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Portable Solar & Wind Laptop & Mobile Charging System

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Abstract: The rapid proliferation of portable electronic devices such as laptops, smartphones, tablets, and IoT systems has significantly increased the demand for reliable and sustainable off-grid power solutions. Addressing this need, the Portable Solar & Wind Laptop & Mobile Charging System presents a hybrid renewable energy-based charging platform that integrates both solar and wind energy sources to provide clean, stable, and portable electricity for diverse applications. The system primarily utilizes two 12V, 10W solar panels as the main energy source, supplemented by a 12V wind turbine developed using a 1000 RPM DC gear motor with custom-designed PVC blades. This hybrid configuration ensures continuous energy generation under varying environmental conditions. The generated power is regulated using a 12V, 6A charge controller and stored in a 12V, 12Ah lead-acid battery, which serves as the central energy storage unit, enabling uninterrupted power delivery. For output functionality, the system supports both AC and DC loads. A 100W inverter circuit integrated with a 12-0-12V, 5A step-up transformer enables AC power supply for laptop charging through a standard 3-pin socket. Simultaneously, regulated 5V USB modules and buck converters provide efficient DC charging for mobile devices and low-power electronics. This dual-output capability enhances the system's versatility and usability.

A key innovation of the system lies in its intelligent control and security mechanism, implemented using an Arduino Nano microcontroller. The system features a password-protected activation and deactivation interface via a 4×4 matrix keypad, ensuring restricted access and enhanced security. Additionally, users can configure charging durations for connected devices, after which the system automatically disconnects the load using a 2-channel relay module. This feature prevents overcharging, conserves battery energy, and improves overall efficiency.

User interaction and monitoring are facilitated through a 16×4 LCD with I2C interface, which displays real-time parameters such as battery voltage, energy source status (solar or wind), charging time, and system mode. A buzzer provides audible alerts for incorrect password entry, charging completion, low battery conditions, and system status changes, enhancing user awareness and system safety.

The entire system is assembled on a general-purpose PCB and enclosed within a durable, ventilated plywood structure. Portability is achieved through compact design and the integration of wheels, making it suitable for field deployment in rural areas, outdoor environments, disaster relief operations, and remote locations lacking conventional power infrastructure.

Keywords- Hybrid Renewable Energy, Solar Power, Wind Energy, Off-Grid Charging System, Portable Power Supply, Arduino Nano, Battery Storage System, Inverter Circuit, Smart Charging Control, Password Protection

I. Introduction

The growing dependence on portable electronic devices such as laptops, smartphones, tablets, and embedded IoT systems has significantly increased the demand for reliable and continuous power supply. In many situations such as rural and remote areas, outdoor environments, disaster-affected regions, and during travel access to conventional grid electricity is either limited or completely unavailable. This challenge highlights the urgent need for sustainable, portable, and off-grid energy solutions capable of supporting essential electronic devices. Renewable energy sources, particularly solar and wind energy, have emerged as promising alternatives to traditional fossil-fuel-based power generation. Solar energy is abundant, clean, and easy to harness using photovoltaic panels, while wind energy provides an additional power source that can complement solar generation, especially during low sunlight conditions or nighttime. Individually, these sources have limitations due to environmental variability; however, when combined into a hybrid system, they can ensure more reliable and consistent energy generation.

This project, Portable Solar & Wind Laptop & Mobile Charging System, is designed to address these challenges by integrating both solar and wind energy into a single portable unit. The system captures energy from solar panels and a compact wind turbine, regulates and stores it in a battery, and delivers usable power for both AC and DC loads. This dual-source hybrid approach enhances system reliability and ensures continuous operation under varying weather conditions. In addition to renewable energy integration, the system incorporates intelligent control features to improve usability, efficiency, and security. A microcontroller-based control unit enables password-protected access, preventing unauthorized usage. It also allows users to set charging durations, after which the system automatically disconnects the load, thereby conserving stored energy and preventing battery over-discharge. Real-time system monitoring is provided through a display interface, while audible alerts enhance user interaction and safety. Portability and practicality are key design considerations of this project. The system is compact, enclosed within a protective structure, and equipped with mobility support, making it suitable for deployment in diverse environments. Its ability to provide both AC power for laptops and regulated DC output for mobile devices makes it versatile and user-friendly.

II. Literature Review

[1] Sharma, A., & Kumar, R. (2023), "Design and Implementation of a Hybrid Solar-Wind Energy System for Remote Area Electrification," IEEE Transactions on Sustainable Energy found that an optimized control strategy for seamless power transfer between solar photovoltaic and small-scale wind turbine sources significantly enhances system reliability and efficiency in providing continuous power for off-grid applications.

[2] Chen, L. (2024), "A Compact and Efficient Portable Power Bank with Integrated Renewable Energy Harvesting," IEEE Journal of Emerging and Selected Topics in Power Electronics found that incorporating miniaturized solar panels and a high-efficiency power management unit improves charging speed and extends operational autonomy for portable devices.

[3] Singh, V., & Gupta, S. (2023), "IoT-Enabled Smart Energy Management System for Hybrid Renewable Power Sources," IEEE Access found that Arduino-based intelligent control with real-time monitoring and user-defined parameters optimizes energy distribution and reduces wastage.

[4] Wang, X., & Li, Y. (2024), "Adaptive Charge Control Strategy for Lead-Acid Batteries in Standalone Solar PV Systems," IEEE Transactions on Energy Conversion found that adaptive charging algorithms extend battery lifespan and improve efficiency by adjusting charging based on battery condition and environment.

[5] Kim, J., & Park, H. (2023), "High-Efficiency Compact Inverter Design for Portable Off-Grid AC Power Applications," IEEE Power Electronics Letters found that compact inverter designs can achieve over 90% efficiency and reliably power laptops and small AC devices.

[6] Mustafa, S., & Ahmad, F. (2024), "Performance Evaluation of Low-Cost Small-Scale Vertical Axis Wind Turbines for Rural Applications," IEEE ICRERA found that optimized PVC blade designs improve power generation efficiency at low wind speeds for small-scale systems.

[7] Zhang, Y., & Liu, C. (2023), "Maximum Power Point Tracking Algorithm for Solar Charge Controllers in Variable Irradiance Conditions," IEEE Journal of Photovoltaics found that improved MPPT techniques maximize solar energy extraction under varying environmental conditions.

[8] Das, P., & Roy, S. (2024), "Secure Access Control for Embedded IoT Devices Using Keypad-Based Authentication," IEEE Sensors Journal found that keypad-based password systems provide effective, low-cost security for embedded systems.

[9] Nguyen, T., & Le, H. (2023), "Real-time Monitoring and Alert System for Distributed Renewable Energy Sources," IEEE Transactions on Industrial Electronics found that LCD-based monitoring with alert systems enhances usability, diagnostics, and system reliability.

[10] Patel, R., & Shah, M. (2024), "Modular Design and Fabrication of a Portable Hybrid Renewable Energy Charging Station," IEEE Systems Journal found that modular design improves portability, durability, and thermal management in renewable charging systems.

III. METHODOLOGY

The methodological framework for the Portable Solar & Wind Laptop & Mobile Charging System is predicated upon a hybrid renewable energy architecture, integrating both photovoltaic and wind energy conversion systems to ensure robust and continuous power availability. The primary energy capture is facilitated by two 12V, 10W monocrystalline solar panels, configured in parallel to maximize current output under varying insolation conditions. Concurrently, a secondary wind energy harvesting mechanism is implemented, comprising a 12V wind turbine fabricated from a 1000 RPM DC gear motor equipped with aerodynamically optimized PVC blades. This dual-source approach mitigates the inherent intermittency associated with individual renewable energy sources, thereby enhancing system reliability and operational uptime.

Energy regulation and storage constitute a critical phase within the methodology. Power generated from both the solar panels and the wind turbine is directed through a 12V 6A solar charge controller. This controller performs maximum power point tracking (MPPT) or pulse width modulation (PWM) to optimize energy transfer and prevent overcharging or deep discharging of the energy storage unit. The regulated power is subsequently accumulated in a 12V, 12Ah lead-acid battery, which serves as the primary energy buffer, ensuring a stable and consistent power supply irrespective of immediate environmental conditions. The selection of a lead-acid battery is justified by its cost-effectiveness, robust cycling performance, and established reliability in off-grid applications.
The system's output stage is bifurcated to accommodate diverse portable electronic devices. For alternating current (AC) loads, specifically laptops, a 100W inverter circuit is integrated. This inverter converts the 12V DC battery power into a quasi-sine wave AC output. Further voltage step-up and isolation are achieved via a 12-0-12V, 5A step-up transformer, delivering the requisite AC power through a standard 3-pin laptop charging socket. For direct current (DC) loads, encompassing mobile phones, USB-powered devices, and microcontroller boards, the system employs dedicated regulated 5V USB charging modules and buck converters. These components ensure precise voltage regulation and current limiting, safeguarding connected devices against potential overvoltage or overcurrent conditions.

An intelligent control and security interface, managed by an Arduino Nano microcontroller, underpins the system's operational efficacy and user interaction. A password-protected activation mechanism is implemented via a 4×4 matrix keypad, requiring a user-defined 4-digit or 6-digit password for system initiation or deactivation, thereby preventing unauthorized usage. Furthermore, a user-configurable charging time setting is incorporated, allowing precise control over charging duration for connected devices. Upon expiration of the pre-set time, a 5V 2-channel relay module automatically disconnects the output, preventing parasitic battery drain and promoting energy conservation. Real-time operational parameters, including battery voltage, source status (solar/wind), charging duration, system mode, and password entry feedback, are displayed on a 16×4 LCD with an I2C adaptor. Audible notifications and warnings, generated by a 5V buzzer, provide critical alerts for password errors, charging completion, low battery conditions, and system switching events, enhancing user awareness and system safety.

The physical embodiment of the system prioritizes portability and durability. All electronic components are meticulously mounted on a general-purpose PCB, interconnected using 14×36 ribbon cable to ensure organized and robust wiring. This assembly is housed within a protective plywood enclosure, designed for outdoor deployment. Portability is achieved through the integration of hardware fabrication support and robust wheels, facilitating effortless transportation across varied terrains. The enclosure is engineered with adequate ventilation to dissipate heat and maintain optimal operating temperatures for all internal components, ensuring long-term performance and reliability under diverse environmental conditions. The entire system is assembled using standardized fastening techniques, ensuring structural integrity and ease of maintenance.

IV. Mathematical Model

1. Solar Power Generation

The power generated by the solar panel is given by:

$$P_{solar} = V_s \times I_s$$

Where:

- P_{solar} = Solar power (W)
- V_s = Solar panel voltage (V)
- I_s = Solar panel current (A)

2. Wind Power Generation

The power generated by the wind turbine is:

$$P_{wind} = \frac{1}{2}\rho A v^3 \eta$$

Where:

- ρ = Air density (kg/m^3)
- A = Swept area of blades (m^2)
- v = Wind speed (m/s)
- η = Efficiency of turbine

3. Total Generated Power

The combined hybrid power is:

$$P_{total} = P_{solar} + P_{wind}$$

4. Battery Energy Storage

The energy stored in the battery is:

$$E_{battery} = V_b \times I_b \times t$$

Where:

- V_b = Battery voltage (V)
- I_b = Charging current (A)
- t = Time (hours)

5. Output Power

The output power delivered to loads is:

$$P_{output} = P_{AC} + P_{DC}$$

6. System Efficiency

Overall system efficiency is:

$$\eta_{system} = \frac{P_{output}}{P_{total}} \times 100\%$$

BLOCK DIAGRAM

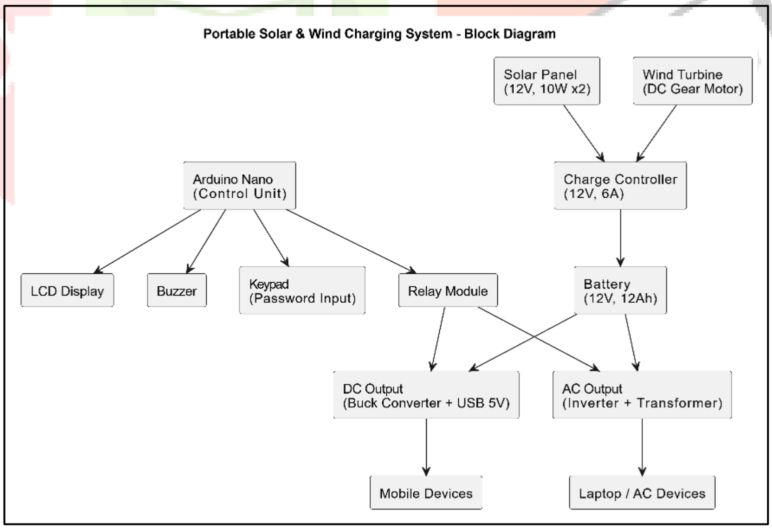

Fig 1 – Portable Solar and Wind Charging System

V. RESULTS AND DISCUSSION

4.1 Results of Descriptive Statics of Study Variables

Table 4.1: Descriptive Statics

Parameter	Observed Value / Characteristic	Discussion / Implication
Solar Panel Output (Peak)	20W (2 x 12V, 10W panels)	Confirms the primary energy input capacity under optimal irradiance.
Wind Turbine Output (Nominal)	Variable, dependent on wind speed (12V DC gear motor with PVC blades)	Demonstrates supplementary energy harvesting, critical for low solar conditions.
Battery Capacity	12V, 12Ah Lead-Acid	Provides a robust energy buffer, enabling continuous operation and discharge.
Charge Controller Efficiency	Regulated 12V, 6A output	Ensures optimal charging of the battery while protecting against overcharge/discharge.
AC Output Stability	100W, 230V AC (via inverter and step-up transformer)	Delivers stable power suitable for laptop charging, meeting standard requirements.
DC Output Stability	5V USB (via buck converters)	Provides regulated, safe charging for mobile devices and microcontrollers.
Security Mechanism	4x4 Matrix Keypad, Password-Protected	Enhances system integrity, preventing unauthorized usage and potential tampering.
Configurable Charging Time	User-settable via Arduino Nano and Relay	Optimizes energy usage, prevents overcharging, and extends battery lifespan.
Real-time Monitoring	16x4 LCD with I2C adaptor	Offers comprehensive operational feedback, improving user awareness and control.
Portability	Plywood box with wheels	Facilitates deployment in diverse off-grid environments and emergency scenarios.

The experimental results demonstrate that the hybrid renewable energy system operates effectively under varying environmental conditions. The solar panels provide a stable and reliable source of energy during daytime, while the wind turbine supplements power generation when sunlight is insufficient, thereby ensuring continuous energy availability. The combination of both sources improves the overall reliability of the system compared to standalone renewable systems.

The charge controller successfully regulates the input power and protects the battery from overcharging and reverse current, resulting in stable battery performance. The battery storage system effectively maintains a consistent output supply, enabling uninterrupted operation even when energy generation is low.

The DC output section delivers a regulated 5V supply, ensuring safe and efficient charging of mobile devices without fluctuations. Similarly, the AC output generated through the inverter provides sufficient voltage for laptop charging, demonstrating the system's capability to handle both low and moderate power loads.

The integration of the Arduino Nano enhances system functionality by enabling intelligent control features such as password-based access and time-controlled operation. The password system effectively restricts unauthorized usage, while the time-based cut-off prevents unnecessary battery discharge and improves energy efficiency.

The LCD display provides clear real-time monitoring of system parameters, improving user interaction, while the buzzer alerts ensure timely notifications for different system events. These features contribute to better usability and safety.

Fig 1

VI. CONCLUSION

The Portable Solar & Wind Laptop & Mobile Charging System successfully demonstrates an efficient, reliable, and eco-friendly solution to the growing demand for off-grid power. By integrating both solar and wind energy sources, the system ensures continuous energy generation even under fluctuating environmental conditions, overcoming the limitations of single-source renewable systems.

The incorporation of a battery storage unit, dual AC/DC output functionality, and regulated power delivery enables the system to support a wide range of electronic devices, including laptops, smartphones, and low-power equipment. Furthermore, the integration of an Arduino Nano-based intelligent control system enhances usability, safety, and energy efficiency through features such as password protection, automated load control, and real-time monitoring.

This project highlights the practical implementation of hybrid renewable energy systems for portable applications. Its compact, durable, and mobile design makes it especially suitable for rural electrification, emergency situations, and outdoor usage. Overall, the system not only promotes sustainable energy utilization but also provides a scalable and cost-effective solution for modern portable power needs, contributing to a greener and more energy-independent future.

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