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AI Optimization for Hybrid Sources in Battery Management System

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ABSTRACT - This paper presents a hybrid power generation system that solar power and wind such as renewable energy supports regular electricity settings. Integrate with mixture of power production in stations for renewable energy out turn intermittent possibility and differ the load requirements causes challenges combat. Battery cells in the mixing of in active will be enabled, battery management system (BMS) settings for charging in cycles improve and through safe limitations outside the cells running condition to prevention this reduce. A battery life times lasting besides change expenses in low conventional power system essential to ensure efficiency of power utilization is well for smart grid modern hybrid power system energy optimization. It is beneficial based on intelligent decision-making, the system adaptively and intelligently controls the power, optimizing battery performance. This results in reduced energy losses, improved power system reliability and efficient utilization of renewable energy sources. The proposed approach supports sustainable energy management and is suitable for modern smart grid applications.

KEYWORDS: Hybrid Renewable Energy System, Solar-Wind Integration. AI-Based Energy Management, Battery Management System.

I. INTRODUCTION

The rapid growth in global energy demand and the depletion of conventional fossil fuel resources have increased the need for renewable energy–based power systems. Renewable energy sources such as solar and wind are widely used because they are environmentally friendly, sustainable, and reduce carbon emissions. However, these sources are intermittent and unpredictable, which makes efficient power management a challenging task. To ensure continuous and stable power supply, hybrid energy systems combined with intelligent control techniques are becoming increasingly important.

A Battery Management System (BMS) plays a vital role in renewable energy systems by monitoring and controlling the charging and discharging of batteries. It ensures battery safety, improves battery life, and maintains optimal performance. In hybrid renewable systems that integrate solar and wind energy sources, the BMS must manage multiple energy inputs while maintaining stable voltage and current levels for the connected load. Without proper management, batteries may suffer from overcharging, deep discharging, or inefficient energy utilization.

To address these challenges, Artificial Intelligence (AI) techniques can be used to optimize energy flow and improve decision-making in hybrid power systems. AI algorithms can analyze real-time data such as voltage, current, and load conditions to determine the most efficient way to utilize available energy sources. By integrating AI with embedded systems, the hybrid power system can automatically adjust charging, discharging, and load distribution, thereby improving system efficiency and reliability.

In the proposed system, solar and wind energy sources are integrated through power conditioning circuits such as a boost converter and voltage regulator. The generated energy is stored in a battery that is monitored and controlled by a Battery Management System. An Arduino Uno microcontroller collects voltage and current data from sensors and processes it using an AI-based embedded C program. The system also includes IoT connectivity and an LCD display using I2C communication for real-time monitoring of system parameters. A relay module controls the connection between the battery and the load, while a DC-to-AC converter supplies AC power to the load.

The integration of AI optimization with hybrid renewable energy sources provides an intelligent and efficient energy management solution. This system helps improve battery performance, maximize renewable energy utilization, and ensure reliable power supply for various applications such as smart homes, remote power systems, and micro grid energy management.

II. PROPOSED SYSTEM

The proposed system introduces an Artificial Intelligence (AI)–based optimization technique for managing hybrid renewable energy sources integrated with a Battery Management System (BMS). The system combines solar and wind energy sources to generate electrical power and store it in a rechargeable battery. An intelligent control mechanism is used to efficiently manage energy flow between the renewable sources, battery storage, and load.

In the proposed model, a microcontroller-based control unit (such as Arduino Uno) continuously monitors important battery parameters including voltage, current, and charging status through sensing modules. The collected data is processed using an AI-based algorithm that analyzes energy availability and load demand. Based on this analysis, the system automatically decides the optimal charging or discharging strategy for the battery, ensuring efficient energy utilization and improved battery performance.

The generated power from renewable sources is regulated using power conditioning circuits such as boost converters and voltage regulators before being stored in the battery. A relay module is used to control the power supply to the load depending on battery condition and energy availability. The system also includes an IoT communication module and an LCD display with I2C interface to provide real-time monitoring of system parameters such as battery voltage, power generation, and load status.

Additionally, a DC-to-AC inverter is used to convert stored DC power from the battery into AC power for operating electrical loads. The integration of AI optimization helps in predicting energy demand, improving battery life, and reducing energy losses. This intelligent system enhances the overall efficiency, reliability, and sustainability of hybrid renewable energy systems, making it suitable for applications such as smart homes, microgrids, remote power systems, and renewable energy storage solutions.

III. EXISTING SYSTEM

In existing renewable energy systems, hybrid energy sources such as solar and wind are integrated with battery storage to supply power to electrical loads. These systems generally use conventional control methods and simple battery management techniques to regulate energy flow. The battery management system monitors parameters such as battery voltage, current, and temperature to ensure safe operation. Basic controllers or microcontrollers are commonly used to manage charging and discharging processes.

Most traditional hybrid energy systems rely on rule-based control or fixed algorithms to distribute power between renewable sources and the battery. These systems typically use charge controllers, voltage regulators, and DC-DC converters to maintain proper voltage levels. The energy generated from renewable sources is stored in batteries and later supplied to loads through inverters or power converters. Although these systems can provide backup power and support renewable energy integration, their control strategies are limited in adapting to changing environmental conditions. In many existing systems, the decision-making process is not intelligent and cannot predict energy demand or generation patterns. As a result, inefficient energy utilization, battery overcharging, deep discharging, and reduced battery lifespan may occur. The lack of advanced monitoring and optimization techniques also limits the overall performance and reliability of the system. Furthermore, most conventional systems do not include real-time monitoring or IoT connectivity, making it difficult to analyze system performance remotely. Therefore, existing hybrid battery management systems face challenges in terms of energy optimization, battery safety, and system efficiency. These limitations highlight the need for an advanced solution that integrates artificial intelligence and intelligent monitoring to improve hybrid energy management and battery performance.

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IV. BLOCK DIAGRAM

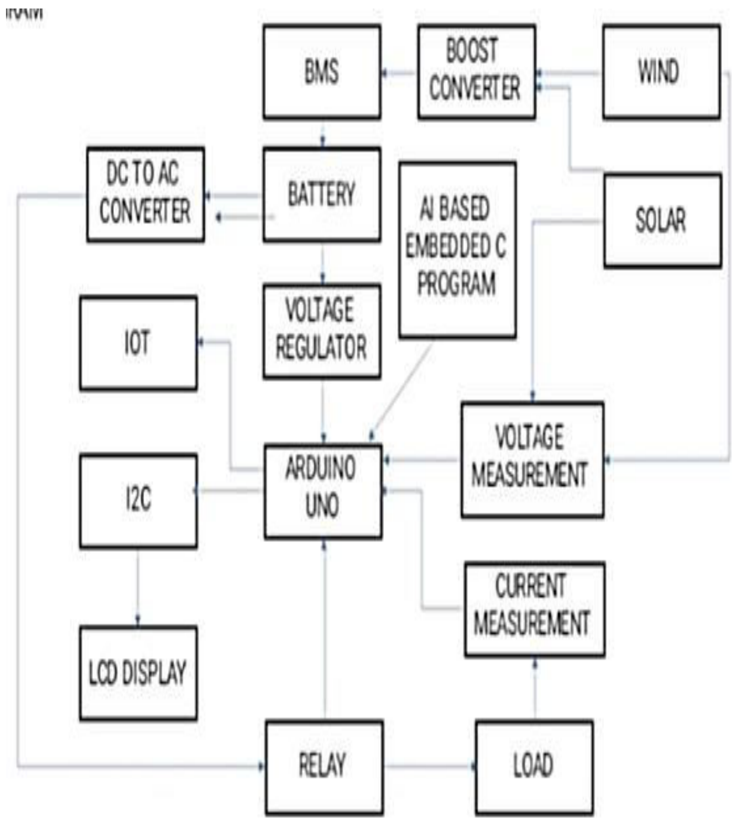

Fig: (1)

V. COMPONENTS RECQUIRED

- BMS
- DC TO AC CONVERTER
- BATTERY
- VOLTAGE REGULATOR
- BOOST CONVERTER
- WIND
- SOLAR
- ARDUINO UNO
- VOLTAGE MEASUREMENT
- CURRENT MEASUREMENT
- RELAY
- I2C
- IOT MODULE
- LCD DISPLAY

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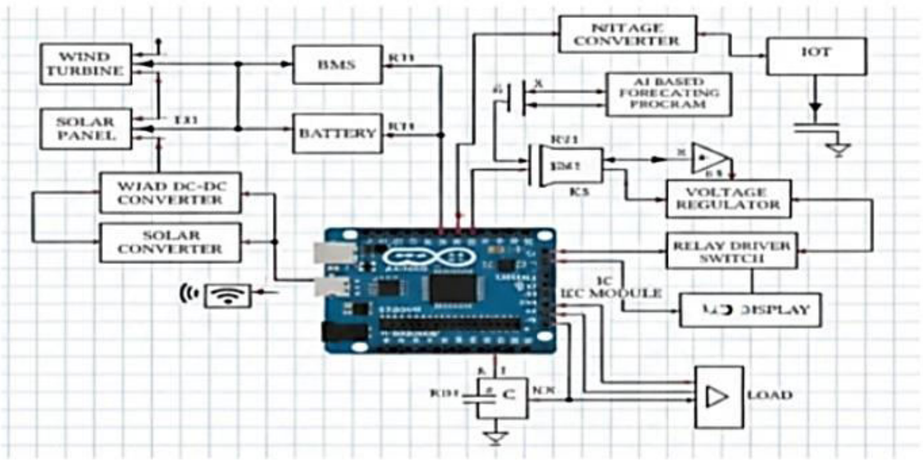
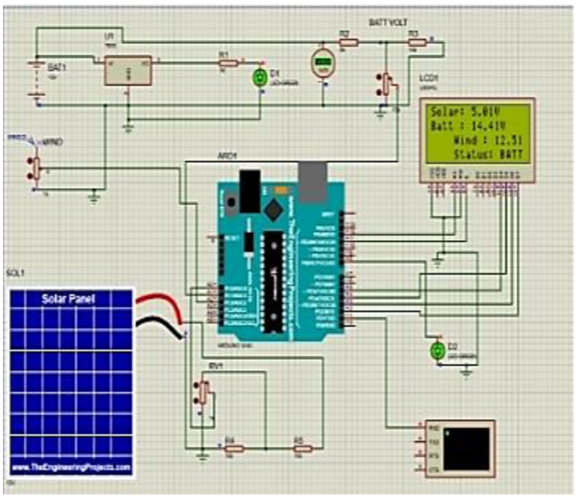
VI. CIRCUIT MODELLING



The circuit represents a hybrid renewable energy system involving solar and wind power with an Arduino microcontroller as its controller.

Fig: (a)



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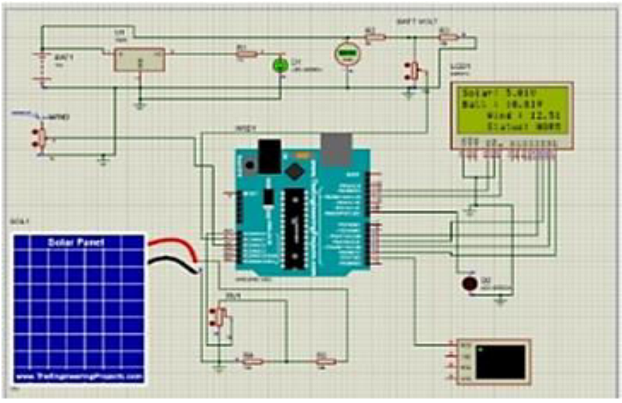

Arduino microcontroller as its controller. The wind turbine and solar panel produce the variable DC voltage that is conditioned through DC–DC converters and one solar converter to supply an invariable voltage.

This controlled power is controlled by a BMS who carefully control the charging and discharging of the battery by monitoring both voltage and current. The Arduino is used as a master, collecting the data from the sensors and switching things on using a relay driver circuit. A voltage stabilizer minimizes the variance to sensitive electronics, and a DC module and filter capacitors eliminate ripples.

An Artificial Intelligence (AI) forecasting application forecasts the energy supply and an IoT module allows remote monitoring and data transmission. System status and electrical parameters are presented on an LCD and the conditioned output power is transferred to load, resulting in efficient, reliable and intelligent use of energy.

VII. SIMULATION MODELLING

The simulation models a solar-energy powered monitoring and control system for an Arduino Uno. On the simulation results, we can see that solar panel delivers DC power(through regulator and charging circuit) to battery and arduino. The Arduino is constantly sampling readings from the sensors such as battery voltage, charging current and temperature (the numerical reading are displayed on the LCD). These results also verify that the system is sensing real-time parameters appropriately and digitizing them.

The LCD shows successful retrieval and presentation of data, the battery voltage is stable and charging is

controlled. Furthermore the switching devices (relay or transistor, and displays) react to what has been sensed, which also demonstrates that the control logic is operating correctly. Overall, the simulation results confirm that the system is capable of real-time monitoring solar input energy, charging control of batteries and displaying operation parameters for efficient and safe solar powered system.
The output of the simulation shows that there is a true functioning of the solar power monitoring and control system under simulated environment. The DC voltage from the solar panel is sensed by the Arduino via a voltage and current sensing circuits. The microcontroller is constantly processing these sensed values.
Solar / Battery voltage (V) – displays the actual battery or solar source Voltage detection.

I (min-I) – denotes as the charging or load current.

Power (W) – computed by Arduino from voltage and current reading.

Battery Status - not just charging

During the simulation: When the voltage of the solar power is enough, it begins to work and charge the battery bank and finally make the battery full under high voltage.
The relay or switching circuit are turned on off in response to pre-set voltage limits, and thereby failure of over-charging and deep discharge is avoided .Indicator LEDs turn ON/OFF to the condition.

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VIII. APPLICATIONS AND FUTURE SCOPE

The proposed AI-optimized BMS is suitable for smart grids, microgrids, electric vehicle charging stations, remote rural electrification, and industrial hybrid power plants. Future work includes real-time hardware implementation, IoT-based monitoring, and digital twin integration.

IX. CONCLUSION

In this paper, an intelligent AI optimization framework for hybrid energy sources integrated with a Battery Management System (BMS) has been successfully developed and tested. The proposed system efficiently integrates renewable energy sources such as solar and wind energy with battery storage systems to overcome the difficulties associated with intermittent power supply, dynamic load, and battery degradation. The BMS continuously tracks critical battery parameters such as state of charge (SOC), state of health (SOH), temperature, and voltage using AI-driven decision-making. The proposed optimization system improves charging and discharging operations by identifying the optimal energy source based on availability and demand. This leads to efficient energy management, reduced power losses, and balanced battery usage.

The intelligent control system also reduces battery cell stress, thereby increasing battery life and system reliability. The simulation results confirm the effectiveness of the proposed approach by demonstrating stable power flow management, enhanced battery performance, and better performance compared to conventional rule-based systems.In conclusion, the proposed AI-optimized hybrid BMS system is an efficient and flexible solution for contemporary energy management systems, especially in renewable energy integration, electric vehicles, and smart grid systems. The results clearly show that intelligent optimization techniques are essential for developing sustainable, efficient, and reliable energy management systems.

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