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IoT-Enabled Hybrid Solar-Wind EV Charging System with Battery Storage and Automatic Source Switching

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Abstract: The use of Electric Vehicles (EVs) is increasing day by day, and this creates a need for a reliable and eco-friendly charging system. Most of the existing EV charging systems depend on grid electricity, which can be costly and not environmentally friendly. To overcome this problem, this project presents the design and implementation of an off-board hybrid EV charging system using solar, wind, and grid energy sources. The system is designed to provide continuous charging by automatically selecting the available energy source based on voltage level.

In this project, a solar panel and a wind energy source (DC motor) are used as primary renewable energy sources. When either of these sources produces sufficient voltage, it is used for charging. If both sources are not available, the system switches to grid supply as a backup. A battery charge controller is used to ensure safe charging of Li-ion batteries, and a DC-DC boost converter is used to maintain stable output voltage. The system is controlled by an Arduino Nano, which manages source selection and relay switching. An ESP8266 NodeMCU module is used for IoT-based monitoring, allowing real-time data display through a web interface.On the vehicle side, a battery monitoring system is used to measure voltage and current for safe operation. It also provides automatic switching between main and backup battery to ensure continuous power supply to the load.

The hardware model of the system was successfully developed and tested under different conditions. The results show that the system can provide continuous, efficient, and reliable EV charging. The integration of renewable energy sources reduces dependence on grid power and supports clean energy usage. Overall, the project demonstrates a simple, cost-effective, and sustainable solution for future electric vehicle charging systems.

Keywords: Electric Vehicle (EV), Hybrid EV Charging System, Solar Energy, Wind Energy, Off-Board Charging, Renewable Energy Integration, Battery Management System (BMS), DC-DC Converter, SEPIC Converter, Bidirectional Converter, Arduino Nano, IoT Monitoring, ESP8266, Smart Charging System, Energy Storage System (ESS), Automatic Source Switching, Sustainable Energy, EV Infrastructure, Power Electronics, Green Energy.

I. INTRODUCTION

Electric vehicles (EVs) are becoming more popular in India and around the world because they are cleaner and more eco-friendly compared to petrol and diesel vehicles. As the number of EV users increases, the need for proper and reliable charging systems is also growing.

At present, most EV charging depends on grid electricity, which can be costly and not always reliable due to power cuts, voltage fluctuations, and dependence on fossil fuels. To overcome these problems, renewable energy sources like solar and wind are being used for EV charging. Solar energy is freely available and suitable for India, but it cannot provide power during night time or cloudy conditions. Wind energy can support power generation when sunlight is low, making the system more reliable. In this project, a hybrid EV charging system is developed using solar, wind, and grid energy sources along with battery storage. The system is designed to automatically select the available source based on voltage level, giving priority to renewable sources and using grid as a backup when needed. Converters like SEPIC and bidirectional DC-DC converters are used to maintain stable voltage and manage energy flow safely. A microcontroller-based control system ensures automatic switching, while sensors and IoT technology help in real-time monitoring. This hybrid approach improves efficiency, reduces electricity cost, and ensures continuous charging in all conditions. Overall, the project provides a simple, cost-effective, and eco-friendly solution for EV charging, supporting the future growth of sustainable transportation.

A. Objectives of the Project

1) To design a hybrid EV charging system using solar, wind, and grid energy sources.
2) To provide continuous and reliable EV charging by automatically switching between available energy sources.
3) To use battery storage for storing extra energy and supporting charging during night or low power conditions.
4) To maintain stable voltage and safe charging using converters, relays, and control circuits.
5) To develop a smart monitoring system using microcontroller and Wi-Fi for real-time data display and control.

B. Scope of the Project

This project mainly focuses on the design and development of a hybrid electric vehicle charging system using solar, wind, and grid energy sources. The system is planned to collect energy from a solar panel and a small wind source (DC motor), and automatically select the available source based on voltage level. If both solar and wind sources are not sufficient, the system will switch to grid supply to ensure continuous charging. The project also includes the use of a battery charge controller and Li-ion battery bank to store excess energy and provide backup during night time or low energy conditions. The scope covers the integration of all these components into a single system for smooth and efficient operation.

The project also includes the development of a control and monitoring system using Arduino Nano and ESP8266 NodeMCU. Sensors are used to measure voltage and current, and the microcontroller controls relays for automatic source switching. The system also provides real-time monitoring using Wi-Fi and a web interface developed with HTML and PHP. The scope of the project is limited to small-scale implementation using available components, but the concept can be extended to large-scale EV charging stations. Overall, the project aims to study performance, improve reliability, and promote the use of renewable energy for sustainable EV charging.

II. REVIEW OF LITERATURE

Many recent research studies focus on improving electric vehicle (EV) charging systems using renewable energy sources, especially solar power. Several papers explain different types of EV charging methods, converter topologies like SEPIC, Zeta, and bidirectional DC-DC converters, and the use of battery storage systems for continuous power supply.Researchers have also discussed hybrid charging systems where solar energy is combined with batteries or grid supply to improve reliability. Some studies focus on techno-economic analysis, showing that solar-based EV charging can reduce electricity cost and carbon emissions. Other works highlight the importance of smart control techniques, including artificial intelligence and IoT-based monitoring, to improve system efficiency and user interaction. Many authors also explain how bidirectional converters help in managing charging and discharging of batteries, and how energy can be stored and reused effectively. In addition, research papers discuss real-time challenges like fluctuating solar output, converter efficiency, and system stability.Overall, the literature clearly shows that renewable energy-based EV charging is a growing field, and hybrid systems with proper control and storage provide better performance compared to traditional grid-based charging systems.

A. Identification of Gaps

From the above literature, it is clear that most studies focus mainly on individual aspects such as converter design, solar integration, or large-scale charging stations, but very few works provide a complete, simple, and practical hybrid system combining multiple energy sources like solar, wind, and grid together. Many research papers are based on simulation results and lack real hardware implementation, which creates a gap between theory and practical application. Also, continuous power availability is not fully addressed, especially during night time or low renewable energy conditions. Automatic source selection and real-time switching between multiple sources are not clearly implemented in many systems. In addition, IoT-based monitoring and user-friendly interfaces are not deeply integrated in most studies. There is also less focus on small-scale, low-cost systems that can be easily implemented in rural or local areas. Therefore, this project aims to fill these gaps by developing a hardware-based hybrid EV charging system with solar, wind, and grid integration, along with automatic control, battery backup, and real-time monitoring, making it more practical, reliable, and suitable for real-world applications.

III. METHODOLOGY

The methodology of this project begins with understanding the need for a reliable and continuous electric vehicle charging system. As EV usage is increasing, there is a strong need for a system that can work without interruption and reduce dependence on the power grid. In this project, we focus on using renewable energy sources like solar and wind along with grid backup.

The main aim is to design a hybrid system that can automatically select the available source and provide stable charging. Before starting the design, we studied the problems in existing charging systems such as power cuts, high electricity cost, and lack of renewable integration. Based on this understanding, we planned a system that can overcome these issues. This initial study forms the base of the entire project and helps in deciding the system design and working approach.

After identifying the problem, the next step is to study the basic working principles of all components used in the system. We studied how solar panels generate electricity from sunlight and how their output changes with weather conditions. Similarly, we studied how a DC motor can act as a wind energy generator when rotated. We also learned about battery charging methods, Li-ion battery characteristics, and the importance of proper charging control. The working of DC-DC boost converters, relays, and microcontrollers was also studied in detail. This theoretical understanding is very important because it helps in designing a safe and efficient system. Without proper knowledge of these components, the system may not work correctly or may cause damage to the battery.

Once the theoretical study is completed, the system design is planned using a block diagram. The block diagram clearly shows how solar, wind, and grid sources are connected in the system. It also shows how the energy flows from these sources to the battery and then to the EV charging port. The block diagram includes important components like relays, charge controller, boost converter, microcontroller, and sensors. This step helps in visualizing the complete system and understanding the connections between different parts. It also makes it easier to identify where control and monitoring are required. The block diagram acts as a guide for further hardware development and implementation.

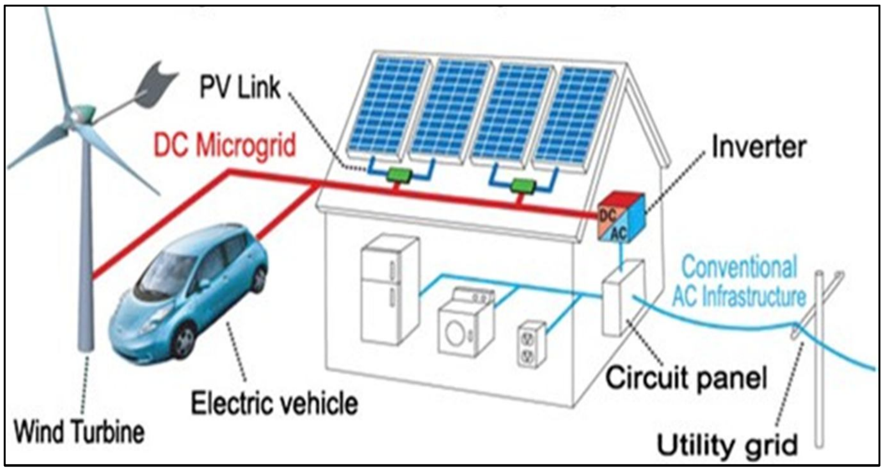

Fig 1. Wind and Solar Power System

After preparing the block diagram, the next step is component selection. All components are selected based on the system requirement, voltage level, current rating, and availability. The Arduino Nano is selected as the main controller because it is simple, low-cost, and easy to program. The ESP8266 NodeMCU is used for Wi-Fi communication and IoT-based monitoring. A 5W solar panel is selected for generating solar power, and a DC motor is used to simulate wind energy. A 12V relay is used for switching between different energy sources. The boost converter is used to increase voltage to the required level, and a battery charge controller is used to protect the battery. Li-ion cells are selected for energy storage because of their high efficiency and compact size.

The solar panel is connected as the primary renewable energy source in the system. It generates DC power when sunlight falls on it. The output voltage and current depend on the intensity of sunlight. This output is monitored and then sent to the system for charging. If the voltage produced by the solar panel is sufficient (around 6V or above), it is selected as the charging source. The solar energy is clean and free, so it is given priority in the system. Proper connections and wiring are done to ensure that the solar panel works safely and efficiently.

The wind energy source is implemented using a DC motor, which acts as a generator when rotated. When wind is available, the motor rotates and generates electrical energy. This energy is also fed into the system and monitored for voltage level. If the wind source produces sufficient voltage, it can also be used for charging. In some conditions where sunlight is low, wind energy can still provide power. This makes the system more reliable. The combination of solar and wind ensures better energy availability compared to using a single source.

The system uses relays for automatic switching between different energy sources. The relay is controlled by the Arduino Nano based on the voltage level from each source. If the solar or wind source produces sufficient voltage, the relay connects that source to the charging circuit. If both sources are not available or produce low voltage, the relay switches to grid supply. This automatic switching removes the need for manual control and ensures continuous operation. Proper relay connections are important to avoid short circuits and ensure smooth switching.

When both solar and wind sources are not available, the system uses grid power as a backup. The grid supply ensures that the EV can be charged at any time, even during night or bad weather. The grid power is converted to DC and then supplied to the charging circuit. This makes the system reliable and suitable for real-life applications. The grid acts as a secondary source, while solar and wind are primary sources.

The battery charge controller is used to manage the charging of Li-ion batteries. It regulates the voltage and current supplied to the battery to prevent overcharging and deep discharge. This increases the life of the battery and ensures safe operation. The charge controller also helps in maintaining proper charging cycles and protects the battery from damage. It plays a very important role in the system.

The boost converter is used to increase the voltage to the required level for charging. Since the voltage from solar and wind sources may not be constant, the boost converter helps in maintaining a stable output. This ensures proper charging of the battery and EV. The converter is adjusted to give the required output voltage. It also improves the efficiency of the system.

The Arduino Nano acts as the brain of the system. It reads the voltage values from different sources and controls the relay switching accordingly. It also monitors the system performance and ensures proper operation. The control program is written using Embedded C in Arduino IDE. The microcontroller makes the system smart and automatic.

The ESP8266 NodeMCU is used for IoT-based monitoring. It connects the system to the internet using Wi-Fi. Data such as voltage, current, and charging status are sent to a web server. The user can monitor the system using a web page developed using HTML and PHP. This makes the system user-friendly and modern.

The circuit is then assembled by connecting all components properly. Proper wiring, soldering, and insulation are done to ensure safety. The circuit diagram is followed carefully during assembly. All components are tested individually before connecting them to the main system.

After completing the hardware setup, the system is tested under different conditions. Tests are conducted during sunlight, low sunlight, wind conditions, and grid supply. The performance of the system is observed and recorded. This helps in understanding how the system works in real conditions.

The system generates electricity using solar and wind energy and stores the excess energy in a battery pack. An Arduino-based controller with IoT interface monitors the energy sources and automatically selects the best available power source to charge an Electric Vehicle (EV) or load.

Finally, the results are analysed to check the efficiency and reliability of the system. Any issues found during testing are corrected. The overall performance is evaluated based on stability, switching, and charging efficiency. This methodology ensures that the system is properly designed, implemented, and tested for real-world use.

A. Block DiagramOff-Board Hybrid Charging Phase

The off-board hybrid charging system is designed to use multiple energy sources such as solar, wind, and grid power to provide continuous charging for electric vehicles. In this system, the solar panel and wind source (DC motor) act as the main renewable energy inputs. The output from these sources is continuously monitored for voltage level. If either solar or wind source produces sufficient voltage (around 6V or above), that source is selected for charging using relay switching. The relay is controlled by the Arduino Nano, which acts as the main controller of the system. If both solar and wind sources are not available or produce low output, the system automatically switches to the grid supply as a backup source. The selected power source is then passed through a battery charge controller, which regulates voltage and current to safely charge the Li-ion battery. A DC-DC boost converter is used to increase and maintain the required voltage level for proper charging. Sensors are used to measure voltage and current, and this data is sent to the microcontroller for monitoring and control. The ESP8266 NodeMCU module is used for Wi-Fi communication, which sends real-time data to a web server for user monitoring. Overall, this block diagram shows a smart hybrid system that ensures uninterrupted and efficient EV charging by selecting the best available energy source automatically.

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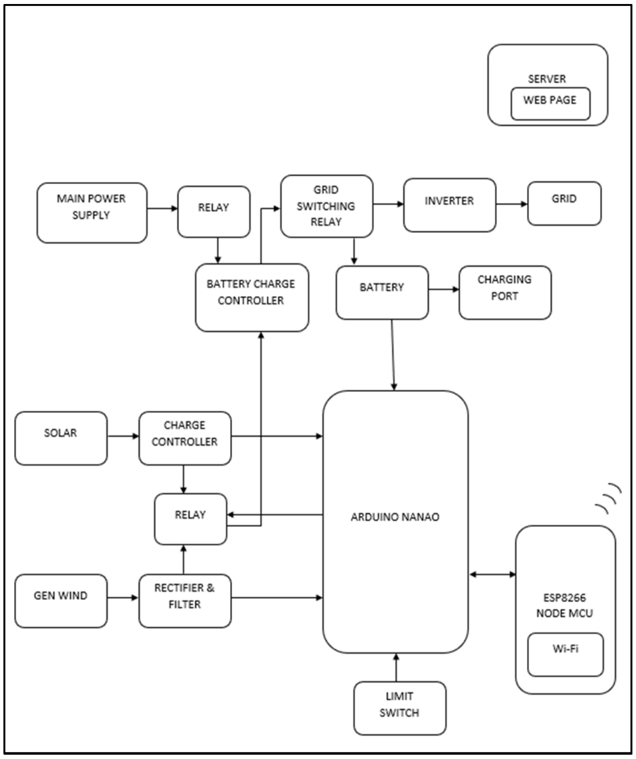

Fig 2. Offboard Hybrid Charging

B. Vehicle Phase

The vehicle phase of the system focuses on managing the charging and operation of the EV battery using the power supplied from the off-board charging system. In this phase, the EV battery is connected to a charging port, which receives regulated power from the hybrid charging unit. A battery charge controller is used to ensure safe charging by controlling voltage and current and preventing overcharging or deep discharge. Voltage and current sensors are connected to monitor the battery condition continuously. These sensor values are sent to the Arduino Nano, which analyses the battery status and controls the charging process accordingly. A relay is used to connect or disconnect the battery based on the charging condition and safety requirements. The system may also include a secondary battery or backup system to support continuous operation. The ESP8266 NodeMCU is used to send battery status and charging information to a web server through Wi-Fi, allowing real-time monitoring by the user. The LCD display can also show important parameters like voltage, current, and charging status locally. This phase ensures that the EV battery is charged safely, efficiently, and continuously, while also providing monitoring and control features for better performance and user convenience.

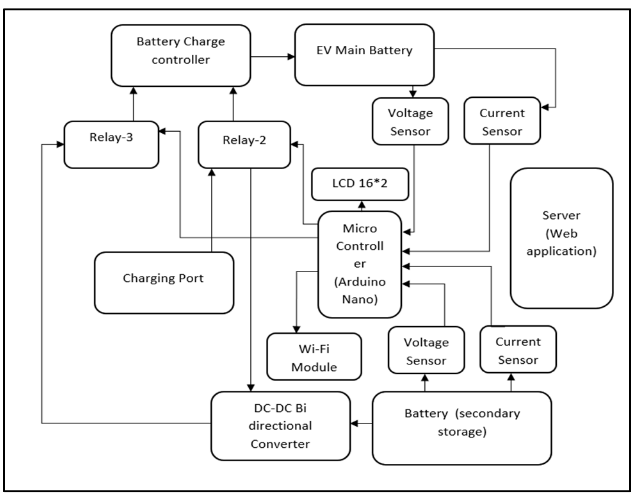

Fig 3. Vehicle Phase

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The circuit diagram represents an off-board hybrid EV battery charging system that uses solar, wind, and grid power sources to provide continuous charging. The solar panel acts as the primary renewable energy source and is connected to a solar charge controller. This controller regulates the output from the solar panel and ensures that the voltage and current are safe for further use. The regulated output is then fed into the system, where it is monitored and controlled. Along with solar energy, a wind energy source is also included using a DC motor, which acts as a generator when rotated. The output from the wind source is passed through a rectifier and filter circuit consisting of diodes and capacitors to convert AC-like output into smooth DC supply.

The system includes multiple relays which are used for automatic switching between solar, wind, and grid sources. These relays are controlled by the Arduino Nano microcontroller. The microcontroller continuously monitors the voltage levels from each energy source and decides which source should be used for charging. If either solar or wind source produces sufficient voltage, the relay connects that source to the charging circuit. If both renewable sources are not available or produce low output, the system switches to the grid supply. The grid input is passed through a rectifier and filtering circuit to convert AC to DC before supplying it to the system. This ensures that the system can provide uninterrupted charging under all conditions.

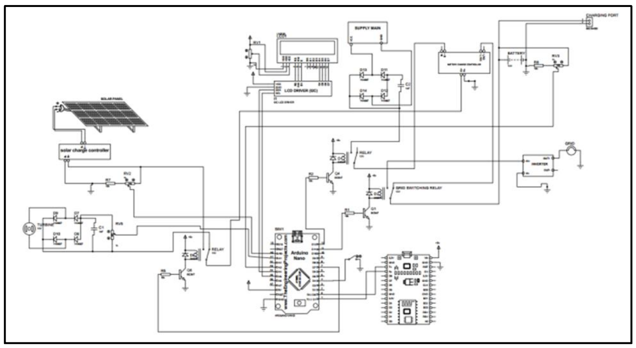

Fig 3. Offboard EV Battery Charger using PV Array

The battery charge controller plays an important role in protecting and managing the charging of the battery. It controls the voltage and current supplied to the battery and prevents overcharging, overheating, and deep discharge. The Li-ion battery is connected to the system through this controller, which ensures safe and efficient charging. A DC-DC boost converter is also used in the circuit to increase the voltage to the required level for proper charging. Since the input voltage from renewable sources may vary, the boost converter helps in maintaining a stable output voltage.

The Arduino Nano acts as the main control unit of the system. It receives inputs from different parts of the circuit, including voltage sensing points, and controls the operation of relays accordingly. The microcontroller is programmed using Embedded C in Arduino IDE to perform automatic switching, monitoring, and protection functions. It ensures that the system always uses the best available energy source. A limit switch is also included in the circuit for safety purposes, which helps in controlling the charging process and preventing overcharging conditions.

The system also includes an ESP8266 NodeMCU module, which is used for wireless communication and IoT-based monitoring. This module connects the system to a Wi-Fi network and sends real-time data such as voltage, current, and charging status to a web server. The user can monitor the system using a web page developed using HTML and PHP. Additionally, an LCD display is connected to the Arduino Nano through an I2C interface, which shows important parameters like voltage, charging status, and source selection. This makes the system user-friendly and easy to monitor. The use of relays, converters, microcontroller, and IoT technology ensures automatic operation, safe battery charging, and real-time monitoring. The system is designed to provide continuous and reliable EV charging while promoting the use of renewable energy and reducing dependence on the power grid.

The vehicle phase circuit is mainly designed to monitor the battery condition and control the power supply to the electric vehicle load. In this system, the Arduino Nano acts as the main controller, which continuously checks the battery parameters using different sensors. Voltage sensors (VS1 and VS2) are used to measure the voltage of the main battery and the secondary battery. These values help in understanding the battery charge level and prevent over-discharge conditions. At the same time, current sensors (CSM1 and CSM2) are used to measure the current flowing in the circuit. This helps in identifying how much power is being used and protects the system from overcurrent or short circuit conditions. All these sensor values are given as input to the Arduino Nano, which processes the data and takes necessary control actions.

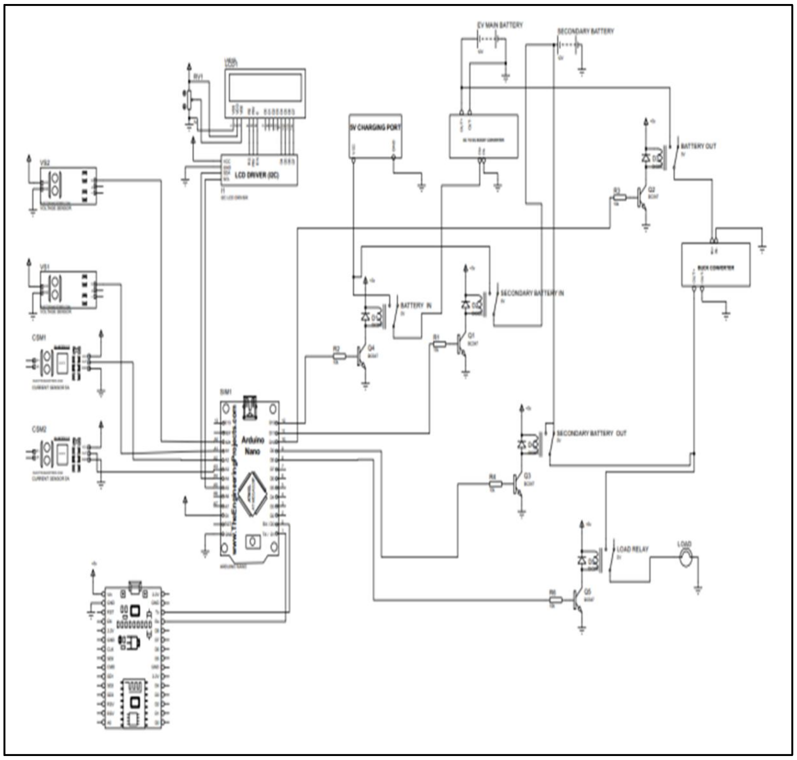

Fig 4. Circuit Diagram Vehicle Phase

Based on the sensor readings, the Arduino Nano controls the relays through transistor switches. Transistors (Q1, Q2, Q3, Q4) act as intermediate switches because the Arduino cannot directly drive the relays. The relays are used to control different operations like connecting the battery, switching between main and secondary battery, and controlling the load. The load relay ensures that power is supplied to the motor or vehicle electronics only when the battery condition is safe. If the battery voltage is within the safe range, the relay remains ON and supplies power to the load. If any abnormal condition is detected, the relay turns OFF to protect the system.

The circuit also includes a secondary battery system, which acts as a backup source. When the main EV battery voltage drops below a certain level, the Arduino automatically switches the load to the secondary battery using relays. This ensures continuous power supply to the vehicle without interruption. The relays named Battery IN, Secondary Battery IN, and Secondary Battery OUT control the power flow between these batteries. The system also manages charging through a 5V charging port, which helps in maintaining the logic circuit or charging the secondary battery. This backup mechanism improves the reliability and safety of the overall system.

For user interaction, an LCD display is connected to the Arduino through an I2C interface. The LCD shows important information such as battery voltage, current, and active power source. This helps the user to easily monitor the system condition in real time. Overall, the vehicle phase circuit ensures safe battery operation, continuous power supply, and proper load management. It combines sensing, control, protection, and user interface into a single system, making it efficient and suitable for electric vehicle applications.

The Arduino Nano acts as the main controller of the vehicle phase circuit. It collects data from sensors, controls relay switching, and manages the overall charging process. The microcontroller is programmed using Embedded C in Arduino IDE to perform automatic control based on predefined conditions. It ensures that the battery is charged safely and efficiently under all operating conditions. The system also includes an LCD display, which shows important parameters such as battery voltage, current, and charging status, making it easy for the user to monitor the system locally.

For remote monitoring, the ESP8266 NodeMCU module is used, which connects the system to the internet through Wi-Fi. The data collected by the microcontroller is sent to a web server, where it can be viewed using a web application developed in HTML and PHP. This allows the user to monitor the charging status and battery condition from anywhere. Overall, the vehicle phase circuit ensures safe battery charging, efficient energy management, and real-time monitoring, making the system reliable and user-friendly for electric vehicle applications.

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IV. RESULTS

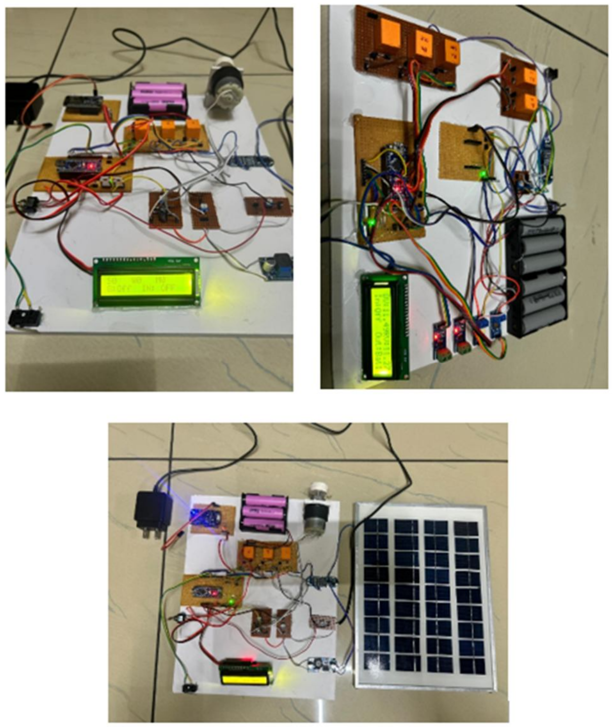

Fig 5. Output Photos

The hardware model of the proposed off-board hybrid EV charging system was successfully designed and implemented using all the required components. The system was tested under different conditions such as solar input, wind input, and grid supply. During testing, it was observed that the system was able to automatically select the available power source based on voltage level. When solar or wind source produced sufficient voltage (around 6V or above), the system selected that source for charging. When both renewable sources were not available, the system successfully switched to grid supply without any interruption. The relays operated correctly as per the control signals from the Arduino Nano. The battery charge controller maintained safe charging conditions and prevented overcharging. The boost converter provided stable voltage output for charging. Overall, the hardware setup worked properly and achieved the expected performance, proving that the system is reliable and efficient for EV charging.

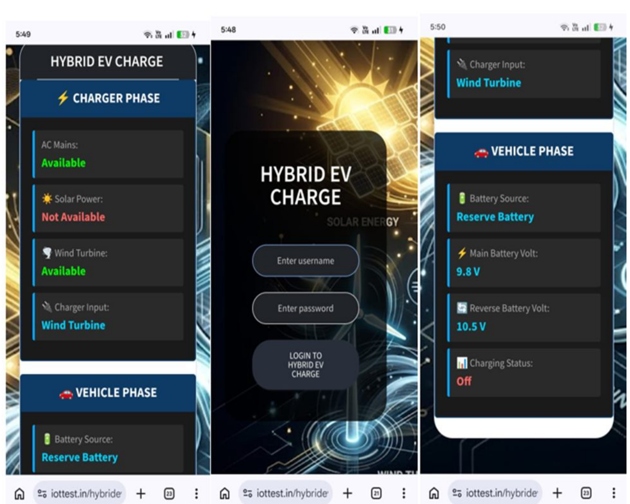

Fig 5. Interface

The monitoring interface for the system was successfully developed using HTML and PHP. The ESP8266 NodeMCU module was used to send real-time data such as voltage, current, and charging status to the web server. The web page displayed the system parameters clearly, allowing the user to monitor the charging process easily. The interface showed which power source was currently active (solar, wind, or grid) and also displayed battery status. The data was updated in real time, which confirmed proper communication between hardware and software. The interface was tested and worked correctly during the system operation. Screenshots of the web interface are attached in the report as proof of successful implementation. This monitoring system improves user convenience and provides better control over the charging system.

The system includes a login feature to provide secure access to the monitoring interface. In this project, a simple username and password-based login system is developed using HTML and PHP. The user must enter the correct login details to access the system dashboard. This helps in protecting the system data and prevents unauthorized access. The login page is designed in a simple and user-friendly manner so that it is easy to use. Once the correct username and password are entered, the user is redirected to the main interface where system details are displayed.

After successful login, the user can view two main sections in the interface, which are the Charger Phase and the Vehicle Phase. The Charger Phase screen displays information related to the off-board charging system. It shows the status of solar, wind, and grid sources, and indicates which source is currently active. It also displays voltage levels and charging status of the battery. This helps the user to understand how the energy sources are being used and whether the system is working properly.

V. CONCLUSION

The project titled "Design and Performance Evaluation of an Off-Board Hybrid Solar PV Based Electric Vehicle Charging System" has been successfully designed and implemented. The system uses a combination of solar, wind, and grid energy sources to provide continuous and reliable charging for electric vehicles. The hardware model was developed using components like Arduino Nano, relays, boost converter, battery charge controller, and Li-ion battery. The system was tested under different conditions, and it was observed that the automatic switching between energy sources worked properly based on voltage availability. The use of renewable energy sources helped in reducing dependence on grid electricity and made the system eco-friendlier and more cost-effective. The battery was charged safely and efficiently with proper control of voltage and current.

In addition to hardware implementation, an IoT-based monitoring system was also developed using ESP8266, HTML, and PHP. This allowed real-time monitoring of system parameters such as voltage, current, and charging status through a web interface. The login system ensured secure access, and the separation of charger phase and vehicle phase made the interface user-friendly. Although the system is implemented on a small scale, it clearly demonstrates the concept of a smart hybrid EV charging system. With further improvements and scaling, this system can be used for practical applications in EV charging stations. Overall, the project proves that combining renewable energy with smart control and monitoring can provide an efficient, reliable, and sustainable solution for future electric vehicle charging needs.

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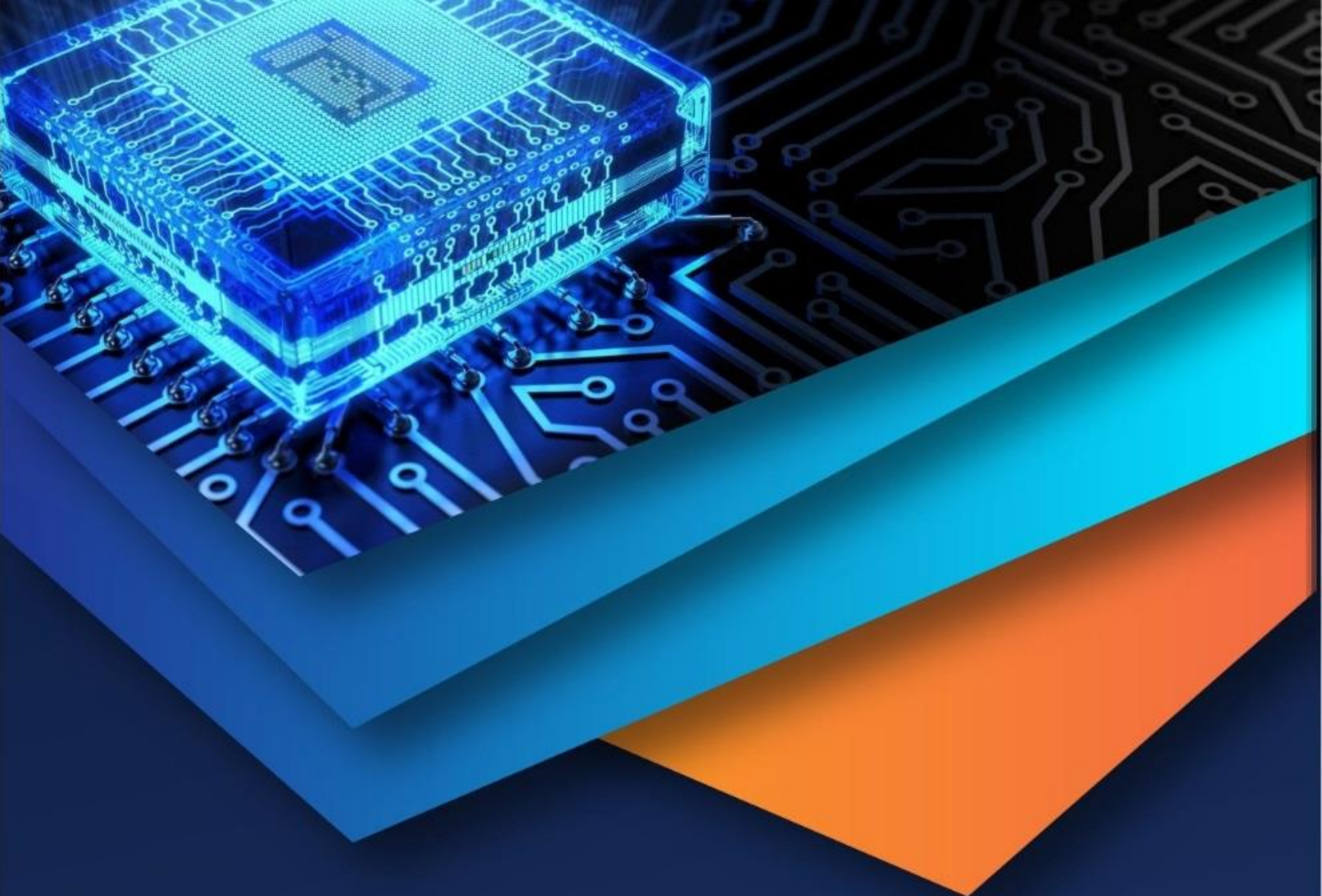

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