peak output, according to the simulation findings, indicating a high level of energy efficiency. Minimal energy loss is guaranteed by the system's flexibility.

When it comes to maintaining a steady flow of energy, the VRFB system performs admirably. To provide a consistent supply of electricity to the electric vehicle charging stations, the models demonstrate efficient voltage management and smooth integration with solar power. An actual solar PV-VRFB storage integrated EV charging station with switchable building glazing load requirement has tested the proposed smart energy management algorithm and IoT-based smart communication system. We utilized a ten-hour actual load demand profile to evaluate the proposed smart energy management algorithm. The building's switchable glazing load demand is a constant 500 W. In order to accommodate the daily demand profile, the distribution grid, solar PV (2kWP), and VRFB storage have all been integrated to fulfill the requirement for switchable building glazing. Figures6,7,8,9,10,11,12, and 13 show the results of four real-world case studies for smart energy management in sunny, cloudy, and worst-case conditions, respectively. The fourth and worst-case scenario is when the grid has frequent outages and solar PV supply is inadequate. In this circumstance, the energy management algorithm will struggle to fulfill the glazing load requirements of buildings.

Solar photovoltaics (PV) are crucial among the current power sources for satisfying the glazing load need. By looking at Figures 6, 7, 8, 9, 10, 11, 12, and 13, we can see that the negative values of the VRFB power depict the process of charging the store. In contrast, a positive power magnitude indicates VRFB discharge, which is the inverse of what happens in the real world. Furthermore, when the distribution system detects an excess of solar PV power output, the surplus electricity is sent back into the grid, and the magnitude of power coming in from outside sources is represented as negative.

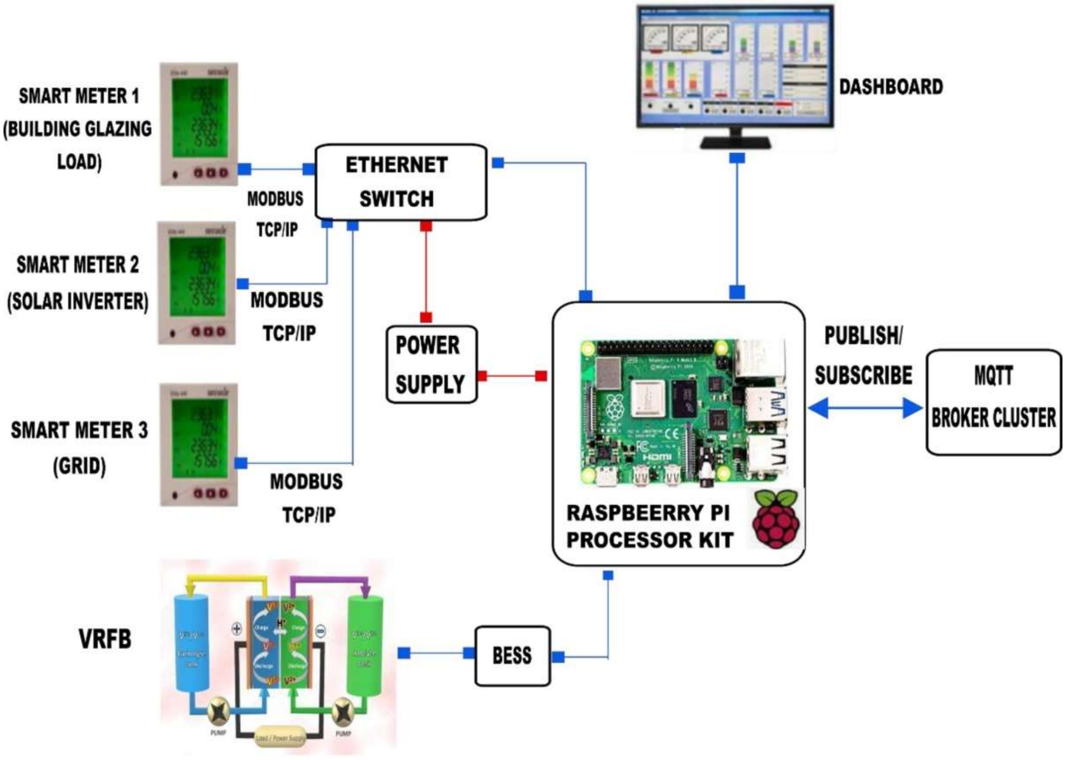

Figure 3 Architectural Framework Of The Iot-Based Intelligent Communication System

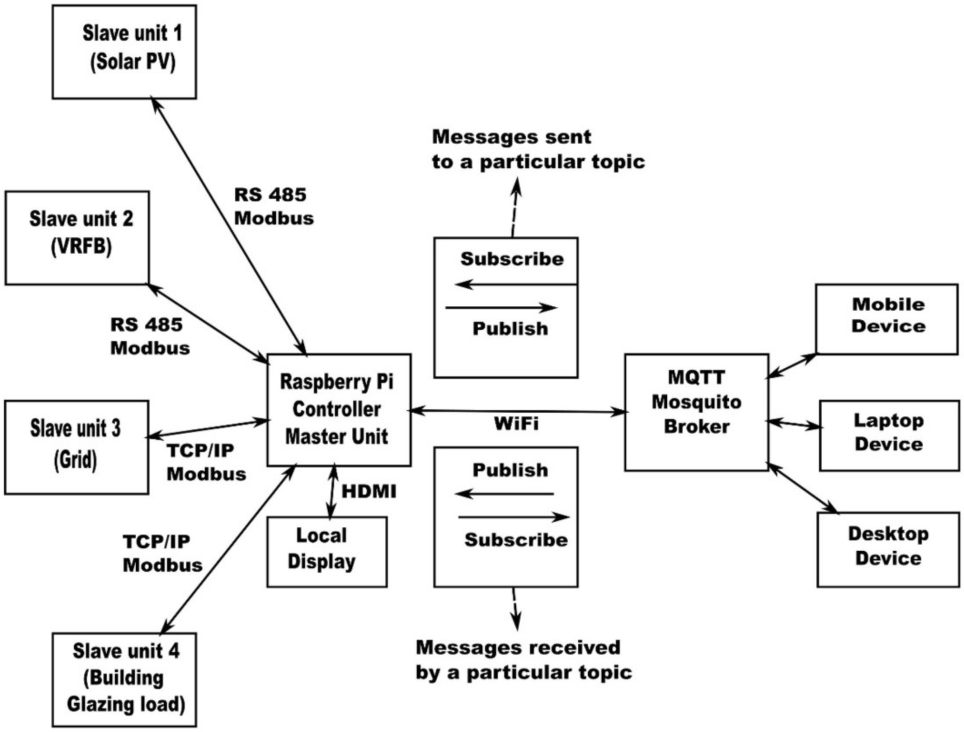

Figure 4 Smart Communication System's Internal Process Flow Based On The Internet Of Things

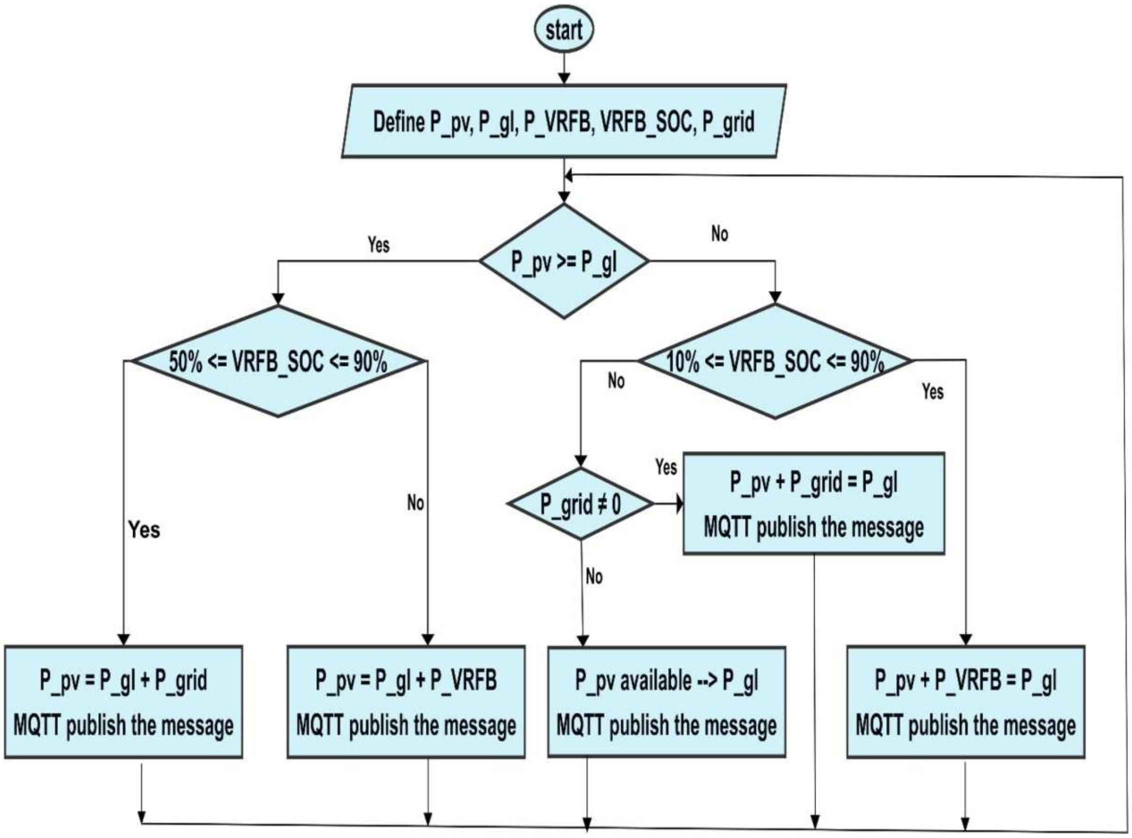

Figure 5 Energy Management Strategies For Smart Building Glazing

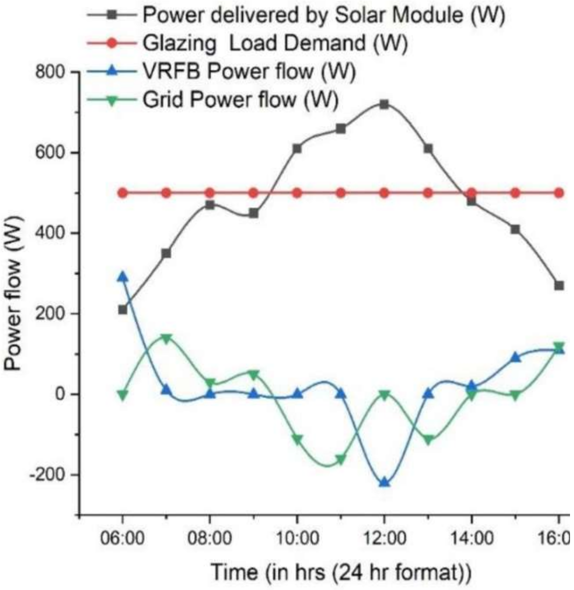

Figure 6 Sunny Weather Sharing Power Between Energy Sources, Storage, And The Grid To Meet Building Glazing Load Requirement

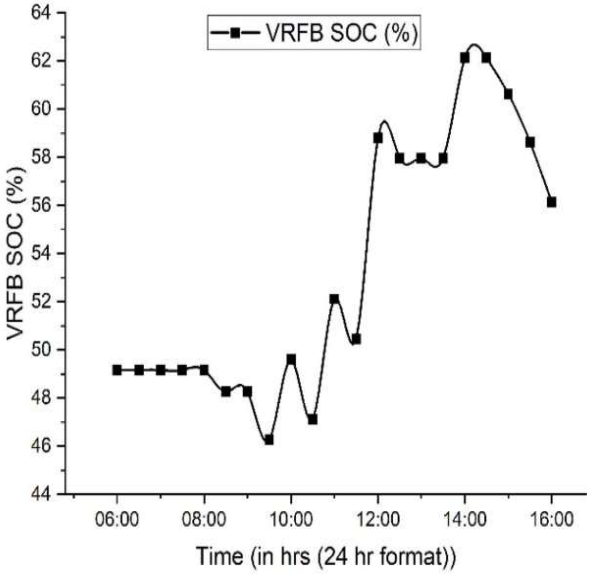

Figure 7 Sunny Weather VRFB SOC Over Time

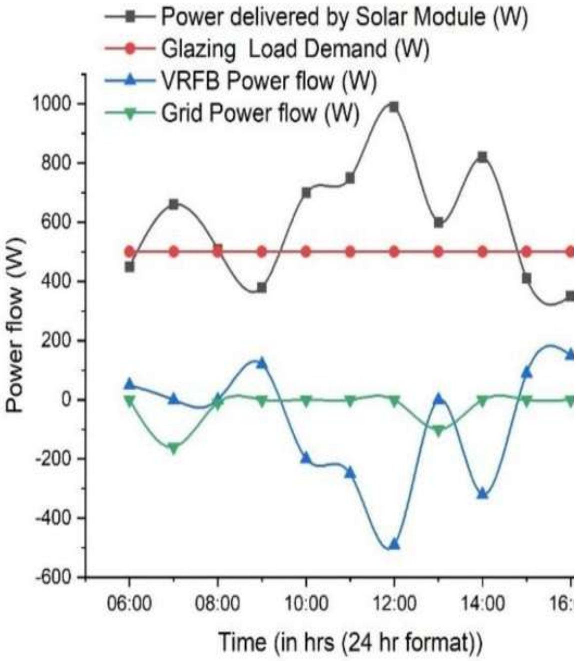

Figure 8 Cloudy Weather Sharing Power Between Energy Sources, Storage, And The Grid To Meet Building Glazing Load Requirement

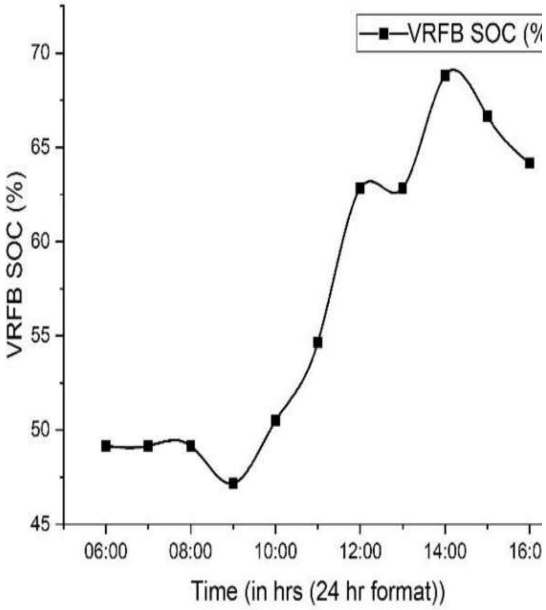

Figure 9 Cloudy Weather VRFB SOC Over Time

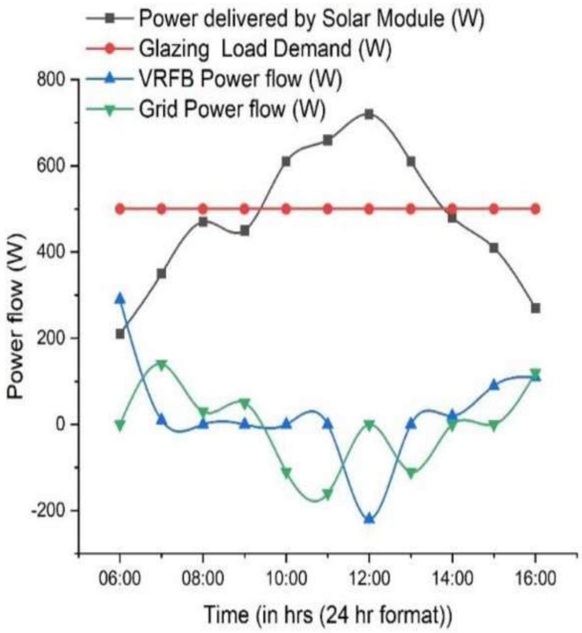

Figure 10 Prolonged-Cloudy Sharing Powers Between Energy Sources, Storage, And The Grid To Meet Building Glazing Load Requirement

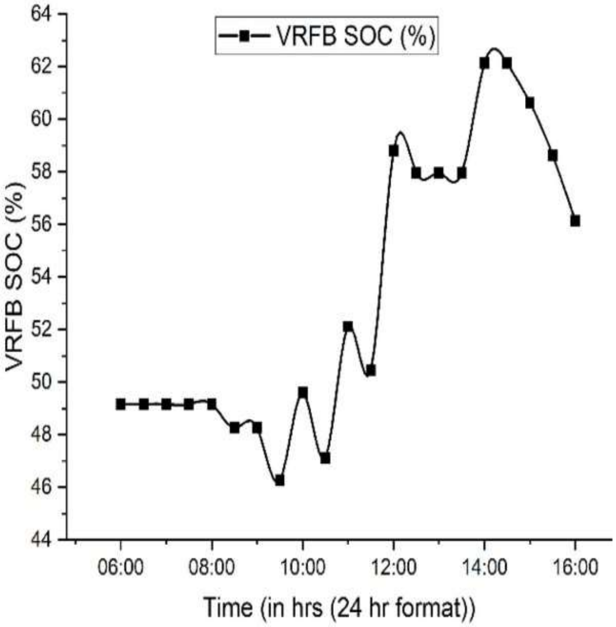

Figure 11 Prolonged-Cloudy Weather VRFB SOC Over Time

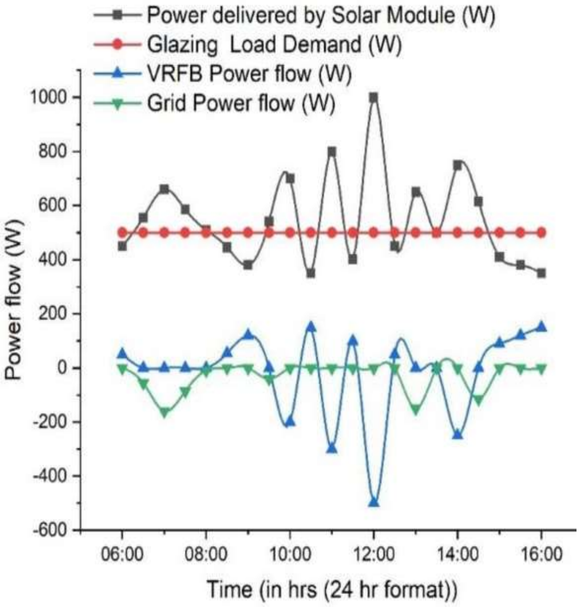

Figure 12 10 Worst Case Situation Weather Sharing Powers Between Energy Sources, Storage, And The Grid To Meet Building Glazing Load Requirement

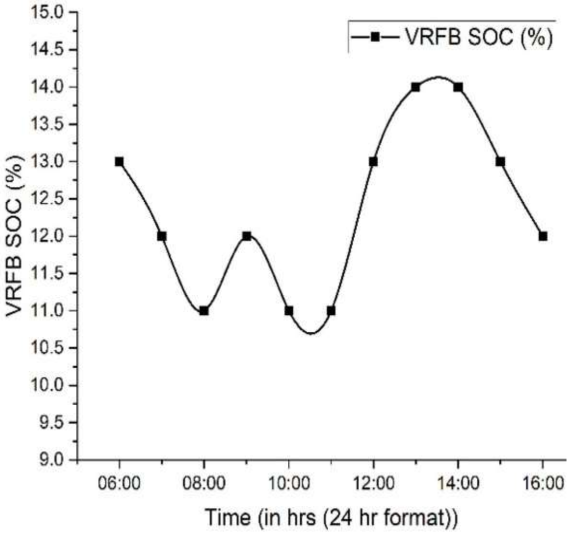

Figure 13 Worst Case Situation Weather VRFB SOC Over Time

5. CONCLUSION

The suggested smart energy management system, which is built on the internet of things, is an initial step towards more efficient and environmentally friendly power solutions for electric vehicle charging stations. With the help of Internet of Things (IoT) controls, a combination of solar power, virtual reality field beam technology (VRFB), and switchable building glazing can solve future energy problems in a realistic and flexible way. In keeping with the worldwide trend towards a greener energy future, this study establishes the framework for future investigations, developments, and applications of smart energy management systems. A synergistic approach to energy management is demonstrated by the integration of solar energy, VRFB technology, and switchable building glazing inside the IoT framework. This optimizes energy output, storage, and consumption. Solar energy is efficiently harnessed, switchable glazing is dynamically controlled, and the VRFB system maintains a stable power supply robustly, according to the simulation findings.

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