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Modeling and Simulation of a Grid-Connected Solar–Wind Hybrid Renewable Energy System with Controlled Inverter

Brijesh Kumar Pandey[1,*], Abhimanyu Kumar[2], Rohit Gedam[3], Ambrish Pati Tripathi[4]

Abstract

Solar and wind energy offer eco-friendly and renewable options to conventional energy sources, holding great promise for the future. This research delves into the modeling and simulation of a grid-connected solar–wind hybrid renewable energy system employing a controlled inverter. The study examines the individual photovoltaic (PV) and wind energy conversion systems and investigates their seamless integration to create a powerful hybrid generation system. To maximize energy use, the application of maximum power point tracking (MPPT) algorithms is investigated. The application of MPPT algorithms is examined for both solar and wind subsystems in order to improve energy extraction under different climatic situations. By continuously modifying operating points to optimize power output, these control systems allow for the best possible use of the renewable resources that are available. To ensure steady functioning and smooth communication with the electrical grid, a regulated inverter is used to adjust voltage, frequency, and power quality. To assess system performance under various operating circumstances, extensive simulation studies are conducted using suitable modeling tools. The simulation results show the viability, stability, and dependability of the suggested hybrid renewable energy system, emphasizing its capacity to provide steady electricity with increased efficiency. Overall, the results show that grid-connected solar–wind hybrid systems provide a reliable, effective, and sustainable option for the production of renewable energy in the future. Through comprehensive simulations, the paper validates the feasibility, stability, and reliability of the proposed hybrid system, underlining its potential as a sustainable and efficient energy solution.

Keywords: Solar energy, wind energy, hybrid renewable energy, grid-connected system, controlled inverter, simulation, sustainability

***Author for Correspondence**
Brijesh Kumar Pandey
E-mail: brijeshpandey20122012@gmail.com

[1]Assistant Professor, Department of Electrical & Electronics Engineering, RKDF University, Bhopal, Madhya Pradesh, India
[2]Associate Professor, Department of Electrical & Electronics Engineering, Vedica Institute of Technology, Bhopal, Madhya Pradesh, India
[3]Assistant Professor, Department of Electrical & Electronics Engineering, Vedica Institute of Technology, Bhopal, Madhya Pradesh, India
[4]Assistant Professor, Department of Electrical & Electronics Engineering, Institute of Polytechnic Engineering RKDF University, Bhopal, Madhya Pradesh, India

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INTRODUCTION

Solar energy is a green, inexhaustible, and ecological energy source. Hydrogen is currently one of the most promising alternatives to conventional energy sources. Therefore, the use of photovoltaic solar energy to generate power from the sun is increasing. A solar photovoltaic system, cell, or module converts solar energy directly into electricity [1–3]. A photovoltaic solar module is created when several cells are connected in series and parallel. More photovoltaic solar cells are used for a photovoltaic cell, and more cells are used to form a photovoltaic module. The solar energy obtained from a solar photovoltaic cell is not constant. The amount of energy obtained from a photovoltaic system depends on the voltage of the PV generator and the current set point [4]. Furthermore, environmental factors such as temperature and solar radiation affect performance. At a uniform solar radiation level without partial shading, the non-linear current-voltage (IV) characteristics of a solar photovoltaic module have an optimal operating point corresponding to a single

Maximum power point (MPP) on the power curve [5]. A solar module is really composed of several solar cells connected in series or parallel. If some of the panel's cells are shaded, it can be due to surrounding buildings, clouds in the sky, or birds landing on solar panels. The PV Features solar panels are very complicated because there are several points of maximum power on the characteristics of photovoltaic [6]. Currently, stand-alone solar and photovoltaic systems are being promoted on a relatively larger scale around the world. Due to their seasonality, these autonomous systems are unable to supply a steady supply of energy. For example, a stand-alone photovoltaic solar system cannot provide reliable power on non-sunny days.

Modeling of PV Array

The grid-connected photovoltaic system is a more dependable way to meet energy demand. The network connection of a photovoltaic power generation system has the advantage of more efficient use of the generated energy. The inverter, which transforms the DC energy produced by the PV modules into alternating current, connects the PV systems to the grid. Inverter technology is very important to ensure a reliable connection and safe operation of the photovoltaic network. In general, inverters with controlled voltage sources are used to connect the renewable energy system (RES) to the network. The network may be at risk from energy quality issues like harmonics as a result of the penetration of power electronic converters. These harmonics can cause the protection relays and other control devices to malfunction. Therefore, harmonics must be reduced. Active shunt power filters have been recognized as the most efficient harmonic compensation technique.

The configurations of the active photovoltaic shunt power filter system are shown in Figure 1. In a photovoltaic system, solar energy is transformed into electrical power.

Because photovoltaic power varies according to climatic conditions, the maximum power of the photovoltaic generator is coupled with an MPPT (maximum power point tracker). Because photovoltaic energy sources generate variable DC power, they require conditioning before being connected to an intermediate circuit. A DC–DC converter serves this purpose. The output of the DC–DC converter is connected to an intermediate circuit capacitor, which is then connected to the grid via an inverter.

Solar-Powered Cell

The fundamental units of a photovoltaic cluster are the PV cells. Silicon and other semiconductor materials are used to fabricate them. To create a positive electric field on one side and a negative electric field on the other, a delicate semiconductor wafer is highly intricate. Electrons are released from the molecules of the semiconductor material when light strikes them. By chance, an electrical circuit connecting a conveyor to both sides of the semiconductor initiates the flow of electrons to produce an electric current. It can be round or square in shape.

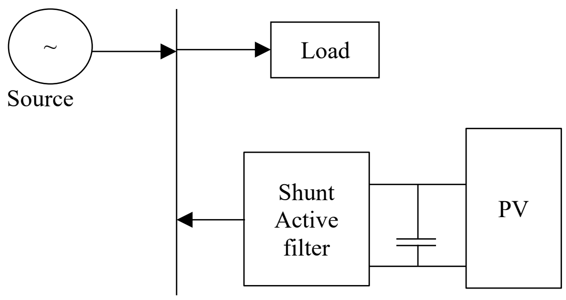

Figure 1. Configurations of a photovoltaic interactive shunt active power filter system.

Photovoltaic Array

Again, the power generated by a single module is insufficient to meet the performance requirements for most practical purposes. Molds for PV Motors, lights, and other loads can be powered by the DC output that these inverters can transform into AC. For higher voltages, the modules are connected in series; to satisfy the current requirements, they are then connected in parallel.

$$I_o = I_{PV} - I_D(V) - I_{SH}(V) \tag{1}$$

Where, (V) shows the dependency of the diode current and resistor current on the terminal voltage, which is independent of the irradiation value (Figure 2).

LITERATURE REVIEW

Fuzzy logic control (FLC) for monitoring the maximum power (MPPT) on the connection of the wind turbine to the permanent magnet synchronous generator (PMSG). The proposed fuzzy controller follows the MPP by measuring the charging voltage and current [7]. This controller calculates the load power and is sent using a fuzzy logic system. The main objective of this study is to design a fuzzy logic controller in the DC/DC converter (boost converter) model. This technique enables the MPPT controller output (duty cycle) to modify the drive's input voltage to monitor the wind turbine's greatest power point. [6] studied the status of the available MPPT algorithms.

Therefore, owing to the nature of the wind that changes instantaneously, it is only desirable to have an optimal generator speed that ensures, at a given moment, that the maximum energy is obtained from the available wind. Therefore, it is important to integrate a controller that can follow the maximum peak regardless of the wind speed. Available MPPT algorithms can be classified according to the control variables, with or without a sensor, as well as the technique used to identify the maximum peak. The performance of the selected MPPT algorithms was compared based on various speed responses and their ability to achieve maximum energy efficiency.

A new method for detecting the MPP of a wind energy conversion system based on a synchronous permanent magnet generator. After determining the best system relationship for MPP detection, the method regulates the system in accordance with this connection. The design process is described, and a theoretical analysis of the validity of the technique is conducted. The primary benefit of the proposed method is that it responds accurately and quickly to variations in wind speed without the need for an anemometer or prior system knowledge. It can also update the time-dependent parametric changes of the turbines or generators.

A novel adaptive approach for energy management in autonomous hybrid systems was proposed, which uses FLCs and an artificial neural network (ANN) to govern the energy flow between the energy storage components and the hybrid power system to meet load requirements [8].

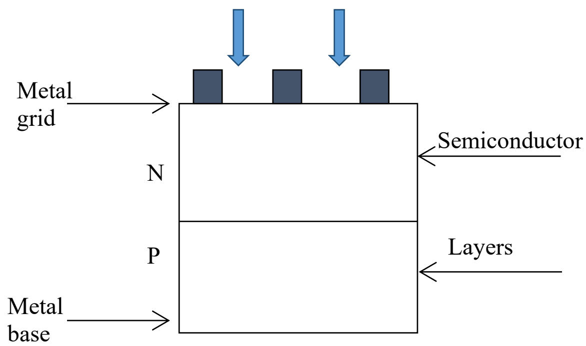

Figure 2. Structure of a PV cell.

For various types of photovoltaic panels (PV), neural network control is utilized to achieve the MPP. To maximize performance, a sophisticated fuzzy logic controller was developed to supply power to the hybrid system and regulate the charge flow and discharge current. A hybrid system that included solar modules, a wind turbine, an accumulator, and a proton-exchange membrane fuel cell (PEMFC) was used to evaluate the performance of the proposed management system. A fuzzy logic controller regulates the battery temperature to increase the PEMFC generating efficiency and prolong its lifespan. The dynamic behavior of the suggested model was examined under various operational scenarios. The designed system uses real-time parameter measurements as its inputs. The suggested model and associated control technique provide an ideal tool for maximizing the performance of hybrid systems, such as those utilized in smart home applications.

METHODOLOGY

The world's energy demand is growing exponentially. Introduction of renewable energy plants helps to meet the energy demand to some extent. The concept of green energy can be attained by the use of more renewable generating plants. Renewable power generation units may be based on solar photovoltaic (PV), wind, micro-hydro, tidal, or a combination of these systems called hybrid energy systems. The economic viability of these isolated power systems depends on the optimum selection of resources. The improvement in power electronics technology boosted the use of renewable sources in an effective way. The injection of RES generated power to the main grid by the use of power electronic inverters was a breakthrough. However, the introduction of power electronic converters and non-linear loads causes problems with power quality. A conventional technique for mitigating power quality problems is using passive inductor–capacitor (LC) filters at the load centers, but the use of passive filters may result in parallel resonance with power system circuit impedance. Moreover, they have poor flexibility for dynamic compensation of different frequency components. Introduction of active filters into the system is an effective way to mitigate power quality problems (Table 1).

Modeling of PV Arrays

A PV energy conversion system comprises a PV module, an electrical converter, a DC–DC device, and ideally, an energy storage system (ESS). To produce the designated rated power, PV cells are joined in series and parallel to form a PV module. Depending on the purity of the semiconductor, the cells may have a monocrystalline or polycrystalline structure. Compared to monocrystalline cells, whose effectiveness can reach 20%, polycrystalline cells, which have a limiting potency of approximately 13–14%, are less cost-effective. This circuit, known as the one-diode or five-parameter model, is depicted in Figure 3 and consists of a photocurrent source, diode, and serial and shunt resistors. The output current affects the computations of the one-diode model.

$$I_o = I_{PV} - I_D(V) - I_{SH}(V)$$

Whereas the resistor and diode currents are independent of the irradiation value, (V) illustrates their dependence on the terminal voltage.

I_D is the diode's current.

When the temperature is 25°C, and the irradiation is 1000 W/m^2, the photovoltaic current is known as IPV.

The Wind System Model

Wind energy is transformed into mechanical energy by wind turbines. Figure 3 illustrates how the power output of a wind turbine can be described, and the aerodynamic torque is determined by

$$P_w = 0.5 C_p \rho A V_w^3 \tag{2}$$

$$T_w = \frac{P_w}{\omega_W} \tag{3}$$

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Where,
P_W = wind turbine power (in Watt)
P= air density (in kg/m^3)
A = rotor area (in m^2)
V_W = velocity of wind (in m/sec)
ω = turbine rotor speed (in rad/sec)/
C_P = power coefficient, which is a function of the tip speed and blade pitch angle.

Two scenarios were simulated in this study.

Table 1. Review of maximum power point tracking (MPPT) algorithms for photovoltaic and hybrid energy systems.

Reference	Main focus	Key contributions
[9]	Asymmetrical FLC-based MPPT	• Presented an asymmetrical FLC-based MPPT algorithm for PV systems. • Proposed two MF design methodologies to improve the effectiveness of the MPPT method. • Utilized the PSO technique for optimizing MF setting values, supported by a designed cost function. • Demonstrated superior tracking speed/tracking accuracy compared to traditional P&O and symmetrical FLC-based MPPT methods.
[10]	Grid-connected hybrid energy system	• Aimed at developing and simulating a hybrid energy system connected to the grid. • Implemented the MPPT technique for maximum power extraction from individual systems. • Employed an inverter for DC bus voltage regulation and stabilization when energy sources are diminished.
[11]	Maximum power point tracking for wind-solar hybrid system	• Proposed a method to operate a wind-solar hybrid system at its maximum power point using power electronic devices and control methods. • Developed and simulated the hybrid system in MATLAB Simulink under varying environmental conditions. • Demonstrated successful tracking of maximum power from the hybrid system.
[12]	Integration of wind and solar power systems	• Studied a unique integration of wind energy from a grid-connected permanent magnet synchronous generator (PMSG) and solar power systems. • Adopted the MPPT technique to extract the maximum power from both wind and solar energy systems. • Utilized sensor-less rotor speed estimator for wind generator operation and maintained continuity of supply to the load through appropriate integration of outputs from wind and solar power systems.

MF: Membership function, PSO: Particle swarm optimization, P&O: perturb and observe.

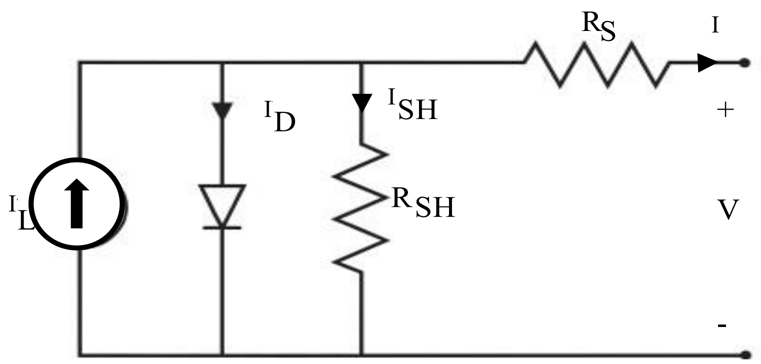

Figure 3. Simplified circuit diagram of a solar PV cell.

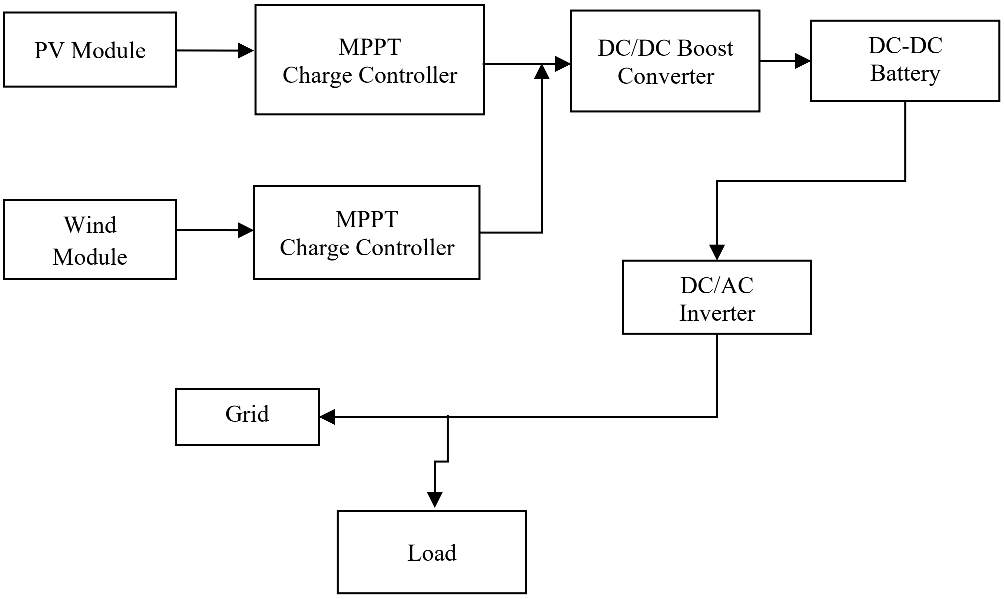

Figure 4. Block diagram of Scenario I (solar–wind hybrid renewable energy system).

Situation (Grid System for Solar–Wind Renewable Energy)

A grid-connected wind-solar hybrid RES was simulated and examined in this study. A general block diagram of the system under discussion is shown in Figure 4. A conventional inverter connects the RES to the grid. In this case, the inverter not only acts as an interface mechanism for the actual power flow to the grid but also enhances the power quality. The performance of the inverter is significantly influenced by the control techniques of the system.

SIMULATION AND RESULT ANALYSIS

Implementation Details

This chapter comprises an analytical and numerical description of the proposed algorithm for sentiment analysis of movie reviews, which is simulated to obtain the performance of the proposed algorithm.

The following configuration was used to simulate the proposed method to assess its performance:

Pentium Core I5-2430M CPU with 64-bit OS, 2.40 GHz, and 4GB RAM

THE MATLAB PLATFORM

Simulation Environment

MATLAB, or MATrix LABoratory, is a computer software created specifically for quick and simple logical calculations and input/output operations. It offers hundreds of built-in functions for a wide range of calculations and toolboxes for diverse areas of analysis, including statistics, optimization, partial differential equation solving, and information analysis.

The implementation or simulation of the algorithm performance was demonstrated in this research project using the MATLAB platform. Toolboxes for fuzzy inference systems were utilized, along with some built-in graph-generation methods. MATLAB functions were used to produce simulation results and compare the performance of the constructed model with that of some existing models.

Simulation Outcomes

Power-control strategies for a grid-connected hybrid generation system with flexible power transfer are presented in the proposed system. Maximum use of publicly accessible renewable energy sources, such as solar and wind power, is made possible by this hybrid system (Figure 5). For this, the system will employ an MPPT algorithm in addition to the conventional perturb and observe method. Additionally, depending on the energy sources' availability, this setup enables the two sources to provide the load either independently or concurrently.

The primary factor influencing mechanical output from wind energy and solar cell operating voltage in the case of solar energy output power is the turbine rotor speed (Figure 6). A wind turbine and a PMSG are combined to create a wind energy conversion system.

The DC output from unconventional energy is transformed into usable AC power for the connected load by the inverter (Figure 7). Normal operating conditions for this hybrid system include normal room temperature for solar energy and typical wind speed at a plain location for wind energy (Table 1).

To demonstrate the working principle, viability, and dependability of this suggested system, the simulation results are displayed (Figure 8).

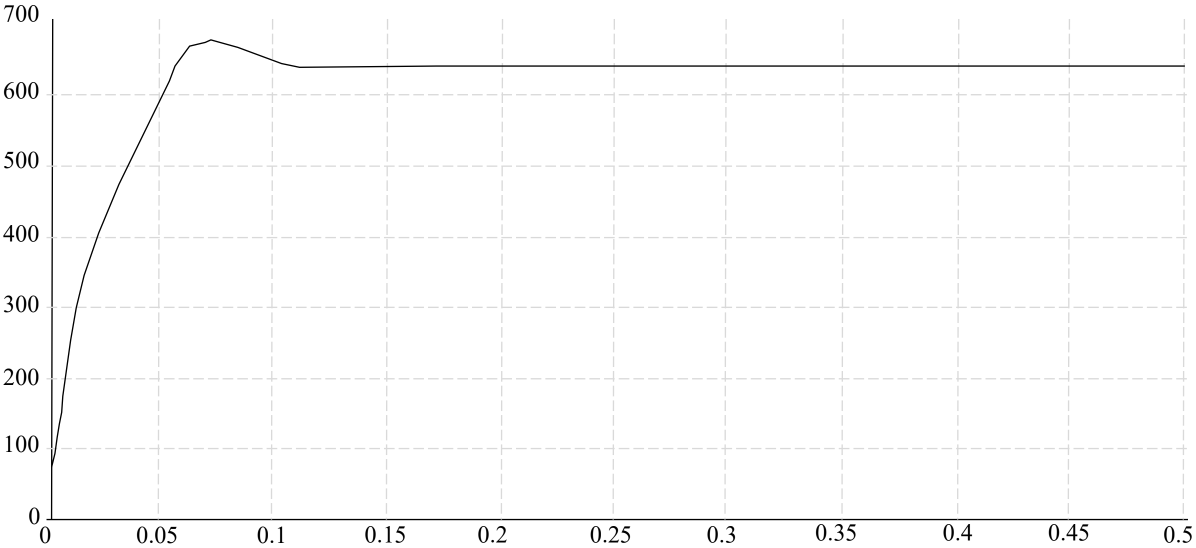

Figure 5. DC **v**oltage obtained in a solar–wind hybrid renewable energy system.

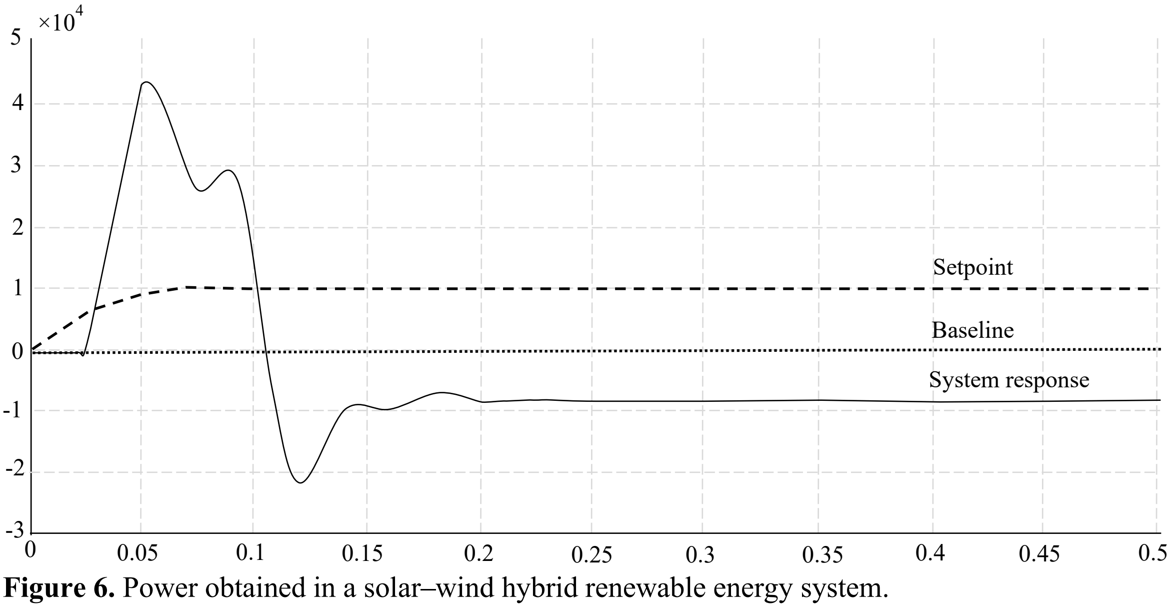

Figure 6. Power obtained in a solar–wind hybrid renewable energy system.

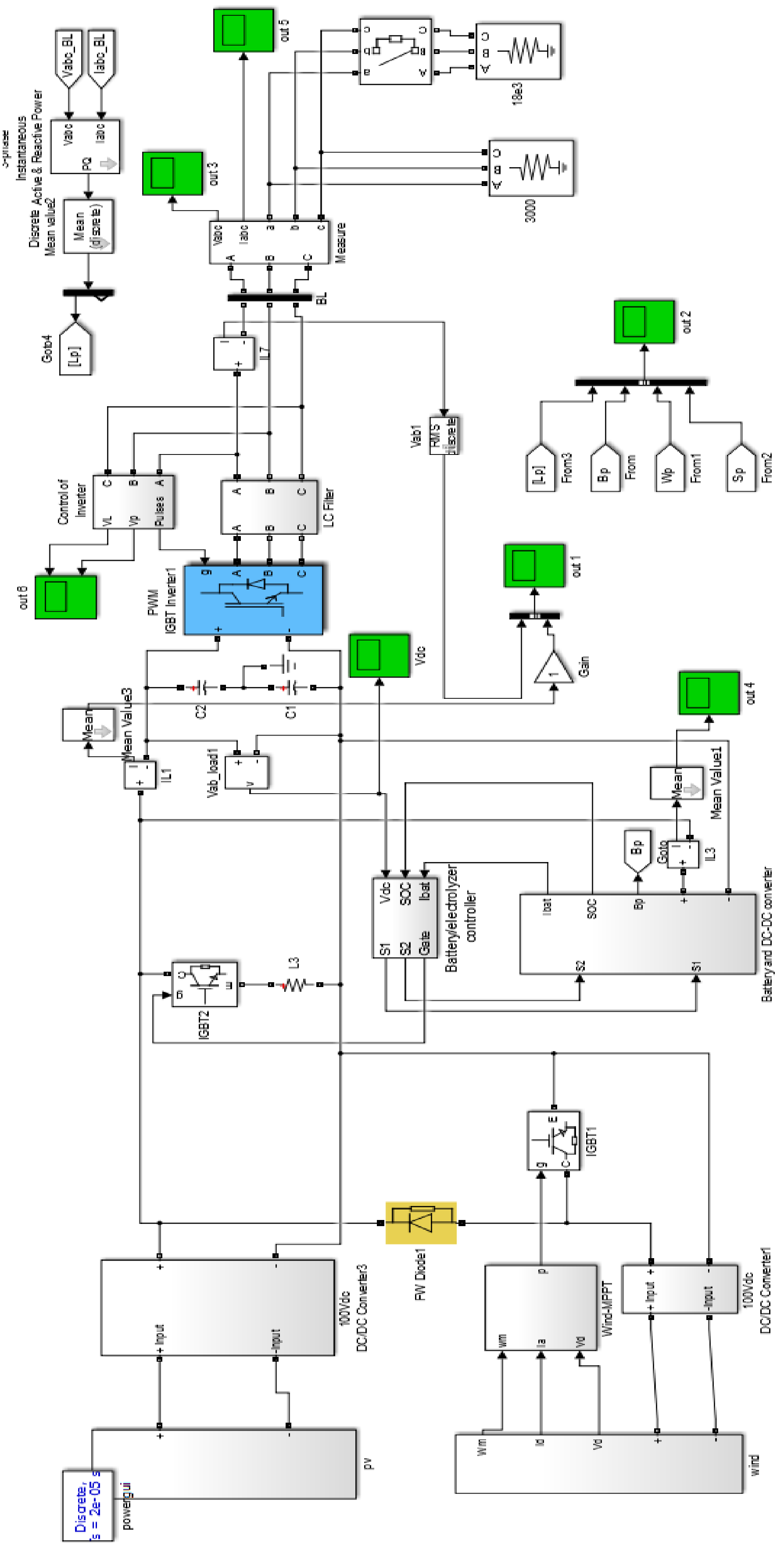

Figure 7. Solar–wind hybrid renewable energy system with controlled inverter model in MATLAB Simulink

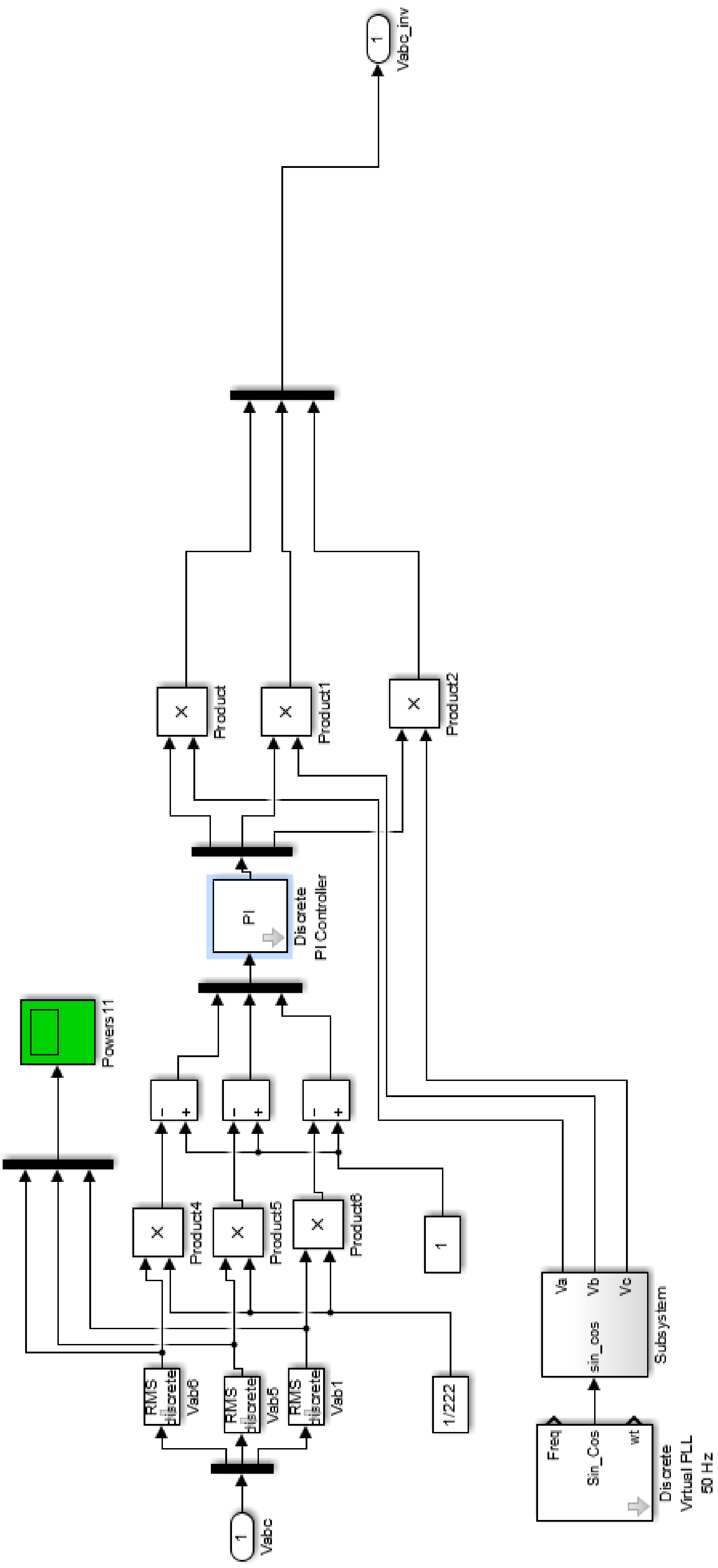

Figure 8. MATLAB Simulink model of controlled inverter for solar–wind RE System.

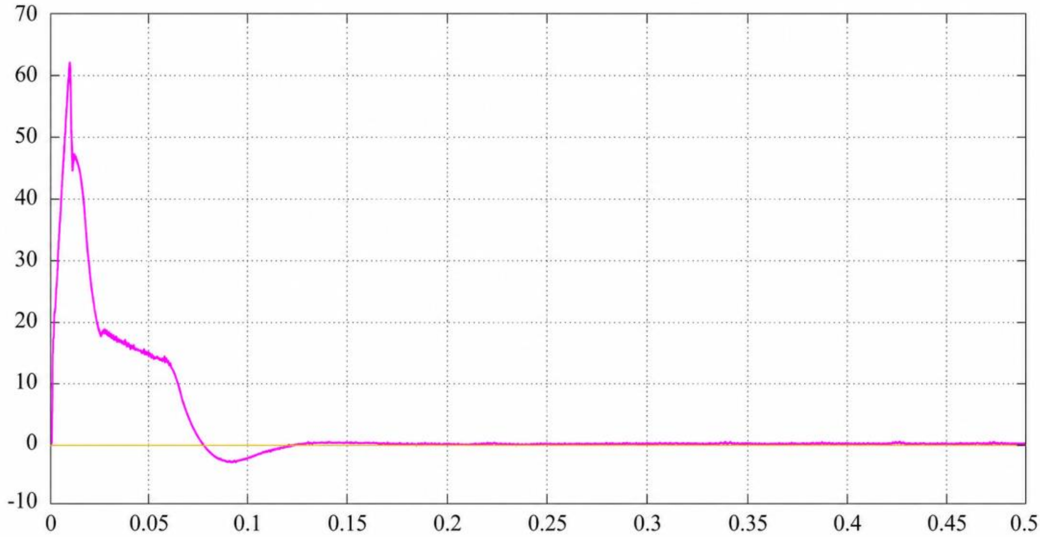

Figure 9. Current obtained in a solar–wind hybrid renewable energy system.

Table 2. Scenario I system parameters.

S.N.	System parameters	Values
1	Hybrid system	Solar and wind system
2	Solar panels	11×2=666 V
3	Wind speed	12 m/s
4	Storage battery	200 volts, 6.5 Ah Ni-MH battery
5	LC filter	L = 50 milli H, C = 2000 μF
6	3-phase Resistor–Inductor–Capacitor load	3 kW
7	Proportional gain (K_p)	0.5
8	Integral gain (K_i)	7.5
9	Inverter	Carrier frequency= 2000 Hz, sampling time= 20 μs
10	Switching device	IGBT

CONCLUSION

This research highlights the significance of solar and wind energy as green and renewable sources, The solar–wind renewable energy system with a controlled inverter simulation results from the MATLAB Simulink Model are quite encouraging (Figure 9). Under typical operating conditions, the inverter efficiently transformed the unconventional DC output into usable AC power for the associated load (Table 2). The graphs depicting the DC voltage, power output, and current obtained demonstrate the system's stability, feasibility, and reliability, supporting its potential as an eco-friendly and sustainable energy solution for the future which are increasingly being recognized as promising alternatives to conventional energy. The integration of photovoltaic and wind energy systems in a grid-connected solar–wind hybrid configuration demonstrates great potential for sustainable power generation. Optimal use of freely available resources and effective energy conversion are guaranteed by the application of MPPT algorithms. The simulation results validate the stability, feasibility, and reliability of the proposed hybrid system, positioning it as a viable, eco-friendly solution for meeting energy demands.

A grid-connected solar–wind hybrid RES with a controlled inverter offers a compelling solution for sustainable power generation. By combining photovoltaic and wind energy sources with efficient MPPT algorithms, the system maximizes the utilization of renewable resources. The stability and viability of this environmentally friendly energy solution were confirmed by the simulation results. This study highlights the potential for a reliable and continuous energy supply while reducing dependence on conventional power sources. As the demand for green and renewable energy increases, the proposed system presents a promising path towards a cleaner and more sustainable future.

REFERENCES

1. Khare A, Rangnekar S. A review of particle swarm optimization and its applications in solar photovoltaic system. Appl Soft Comput. 2013;13(5):2997-3006. doi:10.1016/j.asoc.2012.11.033.
2. Nema P, Nema RK, Rangnekar S. A current and future state of art development of hybrid energy system using wind and PV-solar: A review. Renew Sustain Energy Rev. 2009;13(8):2096-103. doi:10.1016/j.rser.2008.10.006.
3. Rehman S, Mahbub Alam MM, Meyer JP, Al-Hadhrami LM. Feasibility study of a wind-PV-diesel hybrid power system for a village. Renew Energy. 2012;38(1):258-68. doi:10.1016/j.renene.2011.06.028.
4. Haruni AMO, Negnevitsky M, Haque ME, Gargoom A. A novel operation and control strategy for a standalone hybrid renewable power system. IEEE Trans Sustain Energy. 2013;4(2):402-13. doi:10.1109/TSTE.2012.2225455.
5. Liu F, Duan S, Liu F, Liu B, Kang Y. A variable step size INC MPPT method for PV systems. IEEE Trans Ind Electron. 2008;55(7):2622-8. doi:10.1109/TIE.2008.920550.
6. Kamarzaman NA, Tan CW. A comprehensive review of maximum power point tracking algorithms for photovoltaic systems. Renew Sustain Energy Rev. 2014;37:585-98. doi:10.1016/j.rser.2014. 05.045.
7. Anurag A, Bal S, Sourav S, Nanda M. A review of maximum power-point tracking techniques for photovoltaic systems. Int J Sustain Energy. 2016;35(5):478-501. doi:10.1080/14786451.2014. 918979.
8. Tsai MF, Tseng CS, Hung YH. A novel MPPT control design for wind-turbine generation systems using neural network compensator. In: Proceedings of IECON 2012—38th Annual Conference of the IEEE Industrial Electronics Society; 2012. p. 3521-6. doi:10.1109/IECON.2012.6389333.
9. Xia Y, Ahmed KH, Williams BW. A new maximum power point tracking technique for permanent magnet synchronous generator based wind energy conversion system. IEEE Trans Power Electron. 2011;26(12):3609-20. doi:10.1109/TPEL.2011.2162251.
10. Natsheh EM, Albarbar A. Hybrid power systems energy controller based on neural network and fuzzy logic. Smart Grid Renew Energy. 2013;4:187-97. doi:10.4236/sgre.2013.42023.
11. Radianto D, Asfani DA, Hiyama T. Fuzzy logic controller based maximum power point tracking for total cross tied photovoltaic under partial shading. Int Rev Autom Control. 2013;6:264-9.
12. Cheng PC, Peng BR, Liu YH, Cheng YS, Huang JW. Optimization of a fuzzy-logic-control-based MPPT algorithm using the particle swarm optimization technique. Energies. 2015;8(6):5338-60. doi:10.3390/en8065338.