International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 21 No. 3 (1) 2025



ijerst.editor@gmail.com

editor@ijerst.com

International Journal of Engineering Research and Science & Technology
ISSN 2319-5991 www.ijerst.com
Vol. 21, No. 3(1), 2025
© 2025 IJERST. All Rights Reserved

Research Paper

GRID INTEGRATED ANALYSIS OF HYBRID PHOTOVOLTAIC AND WIND POWER GENERATION

Mr. D.VAMSHI
Asst Professor of the department Electrical and Electronics Engineering
Malla Reddy College of Engineering &Technology College Hyderabad, Telangana

B. RAJ KUMAR
Electrical and Electronics Engineering
Malla Reddy College of Engineering &Technology College
Hyderabad, India 22N3A0206@mrcet.ac.in

J. KARTHIK
Electrical and Electronics Engineering
Malla Reddy College of Engineering &Technology College
Hyderabad, India 21N31A0212@mrcet.ac.in

B. PRAKASH
Electrical and Electronics Engineering
Malla Reddy College of Engineering &Technology College
Hyderabad, India 21N31A0202@mrcet.ac.in

ABSTRACT

The power provided by a wind turbine is designed to suit the linear induction generator. The **Archimedese wave swing (AWS)** theory is used for the induction generator. A typical connection from dc bus bar through the voltage source converter connects the output terminal of the hybrid system (VSC).

This dc power is therefore transformed into ac power by the inverter of the voltage source (VSI). In order to smooth the rib, the electricity supplied to the power grid of the distribution side is indicated by a supercapacitor (SC). This paper suggests a control system to maintain the equilibrium between the distribution network's generated side and grid.

To achieve the purpose, the traditional stabilization tool is added to the device under different conditions and approves the efficiency and performance of the topology used for control and the hybrid photovoltaic and wind turbines**.**

The results highlight the potential for enhanced energy reliability, reduced carbon emissions, and improved grid efficiency when these renewable sources are effectively integrated.
Recommendations are provided for optimizing grid operations and policy frameworks to support large- scale adoption of renewable energy technologies**.**

Keywords — ***Grid integration, photovoltaic system, wind power generation power system stability, energy storage, power quality.***

Received: 15-08-2025 Accepted: 17-09-2025 Published: 24-09-2025

INTRODUCTION

The global transition towards clean and sustainable energy sources has led to the rapid growth and deployment of renewable energy technologies, particularly photovoltaic (PV) and wind power systems. These technologies have become key components in the efforts to reduce greenhouse gas emissions, decrease dependence on fossil fuels, and enhance energy security. Among the various renewable sources, solar and wind energy stand out due to their abundance, maturity, and rapidly decreasing costs. However, their integration into existing electrical grids introduces a complex set of technical and operational challenges.

Photovoltaic and wind energy are inherently variable and intermittent, influenced by weather patterns, geographical conditions, and diurnal cycles. This variability can lead to fluctuations in power generation, which may affect grid stability, power quality, and reliability. Unlike conventional generation units that provide controllable and predictable output, renewable sources demand advanced grid management techniques, including forecasting, load balancing, frequency regulation, and voltage control.

As sustained sources of energy have a high impact on the atmosphere, the voltage from sources is discontinuous or intermittent. To promote this, energy sources combine in order to define the network of renewable resources and MPPT control computers are required to track the most exceptional energy sources

Grid integration of renewable energy systems involves synchronizing the generated power with the utility grid in a stable, efficient, and reliable manner. This requires a multi-disciplinary approach that includes power electronics (e.g., inverters and converters), energy storage systems, smart grid technologies, and regulatory frameworks. Hybrid systems combining PV and wind power offer a promising solution, as their complementary generation patterns can mitigate individual variability and improve overall output consistency.

This study aims to analyze the performance and impacts of grid-integrated PV and wind systems through simulation, modelling and case studies. Key focus areas include grid connection requirements, dynamic behavior under varying conditions, power quality issues, and the role of energy storage in smoothing out supply-demand mismatches. By understanding these factors, grid operators, policymakers, and engineers can develop strategies to enhance grid flexibility, ensure reliable operation, and support the increasing penetration of renewable energy into modern power systems.

1. ARRANGEMENTS OF THE DESINGED MODEL

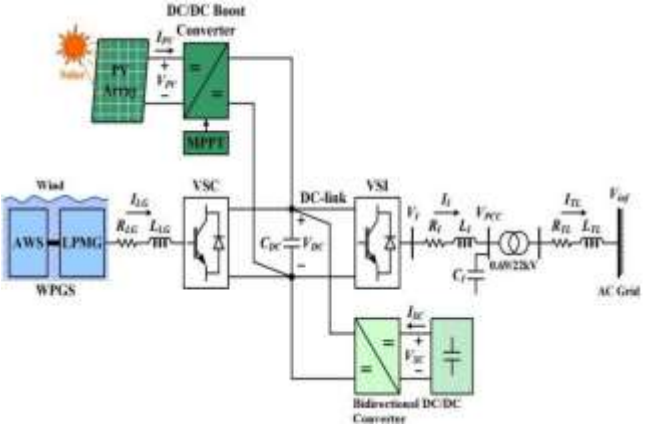


Fig.1 Schematic design of the PV and Wind system connected to the distribution grid.

Figure 1 illustrates the schematic design of a hybrid photovoltaic (PV) and wind power generation system integrated with a distribution grid. The system comprises a PV array, a wind power generation system (WPGS), a DC-link, a voltage source converter (VSC), a voltage source inverter (VSI), a bidirectional DC/DC converter, and connection to the AC grid.

Detailed Component Breakdown and Functionality:

V Array: The solar energy is captured by the PV array, generating a DC voltage (V_{PV}) and current .

DC/DC Boost Converter: A DC/DC boost converter is employed to step up the voltage from the PV array to a suitable level for the DC-link. This converter incorporates a Maximum

Power Point Tracking (MPPT) algorithm to ensure optimal power extraction from the solar panels.

Wind Power Generation System (WPGS): The WPGS consists of an Aerodynamic Wind System (AWS) coupled with a Linear Permanent Magnet Generator (LPMG).

Voltage Source Converter (VSC): The VSC interfaces the WPGS with the DC-link, converting the variable AC output of the WPGS to a stable DC voltage (V_{DC}). The DC-link capacitance (C_{DC}) stabilizes the DC voltage.

DC-Link: The DC-link acts as an energy buffer, smoothing out fluctuations from both the PV and wind sources.

Voltage Source Inverter (VSI): The VSI converts the DC voltage from the DC-link into AC voltage (V_{PCC}) for grid integration. The inverter output is filtered through an inductor (L₁) and capacitor (C₁) to reduce harmonics.

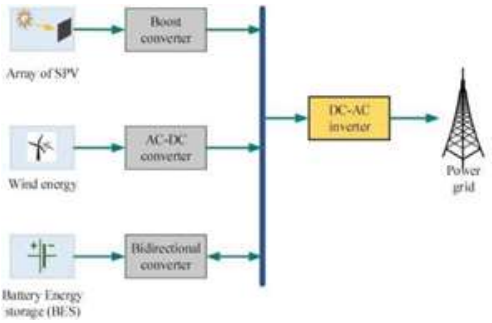
Bidirectional DC/DC Converter: This converter manages the power flow between the DC-link and a storage component (represented by V_{SC} and I_{SC}). It enables bidirectional power transfer, facilitating energy storage and release as required.

AC Grid Connection: The system is connected to the AC grid via a transformer (0.69/22kV).

Operational Flow and Control:

The diagram illustrates the flow of energy from the renewable sources (solar and wind) to the AC grid. The MPPT algorithm in the PV system ensures maximum power extraction under varying solar irradiance. The VSC and VSI regulate the voltage and frequency for grid compatibility. The bidirectional DC/DC converter facilitates energy storage and release, enhancing the system's stability and reliability

2. METHODOLOGY



The methodology for **Solar Photovoltaic (SPV) Energy Conversion:**

Array of SPV: The process begins with the solar photovoltaic array, which directly converts sunlight into direct current (DC) electricity.

Boost Converter: A DC-DC boost converter is employed to step up the voltage from the SPV array to a level suitable for the DC bus. This stage often incorporates Maximum Power Point Tracking (MPPT) to optimize the power extraction from the solar panels, ensuring maximum efficiency under varying irradiance conditions.

Wind Energy Conversion:

Wind Energy: Wind turbines convert the kinetic energy of wind into mechanical energy, which is then transformed into electrical energy, typically AC.

AC-DC Converter: The AC output from the wind turbine generator is converted to DC using an AC-DC converter (rectifier). This step is necessary to integrate the wind energy into the common DC bus.

Battery Energy Storage (BES):

Battery Energy Storage (BES): The BES system, represented by a battery bank, acts as an energy buffer.

Bidirectional Converter:

A bidirectional DC-DC converter is used to manage the charging and discharging of the batteries. This converter allows power to flow in both directions:

Charging: When excess energy is available from the solar or wind sources, the batteries are charged.

Discharging: When the renewable sources are insufficient or during peak demand, the batteries discharge to supplement the power supply.

DC Bus and Inversion:

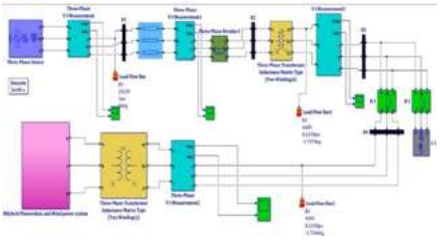
Common DC Bus: All the DC outputs from the SPV, wind, and BES are connected to a common DC bus. This bus serves as a central point for energy integration and management.

DC-AC Inverter: A DC-AC inverter is used to convert the DC power from the bus into alternating current (AC) power, which is compatible with the power grid.

Grid Connection:

Power Grid: The AC power from the inverter is then fed into the power grid, contributing to the overall electricity supply.

3. SIMULATION MODELS



1. **Hybrid PV-Wind System Integration**:

The model simulates a hybrid power system combining photovoltaic (PV) and wind energy sources, represented by the "Hybrid Photovoltaic and Wind power system".

2. **Three-Phase Power Flow Analysis:** It focuses on analyzing the three-phase power flow within the grid,utilizing"Three-Phase V-I Measurement" blocks to track voltage and current.

3. **Grid Connection and Source:** The "Three-Phase Source" block simulates the main power grid connection, providing the base voltage and frequency.

4. **Transformers for Voltage Adjustment:** "Three-Phase Transformer Inductance Matrix Type (Two Windings)" blocks are used to step up or step down voltage levels at different stages of the grid.

5. **Load Flow Bus Analysis:** "Load Flow Bus" blocks provide crucial information about voltage magnitudes and phase angles at different points in the network, enabling power flow analysis.

6. **Circuit Breaker for Fault Simulation:** The "Three-Phase Breaker" block is likely used to simulate fault conditions or switching operations within the grid.

7. **Discrete Simulation:** The "Discrete Se-05 s" label indicates the simulation is performed using a discrete-time solver with a sample time of 0.05 seconds.

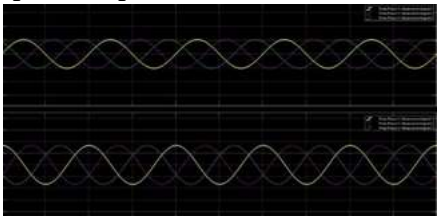
8. **Bus Connections and Interconnections**: The model shows the interconnection of different buses (B1, B2, B3, B4) and lines (L1) representing the grid network.

9. **Voltage and Current Measurements**: The voltage and current measurements are essential for evaluating the system's performance and stability.

10. **Matlab Environment:** This appears to be a simulation built using Matlab/Simulink, a common tool for power system modeling and analysis, allowing for visual representation and detailed analysis of the system's behavior.

4. RESULT

4.1 Three phase input:



Balanced Three-Phase System: The image strongly suggests that the simulation is modeling a balanced three-phase system. The 120-degree phase shift and consistent amplitudes are the defining characteristics of such a system.

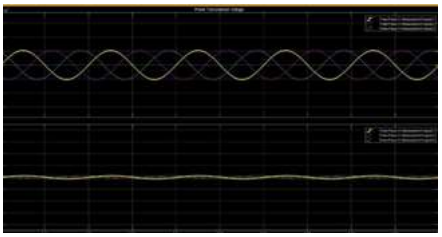
Comparison or Different Locations: The presence of two separate plots implies that the simulation is comparing two different scenarios or analyzing the voltage at two different locations within the

system. This could be, for example:

Voltage at the source vs. voltage at the load: Comparing the generated voltage to the voltage after transmission or transformation.

Voltage before and after a fault: Analyzing the impact of a fault on the voltage waveforms. Voltage with different system parameters: Investigating the effect of changing system parameters on the voltage.

4.2 Wave Form for Load Bus1:



X-Axis (Horizontal):

Time (likely): The x-axis likely represents time, as it shows the progression of the sinusoidal waveforms over a period. This is typical for visualizing AC voltage signals.

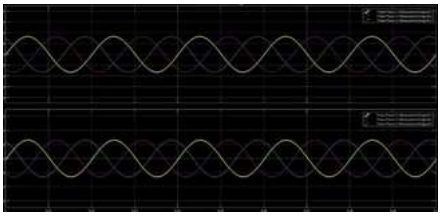
Units: The units are not explicitly labeled, but the presence of numbers like "3.01", "3.03", "3.06", etc., suggests the x-axis might be in seconds (s) or a related time unit.

Y-Axis (Vertical):

Voltage (likely): The y-axis represents voltage, as the plots are labeled "Power Transmission Voltage".

Units: The y-axis has a scale of 10^5 in the top plot and 10^0 in the bottom plot. This indicates that the top plot is showing voltage in the order of hundreds of thousands of volts (e.g., kilovolts), while the bottom plot shows voltage in the order of single.

4.3 Wave form for Load Bus 2:



X-Axis (Time): The x-axis still represents time, showing the progression of the voltage waveforms. The specific time scale (likely seconds) would be important for analyzing the frequency and stability of the system.

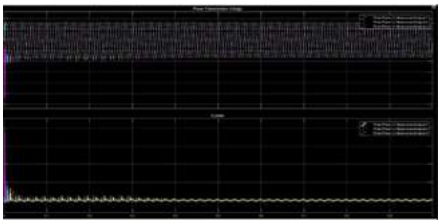
Y-Axis (Voltage): The y-axis represents voltage. The different scales of the two plots suggest a significant voltage transformation or a control signal representation.

Variations:

Top Plot: High voltage, possibly the raw output from the wind turbine generator.

Bottom Plot: Lower voltage, representing the grid-connected voltage after conversion or a control signal. The fluctuations suggest the system is responding to variations in wind speed or the control system is actively regulating the voltage.

5.3 Output of grid integrated analysis of hybrid photovoltaic and wind power generation



Voltage Plot (Top):
High Amplitude: The voltage plot shows a relatively high and stable voltage waveform. This is expected for a grid-connected system, as the voltage is typically regulated to meet grid standards.

Consistent Sinusoidal Shape: The voltage waveforms are close to ideal sinusoidal shapes, indicating a well-regulated voltage.

Current Plot (Bottom):

Low Amplitude with Harmonics: The current plot shows a low amplitude current waveform, but it's not a pure sinusoid. Instead, it exhibits noticeable harmonics (distortions).

Spikes and Oscillations: The current waveform has some spikes and oscillations, particularly at the beginning of the simulation.

5. CONCLUSION AND FUTURE SCOPE

The grid-integrated analysis of hybrid photovoltaic and wind generation demonstrates

the potential of combining these renewable energy sources to achieve a stable, efficient, and sustainable power supply. By leveraging the complementary nature of solar and wind energy, the hybrid system effectively addresses the intermittency challenges associated with standalone renewable sources, ensuring a continuous and reliable electricity supply. The integration of advanced power electronics, energy storage solutions, and smart grid technologies enhances system efficiency, optimizes power distribution, and maintains grid stability.

The analysis highlights significant reductions in carbon emissions and reliance on fossil fuels, contributing to a cleaner environment and supporting global efforts toward sustainable energy development. Despite challenges such as initial setup costs, land availability, and maintenance requirements, technological advancements and supportive policies continue to improve the feasibility and adoption of hybrid renewable energy systems. The study confirms that hybrid photovoltaic and wind generation, when properly integrated with the grid, offers a viable and scalable solution for meeting growing energy demands while promoting environmental sustainability.

FUTURE SCOPE:

The future of hybrid photovoltaic and wind energy systems will be significantly influenced by advancements in power electronics and smart grid technologies. The development of more efficient inverters, power converters, and intelligent controllers will enhance the seamless integration of renewable energy into the grid.

Smart grids equipped with Al-driven predictive analytics and automated energy management systems will optimize energy distribution, reduce losses, and ensure grid stability. Real-time monitoring and adaptive control mechanisms will enable better synchronization of hybrid renewable energy sources with conventional power grids, improving overall energy efficiency.

[1] Ge, X.-J., Sun, Y., Wang, Z.-H., & Tang, C.-S. (2019). A single-source switched-capacitor multilevel inverter for magnetic coupling wireless power transfer systems. Electrical Engineering. doi:10.1007/s00202-019-00850-5.

[2] S.-K. Kim, J.-H. Jeon, C.-H. Cho, J.-B. Ahn, and S.-H. Kwon, “Dynamic modeling and control of a grid-connected hybrid generation system with versatile power transfer,” IEEE Trans. Industrial Electronics, vol. 55, no. 4, pp. 1677-1688, Apr. 2018.

[3] X. Liu, P. Wang, and P. C. Loh, “A hybrid ac/dc microgrid and its coordination control,” IEEE Trans. Smart Grid, vol. 2, no. 2, pp. 278-286, Jun. 2016.

[4] M. M. R. Singaravel and S. A. Daniel, “MPPT with single dc-dc converter and inverter for grid-connected hybrid wind-driven PMSG-PV system,” IEEE Trans. Industrial Electronics, vol. 62, no. 8, pp. 4849- 4857, Aug. 2015.

[5] Y. J. Reddy, Y. V. P. Kumar, K. P. Raju, and A. Ramesh, “Retrofitted hybrid power system design with renewable energy sources for buildings,” IEEE Trans. Smart Grid, vol. 3, no. 4, pp. 2174-2187, Dec. 2014.

[6] C. Wang and M. H. Nehrir, “Power management stand-alone wind/photovoltaic/fuel cell energy system,” IEEE Trans. Energy Conversion, vol. 23, no. 3, pp. 957-967, Sep.2018.

[7] L. N. Khanh, J.-J. Seo, Y.-S. Kim, and D.-J. Won, “Power-management strategies for a grid-connected PV-FC hybrid system,” IEEE Trans. Power Delivery, vol. 25, no. 3, pp. 1874-1882, Jul. 2017.

[8] P. Garcia, C. A. Garcia, L. M. Fernandez, F. Llorens, and F. Jurado, “ANFIS-based control of a grid-connected hybrid system integrating renewable energies, hydrogen and battery,” IEEE Trans. Industrial Informatics, vol. 10, no. 2, pp. 1107-1117, May 2016.

[9] B. Liu, F. Zhuo, Y. Zhu, and H. Yi, “System operation and energy management of a renewable energy-based dc micro-grid for high penetration

depth application," IEEE Trans. Smart Grid, vol. 6, no. 3, pp. 1147-1155, May 2016.

[10] D. Abbes, A. Martinez, and G. Champenois, "Eco-design optimization of an autonomous hybrid windphotovoltaic system with battery storage," IET Renewable Power Generation, vol. 6, no. 5, pp. 358-371, Sep. 2016.

[11]M. B. Shadmand and R. S. Balog, "Multi-objective optimization and design of photovoltaic-wind hybrid system for community smart dc microgrid," IEEE Trans. Smart Grid, vol. 5, no. 5, pp. 2635-2643, Sep. 2014.

[12]N. Patel, N. Gupta, and B. C. Babu, "Photovoltaic System Operation as DSTATCOM for Power Quality Improvement Employing Active Current Control," IET Generation, Transmission & Distribution, May 2019.

[13]N. Patel, A. Kumar, N. Gupta, S. Ray, and B. C. Babu, "Optimized PI-4VPI Current Controller for Three-Phase Grid-integrated Photovoltaic Inverter under Grid Voltage Distortions," IET Renewable Power Generation, vol. 14, no. 5, pp. 779-792, Nov. 2019.

[14]S. Mishra and D. Ramasubramanian, "Improving the small signal stability of a PV-DE- dynamic load-based microgrid using an auxiliary signal in the PV control loop," IEEE Trans. Power Systems, vol. 30, no.1, pp. 166-176, Jan. 2018.