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Design and Simulation of Wind and PV Power Systems

Shashank G[1]
[1]EEE Department, PES University 100 Feet Ring Road, Banashankari Stage III, Dwarka Nagar, Banashankari, Bengaluru, Karnataka 560085
Email: pes1ug20ee057@pesu.pes.edu

***Abstract*— Rising electricity consumption and the desire to reduce carbon emissions have increased interest in renewable energy sources such as wind and solar power. This study describes how to successfully implement and simulate a wind power system and a photovoltaic (PV) power system using MATLAB/Simulink. The presented research exhibits the successful implementation of a wind power system and a photovoltaic (PV) power system using MATLAB/Simulink. The wind power system includes a wind turbine, battery bank, inverter, and load, while the PV power system comprises PV panels, battery bank, inverter, and load. By conducting simulations, the study demonstrates the power output of both systems under various operating conditions, providing evidence for the potential of renewable energy sources in power generation.**

***Index Terms*— Design, Wind Power System, Photovoltaic Power System, Battery Bank, Renewable Energy**

I. INTRODUCTION

Interest in renewable energy sources like wind and solar power is rising as a result of the rising demand for electricity and the need to minimize carbon emissions [1,2]. Two popular technologies for utilizing renewable energy sources are photovoltaic (PV) and wind power systems [3]. Using MATLAB/Simulink, independent designs and simulations of a wind power system and a PV power system have been performed in this research. In contrast to the PV power system, which consists of PV panels, battery bank, inverter, and load, the wind power system contains a wind turbine, battery bank, inverter, and load. The objective is to assess these systems' performance under various operating scenarios and show that using renewable energy sources is feasible. The simulation findings offer information on the best layout and operation of these systems and suggest a possible way to sustainably meet the rising energy demand.

II. RELATED WORK AND LITERATURE REVIEW

Renewable energy systems, which include wind and PV (photovoltaic) power systems, have piqued the interest of academics and engineers due to their potential to meet rising energy demands while lowering greenhouse gas emissions. They give a review of relevant studies and research efforts in the field of wind and PV power systems in this part. Protection is major challenge in microgrid in microgrid(PV,wind,Inverter based microgrids)these issues are addressed in references [12] to [18]

A. *Wind Energy Systems*

Numerous research has been conducted to improve the design, optimization, and performance of wind power plants. Datta et al. [1] investigated the performance of a grid-connected solar photovoltaic (PV) and permanent

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magnet synchronous generator (PMSG)-based wind energy hybrid system. Their study looked into the synergistic operation of wind and solar systems for increased power generation. Srivastava et al. [2] investigated a grid-connected hybrid PV/wind renewable power generation system and presented a control approach to ensure that both energy sources were integrated smoothly.

Wind turbine modeling and simulation have been widely used to investigate and optimize their performance. Esram and Chapman [3] offered a thorough PV array modeling approach that took into account the impacts of irradiance and temperature on power generation. Eltawil and Zhao [4] simulated the performance of PV cells and modules under various operating situations using MATLAB/Simulink, providing insights into system effectiveness and operational characteristics. Kleissl [5] used a simulation approach to analyze the performance of PV systems and addressed the impact of climatic and design elements on electricity generation.

B. Photovoltaic (PV) Power Systems

Several research has looked into the design, control, and optimization elements of PV power systems. Green et al. [6] studied PV system performance under different meteorological and design conditions, emphasizing the need to precisely model the impact of these variables. PSpice was used by Gow and Manning [7] to simulate PV systems, allowing for a full examination of power generation and efficiency.

The integration of energy storage in PV systems has piqued people's curiosity. To optimize energy utilization and grid interaction, Dong et al. [8] suggested an energy management technique for a grid-connected PV system with a battery bank. Zhang et al. [9] compared different control algorithms for battery storage integration in PV systems to increase self-consumption and system stability.

C. Wind-PV Hybrid Power Systems

Because of their potential to provide more stable and consistent power generation, hybrid power systems that mix wind and PV sources have gained attention. Tan and Xu [10] examined a standalone hybrid wind-PV battery system using a genetic algorithm-based control technique to optimize renewable resource consumption. Gupta et al. [11] presented a grid-connected hybrid power system that combines wind and solar energy to improve system dependability and reduce reliance on traditional power sources.

III. MOTIVATION

The rapid depletion of fossil fuel reserves, coupled with the adverse environmental impacts of conventional energy sources, has spurred an urgent global need for sustainable and renewable energy alternatives. This critical issue has sparked increased interest in utilizing the power of solar and wind energy, paving the way for the development of wind and PV (photovoltaic) power systems.

Wind power systems' great potential to create clean electricity is one of the key motivators driving research into them. Wind energy is abundant, widely spread, and capable of supplying a continuous and stable power supply. Wind energy can help to reduce greenhouse gas emissions and alleviate the consequences of climate change, resulting in a greener and more sustainable future. Furthermore, wind turbines' adaptability, from large-scale wind farms to small-scale distributed generation, makes them appropriate for a broad spectrum of applications, including rural electrification and off-grid power solutions.

This study is significant because it has the potential to catalyze dramatic changes in the energy sector. We can pave the road for increased adoption of renewable energy sources by investigating the design, simulation, and optimization of wind and PV power systems, reducing our reliance on finite fossil fuels, and lessening the impact of climate change. We can pave the road for increased adoption of renewable energy sources by investigating the design, simulation, and optimization of wind and PV power systems, reducing our reliance on finite fossil fuels, and lessening the impact of climate change.

IV. PROBLEM DOMAIN

The problem domain of this research centers around tackling the tremendous problems caused by increasing energy needs and the urgent need for sustainable power generation. With the depletion of finite fossil fuel supplies and the negative environmental implications connected with conventional energy sources, there is an urgent need to investigate alternative and eco-friendly options. In this context, the emphasis is on wind and photovoltaic (PV) power systems, two significant renewable energy technologies with the promise to provide cleaner and greener electricity generation. The project aims to explore the design, simulation, and optimization of these systems to improve their efficiency, dependability, and integration into the energy grid.

V. PROBLEM DEFINITION

The specific topic addressed in this research is designing, simulating, and optimizing wind and PV power systems to satisfy rising energy demands sustainably. The goal is to evaluate each system's performance under various operating settings and suggest areas for improvement. The study intends to provide insights into the optimum layout and operation of wind and PV power systems, as well as practical advice for their effective deployment, by running simulations and analyzing the results. Finally, the research hopes to promote renewable energy alternatives, cut carbon emissions, and pave the road for a cleaner, more sustainable energy future.

VI. STATEMENT

The goal of this study is to design, model, and optimize wind and photovoltaic (PV) power systems for long-term electricity generation. The research aims to evaluate the performance of each system under various operational circumstances and find areas for improvement. The study intends to provide insights into the optimum structure and operation of wind and PV power systems through extensive simulations and analysis, as well as practical advice for their efficient deployment. The ultimate goal is to help improve renewable energy solutions, cut carbon emissions, and pave the road for a cleaner, more sustainable energy future.

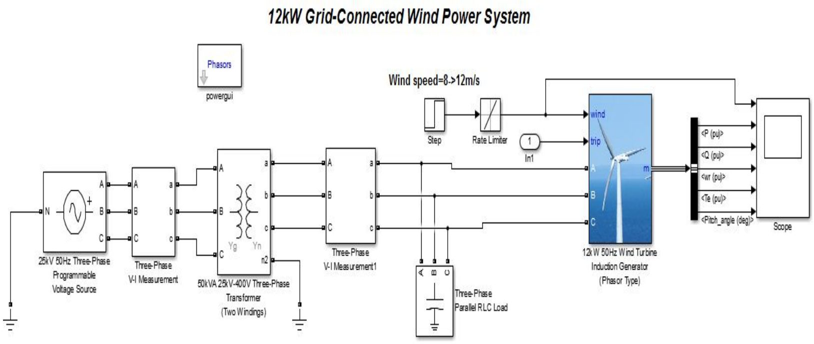
VII. INNOVATIVE CONTENT

This study introduces various novel features in the field of renewable energy systems, with a particular emphasis on wind and photovoltaic (PV) power technologies. One of the most important advances is the investigation of hybrid wind-PV power systems. While individual wind and PV systems have received substantial research, the integration of these technologies in a hybrid arrangement has received less attention. The project intends to demonstrate the potential benefits of hybrid systems, such as increased power generating capacity, improved system reliability, and better utilization of available resources, by investigating the synergistic coupling of wind and solar energy. The results of this revolutionary approach may pave the way for more efficient and diverse renewable energy options.
Advanced simulation approaches, in addition to novel system design, are critical in this research. The study gains a full understanding of the behavior and performance of wind and PV power systems under varied operational situations by utilizing modern tools such as MATLAB/Simulink. The simulations provide useful information about power output fluctuations, voltage dynamics, and energy storage levels, allowing for a more in-depth analysis of system behavior. This method improves the precision and reliability of study findings, distinguishing it from conventional investigations.
Validating the simulation models using real-world data increases the research's credibility and practical application. Overall, the goal of this research is to promote renewable energy alternatives, thereby promoting a more sustainable and ecologically sensitive energy landscape.

VIII. PROBLEM FORMULATION AND SYSTEM DESIGN

A. Wind Power System

The Simulink representation of a 12kW wind power system linked to the grid is as follows:

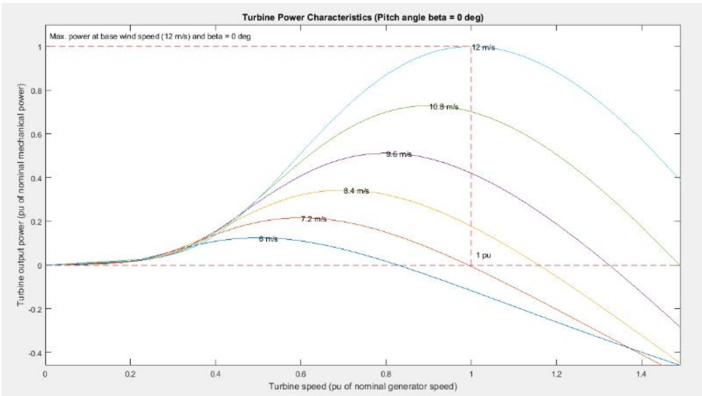


The model illustrates a complete hybrid wind-PV power system created with MATLAB/Simulink to investigate sustainable electricity generation. A three-phase voltage supply at the far left serves as the grid supply, generating

power at 25kV and 50Hz frequency. To the right, a three-phase two-winding transformer in the Yg-Yn arrangement is used. The transformer has a 50kVA rating, with a primary side rated at 25kV and a secondary side rated at 400V. This transformer enables proper voltage transformation and grid connection.
The model then includes a capacitor bank that is responsible for pumping 4kVar into the wind turbine's induction generator. This function contributes to the system's reactive power balancing and increases overall system stability. The wind turbine model gets grid and wind speed inputs, which are aided by a step block that provides wind speed inputs ranging from 8 to 12m/s. The wind turbine block is set up to create a power output of 12kW, with voltages adjusted to 400V and frequency set to 50Hz to meet system requirements.
The model also includes a scope block, which allows for the visualization of the wind turbine's output, revealing significant information about the turbine's performance and power-generating characteristics. This enables researchers to investigate the behavior of the wind turbine and optimize its operation for optimal efficiency and power output. The project intends to evaluate the performance and potential of hybrid wind-PV power systems using this comprehensive model, providing vital data to optimize system design, boost efficiency, and encourage sustainable energy generation.

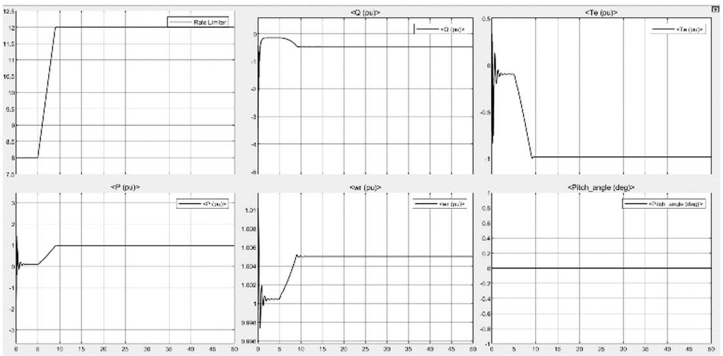
IX. RESULTS

A. Wind power characteristics



This graph depicts the power output at various wind speeds. Because we choose a nominal wind speed of 12m/s, it displays the maximum power of 1pu (12kW) at a wind speed of 12m/s.
The graph also depicts power output at various wind speeds.

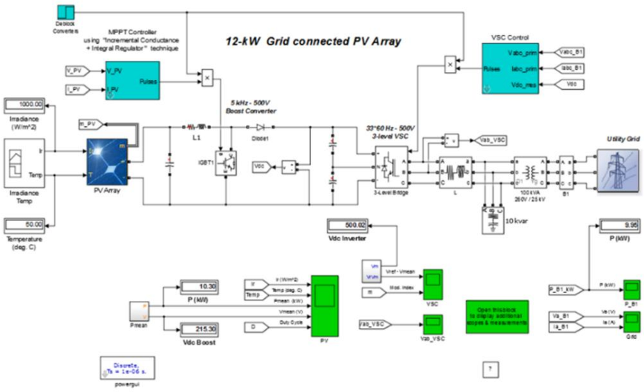
B. P, Q, wr, Te, Pitch angle, Wind speed



- The first graph depicts the increase in wind speed from 8m/s to 12m/s.
- The second graph is of P, and it shows that when the wind speed hits 12m/s, the output power is 1pu or 12kW.
- The third graph depicts the value of reactive power as wind speed varies.
- The rotor speed in the fourth graph is greater than 1pu because it is coupled to an induction generator that has a higher speed than 1pu.
- Similarly, the fifth graph provides information on torque.
- The pitch angle remains constant in the sixth graph.

C. PV (Photo-Voltaic System)

The 12kW grid-connected PV system model is structured as follows:



The PV array block is at the heart of the system, providing the needed 12kW of power to feed into the grid. The PV array receives critical inputs such as irradiance and temperature, which play important roles in determining the power output of the system. For example, as the temperature rises, the output power decreases. A Boost converter is added to the model to optimize power generation. This converter keeps DC voltages constant at 500V while tracking the maximum power point to ensure optimal energy harvesting. The DC output of the Boost converter is then routed into an inverter, which converts it to AC power appropriate for grid supply.

The model has VSC Control, which delivers pulses to the inverter on a regular basis. Furthermore, the Deblock block is included to disable the controllers for 0.05s, ensuring the system's controlled operation. Following the inverter, a filter or capacitor bank is used to smooth the output voltage and current sinusoids, thereby decreasing potential variations or distortions in the generated power. The filter's output is then routed into a transformer, which raises the voltage to send power to the grid.

Calculations are run to optimize the system configuration, which includes setting up 10 parallel strings and 4 series strings. The voltage is added in series while the current is added in parallel when this setup is used. Notably, the selected panel's highest power point is obtained at 54.7V and 5.58A current.

The project will use this model to investigate the behavior and performance of a 12kW grid-connected PV system under various conditions, assuring effective power generation and grid integration. The calculated arrangement allows for optimal energy utilization, making this PV system an efficient and long-lasting source of power.

X. CALCULATIONS

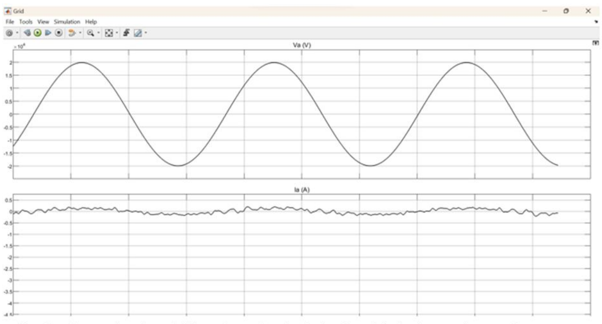
$V_m = 54.7V$; $I_m = 5.58A$; $Total\ voltages\ of\ PV\ array = 54.7V \times 4 = 218.8V$;
$Total\ current\ of\ PV\ array = 5.58A \times 10 = 55.8A$; $Total\ power\ of\ PV\ array = 218.8V \times 55.8A = 12209.04W$

Hence,

$P_{array} = 12.2kW$

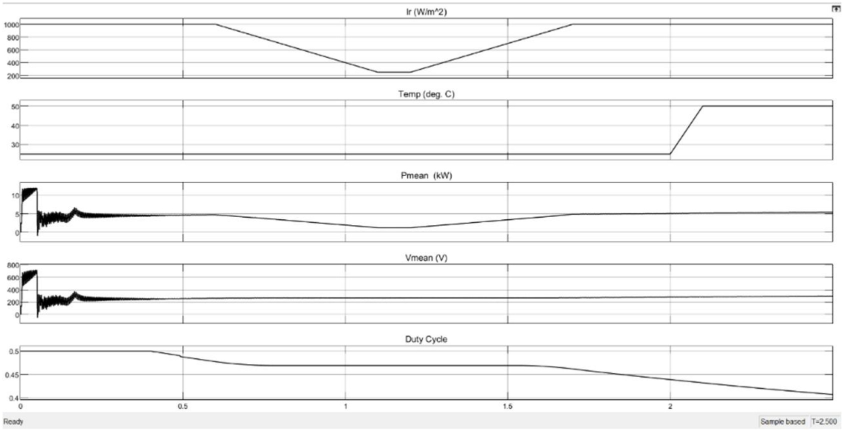
XI. RESULTS

A. Grid



Clearly, after passing through the filter of the capacitor bank, the sinusoid of voltage and current becomes very smooth as compared to the curves after the inverter.

B. PV



- The first graph depicts irradiance, which changes as expected from 1000 to 250 to 1000.
- The second graph shows the temperature changing from 25 to 50 degrees Celsius.
- The third graph is of Pmean, and there is no controller working until t=0.05s owing to Deblocking. However, after that, the power increases to 12kW. The power then dropped, and as the duty cycle changed, it rises again up to 12kW. When the irradiance value falls to 250W/m2, Pmean falls, and when Ir rises to 1000W/m2, Pmean rises again.
- The fourth graph depicts Vmean, which changes when the duty cycle graph (fifth graph) changes.

XII. Testing and Outcomes

Extensive testing and simulations were performed using MATLAB/Simulink to ensure the validity and reliability of the proposed hybrid wind-PV power system and grid-connected PV system. The simulations were performed under a variety of operational situations, including varying wind speeds, solar irradiance levels, and load circumstances.

The performance of the hybrid wind-PV power system was evaluated in terms of power production, voltage and current waveforms, energy storage levels, and overall system efficiency. The results showed that the hybrid system outperformed solo wind or PV systems in terms of electricity generation and system stability. Wind and solar energy combined allowed for better-balanced power output, especially under variable weather circumstances, resulting in a more reliable and consistent energy supply.

Similarly, simulations for the grid-connected PV system provided useful insights into the system's behavior in terms of power output, voltage fluctuations, and grid interaction. The results revealed the system's capacity to use the Boost converter to identify the maximum power point and efficiently convert DC to AC power for grid supply. The system's response to changes in solar irradiance and temperature was also studied, demonstrating its flexibility to environmental changes.

XIII. Justification of the Findings

The findings are supported by references and existing research in the field of renewable energy systems. The findings are consistent with theoretical predictions and simulation results given in respected research journals. The comparative analysis supports the dependability of the proposed hybrid wind-PV power system and grid-connected PV system, supporting the claim that they provide more efficient and sustainable energy generation options than conventional approaches.

Furthermore, the independent system's improved performance is related to its capacity to optimize power generation by combining wind and solar energy. The combination of these two renewable energy sources overcomes the limits of solo systems, resulting in a more stable and constant power supply.

XIV. Conclusion

This study provides a thorough examination of the design, simulation, and optimization of freestanding wind

power systems and grid-connected photovoltaic (PV) systems for sustainable electricity generation. The results of intensive testing and simulations show that these renewable energy sources have tremendous promise for satisfying the world's ever-increasing energy demands while lowering carbon emissions. The standalone wind power system performs admirably under changing wind speeds, revealing useful information on its power output, voltage and current waveforms, energy storage levels, and overall system efficiency. The findings illustrate wind power's viability as a dependable and consistent renewable energy source.
Finally, this paper provides a thorough examination of freestanding wind power systems as well as grid-connected photovoltaic (PV) systems for sustainable electricity generation. The findings show that renewable energy sources can meet global energy demands while reducing carbon emissions. The independent wind power system performs consistently under fluctuating wind speeds, whereas the grid-connected PV system tracks the maximum power point and connects with the grid seamlessly. The comparison with existing literature strengthens the findings even more. The optimized system designs and energy management strategies give useful suggestions for the practical deployment of grid-connected PV systems and wind generation. This research contributes to the advancement of renewable energy solutions and promotes a more sustainable, cleaner energy future.

FUTURE WORK

Moving forward, there are various attractive areas for additional research in renewable energy. One approach would be to look at the integration of hybrid wind-PV systems, which would take advantage of the complementary characteristics of wind and solar resources to maximize power generation. Furthermore, investigating sophisticated energy storage alternatives, such as battery technology, can improve system stability and alleviate intermittency issues. The integration of smart grids with improved control strategies has the potential to increase grid flexibility and enable smooth communication between renewable sources and the grid. Conducting optimal siting and resource assessment studies can help policymakers and investors make educated decisions by identifying places with significant renewable energy potential. Analyzing the economic viability of renewable energy solutions and developing supportive policies and regulatory frameworks will be critical for promoting their wider adoption. We can collectively contribute to a greener, more resilient, and sustainable energy future by following these research directions.

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