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INTEGRATION OF SOLAR AND WIND ENERGY SYSTEM FOR SUSTAINABLE ELECTRIC VEHICLE

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Abstract— The increasing demand for clean and sustainable transportation has accelerated the adoption of electric vehicles (EVs) worldwide. However, the dependency of EV charging systems on conventional grid power creates challenges related to carbon emissions, energy shortage, and grid instability. This paper presents the integration of solar and wind energy systems for sustainable electric vehicle charging applications. The proposed hybrid renewable energy system combines photovoltaic (PV) panels and wind turbines to provide reliable, eco-friendly, and continuous power for EV charging stations. An energy management system is employed to optimize power flow between renewable sources, battery storage, and the electric vehicle load. The hybrid approach enhances system reliability by compensating for the intermittency of individual renewable sources. Solar energy contributes during daytime conditions, while wind energy supports power generation during low sunlight or nighttime periods. The proposed system reduces dependence on fossil fuels, minimizes greenhouse gas emissions, and improves energy efficiency. Simulation and performance analysis demonstrate that the integrated solar–wind EV charging system can effectively meet charging demands with reduced operational cost and environmental impact. The study highlights the potential of renewable energy integration in developing sustainable and smart transportation infrastructure for future energy systems.

Keywords— Electric Vehicle (EV), Solar Energy, Wind Energy, Hybrid System, Renewable Energy, EV Charging, Sustainable Energy, Battery Storage, Smart Grid.

I. INTRODUCTION:

The rapid growth in global energy demand and environmental concerns has increased the need for sustainable and clean energy solutions. Transportation is one of the major contributors to greenhouse gas emissions due to the extensive use of fossil fuel-based vehicles. Electric Vehicles (EVs) have emerged as an effective alternative to conventional vehicles because of their lower environmental impact and improved energy efficiency. However, the widespread adoption of EVs creates additional pressure on conventional power grids, especially during peak charging periods.To address this challenge, the integration of renewable energy sources such as solar and wind energy into EV charging infrastructure has gained significant attention. Solar energy, generated through photovoltaic (PV) systems, provides clean electricity during daytime, while wind energy can generate power under varying weather conditions, including nighttime. Combining these two renewable sources in a hybrid system improves reliability and ensures continuous power availability.

This paper focuses on the integration of solar and wind energy systems for sustainable electric vehicle charging applications. The proposed hybrid renewable energy system aims to reduce dependency on conventional grid electricity, minimize carbon emissions, and enhance energy efficiency. By utilizing energy storage systems and intelligent energy management techniques, the system ensures stable and efficient operation. This approach supports the development of smart and sustainable transportation infrastructure for future energy demands.

II. LITERATURE REVIEW

The integration of solar and wind energy systems for electric vehicles (EVs) has gained significant attention due to the increasing demand for clean and sustainable transportation. Solar photovoltaic (PV) systems are widely used for EV charging because they generate clean electrical energy and reduce dependence on conventional grid power. However, solar energy alone is affected by weather conditions and sunlight availability, which limits continuous power generation.

To overcome these limitations, researchers have proposed hybrid renewable energy systems that combine solar and wind energy sources. Wind turbines can generate power during low sunlight conditions, improving overall system reliability and ensuring continuous energy supply for EV charging. Many studies also use battery storage systems to store excess renewable energy and provide backup power when renewable generation is low.

Recent research focuses on intelligent control systems using microcontrollers such as Arduino for automatic source monitoring and switching. Voltage sensors, relay circuits, and battery management systems help improve energy efficiency and reliable operation. Therefore, the proposed system aims to develop a sustainable and efficient hybrid solar-wind energy system for electric vehicle applications with continuous and eco-friendly power generation.

III. METHODOLOGY AND SYSTEM:

3.1 METHODOLOGY:

This project follows a structured and systematic approach to develop a hybrid renewable energy system for sustainable electric vehicle applications. The system integrates solar energy, wind energy, battery storage, and intelligent source selection using Arduino Nano for efficient EV operation.

Phase 1: Requirement Analysis and System Design

Target Application: Sustainable electric vehicle charging and operation using renewable energy sources. Energy Sources: Solar panel, wind turbine, and AC grid backup supply. Core Components: Arduino Nano, solar charge controller, wind turbine rectifier, relay circuit, motor driver board, voltage sensors, and 12V battery.

Architecture: Solar Panel + Wind Turbine + Grid Supply → Power Conversion → Battery Storage → Arduino Nano → Relay Source Selection → Motor Driver → EV Motor.

Phase 2: Hardware Prototyping and Power Integration

Component Assembly: Solar panel connected through a DC–DC charge controller, wind turbine connected through an AC-to-DC rectifier, and AC grid connected using an AC-to-DC adapter.

Monitoring System: Solar voltage sensor, wind voltage sensor, and battery voltage sensor interfaced with Arduino Nano. Actuation and Control: Relay circuit connected for automatic source switching and motor driver board connected for EV motoroperation.

Power Supply: 12V DC battery used for energy storage and continuous power delivery.

Phase 3: Controller Programming and Energy Management

Development Environment: Arduino IDE used for embedded system programming. Control Functions: Implemented voltage monitoring, source selection logic, battery management, and relay control using Arduino Nano.System Operation: The controller continuously checks available power sources and automatically switches between solar, wind, and grid supply based on voltage conditions.Motor Control: Motor driver board controls the speed and operation of the DC motor representing the electric vehicle load.

Phase 4: System Testing and Performance Evaluation

Performance Analysis: Tested system performance under different solar and wind conditions. Parameters Monitored: Battery charging status, source voltage levels, relay switching response, and motor operation efficiency. Evaluation: The hybrid system was analysed for reliability, uninterrupted power supply, renewable energy utilization, and reduction in dependency on conventional grid power.

3.2 SYSTEM:

The proposed system integrates solar and wind energy sources for sustainable electric vehicle operation. An Arduino Nano controls voltage monitoring, battery storage, and automatic source selection using relay circuits. The regulated power drives the EV motor through a motor driver board, ensuring efficient energy utilization, reliable operation, and reduced dependence on conventional grid power.

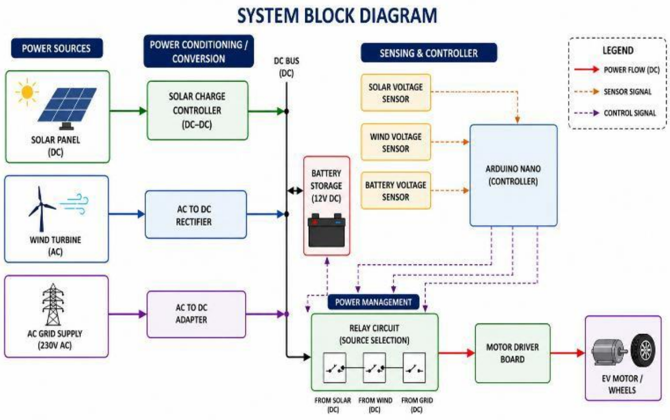


Fig1: system block diagram Of Solar and Wind Energy System

A. *System Overview*

The proposed system consists of renewable energy generation, power conditioning, sensing, processing, energy management, and motor driving units. The integration of solar and wind energy sources ensures continuous and sustainable power supply for electric vehicle operation. The system performs real-time voltage monitoring, automatic source selection, battery charging, and motor control for efficient energy utilization.

B. *Renewable Energy Generation Unit*

The renewable energy generation unit consists of a solar panel and wind turbine. The solar panel converts sunlight into DC electrical energy, while the wind turbine generates AC electrical power from wind energy. These renewable sources act as the primary power supply for the electric vehicle system.

C. *Power Conditioning Unit*

The power conditioning unit includes a solar charge controller, AC-to-DC rectifier, and AC-to-DC adapter. The solar charge controller regulates the output voltage from the solar panel. The wind turbine output is converted into DC power using a rectifier circuit, while the AC grid supply is converted into usable DC power through an adapter. This unit ensures stable and regulated power flow to the battery and load.

D. *Sensing Unit*

The sensing unit consists of solar voltage sensors, wind voltage sensors, and battery voltage sensors. These sensors continuously monitor the voltage levels of different energy sources and battery conditions. The sensed data is transmitted to the Arduino Nano controller for further processing and decision-making.

E. *Processing and Control Unit*

The Arduino Nano serves as the central processing and control unit of the system. It performs the following functions:

- Monitoring voltage levels from renewable sources and battery.
- Processing sensor data for intelligent decision-making.
- Generating control signals for relay switching operation.
- Managing source selection and motor control. The controller ensures smooth coordination between all system components.

F. *Energy Storage Unit*

A 12V DC rechargeable battery is used as the energy storage unit. The battery stores excess energy generated from solar and wind sources and supplies backup power during low generation conditions. This improves system reliability and uninterrupted EV operation.

G. *Source Selection and Power Management Unit*

The relay circuit acts as the automatic source selection unit. Based on the control signals from the Arduino Nano, the relay switches between solar power, wind power, and grid power depending on source availability and voltage conditions. This enables efficient power management and continuous system operation.

H. *Motor Driver and EV Load Unit*

The motor driver board controls the operation of the DC motor representing the electric vehicle load. It receives controlled DC power from the selected energy source and regulates motor speed and performance. This unit demonstrates the practical implementation of renewable energy-powered electric vehicle operation.

IV. WORKING:

The proposed hybrid renewable energy system for sustainable electric vehicle operation works through the integration of renewable energy generation, power conditioning, intelligent control, energy storage, and motor drive operation. The following describes the complete operational workflow of the system:

A. *Solar Energy Generation*

At system startup, the solar panel converts sunlight into DC electrical energy using photovoltaic (PV) cells. The generated power is supplied to the solar charge controller, which regulates the voltage and protects the battery from overcharging. The regulated DC power is then supplied to the common DC bus for battery charging and load operation.

B. *Wind Energy Generation*

The wind turbine converts wind energy into electrical energy. Since the turbine produces AC output, it is connected to an AC-to-DC rectifier circuit which converts the generated AC power into regulated DC power. The converted DC output is combined with the solar power source for efficient hybrid energy utilization.Grid Power Backup Operation

During low solar radiation or insufficient wind conditions, the AC grid supply acts as a backup energy source. The 230V AC supply is converted into DC power using an AC-to-DC adapter and supplied to the battery and load system. This ensures uninterrupted electric vehicle operation under all environmental conditions.

C. *Battery Charging and Energy Storage*

The 12V rechargeable battery stores excess energy generated from solar and wind sources. The stored energy is utilized during low renewable energy availability. The battery provides continuous DC power to the system, ensuring stable EV motor operation and improved reliability.

D. *Voltage Monitoring and Sensor Operation*

Voltage sensors continuously monitor solar voltage, wind voltage, and battery voltage in real time. The sensor outputs are transmitted to the Arduino Nano controller for processing. These measurements help the controller determine the available power source and battery condition.

E. *Intelligent Source Selection and Control*

The Arduino Nano acts as the central control unit of the system. Based on the voltage sensor data, the controller automatically selects the most efficient power source using the relay switching circuit. If solar power is available, the system prioritizes solar energy; otherwise, it switches to wind energy or grid supply. This intelligent switching ensures efficient energy management and uninterrupted operation.

F. *Motor Driver and Electric Vehicle Operation*

The selected DC power source is supplied to the motor driver board. The motor driver regulates the voltage and current supplied to the DC motor representing the electric vehicle load. The motor converts electrical energy into mechanical motion for EV wheel operation.

G. *System Performance and Energy Efficiency*

The hybrid renewable energy system continuously operates by optimizing renewable energy utilization and reducing dependence on conventional grid power. The system improves energy efficiency, minimizes carbon emissions, and supports sustainable electric vehicle applications through reliable power management and intelligent control operation.

V. RESULT & CONCLUSION:

5.1 RESULT:

The hybrid renewable energy system successfully generated electrical power using both solar and wind energy sources under different environmental conditions. The solar panel produced stable DC output during sunlight conditions, while the wind turbine generated power effectively at varying wind speeds. The battery storage system efficiently stored excess energy and

supplied backup power during low renewable energy availability.

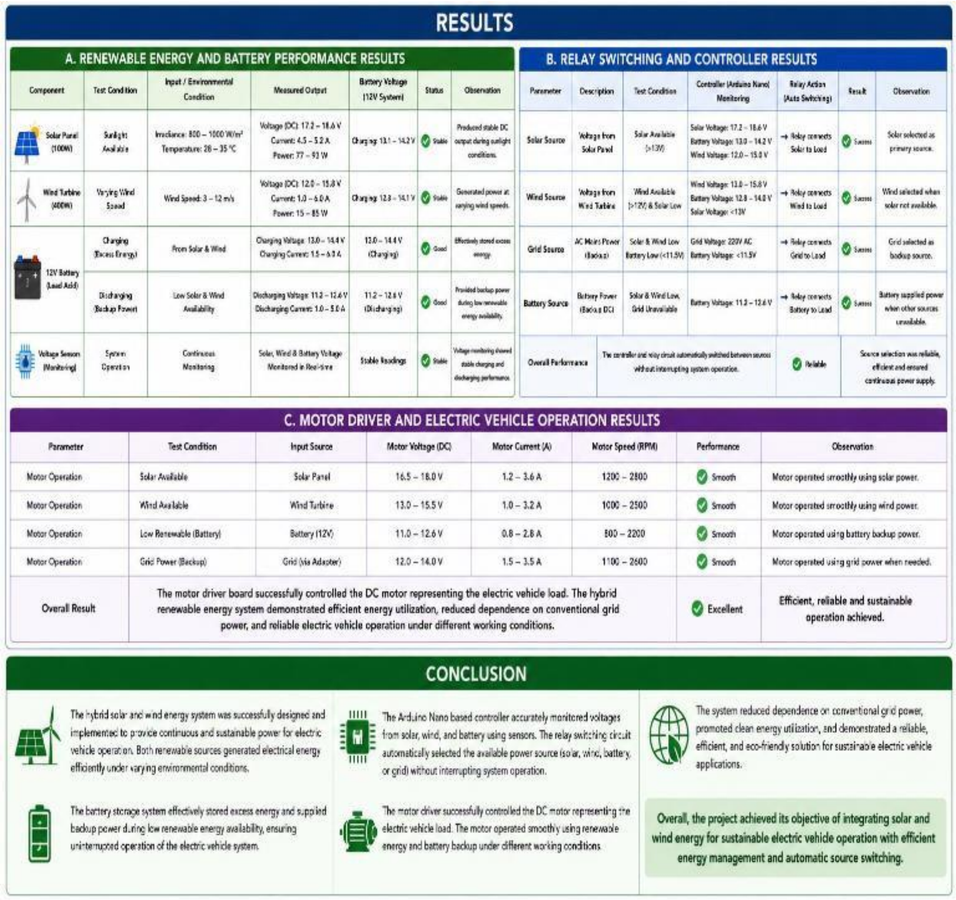
The Arduino Nano controller accurately monitored voltage levels from the solar panel, wind turbine, and battery using voltage sensors. The relay switching circuit automatically selected the available power source without interrupting system operation, ensuring continuous power supply to the electric vehicle system.

The motor driver board successfully operated the DC motor representing the electric vehicle load using renewable energy and battery backup. The overall system demonstrated efficient energy utilization, reduced dependency on conventional grid power, and reliable operation under different working conditions.

5.2 CONCLUSION

The project *"Integration of Solar and Wind Energy System for Sustainable Electric Vehicle"* was successfully designed and implemented. The hybrid renewable energy system effectively combined solar and wind power sources to provide continuous and sustainable energy for electric vehicle operation. The automatic source switching mechanism improved system reliability by selecting the available energy source efficiently.

The battery storage system enhanced energy management by storing excess renewable energy and supplying backup power when required. The proposed system reduced dependence on conventional energy sources, promoted clean energy utilization, and demonstrated an eco-friendly solution for sustainable electric vehicle applications.



RESULTS

A. RENEWABLE ENERGY AND BATTERY PERFORMANCE RESULTS

Component	Test Condition	Input / Environmental Condition	Measured Output	Battery Voltage (12V System)	Status	Observation
Solar Panel (100W)	Sunlight Available	Irradiance: 800 – 1000 W/m² Temperature: 28 – 35 °C	Voltage (DC): 17.2 – 18.6 V Current: 4.5 – 5.2 A Power: 77 – 93 W	Charging: 13.1 – 14.2 V	Stable	Produced stable DC output during sunlight conditions.
Wind Turbine (400W)	Varying Wind Speed	Wind Speed: 3 – 12 m/s	Voltage (DC): 12.0 – 15.8 V Current: 1.0 – 6.0 A Power: 15 – 85 W	Charging: 12.8 – 14.1 V	Stable	Generated power at varying wind speeds.
12V Battery (Lead Acid)	Charging (Excess Energy)	From Solar & Wind	Charging Voltage: 13.0 – 14.4 V Charging Current: 1.5 – 6.0 A	13.0 – 14.4 V (Charging)	Good	Effectively stored excess energy.
	Discharging (Backup Power)	Low Solar & Wind Availability	Discharging Voltage: 11.2 – 12.6 V Discharging Current: 1.0 – 5.0 A	11.2 – 12.6 V (Discharging)	Good	Provided backup power during low renewable energy availability.
Voltage Sensors (Monitoring)	System Operation	Continuous Monitoring	Solar, Wind & Battery Voltage Monitored in Real-time	Stable Readings	Stable	Voltage monitoring showed stable charging and discharging performance.

B. RELAY SWITCHING AND CONTROLLER RESULTS

Parameter	Description	Test Condition	Controller (Arduino Nano) Monitoring	Relay Action (Auto Switching)	Result	Observation
Solar Source	Voltage from Solar Panel	Solar Available (>13V)	Solar Voltage: 17.2 – 18.6 V Battery Voltage: 13.0 – 14.2 V Wind Voltage: 12.0 – 15.0 V	→ Relay connects Solar to Load	Success	Solar selected as primary source.
Wind Source	Voltage from Wind Turbine	Wind Available (>12V) & Solar Low	Wind Voltage: 13.0 – 15.8 V Battery Voltage: 12.8 – 14.0 V Solar Voltage: <13V	→ Relay connects Wind to Load	Success	Wind selected when solar not available.
Grid Source	AC Mains Power (Backup)	Solar & Wind Low Battery Low (<11.5V)	Grid Voltage: 220V AC Battery Voltage: <11.5V	→ Relay connects Grid to Load	Success	Grid selected as backup source.
Battery Source	Battery Power (Backup DC)	Solar & Wind Low, Grid Unavailable	Battery Voltage: 11.2 – 12.6 V	→ Relay connects Battery to Load	Success	Battery supplied power when other sources unavailable.
Overall Performance	The controller and relay circuit automatically switched between sources without interrupting system operation.			Reliable		Source selection was reliable, efficient and ensured continuous power supply.

C. MOTOR DRIVER AND ELECTRIC VEHICLE OPERATION RESULTS

Parameter	Test Condition	Input Source	Motor Voltage (DC)	Motor Current (A)	Motor Speed (RPM)	Performance	Observation
Motor Operation	Solar Available	Solar Panel	16.5 – 18.0 V	1.2 – 3.6 A	1200 – 2800	Smooth	Motor operated smoothly using solar power.
Motor Operation	Wind Available	Wind Turbine	13.0 – 15.5 V	1.0 – 3.2 A	1000 – 2500	Smooth	Motor operated smoothly using wind power.
Motor Operation	Low Renewable (Battery)	Battery (12V)	11.0 – 12.6 V	0.8 – 2.8 A	800 – 2200	Smooth	Motor operated using battery backup power.
Motor Operation	Grid Power (Backup)	Grid (via Adapter)	12.0 – 14.0 V	1.5 – 3.5 A	1100 – 2600	Smooth	Motor operated using grid power when needed.
Overall Result	The motor driver board successfully controlled the DC motor representing the electric vehicle load. The hybrid renewable energy system demonstrated efficient energy utilization, reduced dependence on conventional grid power, and reliable electric vehicle operation under different working conditions.					Excellent	Efficient, reliable and sustainable operation achieved.

CONCLUSION

The hybrid solar and wind energy system was successfully designed and implemented to provide continuous and sustainable power for electric vehicle operation. Both renewable sources generated electrical energy efficiently under varying environmental conditions.

The battery storage system effectively stored excess energy and supplied backup power during low renewable energy availability, ensuring uninterrupted operation of the electric vehicle system.

The Arduino Nano based controller accurately monitored voltages from solar, wind, and battery using sensors. The relay switching circuit automatically selected the available power source (solar, wind, battery, or grid) without interrupting system operation.

The motor driver successfully controlled the DC motor representing the electric vehicle load. The motor operated smoothly using renewable energy and battery backup under different working conditions.

The system reduced dependence on conventional grid power, promoted clean energy utilization, and demonstrated a reliable, efficient, and eco-friendly solution for sustainable electric vehicle applications.

Overall, the project achieved its objective of integrating solar and wind energy for sustainable electric vehicle operation with efficient energy management and automatic source switching.

FIG 2: RESULT & CONCLUSION OF SOLAR AND WIND ENERGY SYSTEM

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