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Research Paper

SIMULATION OF HYBRID PV - WIND ENERGY SYSTEM USING MATLAB/SIMULINK

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ABSTRACT

This project focuses on the design and development of a multi-input inverter for a grid-connected hybrid renewable energy system that integrates photovoltaic (PV) and wind energy sources. The proposed system combines a multi-input buck/buck-boost DC–DC converter with a full-bridge DC–AC inverter, enabling efficient power conversion from multiple renewable sources using a single inverter unit. This integrated approach reduces hardware complexity, system cost, and conversion losses while improving overall reliability. To ensure maximum utilization of available renewable energy, a Perturb and Observe (P&O) based Maximum Power Point Tracking (MPPT) algorithm is implemented to extract maximum power from both PV and wind sources under varying environmental conditions. The entire control strategy is implemented using a Digital Signal Processor (DSP), which provides precise and fast control for stable grid interfacing. Additional features such as soft-start operation, overcurrent protection, and voltage regulation are incorporated to enhance system safety and performance. Simulation results validate the proposed inverter's effectiveness, demonstrating efficient power sharing, high conversion efficiency, and stable grid synchronization. The proposed system offers a practical and cost-effective solution for hybrid renewable energy integration in grid-connected applications.

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1. INTRODUCTION

1.1 Background

Energy is essential for industrial development, technological progress, and modern living. For many years, fossil fuels such as coal, oil, and natural gas have been the primary sources of energy. However, excessive dependence on these non-renewable resources has caused serious environmental problems, including air pollution, global warming, and depletion of natural reserves. The emission of greenhouse gases like carbon dioxide has increased climate change, creating an urgent need for clean and sustainable energy alternatives. Renewable energy sources, especially solar and wind, have gained significant importance due to their availability and low environmental impact. Solar energy is converted into electricity using photovoltaic (PV) panels, while wind energy is generated using wind turbines.

Although these sources are eco-friendly, their power output is highly variable. Solar energy depends on sunlight availability, while wind energy varies with wind speed. This intermittency makes it difficult to maintain a stable and continuous power supply when these systems operate independently. To overcome these limitations, hybrid renewable energy systems combining solar and wind power have been introduced. A PV–wind hybrid system improves reliability by utilizing the complementary nature of both sources. When solar power is low, wind energy can compensate, and vice versa. Hence, hybrid systems provide a more stable and efficient solution for renewable energy generation.

1.2 Importance of Hybrid Systems

Hybrid renewable energy systems integrate two or more energy sources to improve system reliability and performance.

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The combination of solar and wind energy is particularly effective because their availability patterns complement each other. Solar power is generally higher during daytime, while wind energy is often available during night hours or different seasons. These systems reduce dependence on fossil fuels and help lower greenhouse gas emissions. Hybrid systems also decrease the need for large energy storage units by ensuring that at least one energy source is available most of the time. In rural and remote areas where grid connectivity is limited, hybrid systems provide a reliable and cost-effective solution for electrification. Additionally, hybrid systems support decentralized power generation, which reduces transmission losses and improves energy security. Their flexibility and efficiency make them suitable for both grid-connected and standalone applications, contributing to a sustainable energy future.

1.3 Objectives of the Study

The main objective of this study is to design and simulate a hybrid photovoltaic–wind energy system using MATLAB/Simulink. The specific objectives include modeling PV and wind energy systems, integrating them through a common DC link, and implementing Maximum Power Point Tracking (MPPT) techniques to maximize energy extraction. The study also aims to include energy storage and an inverter to supply stable AC power and to evaluate system performance under varying environmental conditions. A comparison with standalone systems is conducted to highlight the advantages of the hybrid configuration.

1.4 Methodology Overview

The proposed hybrid system is modeled and simulated using MATLAB/Simulink. The PV system is developed using a single-diode model and controlled using a Perturb and Observe (P&O) MPPT algorithm to ensure maximum power output. The wind energy system is modeled using a wind turbine coupled with a Permanent Magnet Synchronous Generator (PMSG). Both systems are connected to a common DC bus through appropriate converters. A battery energy storage system is included to store excess energy and supply power during low generation periods. The DC power is converted to AC using an inverter to feed AC loads. The system is tested under varying solar irradiance and wind speed conditions to analyze its efficiency, stability, and reliability. The simulation results demonstrate that the hybrid PV–wind system performs better than individual renewable systems.

2.NONCONVENTIONAL ENERGY SOURCES

2.1 INTRODUCTION

This chapter provides a brief overview of the nonconventional energy sources used in the project, including wind energy, hydro power, photovoltaic (PV) systems, and battery storage. Each source is introduced with essential definitions and fundamental concepts to help understand their roles in the overall energy system.

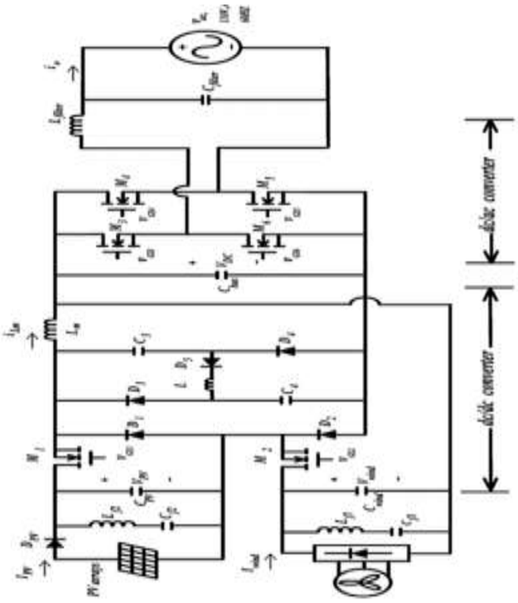


Fig: 2.1 Schematic diagram of the proposed multi-input inverter

The specifications of the solar module supplied by the manufacturer's data sheet are as shown in Table.3.1.

At Temperature T = 25°C, Insulation G=1000W/m²		
Open Circuit Voltage	V_{OC}	21.0 V
Short Circuit Current	I_{SC}	3.74A
Voltage At Maxpower	Vm	17.1V
Current At Max Power	Im	3.5A
Maximum Power	Pm	60.0W

Table 2.1: The key specifications of the solar MSX – 60 PV panel

2.2 Wind System:

Wind energy connected to the power grid is currently experiencing one of the fastest growth rates among all electricity generation technologies, with global annual increases estimated at 20–25%. No other energy source has demonstrated such rapid development. For instance, the total installed global wind power capacity rose from
47.6 GW in 2004 to 58.9 GW in 2005. As a result, wind energy is increasingly being considered a reliable and mainstream source of electricity generation.

Its growing appeal has led many countries to set ambitious targets for expanding wind energy in their national energy strategies. In several nations, wind power has gained a larger share in electricity supply systems. However, this rising share brings new technical challenges. Due to the variable, uncontrollable, and non-dispatchable nature of wind energy, integrating it into power grids where balance and stability are critical can be complex.

Addressing these challenges is essential for continued expansion. Solutions such as combining outputs from multiple wind turbines (aggregation), improving demand and wind forecasting methods, and conducting detailed simulation studies are crucial for enabling higher levels of wind power integration into modern grid systems.

3. POWER ELECTRONIC CONVERTERS

Introduction

Over the past few decades, inverter technology has undergone significant advancements to meet the growing requirements of modern power systems. Conventional two-level inverters were initially used for DC–AC power conversion; however, they faced limitations in high-voltage applications due to excessive switching stress, high dv/dt, and increased harmonic distortion. These issues became more critical when supplying sensitive loads or operating over long transmission lines. Earlier power semiconductor devices also had limited switching speeds, resulting in high switching losses and restricting converter operating frequencies to only a few kilohertz. In addition, their voltage blocking capability was typically below one kilovolt, making traditional inverter topologies unsuitable for medium- and high-voltage applications. These drawbacks highlighted the need for advanced converter structures capable of delivering higher voltage levels with improved efficiency, better waveform quality, and reduced electrical stress on system components.

4.1 Types of Multilevel Inverters

Multilevel inverters (MLIs) have emerged as an effective solution for high-power and high-voltage applications. These inverters generate output voltages with multiple discrete levels, producing waveforms that closely resemble a sinusoidal shape. As a result, they offer several advantages, including reduced harmonic distortion, lower dv/dt, and decreased common-mode voltage. The fundamental principle of multilevel inverters involves connecting multiple low-voltage-rated power semiconductor devices in series, along with multiple DC voltage sources or capacitors. This structure enables the generation of higher output voltages in smaller voltage steps

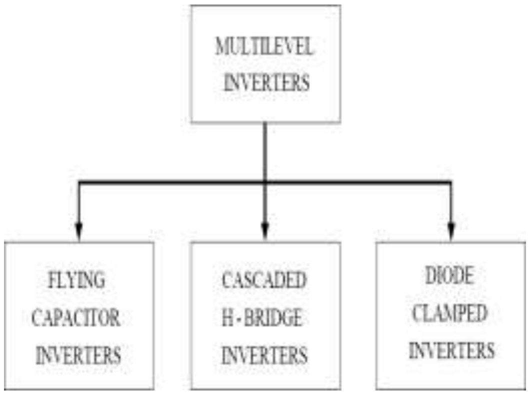


Fig: 3.1 multilevel inverter topologies.

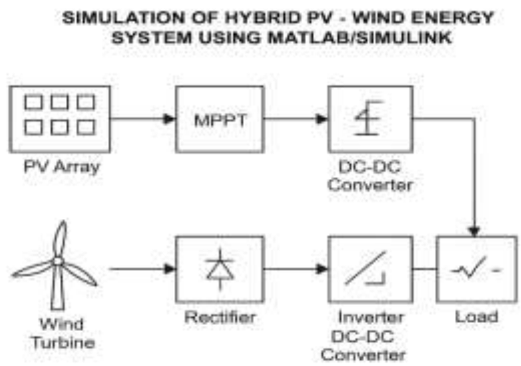
In multilevel inverter systems, increasing the number of output voltage levels typically requires adding more semiconductor switches and DC voltage sources or capacitors. While this improves the quality of the output waveform, it also leads to a more complex, larger, and costlier design for both the power and control circuitry. Furthermore, one of the critical challenges in these systems is maintaining voltage balance across multiple DC stages, which can affect performance and reliability. Due to these design constraints, most practical implementations are limited to three-level or five-level inverters, with the three-level topology being the most widely adopted in industrial applications. Despite the theoretical potential for more levels, real-world applications are often restricted by topology limitations, component count, and system stability. As shown in Figure 3.1, multilevel inverter technologies are generally classified into three major topologies: the diode-clamped (neutral-point clamped) inverter, the flying capacitor inverter, and the cascaded H-bridge inverter.

4.SIMULATION OF HYBRID PV WIND ENERGY SYSTEM USING MATLAB/ SIMULINK

4.1 Introduction:

This chapter presents and analyzes the simulation results of the hybrid photovoltaic (PV)– wind energy system developed in MATLAB/Simulink. The performance of the integrated system was evaluated under different environmental and operating conditions, including variations in solar irradiance, temperature, and wind speed. The results illustrate how each subsystem responds individually and collectively to changing parameters, demonstrating the complementary nature of solar and wind energy sources. Key performance indicators such as output power, voltage stability, efficiency, and battery state of charge were assessed to determine the reliability and effectiveness of the hybrid configuration. The outcomes also compare the hybrid system's performance with that of standalone PV and wind setups to highlight improvements in energy stability and utilization. Overall, the results validate the effectiveness of the proposed hybrid system in providing a consistent and sustainable energy supply.

4.2 Block Diagram Simulation Of Hybrid Pv Wind Energy System Using Matlab And Simulink:



4.3 simulation and results

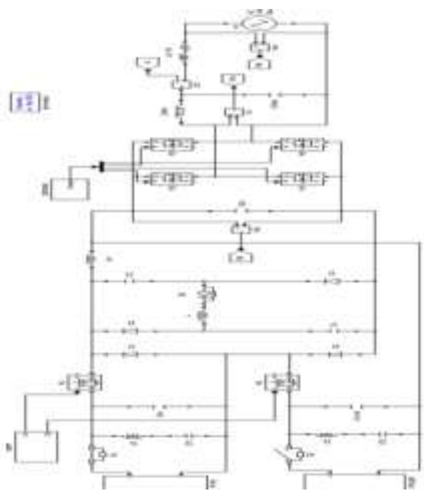


Fig: 6.1. The Proposed Multi-Input Inverter When Only the PV Array Is Supplying Power

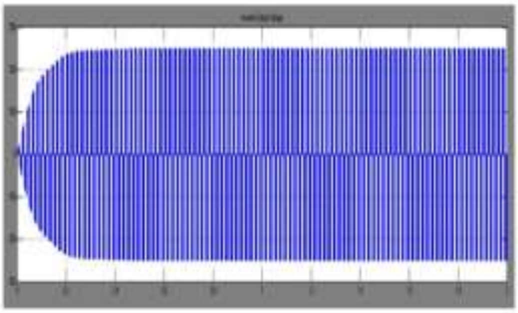
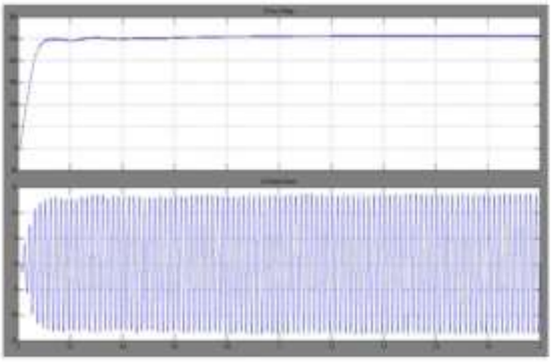


Fig.6.2. Multi-input inverter output voltage

The waveform shows the inverter output voltage, which exhibits a stable sinusoidal pattern with an amplitude of approximately ±300 V, indicating that the inverter effectively converts DC power from the hybrid system into a balanced AC voltage suitable for supplying AC loads.

(a)



(b)

Fig.6.3. Waveforms of the proposed multi-input inverter when only the PV array is supplying power. (a) The dc bus voltage and the ac output current waveforms. (b) The expanded ac output voltage and current waveforms.

The graph illustrates that the DC bus voltage rapidly rises and stabilizes around 250 V, indicating steady-state operation, while the AC output current displays a consistent sinusoidal waveform, confirming efficient inverter operation and stable power delivery to the load

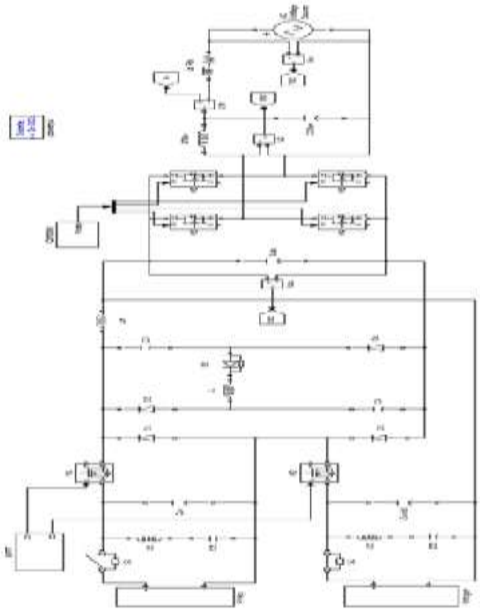
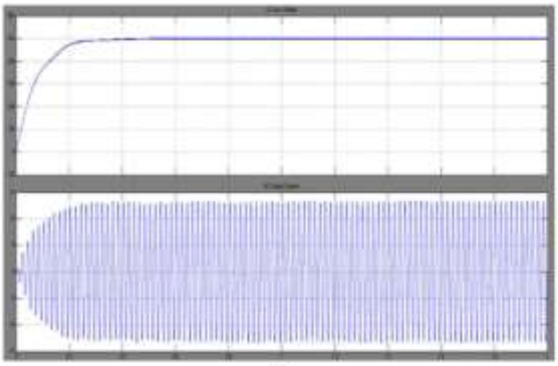
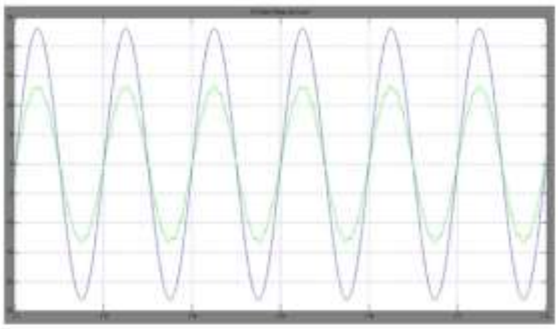


Fig:6.4 The proposed multi-input inverter when only the Wind turbine is supplying power.



(a)

The graph shows that the DC voltage quickly stabilizes around 250 V while the AC current maintains a smooth sinusoidal waveform, indicating stable and efficient inverter operation.



(b)

Fig.6.5. Waveforms of the proposed multi-input inverter when only the Wind turbine is supplying power. (a) The dc bus voltage and the ac output current waveforms. (b) The expanded ac output voltage and current

waveforms.

The waveform shows that the AC output voltage and current are sinusoidal and in phase, indicating efficient power transfer and proper synchronization between the inverter and the load.

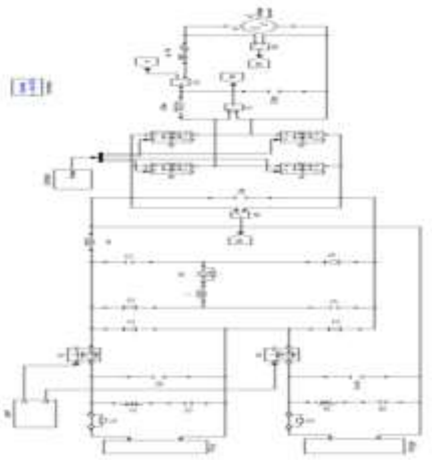
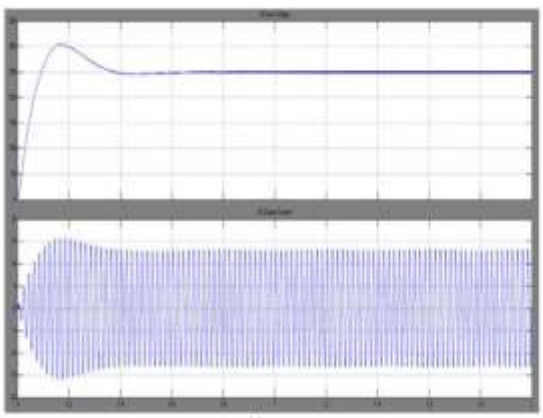


Fig.6.6. the proposed multi-input inverter when both of the PV array and the wind turbine are supplying power.



(a)

The plot shows that the DC bus voltage stabilizes at a steady value after an initial transient, while the AC output current reaches a steady sinusoidal waveform, indicating stable inverter operation.

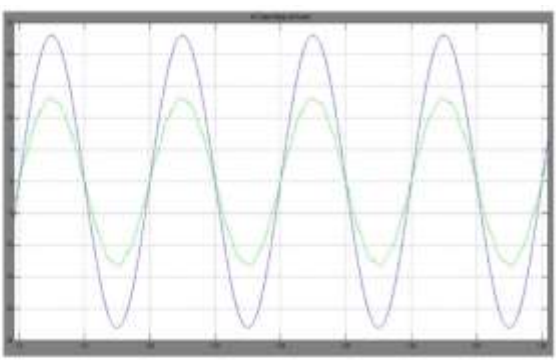


Fig.6.7. Wave forms of the proposed multi-input inverter when both of the PV array and the wind turbine are supplying power. (a) The dc bus voltage and the ac output current waveforms. (b) The Expanded ac output voltage and current waveforms.

The waveform shows that the AC output voltage and current are nearly sinusoidal and in phase, indicating stable inverter performance. The slight distortion and amplitude difference suggest minor harmonic effects and a partially inductive load.

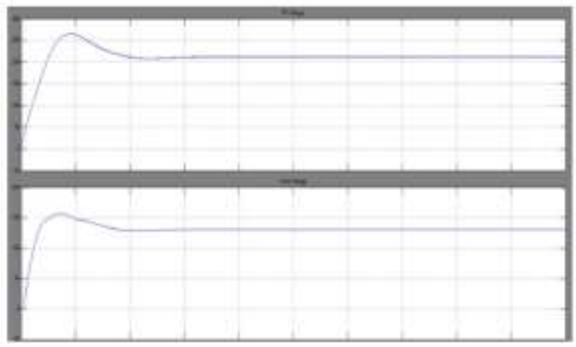


Fig.6.8. Waveforms of the Multi-input inverter when both of the PV array and the wind turbine output voltages

The plots show that both PV and wind voltages rise quickly, experience a small overshoot, and then settle to steady values, indicating stable voltage regulation and proper source synchronization. From the graph PV Voltage: Peaks at around 270 V, then settles to a steady value near 210 V. Wind Voltage: Peaks at about 160 V, then stabilizes around 120 V. These values indicate both sources reach stable operating voltages after initial transients.

CONCLUSIONS

This project presents the design and simulation of a multi-input inverter for a grid-connected hybrid photovoltaic (PV) and wind energy system. The proposed inverter architecture enables efficient power conversion by allowing energy transfer from the PV source, wind source, or both simultaneously. Individual Maximum Power Point Tracking (MPPT) control is implemented for each renewable source using the Perturb and Observe (P&O)

algorithm to ensure maximum energy extraction under varying environmental conditions. The inverter effectively accommodates wide input voltage variations resulting from changes in solar irradiance and wind speed.

The control strategy is developed using MATLAB/Simulink along with supporting analog control circuitry to ensure reliable operation, system protection, and stable performance. Simulation results obtained under different operating conditions validate the effectiveness of the proposed design, demonstrating efficient power sharing, stable voltage regulation, and reliable grid interfacing. The results confirm that the proposed multi-input inverter is a suitable and efficient solution for hybrid renewable energy applications.

FUTURE SCOPE

Hybrid PV–wind energy systems offer significant potential for addressing the increasing global demand for clean and sustainable power. Although this project successfully demonstrates the design and simulation of a hybrid renewable energy system, several opportunities exist for further improvement and expansion. The integration of advanced energy storage technologies, such as lithium-ion batteries or super capacitors, can enhance system reliability by ensuring uninterrupted power supply during periods of low renewable generation. Future research may also focus on implementing intelligent control techniques, including artificial intelligence and machine learning algorithms, to improve power management, load balancing, fault detection, and system optimization. Hardware implementation of the proposed inverter using Digital Signal Processors (DSPs) or Field Programmable Gate Arrays (FPGAs) would enable real-time validation of simulation results and facilitate practical deployment. Additionally, extending the system for full grid-connected operation, smart grid compatibility, and electric vehicle (EV) charging infrastructure can further increase its real-world applicability. These advancements have the potential to improve the efficiency, scalability, and reliability of hybrid renewable energy systems for future energy networks.

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