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IoT-Based Surveillance of Solar-Wind Hybrid Power Charging Systems

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Abstract: *To enhance the use of renewable energy sources for electric vehicle charging and auxiliary power applications, this research introduces an advanced hybrid charging system integrated with Internet of Things (IoT) capabilities. The system efficiently harnesses both solar and wind energy, making it a sustainable and high-performance solution. A key component is the battery storage unit, which ensures effective storage and utilization of renewable energy, minimizing dependence on fossil fuels and improving system reliability. When the vehicle is not connected, the inverter plays a vital role by converting direct current (DC) from renewable sources into alternating current (AC), reducing energy wastage and enabling surplus energy to power other electrical devices. The IoT-enabled real-time monitoring mechanism continuously tracks essential parameters such as energy production, consumption, and battery health. This allows for smart energy management, enabling the system to adapt its operation based on live data to maintain optimal efficiency and reduce energy losses.*

Keywords: Energy optimization, System performance, Sustainable infrastructure, Auxiliary power applications, Energy consumption

I. INTRODUCTION

The move to renewable energy sources has been fuelled by the global energy crisis and growing environmental concerns. Among the different alternatives, solar and wind energy have attracted substantial interest due to their abundance, sustainability, and low environmental impact. However, maintaining a steady and uninterrupted power supply is made more difficult by the intermittent and variable nature of these renewable energy sources. Hybrid energy systems that combine several renewable energy sources have become a viable way to overcome these constraints. By combining the benefits of wind and solar photovoltaic (PV) energy, a solar-wind hybrid charging system ensures increased energy efficiency and dependability [5]. These systems are especially helpful for off-grid power applications, micro grids, distant locations, and electric vehicle (EV) charging stations where reliable energy availability is essential. The usefulness and efficiency of hybrid renewable energy systems are further improved by the integration of Internet of Things (IoT) technologies. Real-time monitoring, data collection, and intelligent management of electricity generation, storage, and distribution are made possible by IoT. IoT-based systems combine wireless communication, cloud computing, and sensors to offer adaptive energy management, predictive maintenance, and remote access. These characteristics reduce operating expenses and downtime in addition to optimising energy use. In order to increase performance, researchers have recently investigated a number of IoT-enabled hybrid energy system elements, utilising machine learning algorithms and sophisticated data analytics. Several studies have examined hybrid renewable energy systems, IoT-based monitoring [1]. Proposed an IoT-enabled smart micro grid system that demonstrated improved reliability and real-time energy optimization [11].

Their research highlighted the benefits of predictive analytics in enhancing system performance [2]. Conducted a detailed study on a solar-wind hybrid system, emphasizing the role of Maximum Power Point Tracking (MPPT) algorithms in optimizing energy extraction under varying environmental conditions. Furthermore [3]. Explored an IoT-based remote monitoring framework for a hybrid energy system, showing how real-time data acquisition can significantly improve fault detection and maintenance efficiency. These studies underline the growing importance of integrating IoT with renewable energy systems to maximize their effectiveness. The inclusion of IoT technologies dramatically transforms how these systems function. By integrating intelligent sensors, automated devices, and cloud computing capabilities, IoT enables continuous, real-time tracking of both energy generation and usage. This constant data flow supports informed decision-making and allows operators to fine-tune system performance based on accurate, up-to-date information. Furthermore, IoT' predictive analytics can detect irregularities or inefficiencies early, allowing for timely maintenance and reducing the risk of unexpected breakdowns. These advantages not only ensure optimal system functionality but also help in minimizing long-term operational expenses [5, 6].

Industrial and urban areas seeking to incorporate renewable energy into their operations. By providing a dependable and environmentally conscious alternative for energy generation, these systems contribute meaningfully to reducing fossil fuel reliance and advancing global environmental goals. This report aims to underscore how the integration of IoT into renewable energy infrastructure can serve as a powerful tool in addressing global energy challenges. By offering a detailed analysis of the system's design, operation, and applications, the report will demonstrate how these innovations are helping to drive the worldwide shift toward clean, sustainable energy [10].

II. METHODOLOGY

An inventive renewable energy solution, the Internet of Things-enabled solar-wind hybrid charging system is made to provide effective and environmentally responsible electric vehicle (EV) charging, especially for two-wheelers. The system maximizes power generation in a variety of climatic situations by utilizing energy from both solar and wind sources. It includes a small wind turbine with a 12W rating as well as solar photovoltaic (PV) panels with ratings of 18.5V and 10W. A Maximum Power Point Tracking (MPPT) charge controller, which maximizes energy harvesting and controls the charging of a 12V, 9Ah lithium-ion battery, is connected to these sources. The battery serves as a primary energy store, powering an inverter, direct DC loads, and the EV charging connector. The inverter malfunctioned The ESP32 microprocessor, which has Bluetooth and Wi-Fi built in, is responsible for the system's intelligent administration. Through embedded sensors that detect temperature, voltage, and current throughout the system, it gathers data in real time.

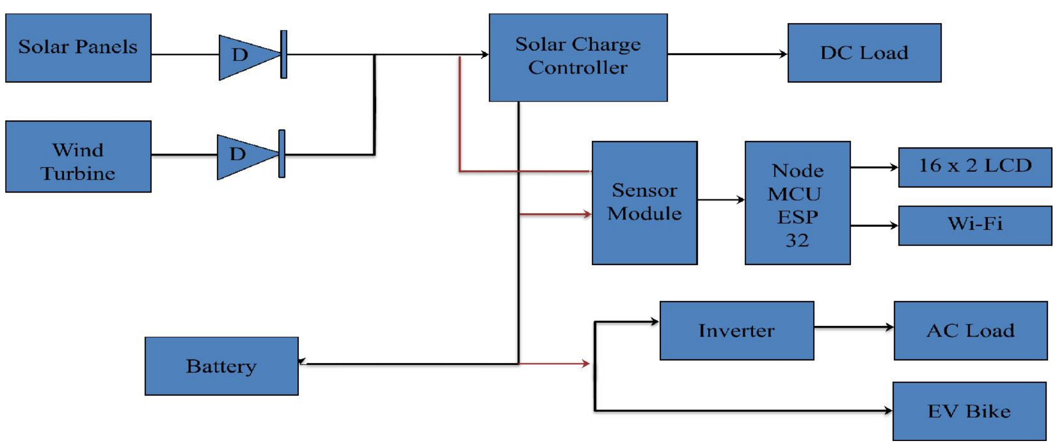

Figure no:1 Block Diagram of the system.

The microcontroller transmits the data to a cloud platform like Blynk for remote monitoring while simultaneously displaying the system's status locally on a 16x2 I2C LCD display. Through a smartphone or online dashboard, customers can monitor energy output, consumption, and battery health from any location thanks to this IoT connection. Additionally, the system facilitates automated notifications and decision-making, which improves dependability and energy efficiency. Through a variety of control modes that modify power flow in response to energy generation, battery state-of-charge (SOC), and EV charging demands, the entire design guarantees intelligent operation. The technology saves excess energy in the battery or redirects it to auxiliary loads when power generation surpasses demand. On the other hand, the battery makes up the difference when generation is low energy supply when combined with IoT intelligence. In the end, by providing scalable and intelligent energy infrastructure, this project helps to lessen reliance on fossil fuels, encourage sustainable transportation, and assist India's renewable energy objectives [5,6,7].

As shown in Fig. No. 1 The block diagram gives a thorough rundown of the Internet of Things (IoT)-enabled solar-wind hybrid charging system, which is intended to deliver an intelligent, sustainable, and continuous power source for ancillary loads and electric vehicle (EV) charging. Two main renewable energy sources—a wind turbine and solar panels—are at the centre of the system. To protect the sources and associated electronics, each source is wired in parallel and has diodes installed to stop reverse current flow. A solar charge controller, which serves as the system's energy regulator, receives these energy inputs. By controlling the input voltage and current, this controller makes sure the linked battery is charged effectively and avoids deep draining or overcharging, which can shorten battery life. Three main channels receive energy from the charge controller. DC loads, such as equipment or parts that use direct current, are directly powered by the first pathway. In order to store excess energy for use in times of low solar irradiation or insufficient wind flow, the battery is charged using the second pathway. Connecting a sensor module to the solar charge controller's output is the third and most clever feature of the system. The NodeMCU ESP32, a microcontroller with integrated Wi-Fi and Bluetooth, receives the data from this module, which gathers important characteristics like voltage, current, and temperature from different areas of the system. The IoT functionality of the system is controlled by the ESP32. The sensor module's data is processed, real-time system information is shown on a 16x2 LCD screen for local monitoring, and the data is concurrently sent over Wi-Fi to a cloud-based platform. Through a smartphone or online interface, users may now remotely monitor the system and get updates or warnings regarding performance parameters like battery level, solar/wind input, or fault circumstances. Additionally, the ESP32 increases system efficiency and user control by enabling data logging for maintenance planning and performance analysis. For traditional AC loads like fans, lights, and small appliances, the battery drives an inverter that transforms 12V DC into 230V AC. Additionally, the main usage of the system is to charge an EV bike using the AC output. In addition to enabling hybrid energy harvesting, this tiered architecture uses intelligent conversion and storage to guarantee power availability. All things considered, the combination of data sensing, smart charge control, renewable energy sources, and Internet of Things capabilities makes this system a very flexible and scalable paradigm for the distribution of clean energy.

2.1. MPPT (Maximum Power Point Tracking)

The voltage level within the system is determined using the Maximum Power Point Tracking (MPPT) method, which is essential for extracting the highest possible power from the solar panels under varying environmental conditions. The system incorporates an incremental conductance algorithm based on MPPT principles, allowing for dynamic adjustments to maintain maximum efficiency. Since the electrical load is inherently non- linear, it does not remain constant and is subject to frequent changes. This fluctuation necessitates the use of non-linear analysis to ensure the system operates smoothly and effectively under different loading conditions.

Things capabilities make this system a very flexible and scalable paradigm for the distribution of clean energy, particularly in semi-urban or off-grid settings where reliable grid power is not assured. MPPT serves as a buck-boost converter, interfacing between the photovoltaic (PV) panels and the wind turbine's control system. This converter can either increase or decrease the voltage level based on the current availability of energy in real time. When the input power from renewable sources is insufficient, the MPPT functions in boost mode to increase the voltage level and maintain a stable output. Conversely, when the voltage exceeds the desired range, it operates in buck mode to lower the voltage. After determining that sufficient energy is available, the system directs the power toward battery storage. The electric vehicle (EV) is charged according to the battery's storage capacity, ensuring that charging is both efficient and safe. During daylight hours, any surplus energy generated by the solar panels is stored in the battery for later use. This stored energy becomes particularly valuable during times when solar generation is low [9].

2.2 Charging Station Model

As shown in figure no. 2, Electric vehicles (EVs) can be efficiently charged using renewable energy (RE) sources such as solar and wind power, which provide clean, sustainable alternatives to conventional fossil-fuel-based electricity. By

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integrating a renewable energy system with an EV charging station, it becomes possible to supply electricity on demand while minimizing environmental impact. These charging setups are typically equipped with intelligent control systems that manage the generation, storage, and distribution of power. Simple control strategies, using extension cables and programmable controllers, can be effectively deployed to regulate the flow of energy from the natural sources to the EVs.

In a practical implementation, solar panels and wind turbines are installed—often on the rooftop of buildings to capture energy from the sun and wind. The generated electrical energy from both sources is then routed to a central power management system. At the heart of this system lies a charge controller based on the Maximum Power Point Tracking (MPPT) algorithm, which plays a vital role in optimizing the energy conversion process. The MPPT controller continuously monitors the input from both the photovoltaic (PV) array and the wind turbine to ensure that the system operates at its most efficient point, regardless of fluctuations in sunlight intensity or wind speed.

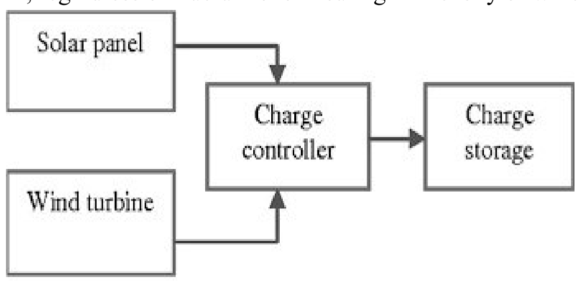

Figure no:2 Charging Station

Functioning as a buck-boost converter, the MPPT system can either increase (boost mode) or decrease (buck mode) the voltage depending on the current power availability and load requirements. When the input power is insufficient, the MPPT raises the voltage to maintain stable output for battery charging. On the other hand, if the voltage from the renewable sources exceeds the desired level, it reduces it accordingly. After determining that the available energy meets the required conditions, the system directs the electricity to the storage battery.

This stored energy can then be used to charge electric vehicles, ensuring a continuous power supply even during periods when solar or wind energy generation is low. Such hybrid renewable systems not only support efficient and eco-friendly transportation but also contribute to reducing the dependency on grid-based electricity and fossil fuels. These smart, self-sufficient charging stations represent a forward-looking solution for green mobility and sustainable urban development.

2.3 Wind Model

Figure no. 3 shows the wind turbine, this hybrid renewable energy system combines solar and wind power to generate electricity. A compact 12-watt wind turbine captures kinetic energy from wind, while solar panels rated at 18.5 volts and 10 watts generate power from sunlight. The system employs a Maximum Power Point Tracking (MPPT) charge controller with a capacity of 24 volts and 30 amps to optimize energy harvesting from both sources. The collected energy is then channeled into a lithium-ion battery rated at 12 volts and 9 amp-hours (AH), serving as the primary energy storage unit. The stored energy provides a continuous supply of power, enabling uninterrupted electric vehicle (EV) charging even during periods of low renewable energy generation. An inverter converts the 12V direct current (DC) stored in the battery into 230V alternating current (AC), powering household or commercial appliances like LED lighting and electric fans. This hybrid system promotes sustainable development and green mobility by reducing reliance on fossil fuels and grid electricity. By combining wind and solar power with smart IoT technology, it offers an eco-conscious, scalable, and energy-efficient alternative to traditional EV charging

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Figure no:3 Wind Turbine

2.4) Solar Model

The solar component of the IoT-enabled hybrid charging system is essential to maintaining sustainability and energy independence in addition to its fundamental functions. In order to effectively capture solar irradiance throughout the day, the solar panels are usually installed in an open space with maximum sun exposure. They work by directly converting sunlight into DC electricity, which is known as the photovoltaic effect. System reliability is increased by the diodes in the circuit acting as blocking devices, which stop the batteries from discharging back into the panels. One important contact between the battery and the solar panels is the solar charge controller. It allows for best power efficiency in addition to controlling voltage and current to avoid overcharging or deep draining of the battery.

Figure no: 4 Solar PV Panel Setup

As shown in fig no 4, When Panels installed on rooftops, PV arrays are typically positioned parallel to the roof's surface, elevated a few inches above it. This slight elevation is essential as it facilitates airflow beneath the panels, helping to cool them and maintain their efficiency. Adequate ventilation reduces the risk of overheating, which can otherwise degrade panel performance over time. In addition, the mounting structures are designed to ensure proper tilt angles and orientation, optimizing the amount of solar energy captured. Ground-mounted systems are often used in areas with larger open spaces and allow for easier maintenance and potential expansion. Overall, the flexibility in installation options makes PV technology adaptable for a wide range of architectural and environmental conditions as shown in figure no. 5.

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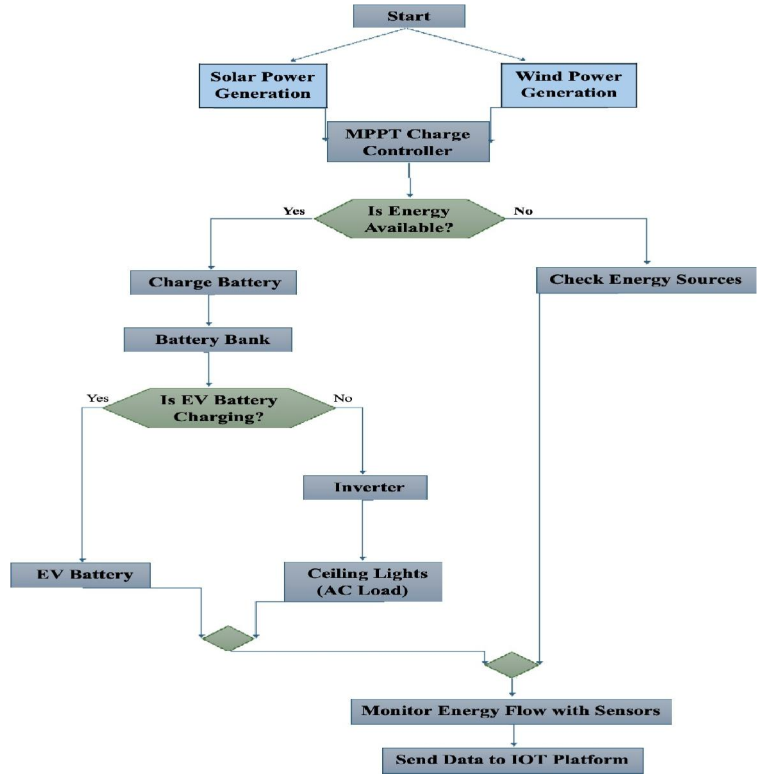

Figure no: 5 Flow chart of the System

III. RESULTS AND DISCUSSION

Voltage readings were recorded throughout the day under varying solar irradiance using the IoT-enabled Solar-Wind EV Charging System. Parameters observed include solar irradiance and voltage across No Load, AC Load, DC Load, EV Load, Battery Load, and All Loads. The figure below shows a bar chart comparing the system's voltage performance across different times of the day. As expected, voltages rise during peak sunlight and drop during evening hours. This reflects the direct impact of solar irradiance on system performance.

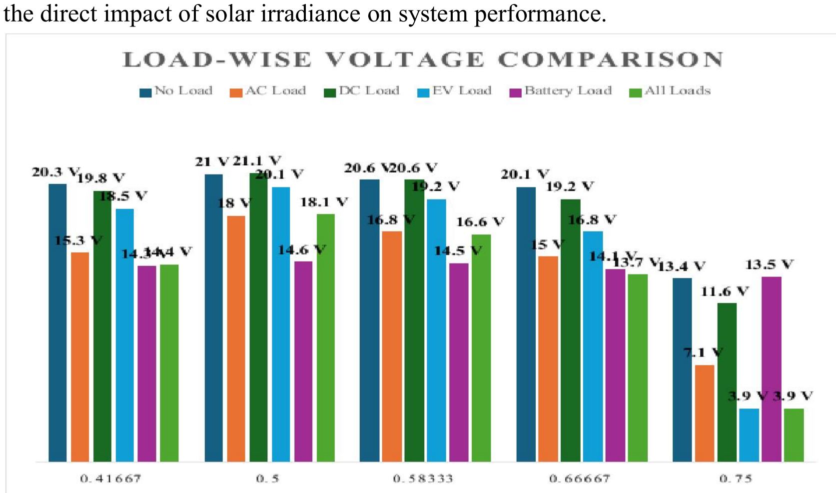

Figure no: 6 Voltage Comparison at Different Load

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Overview of Load Performance

Table No: 1 VOLTAGE Variation across Loads with Time and Solar Irradiance

Sr. No.	Time	Solar Irradiance (W/m²)	AC Load	DC Load	EV Load	Battery Load	All Loads
1	10:00 AM	831 W/m²	15.3V	19.8V	18.5V	14.3V	14.4V
2	12:00 PM	985 W/m²	18V	21.1V	20.1V	14.6V	18.1V
3	2:00 PM	852 W/m²	16.8V	20.6V	19.2V	14.5V	16.6V
4	4:00 PM	471 W/m²	15V	19.2V	16.8V	14.1V	13.7V
5	6:00 PM	17 W/m²	7.1V	11.6V	3.9V	13.5V	3.9V

The (figure no 6) shows graph of Voltage Comparison at Different Load and (Table no 1) shows the table of Voltage Variation Across Loads with Time and Solar Irradiance.

The system performs optimally during the peak sun hours (10 AM to 2 PM), while the performance drops after 4 PM due to lower solar irradiance. Among all loads, the Battery Load remains the most stable, and the No Load condition provides the maximum available voltage. The All-Loads condition puts the most stress on the system, especially when solar input is low.

OVERVIEW OF WIND TURBINE OUTPUT

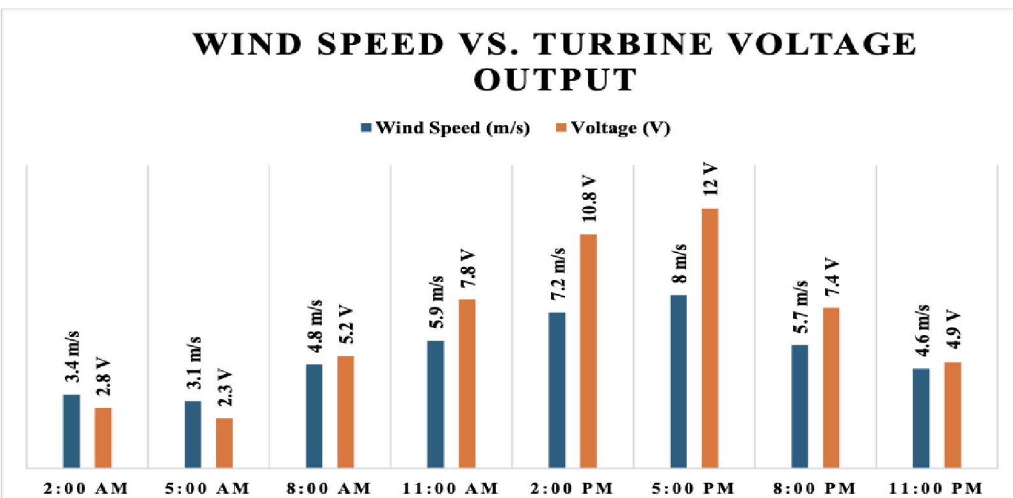

Figure no: 7 Wind Speed vs. Voltage Output from Wind Turbine

As shown in Figure no 7 and Table no 2, Illustrates output of Wind Turbine, The wind turbine exhibited the best voltage output between 11:00 AM and 5:00 PM, aligning with increased wind speeds during that period. Voltage generation shows a direct relationship with wind speed, peaking at 12.0 V under 8.0 m/s wind. Performance drops significantly during low-wind periods, particularly in the early morning and late evening. These findings emphasize the importance of wind forecasting for energy planning in hybrid EV charging systems.

Table No: 2 WIND Speed vs. Voltage Output from Wind Turbine

SR.NO.	Time	Wind Speed (m/s)	Voltage (V)
1	2:00 AM	3.4	2.8
2	5:00 AM	3.1	2.3
3	8:00 AM	4.8	5.2

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4	11:00 AM	5.9	7.8
5	2:00 PM	7.2	10.8
6	5:00 PM	8	12
7	8:00 PM	5.7	7.4
8	11:00 PM	4.6	4.9

Overview of (Hybrid Mode = Solar + Wind) VOLTAGE LOAD PERFOMANCE

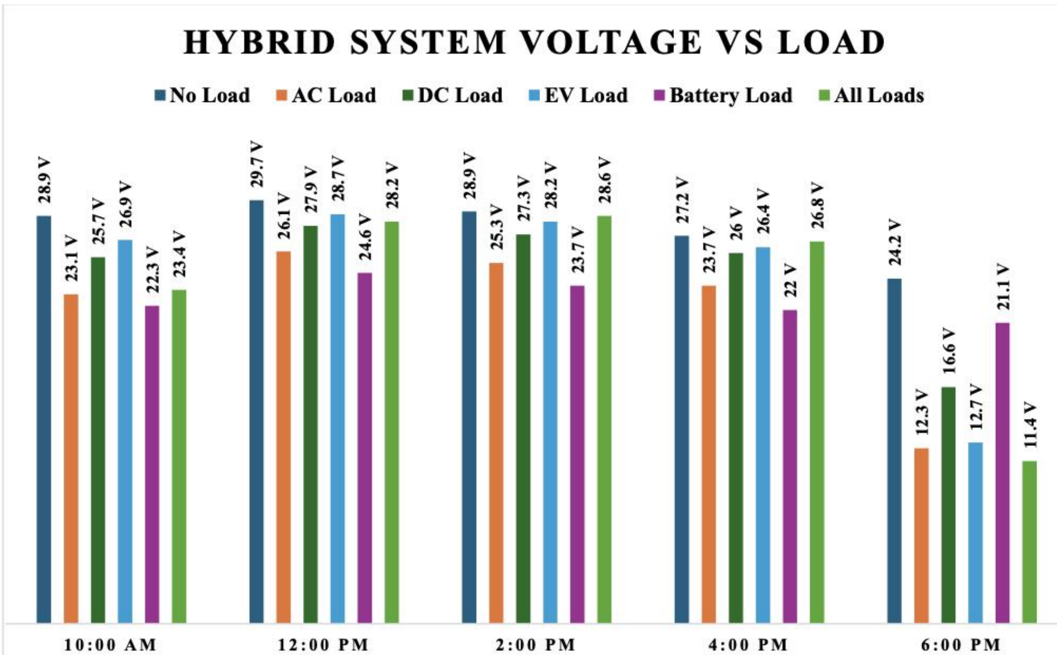

Figure no: 8 Voltage Comparison at Different Load Conditions in Hybrid Mode

SR.NO	Time	No Load	AC Load	DC Load	EV Load	Battery Load	All Loads
1	10:00 AM	28.6	23.1	25.7	26.9	22.3	23.4
2	12:00 PM	29.7	26.1	27.9	28.7	24.6	28.2
3	2:00 PM	28.9	25.3	27.3	28.2	23.7	28.6
4	4:00 PM	27.2	23.7	26	26.4	22	26.8
5	6:00 PM	24.2	12.3	16.6	12.7	21.1	11.4

Table No: 3 Voltage Comparison at Different Load Conditions in Hybrid Mode

As shown in Figure no 8 and Table no 3 illustrates the Output of Hybrid Mode, The combined solar-wind system significantly enhances voltage stability, especially during late afternoon and early evening hours when solar power alone becomes insufficient. Wind energy compensates for the drop in solar irradiance, ensuring that critical loads like batteries and EVs can continue to operate effectively. Overall, the hybrid model demonstrates superior reliability, efficiency, and energy continuity, making it a more resilient solution for sustainable EV charging.

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IoT-Based Performance Monitoring of the Solar-Wind System

Figure no: 9 IoT-Based Performance Monitoring of the Solar-Wind System

IV. CONCLUSION

The hybrid solar-wind electric vehicle charging system is a major advancement in environmentally friendly transportation infrastructure since it combines state-of-the-art technology with renewable energy sources to offer a dependable, effective, and sustainable way to charge electric cars. This cutting-edge solution lessens our reliance on fossil fuels and helps create a cleaner, healthier planet by utilizing solar and wind energy. This system guarantees optimal performance and offers real-time insights into patterns of energy usage thanks to its sophisticated IoT-enabled monitoring capabilities and effective energy storage. This project is a shining example of innovation as the world moves toward a more sustainable future. It shows how hybrid renewable energy systems have the potential to revolutionize the transportation industry and open the door to a more ecologically sensitive and greener future**.**

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