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Hybrid Wind, Battery, and Solar System for Enhanced Efficiency and Reliability of Power System: A Review

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Abstract: *This paper presents the design, integration, and analysis of a hybrid power system combining wind energy, solar photovoltaic (PV) energy, and battery storage to provide a sustainable and reliable energy solution. The proposed system leverages the complementary nature of wind and solar energy, ensuring consistent power generation throughout varying environmental conditions. The inclusion of battery storage enhances energy reliability by mitigating intermittency issues and optimizing energy utilization. Key components of the hybrid system are modeled and analyzed for efficiency, cost-effectiveness, and environmental impact. Simulation results demonstrate the system's ability to meet energy demands while reducing dependency on conventional energy sources. This study provides valuable insights into the design and optimization of hybrid renewable energy systems for both grid-connected and off-grid applications.*

Keywords: Hybrid power system, wind energy, solar photovoltaic (PV), battery storage, renewable energy integration, energy reliability, sustainable energy, energy management, hybrid system optimization

I. INTRODUCTION

The growing demand for sustainable and reliable energy solutions has propelled the exploration and integration of renewable energy sources into hybrid power systems. Among these, wind energy and solar photovoltaic (PV) systems stand out as complementary sources due to their availability in diverse environmental conditions. However, the intermittent nature of these sources necessitates effective energy management and storage solutions to ensure continuous and reliable power supply. The integration of battery storage systems within hybrid energy configurations provides a viable approach to addressing these challenges by stabilizing power output and enhancing energy utilization. This paper focuses on the design, integration, and performance analysis of a hybrid power system that combines wind energy, solar PV, and battery storage. By leveraging the inherent strengths of each component, the proposed system offers a balanced and efficient solution for renewable energy utilization in both grid-connected and off-grid scenarios. The study examines the system's ability to meet energy demands under varying environmental conditions while minimizing reliance on conventional energy sources and reducing environmental impact. Simulation-based analysis is conducted to evaluate the efficiency, cost-effectiveness, and sustainability of the system. The findings highlight the potential of hybrid renewable energy systems in addressing global energy challenges, paving the way for innovative solutions in energy management and renewable energy integration. This paper provides a comprehensive framework for designing and optimizing hybrid power systems to meet the evolving energy needs of modern society.

II. LITERATURE SURVEY

The increasing global focus on sustainable energy systems has driven significant advancements in hybrid power systems integrating renewable energy sources such as wind, solar photovoltaic (PV), and battery storage. This section

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reviews key studies that have contributed to the understanding, design, and optimization of hybrid renewable energy systems.

The inherent variability of renewable energy sources is a significant challenge to their widespread adoption. Research has demonstrated that combining wind and solar energy can leverage their complementary characteristics to mitigate fluctuations in power generation. Li et al. (2018) analyzed the temporal and spatial complementarity of wind and solar energy, concluding that a well-designed hybrid system could stabilize power supply across seasons and geographic locations [1]. Sharma and Mehta (2019) further explored this concept by simulating hybrid systems in different climatic zones, emphasizing that site-specific design is crucial for maximizing energy output and system reliability [2]. Battery storage plays a vital role in addressing the intermittency of renewable energy sources. Kumar et al. (2020) investigated the economic feasibility of integrating advanced battery technologies into hybrid systems, revealing that lithium-ion batteries provide a cost-effective and efficient solution for energy storage [3]. Park et al. (2021) highlighted the importance of battery energy management systems (BEMS) in prolonging battery life and improving energy dispatch in hybrid configurations [4]. Effective energy management strategies are critical to optimizing hybrid systems. Chen et al. (2021) proposed an intelligent energy management algorithm that dynamically allocates power between wind, solar, and battery systems based on real-time demand and environmental conditions [5]. Similarly, Rahman et al. (2022) developed a hybrid power management strategy using artificial intelligence (AI) techniques, which demonstrated improved system efficiency and reliability under varying load conditions [6]. The cost-effectiveness of hybrid systems is another area of extensive research. Ahmed and Khan (2022) performed a detailed economic analysis, showing that hybrid systems are financially viable when optimized for local energy demands and resource availability [7]. Gupta and Sharma (2019) emphasized the role of government subsidies and policy support in promoting the adoption of hybrid systems, particularly in rural and remote areas [8]. Hybrid renewable energy systems offer a promising solution to reducing greenhouse gas emissions and mitigating climate change. Smith et al. (2017) conducted a life cycle assessment of a hybrid wind-solar-battery system, reporting a substantial reduction in carbon emissions compared to traditional fossil fuel-based systems [9]. Chowdhury et al. (2020) evaluated the environmental benefits of hybrid systems deployed in urban areas, demonstrating significant improvements in air quality and reductions in energy-related pollutants [10]. Hybrid systems have shown versatility in both grid-connected and off-grid scenarios. Singh et al. (2021) analyzed grid-connected hybrid systems, highlighting their potential to enhance grid stability and reduce peak demand [11]. Das et al. (2020) examined off-grid applications in rural areas, where hybrid systems provide a reliable and sustainable alternative to diesel generators [12]. Despite the advancements, several challenges persist in hybrid power system design and deployment. These include high initial costs, limited scalability, and technical complexities in system integration. Patel et al. (2021) identified the need for advanced modeling techniques and robust control systems to address these challenges [13]. Future research is expected to focus on improving energy storage technologies, enhancing system flexibility, and developing innovative financing models to accelerate the adoption of hybrid renewable energy systems.

III. METHODOLOGY

The project implementation is done using MATLAB Simulink software. The major blocks is designed in MATLAB as:

1) Simulation of wind energy system using application library in sim power system toolbox.
2) Simulation of solar PV system and MPPT (maximum power point tracking) algorithm using sim power system and commonly used Simulink blocks.
3) Simulation of inverter circuit using power electronics library.
4) Simulation of power system and grid using sim power system toolbox.
5) Simulation of common coupling point for synchronization of wind/solar system to main power system grid.
6) Simulation of infinite bus and LC filter using sim power system toolbox.

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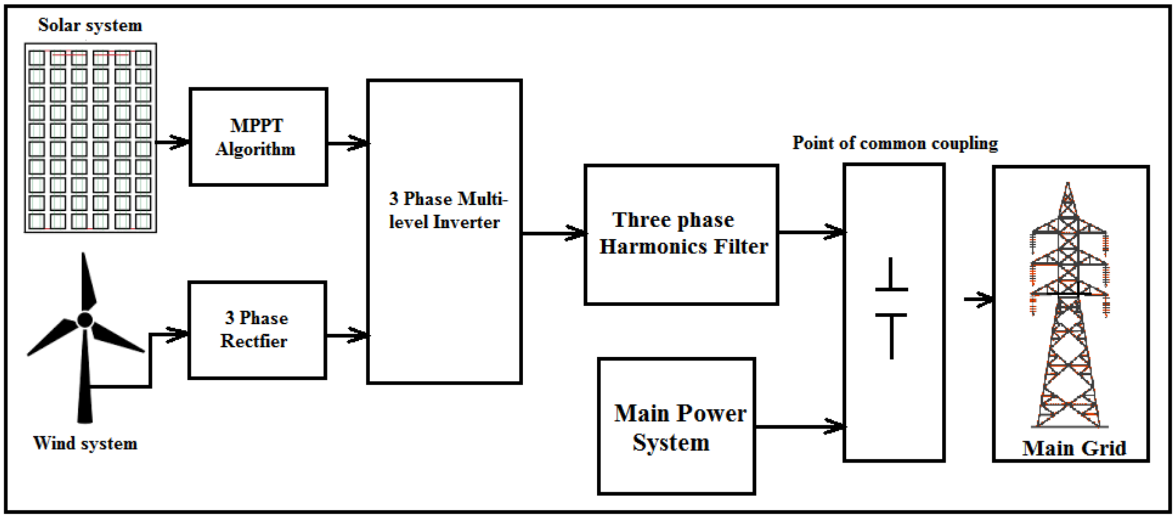

Fig.3. Block diagram of proposed hybrid power system

It proposed methodology shown in figure 3 implemented using MATLAB Simulink software in which Sim power system toolbox utilized for hybrid power system design, wind energy system design, solar pv system, battery energy system and dc to dc converter subsystem design. Figure 4 shows the complete MATLAB simulation model of proposed approach. The complete MATLAB simulation model of hybrid power system in which solar PV system and wind energy system generates DC power. This DC power get fed to MPPT maximum power point tracking system for reaching the maximum available DC power from solar and wind energy system. This maximum available power then fed to inverter which convert this dc power to ac power which fed to AC grid by proper synchronization. In parallel with this process one battery charging unit was connected for charging battery. That battery charging is utilized for dc applications.

Solar PV Subsystem Model

Fig. 4 shows a solar PV subsystem in which solar PV cell output dc terminal connected with maximum power point tracking (MPPT) algorithm block for calibrating or tracking maximum solar dc output voltage according to irradiation available at atmospheric condition.

The interconnection of 36 solar cell for achieving the desire ratings. After series and parallel connection diode connected to solar cell power output for avoiding the back power or reverse bias condition. That diode is called as revere blocking diode which avoid the reverse current of reverse polarity of solar cell during rainy or cloudy season due to shading effect.

Wind energy subsystem model

A wind energy turbine system in which wind turbine generates the AC three phase power then transfer to rectifier circuit for conversion of AC power to DC power. Because solar power system output becomes in DC form but wind energy generator power in AC form then for coupling both the solar and wind energy system we need to convert wind energy AC power into DC power with equal magnitude.

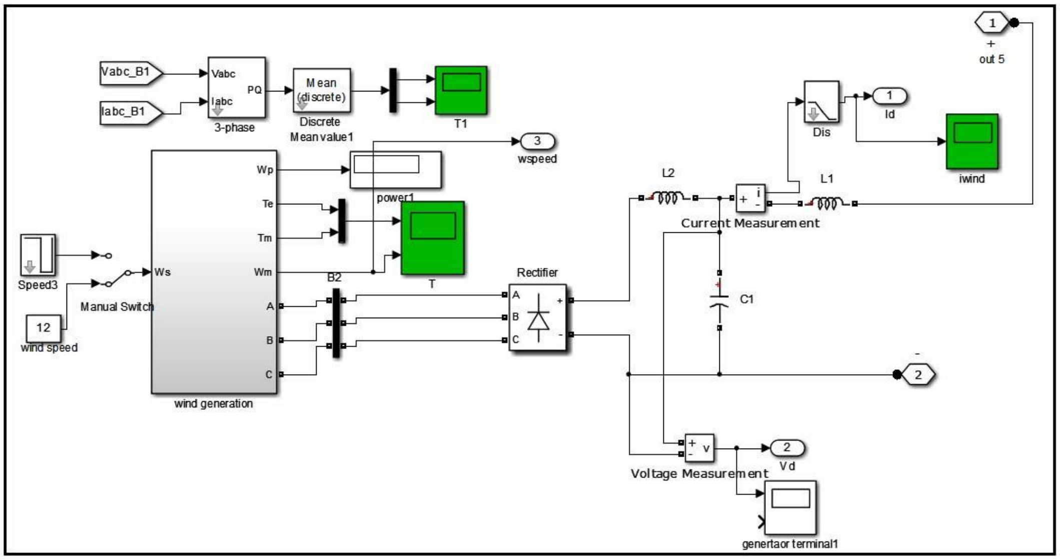

Fig.5. Solar PV subsystem MATLAB model coupled with MPPT algorithm subsystem

MPPT TECHNIQUE

PV modules are fluctuating according to their environmental condition.so we need to use control technique which help to get high power regardless environmental condition alike temp. & irradiance.

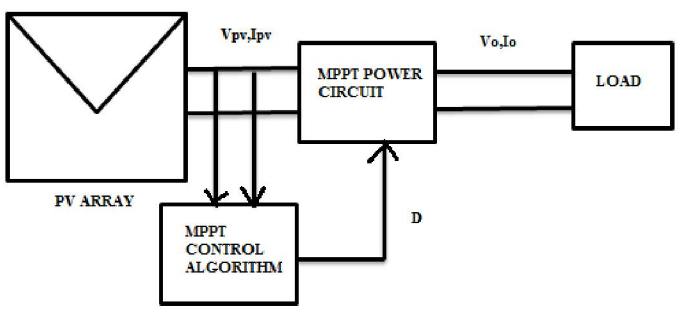

Fig.6 Block diagram of MPPT control

Fig. 4 shows block diagram of MPPT control .There is have to existence a maximum power point because PV cell has nonlinear relationship that is hold on growing with atmosphere condition ,temp.& irradiance level. In this paper perturb and observe (P&O) technique is applied for tracking maximum power at varying temp.& irradiance. It conducts by continually evaluate the terminal voltage and current of PV array, then continually perturbing the voltage by addition small interrupt ,then observing the modification of power to find control signal. Variation developed by variable switching duty cycle. Duty cycle is control by perturb & observation (P&O) MPPT algorithm [6]. DC-DC boost converter is used to convert dc to high level DC output voltage.

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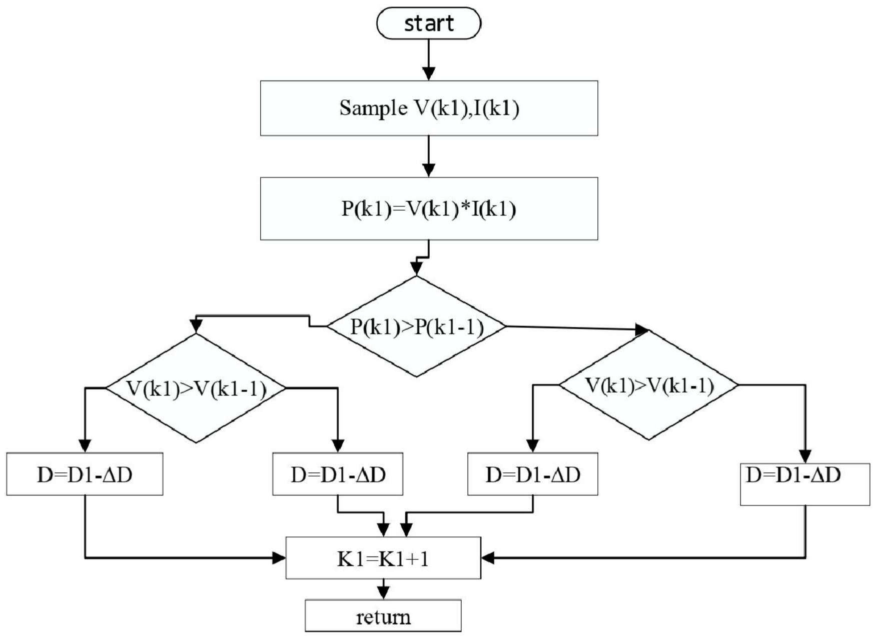

Fig 7 MPPT Flow Chart

FACILITIS REQUIRED FOR PROPOSED WORK

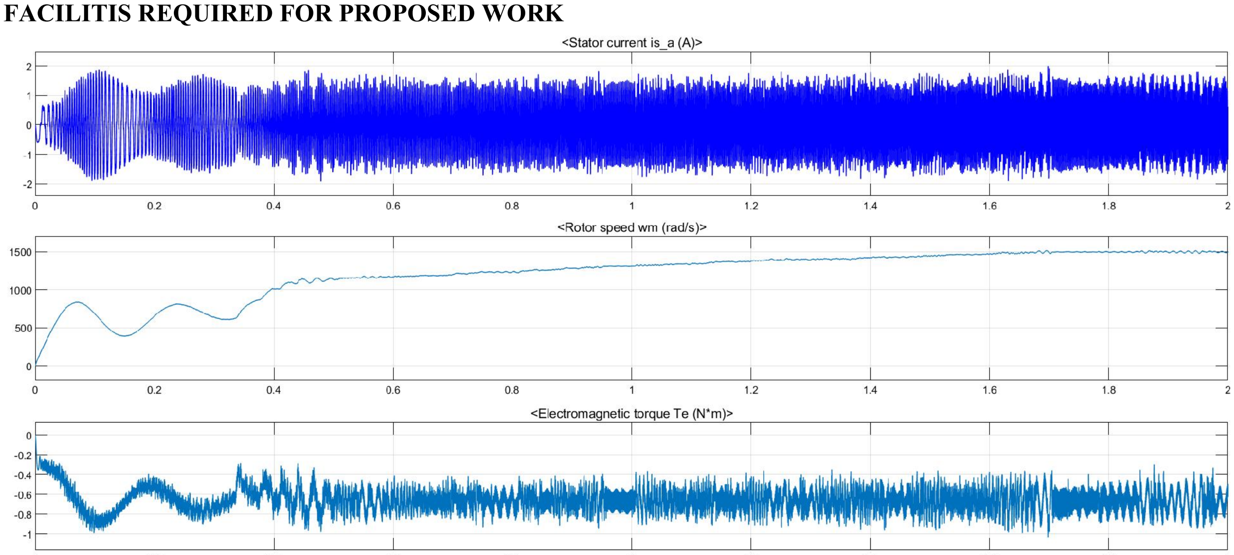

Fig 8 output voltage when hybrid system connected to grid

DC voltage after using boost converter which is boost PV array voltage to a high level dc voltage with MPPT technique & wind turbine output in which PMSG wind turbine produce AC voltage and then rectifier transform AC to DC voltage , Fig.13 show dc boost voltage after coupling both PV/Wind subsystem. Three phase AC voltage after using inverter which is not in pure sinusoidal form & three phase AC voltage without any fluctuation when we connected system to grid respectively.

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IV. CONCLUSION

This Paper represents a hybrid system which is comprised solar and wind generation system and controlled by voltage regulator. By using MATLAB software simulation was controlled .The operation of system is evaluate at various wind speed and irradiance stages. The introduce hybrid system is examine wind speed at 12m/s and solar PV panel at irradiance 1000w/m2 and temp 250 form t= 0 to t=0.3sec. is applied then coupled both DC voltage to DC link is controlled by voltage regulator and performance is evaluate & improved. To fulfill the requirement of electricity in a remote area hybrid system is used. The developed system working is performed in Matlab/Simulink software and results are displayed .Other renewable energy sources is used for hybrid system instead PV/Wind energy sources and to get more reliable and satisfied results several control technique is used for inverter in place of voltage regulator.

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