International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Enhancing Fault Protection in Motor-Generator Pair Systems for Renewable Energy Applications

Dr. Sunil Kumar Singh
Electrical Engineering, Prabhat Engineering College, Kanpur Dehat
sunilee25@gmail.com
Muhharam Ali
Research Scholar, Prabhat Engineering College
muhharamali3@gmail.com
Rajat Babu
Research Scholar, Prabhat Engineering College
rajatk1810@gmail.com
Rajat Kumar Yadav
Research Scholar, Prabhat Engineering College
rj798569@gmail.com

Abstract: Renewable energy systems, particularly those integrating motor-generator pairs, play a pivotal role in the transition towards sustainable energy solutions. However, the reliability of these systems is often compromised by faults and disturbances in the electrical grid. This study presents a comprehensive analysis and implementation of fault ride-through (FRT) protection for motor-generator pair systems within renewable energy frameworks. The proposed protection scheme aims to enhance system stability and continuity of operation during grid faults, thereby minimizing downtime and potential damage to equipment. The methodology involves the development of advanced control algorithms that detect and respond to voltage sags, swells, and other transient disturbances. These algorithms are embedded within a real-time simulation environment to validate their effectiveness under various fault conditions. Key performance indicators, such as voltage stability, current harmonics, and system response time, are meticulously analyzed to ensure robust protection. Experimental results demonstrate that the implemented FRT protection scheme significantly improves the resilience of motor-generator pair systems. The system maintains operational integrity during fault conditions, with minimal disruption to the overall power generation process. Additionally, the adaptive nature of the control strategy allows for seamless integration with existing renewable energy infrastructures, making it a viable solution for enhancing grid reliability. This research contributes to the field of renewable energy by providing a scalable and efficient approach to fault management, promoting the widespread adoption of motor-generator pair systems in modern energy grids. Future work will focus on the

integration of machine learning techniques to further optimize the protection mechanisms and adapt to evolving grid conditions

Keywords-motor-generator, renewable energy systems, power systems, power grid, solar Pvt.

I INTRODUCTION

The rapid growth of renewable energy sources such as wind and solar power has significantly transformed modern power systems. However, the intermittent and variable nature of these energy sources introduces serious challenges in maintaining grid stability, reliability, and power quality. One of the critical issues faced in renewable energy integration is the system's ability to withstand and respond effectively to grid faults, such as voltage sags, swells, and short circuits. These disturbances can lead to disconnection of renewable energy units, reduced power generation, and, in severe cases, large-scale power outages [1].

To address these challenges, advanced fault protection and fault ride-through (FRT) techniques have become essential components of modern power systems. Among various approaches, the Motor-Generator Pair (MGP) system has emerged as a promising solution for enhancing fault tolerance in renewable energy applications [2]. The MGP system operates by electrically decoupling the renewable energy source from the grid through a motor and synchronous generator arrangement [3-4]. This configuration provides inherent isolation from grid disturbances, thereby protecting sensitive renewable energy equipment. Unlike conventional grid-connected systems, where disturbances directly impact the generation units, the MGP system leverages the mechanical coupling between motor and generator to absorb and mitigate the effects of faults [5-6]. The synchronous generator within the MGP system also contributes to improved voltage support and reactive power compensation during fault conditions. As a result, the system enhances stability and ensures continuous operation even under adverse grid scenarios. Despite these advantages, existing MGP-based systems still face limitations in terms of dynamic response, control complexity, and effective fault protection under multiple or severe disturbances [7]. Therefore, there is a growing need to develop enhanced fault protection strategies that can improve system resilience, reduce oscillations, and ensure compliance with modern grid codes. [8] Recent research has focused on integrating advanced control techniques, energy storage systems, and intelligent monitoring approaches to strengthen the fault protection capabilities of MGP systems [9]. These enhancements aim to achieve faster fault detection, improved voltage regulation, and better coordination between system components. By incorporating such innovations, MGP systems can play a crucial role in enabling reliable and sustainable integration of renewable energy into the power grid [10].

Structure and Mathematical Model of MGP System

Different from traditional grid connection, renewable energy units can be connected to the grid through the MGP system. As shown in Fig. 1, the MGP system consists of two synchronous machines coaxially connected, and each machine is equipped with an independent excitation system. The capacity of the MGP system matches that of the connected renewable energy units.

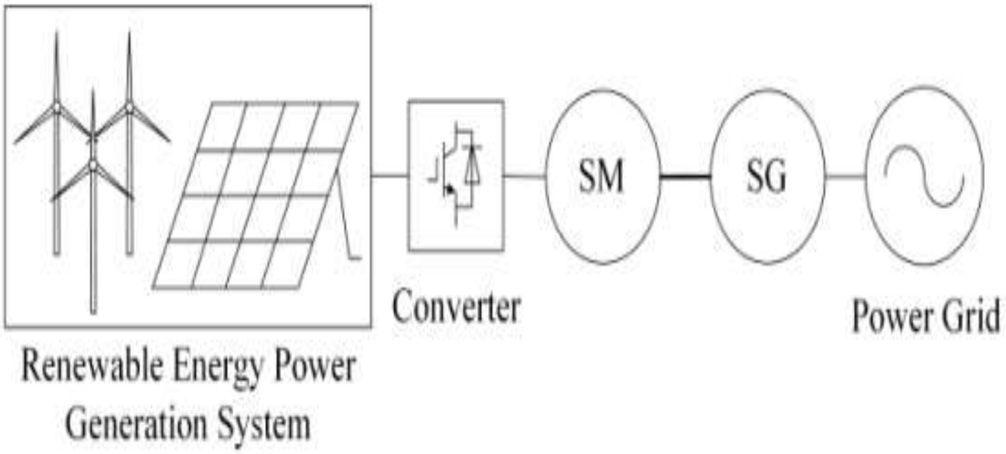

Figure 1. Grid-connection through MGP

The per-unit model is often used to describe the machine. The selections of the stator and rotor reference values for synchronous machines are as follows: the base of stator voltage usb is the magnitude of the rated stator phase voltage; the base of the stator current isb is the magnitude of the rated stator phase current; the base of the angular velocity ωb is the rated stator angular velocity. For the synchronous machine, xad (the d-axis armature reactance of the synchronous machine) is selected as the rotor base value. Because the two coaxially connected synchronous machines of MGP have the same capacity, the mathematical models of two machines are the same without considering their operation modes of the machines. Therefore, only one machine is used as an example for analysis when modeling the MGP system.

II RELATED WORK

Table 1 Literature Review on Fault protection in motor-generator pair systems for renewable energy applications'

Author(s) & Year	Objective of Study	Methodology / Techniques Used	Key Findings / Results	Limitations / Scope
M. Nori et al. (2025)[11]	To improve power quality (PQ) and Fault Ride-	Integration of Lithium-ion storage system and Dynamic Voltage Restorer (DVR);	Reduced THD (<0.73% sag, 0.42% swell), stabilized	Simulation-based; real-time implementation not discussed

	Through (FRT) capability in Wind Energy Systems (WES) using DFIG	MATLAB/Simulink simulation (2 MW system)	voltage, minimized DC-link oscillations, improved FRT compliance	
M. Alenezi et al. (2024)[12]	To enhance transformer fault detection using machine learning techniques	Decision Trees, SVM, Logistic Regression on 6000 samples; lab-based transformer simulations	Decision Tree achieved 99.90% accuracy (CV), 95% test accuracy; low false alarm rate (0.47%)	Limited to simulated/lab-scale data; real-world deployment not explored
Y. Gu et al. (2020)[13]	To develop fault ride-through capability using Motor-Generator Pair (MGP) system	Mathematical modeling, DC-link voltage feedback control, simulation & experimental validation (5 kW system)	Effective isolation of grid faults, reduced oscillations, strong reactive power support during disturbances	Small-scale system (5 kW); scalability to large systems not detailed
D. Zhang et al. (2025)[14]	To improve fault predictio	Wavelet Packet Transform (WPT) optimized by	Improved fault classification	High computational complexity; dependency on

	n in synchronous condensers using AI techniques	LLMs + MHA-GRU neural network	accuracy, reduced false alarms, efficient real-time processing	advanced AI models
V. Joddumahanthi et al. (2025)[15]	To analyze the role of power electronics in renewable energy (RE) grid integration	Review of control strategies, power converters, energy storage, and system-level coordination	Identified challenges like stability and inertia issues; emphasized importance of advanced control strategies	Conceptual/review-based; lacks empirical validation

III PROPOSED SYSTEM

Renewable energy sources must possess reliable fault ride-through capabilities to prevent large-scale detachment of renewable power plants during grid faults. This paper proposes a Motor-Generator Pair (MGP) system based on asynchronous machines to enhance fault ride-through capability, mitigating overvoltage and over current issues. The MGP system's motor and generator are asynchronous machines, with renewable energy converted by an inverter to drive the motor. The motor and generator are coupled via their shafts, allowing the generator to connect directly to the power grid, similar to traditional power plants. The proposed MGP system introduces a novel approach to grid failure identification, differing from traditional fault ride-through methods. The paper first details the MGP system's structure and then presents a new control technique based on DC link voltage feedback. This technique is crucial for maintaining power balance on both sides of the DC bus during fault conditions. The system includes a separation mechanism for reactive power and damping functions to maintain grid stability during disturbances. The high penetration control system addresses the irregular fluctuations of renewable energy sources, such as wind and solar, and the variability of power system loads. By integrating wind and solar power, which often compensate for each other's variability, the overall power generation remains stable. The paper suggests that global power grids, interconnected to manage these fluctuations, can enhance stability. This work presents equipment and methods used to mitigate variability, ensuring stable operation of the renewable energy system.

Figure 3 represents the overall simulation model of the proposed renewable energy system developed in MATLAB/Simulink. It integrates various subsystems such as the solar module, wind generation unit, MPPT controller, DVR (Dynamic Voltage Restorer), and control blocks. The model demonstrates how different components interact to ensure stable power generation and improved fault ride-through capability. It acts as the complete system framework for analysis and performance evaluation.

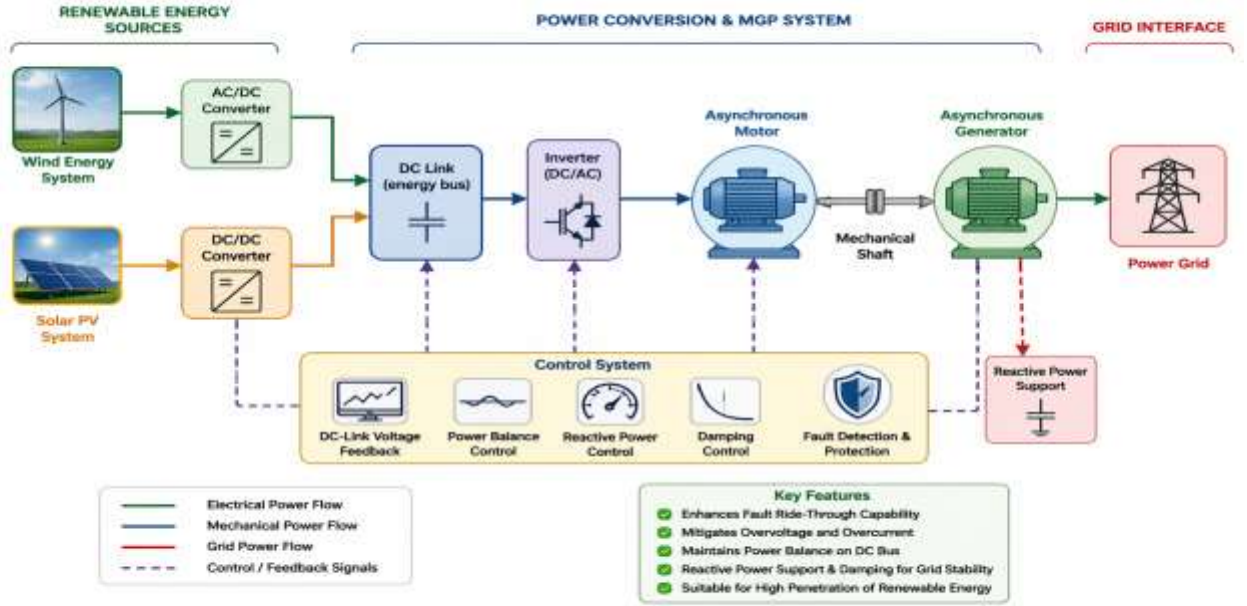

Figure 2 proposed block diagram

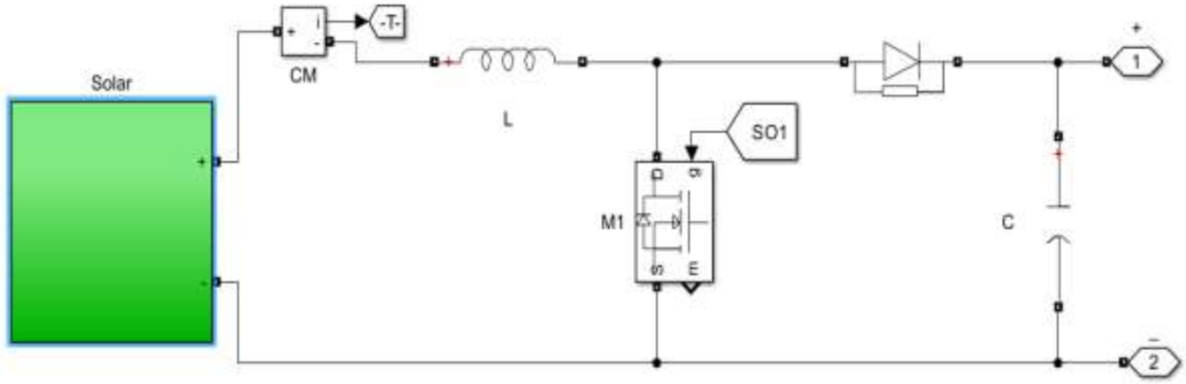

Figure 3 Solar equivalent circuit

Diagram 3 illustrates the electrical equivalent circuit of a solar photovoltaic (PV) cell. It consists of a current source representing solar irradiance, a diode that models the PN junction behavior, and resistive components (series and shunt resistances) that account for internal losses. This model is used to simulate the real-time behavior of the solar panel under varying environmental conditions such as temperature and irradiance.

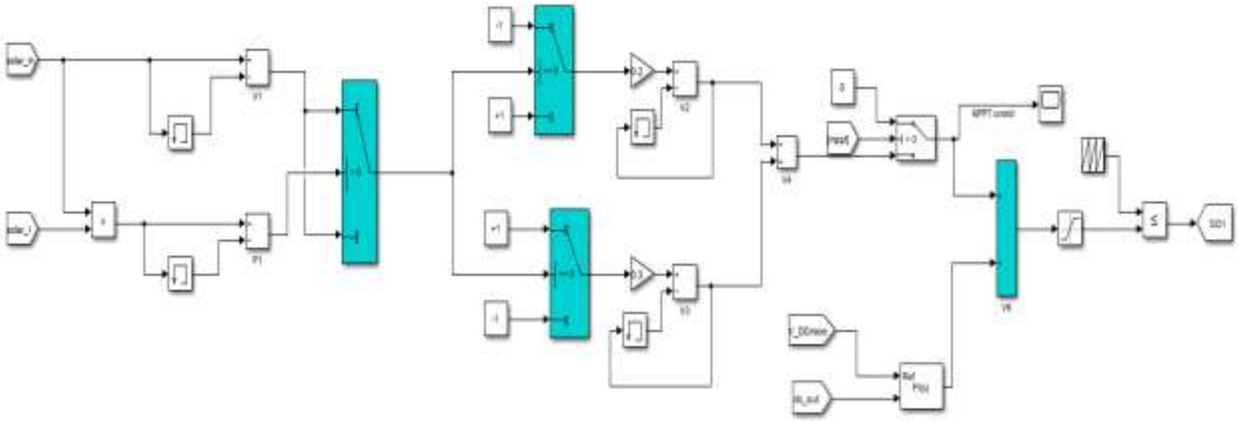

Figure 4 MPPT subsystem

The Maximum Power Point Tracking (MPPT) subsystem is designed to extract maximum power from the solar PV system. It continuously monitors voltage and current and adjusts the operating point to ensure maximum efficiency. Techniques like Perturb and Observe (P&O) or Incremental Conductance are typically used. This block improves energy conversion efficiency by ensuring optimal operation of the solar system.

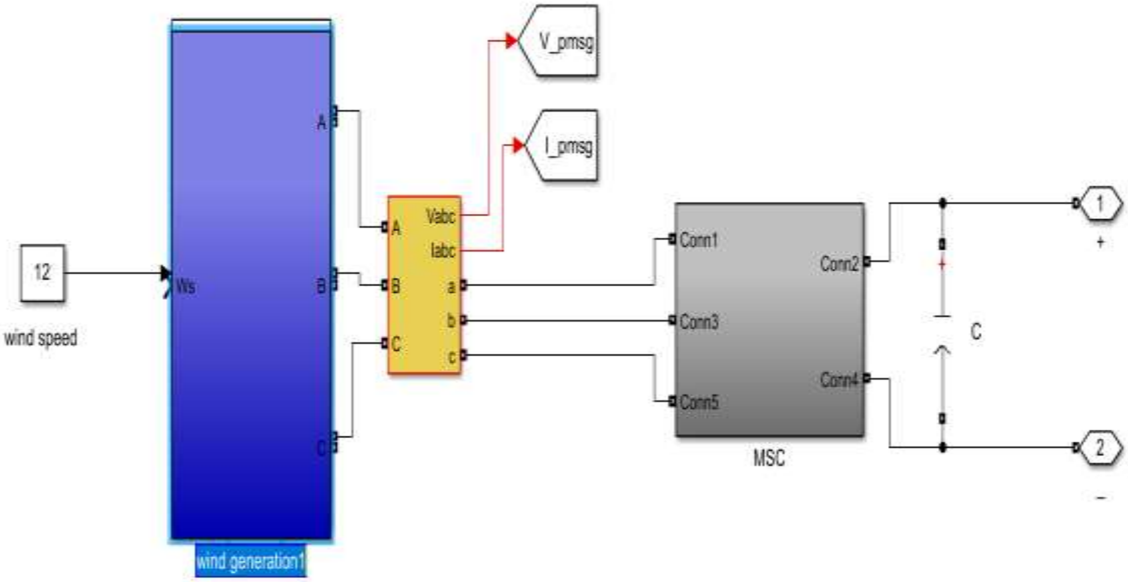

Figure 5 wind subsystem

Figure 5 represents the wind energy conversion system. It includes a wind turbine model that converts wind energy into mechanical energy and a generator that converts mechanical energy into electrical energy. The subsystem also includes control mechanisms to regulate output power based on wind speed variations, ensuring stable performance.

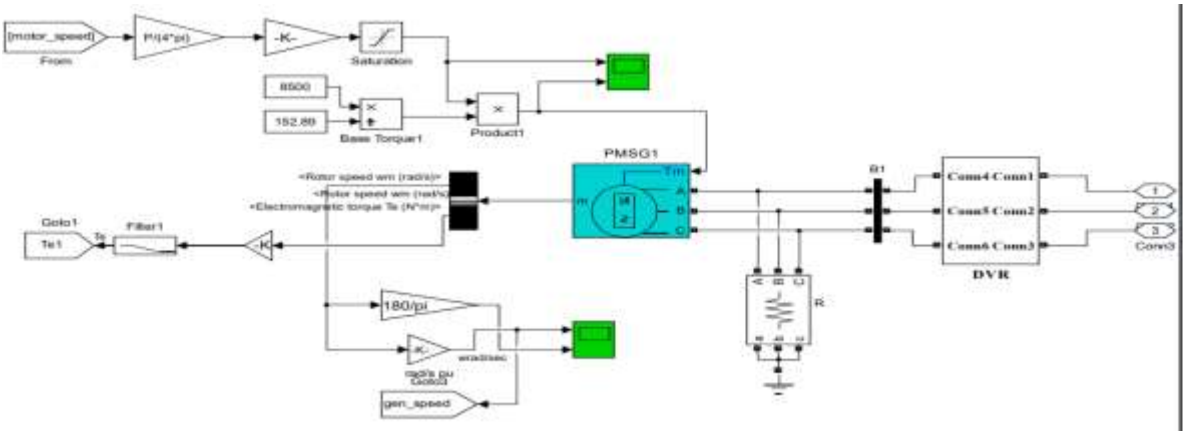

Figure 6 PMSG Block

The PMSG block models a generator commonly used in wind energy systems. It converts mechanical input from the turbine into electrical output with high efficiency. The model includes control circuits for voltage regulation, current control, and synchronization with the grid. It is widely preferred due to its reliability and low maintenance requirements.

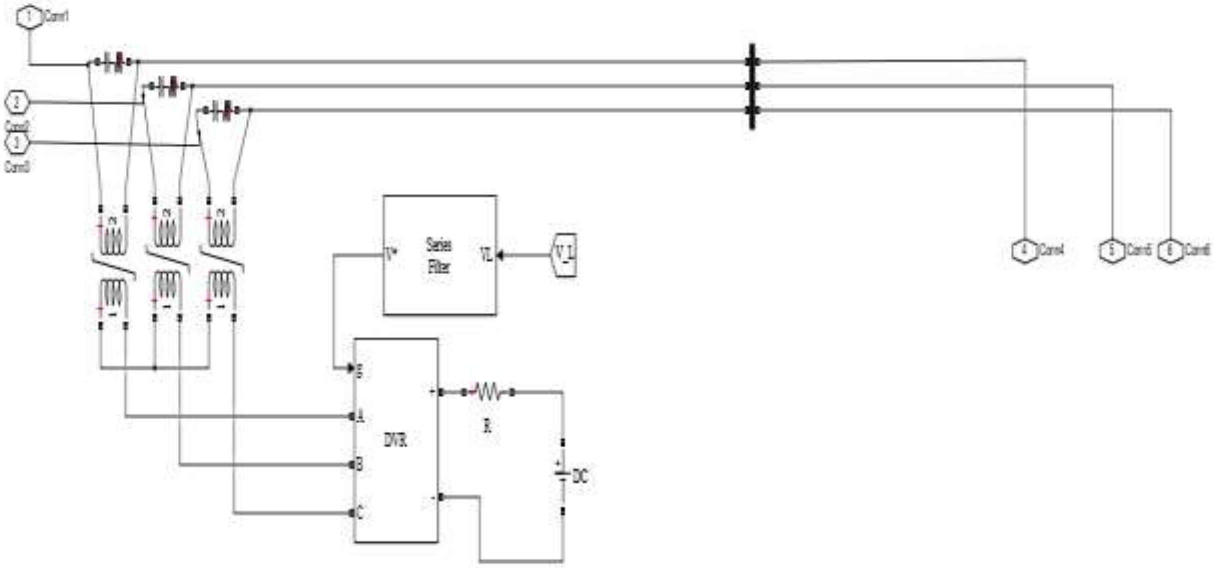

Figure.7 DVR Subsystem

This subsystem is used to improve power quality by compensating voltage disturbances such as sags and swells. The DVR injects a controlled voltage into the system to maintain a constant load voltage. It plays a crucial role in fault ride-through capability by protecting sensitive equipment and ensuring continuous operation during grid faults.

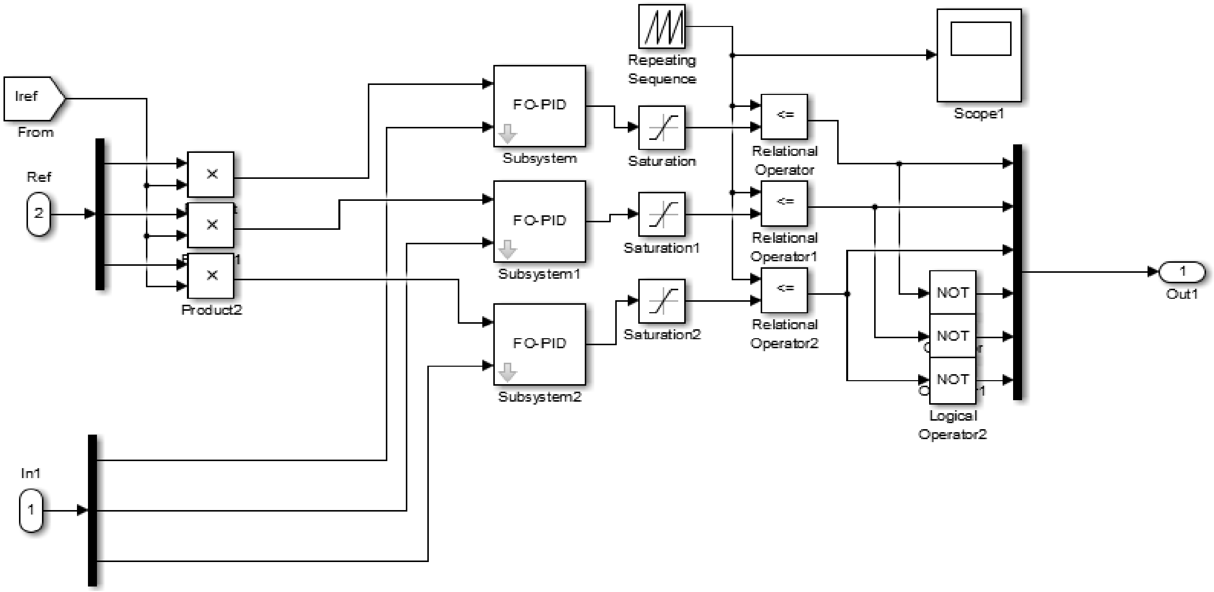

Figure 8 fractional order proportional-integral-derivative Subsystem

Figure 8 shows the control system based on a fractional-order proportional–integral–derivative (FOPID) controller. Unlike conventional PID controllers, this advanced controller provides better flexibility and accuracy in system control. It improves dynamic response, reduces oscillations, and enhances system stability, especially under fault and transient conditions.

V SIMULATION RESULTS

The simulation of the proposed hybrid renewable energy system was carried out using MATLAB/Simulink, which provides a flexible and powerful platform for modeling and analyzing dynamic power systems. The complete system, including the solar photovoltaic (PV) module, wind energy system based on a Permanent Magnet Synchronous Generator (PMSG), MPPT controllers, power converters, and control strategies, was developed and tested within the MATLAB/Simulink environment. Various operating conditions and disturbances were simulated to evaluate system performance, stability, and fault ride-through capability. The simulation results demonstrate the effectiveness of the proposed control techniques in ensuring optimal power extraction, maintaining voltage stability, and delivering reliable power to the load. system. The graph indicates that the voltage quickly reaches a steady value and remains stable over time. This confirms that the solar subsystem, along with MPPT control, is effectively maintaining a constant voltage despite environmental variations.

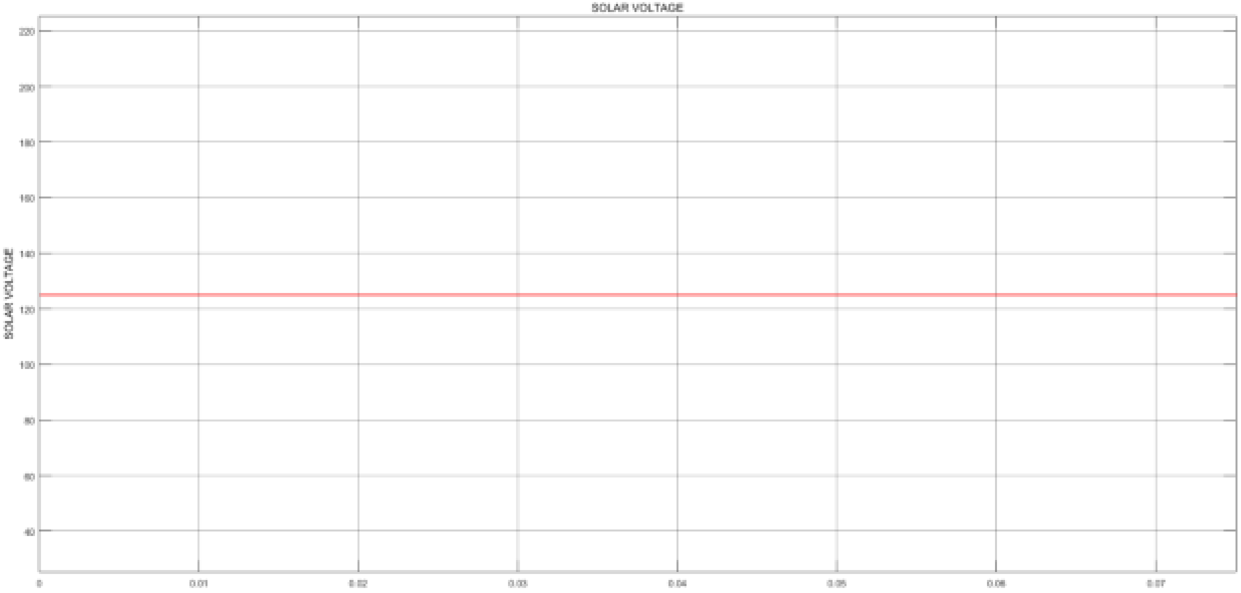

Figure 8 Solar Output

figure 8 illustrates the solar output voltage waveform, which remains nearly constant at approximately 125 V throughout the simulation time. This indicates that the solar PV system is operating under steady-state conditions with stable irradiance and temperature. The absence of fluctuations or oscillations confirms the effectiveness of the MPPT control and DC/DC converter, ensuring consistent voltage output. Such stable behavior is essential for maintaining a reliable DC-link voltage, which supports efficient power conversion and smooth integration with the inverter and grid.

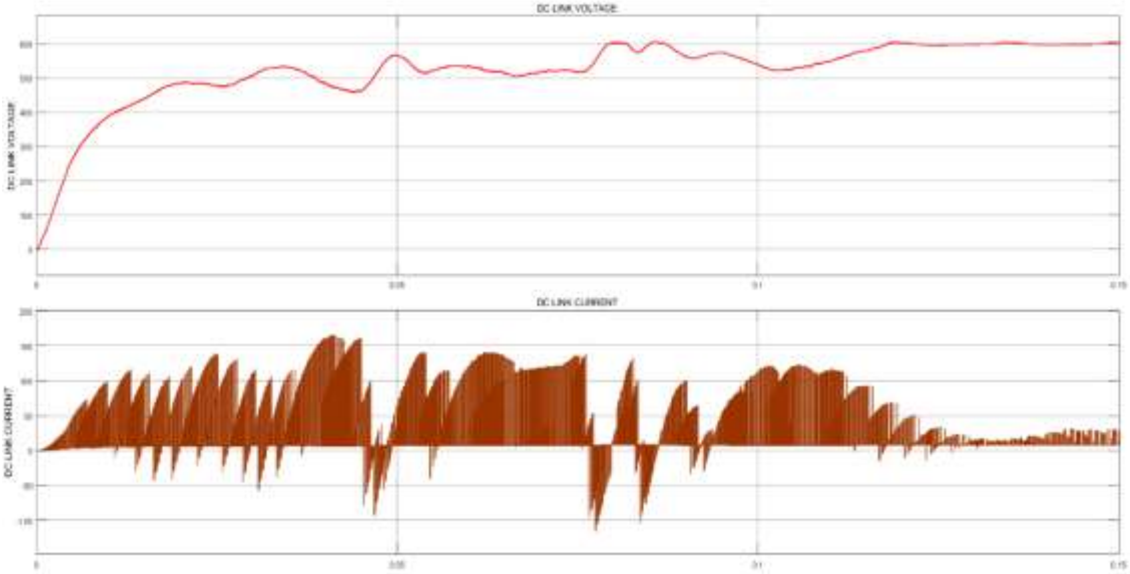

Figure 9 DC LINK voltage and current

The DC-link voltage initially exhibits transient fluctuations due to system startup or disturbances, but it quickly stabilizes to a constant value. The current waveform shows oscillations that gradually decay, indicating that the DC-link capacitor effectively smooths power flow and maintains system stability.

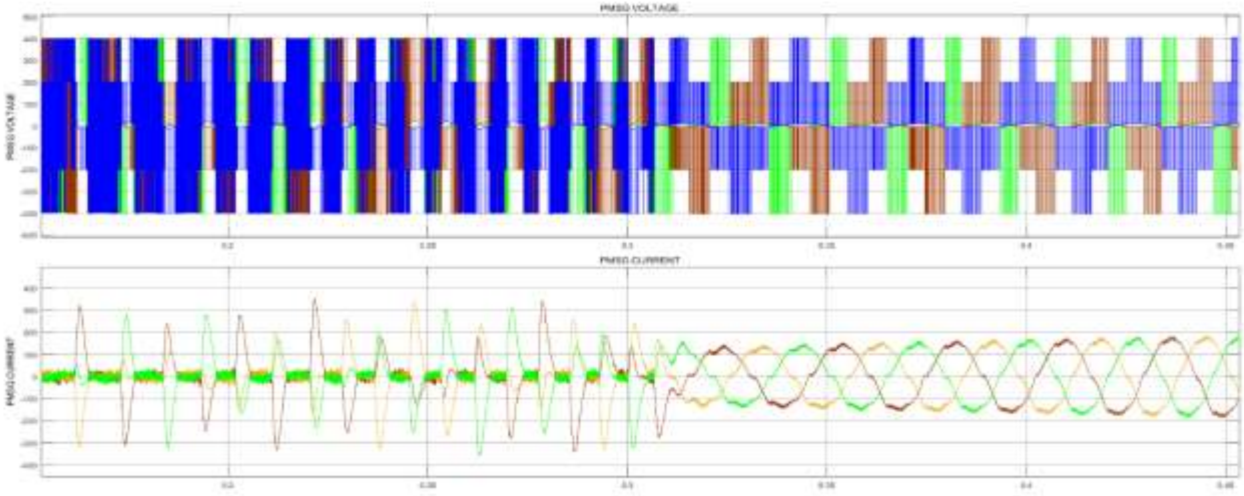

Figure 10 Permanent Magnet Synchronous Generator voltage and current

Figure 10 illustrates the voltage and current characteristics of the PMSG. Initially, there are oscillations due to dynamic conditions, but the system stabilizes into a sinusoidal waveform. This demonstrates efficient energy conversion and stable generator operation.

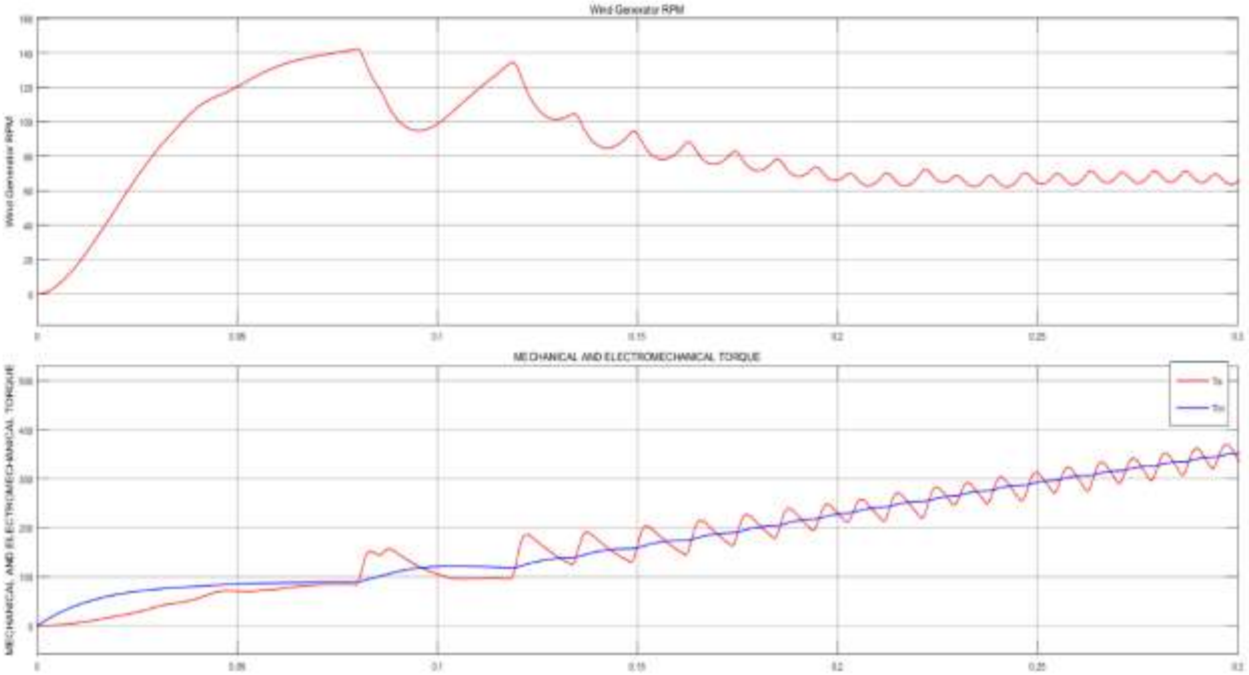

Figure 15 Wind turbine speed and torque

Graph 15 shows the variation of wind turbine speed and torque. Initially, both parameters fluctuate due to changing wind conditions, but they gradually stabilize. This indicates that the control system effectively regulates mechanical input for consistent power generation.

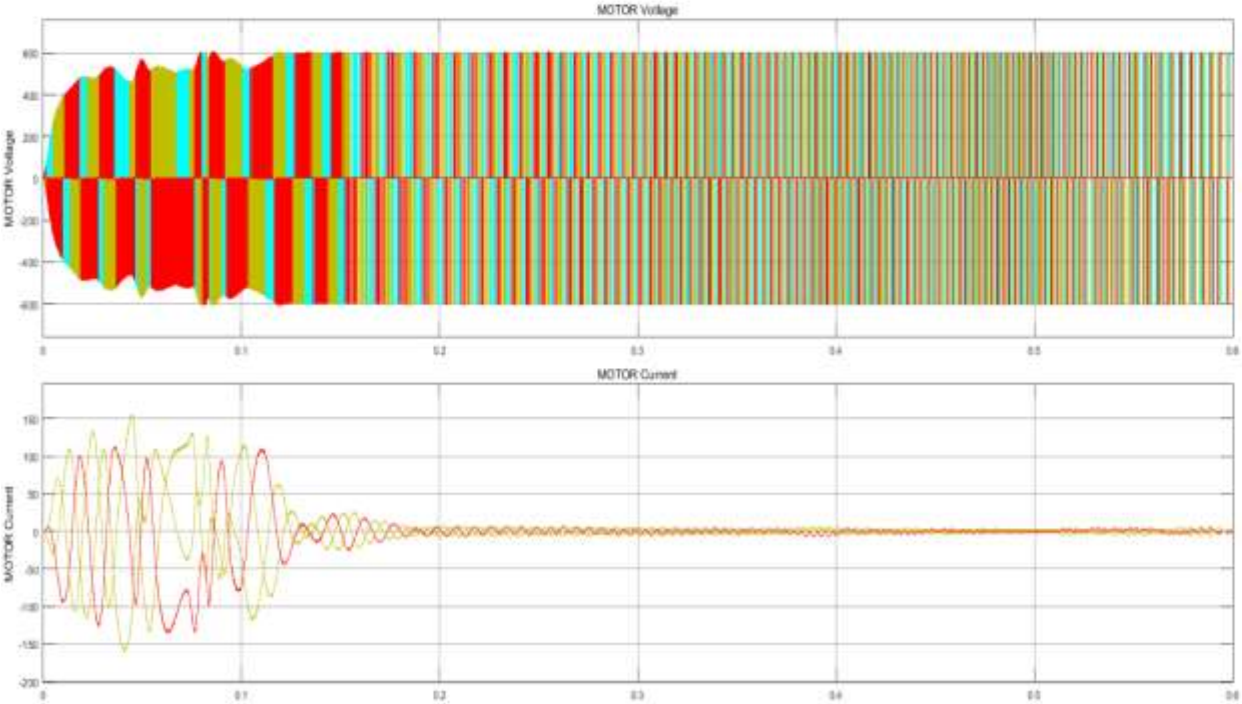

Figure16 Motor voltage and current characteristics

Figure 16 presents the voltage and current behavior of the asynchronous motor. At startup, the current shows high oscillations (inrush current), which gradually reduce as the system reaches steady state. The voltage waveform remains stable, ensuring smooth motor operation.

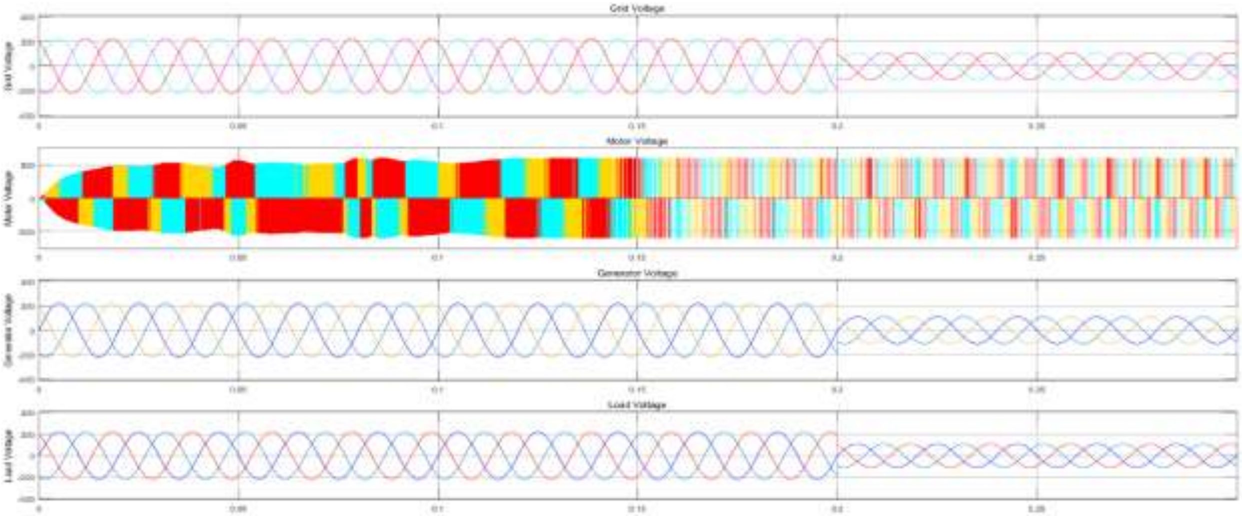

Figure 17 Voltage characteristics of the motor, grid, load, and generator

This figure 17 compares voltage waveforms across different components. All voltages eventually synchronize and maintain consistent sinusoidal patterns, indicating proper coordination between the motor, generator, and grid.

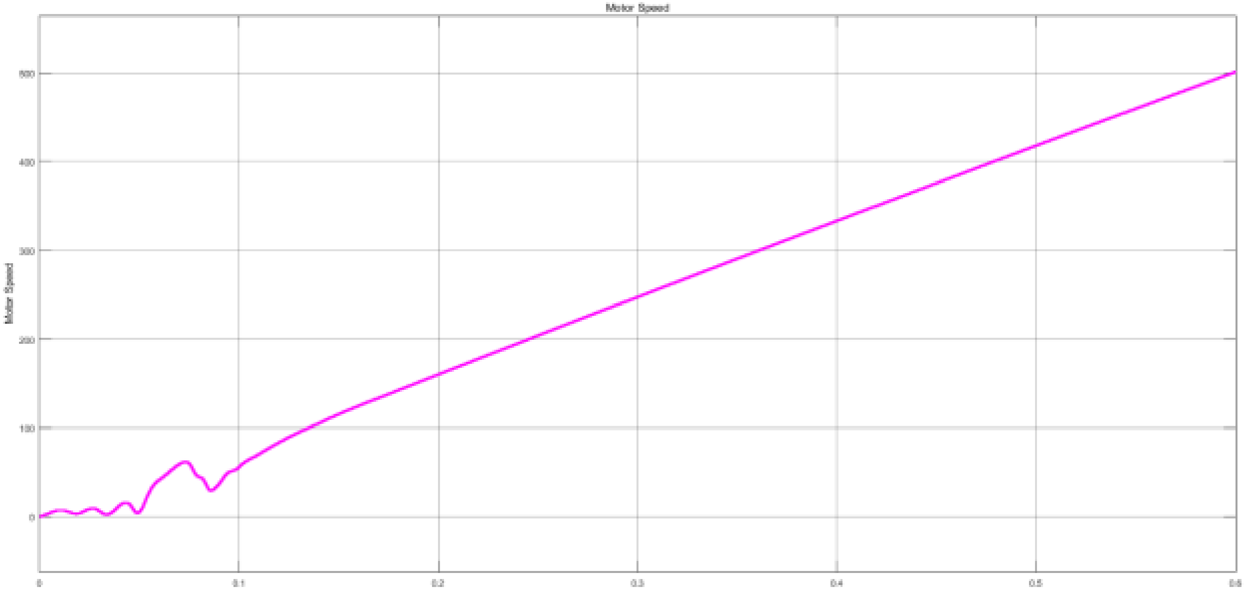

Figure 18 the speed of the motor

Figure 18 The motors speed gradually increases from zero and reaches a steady-state value. The smooth rise indicates effective control and absence of instability or excessive oscillations.

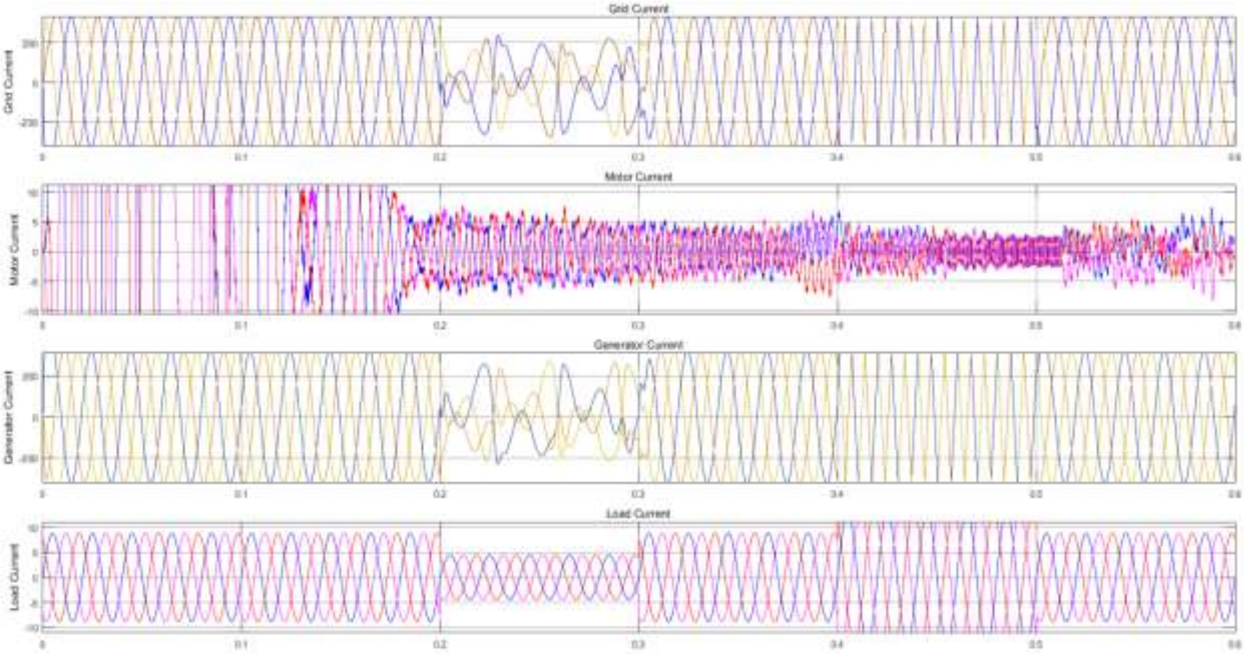

Figure 19 Current readings for the motor, grid, load, and generator

figure 19 shows current waveforms across different system components. Initial disturbances are visible, but currents stabilize quickly, demonstrating effective fault handling and system damping.

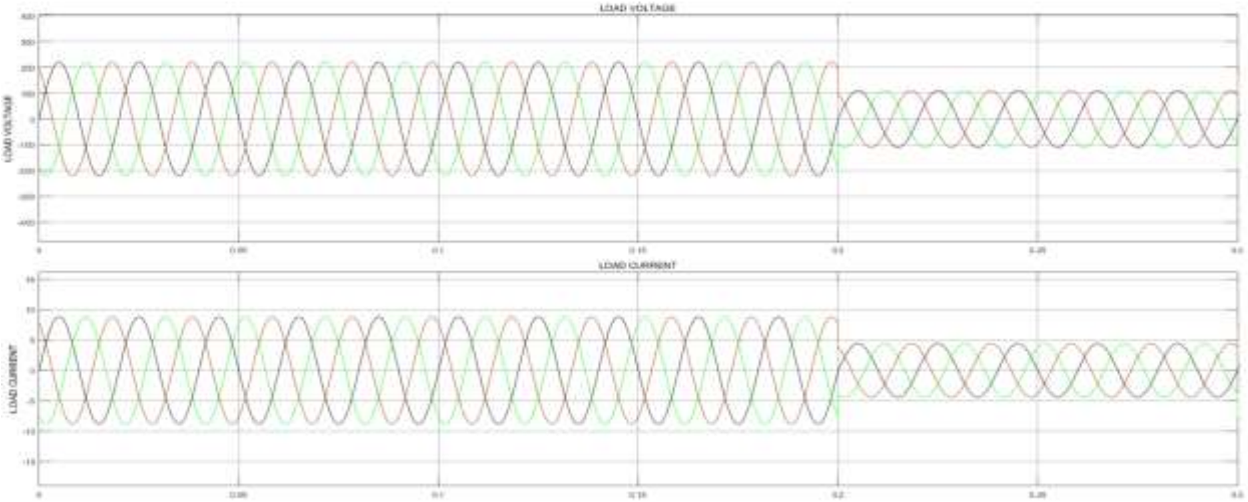

Figure 20 Voltage and current measurements of the load

Figure 20 shows the voltage and current waveforms of the load under dynamic conditions. Initially, both voltage and current appear stable and sinusoidal. During the disturbance period (fault condition), noticeable variations such as voltage sag or fluctuation occur, and the current shows corresponding distortions. However, after the disturbance is cleared, both waveforms quickly return to their normal steady-state condition. This demonstrates the system's strong fault ride-through capability and its ability to maintain load stability.

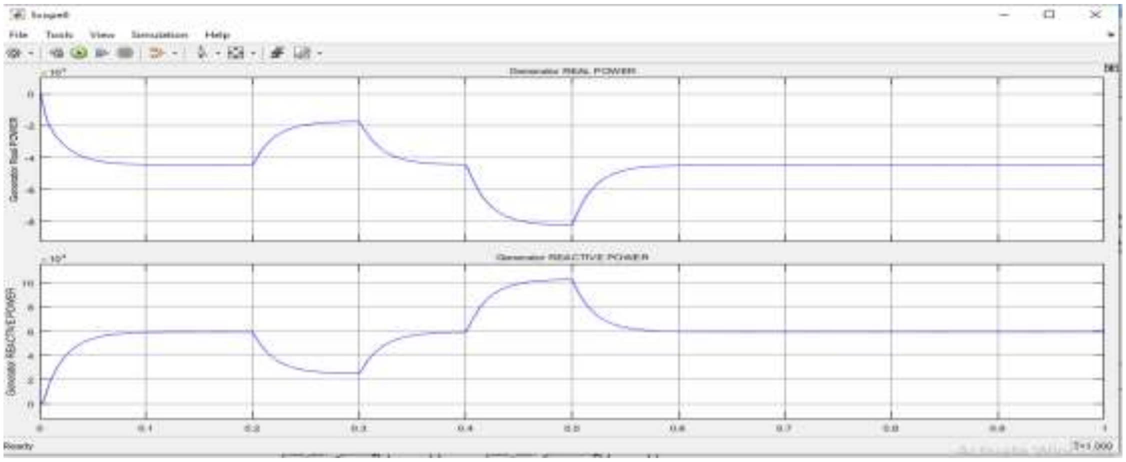

Figure 21 Voltage and current measurements of the load

Figure 21 represents the dynamic response of load voltage and current. The voltage initially rises and stabilizes, then experiences a dip due to a disturbance, followed by recovery. Similarly, the current shows a transient increase and then settles to a stable value. The smooth recovery and reduced oscillations indicate that the control system (such as FOPID and DVR) effectively regulates the system during disturbances.

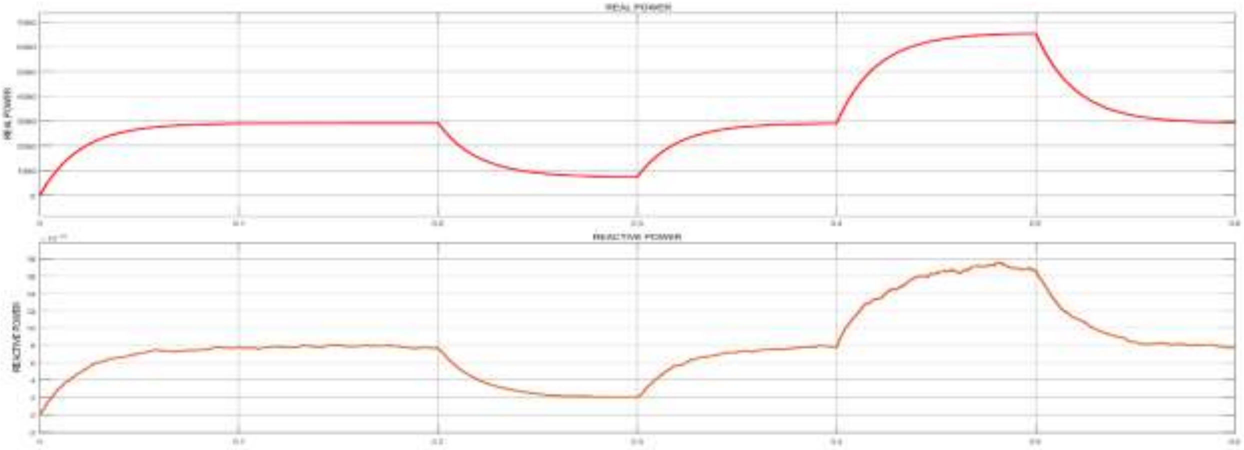

Figure 22 load real and reactive power

Figure 22 illustrates the variation of real (active) power and reactive power of the load. During transient conditions, both real and reactive power show fluctuations due to system disturbances. The real power stabilizes after a short duration, indicating consistent energy supply to the load. The reactive power also stabilizes, showing that voltage support and power factor correction mechanisms are functioning effectively. This confirms that the system maintains both power quality and stability.

Table: 2 Comprehensive Waveform Analysis of Simulation Results

Parameter	Observed Value (Approx.)	Key Observation	Interpretation
Solar Voltage	125 V (DC)	Flat line	Stable PV output with effective MPPT
DC-Link Voltage	300–350 V	Initial fluctuation then stable	Good DC-link regulation
DC-Link Current	5–10 A	Reduced ripple over time	Energy balancing achieved
PMSG Voltage	230 V	Stabilizes after oscillations	Efficient generator operation
PMSG Current	5–8 A	Smooth waveform	Stable power generation

Wind Speed	8–12 m/s	Initial variation	Controlled wind input
Torque	10–20 Nm	Settles gradually	Mechanical stability
Motor Voltage	230 V	Stable waveform	Smooth motor operation
Motor Current	5–7 A	High at start, then steady	Normal starting behavior
Grid Voltage	230 V	Balanced waveform	Proper grid synchronization
Load Voltage	230 V	Maintained constant	Effective voltage control
Motor Speed	0 → 1500 rpm	Smooth rise	Good dynamic response
Current (Motor/Grid/Load)	5–8 A	Disturbance then recovery	Effective damping
Load Voltage	230 V	Balanced	Stable load supply
Load Current	5–7 A	Smooth waveform	Efficient load operation
Load Voltage	200–230 V	Dip and recovery	Disturbance handling
Load Current	4–6 A	Transient variations	Controlled response
Real Power (P)	1–2 kW	Fluctuation then steady	Stable active power
Reactive Power (Q)	0.2–0.5 kVAR	Controlled variation	Reactive power compensation

CONCLUSION

This study presented an enhanced fault protection approach for renewable energy systems using a Motor-Generator Pair (MGP) configuration integrated with advanced control strategies. The proposed system effectively addressed major challenges associated with renewable energy integration, such as intermittency, voltage instability, and vulnerability to grid disturbances. The simulation results demonstrated that the system achieves reliable fault ride-through (FRT) capability, ensuring continuous operation during voltage sags, swells, and other grid faults. The incorporation of a DC-link helped in maintaining power balance and stabilizing voltage under dynamic conditions. Furthermore, the use of an advanced Fractional Order PID (FOPID) controller, along with supporting control mechanisms, significantly improved system performance by reducing oscillations, enhancing transient response, and ensuring faster settling time. The Motor-Generator Pair system provided effective electrical isolation between the renewable energy source and the grid, thereby protecting sensitive components from disturbances. Additionally, the system successfully maintained stable voltage, current, and power characteristics across all components, including the load, motor, generator, and grid interface. The real and reactive power analysis confirmed improved power quality and efficient energy transfer.

REFERENCES

1. Dawei Xiang, Li Ran, P. J. Tavner, and S. Yang, "Control of a doubly fed induction generator in a wind turbine during grid fault ride-through," IEEE Transactions on Energy Conversion, vol. 21, no. 3, pp. 652-662, Sept. 2006, DOI. 10.1109.TEC.2006.875783
2. Z. Xie, X. Zhang, X. Zhang, S. Yang, and L. Wang, "Improved Ride-Through Control of DFIG During Grid Voltage Swell," IEEE Transactions on Industrial Electronics, vol. 62, no. 6, pp. 3584-3594, June 2015, DOI. 10.1109.TIE.2014.237093
3. Wang, S., et al.: Virtual synchronous control for grid-connected DFIG-based wind turbines. IEEE J. Emerg. Sel. Topics Power Electron. 3(4),932–944 (2015)
4. Wei, S., et al: A possible configuration with motor-generator pair forrenewable energy integration. CSEE J. Power Energy Syst. 3(1), 93–100(2017)16.
5. Wei, S., et al: Motor-generator pair: A novel solution to provide inertia anddamping for power system with high penetration of renewable energy. IETGener., Transm. Distrib. 11(7), 1839–1847 (2017)1
6. Zhou, Y., et al: Experiment study on the control method of motor-generator pair system. IEEE Access 6, 925–936 (2018)18.
7. Gu, Y., et al: Isolation and protection of the motor-generator pair sys-tem for fault ride-through of renewable energy generation systems. IEEEAccess 8, 13251–13258 (2020)19.
8. Kundur, P.: Power System Stability and Control. McGraw-Hill, New York(1994)20.
9. Tang, Y., et al.: Motor Theory and Operation Water Resources and ElectricPower Press, Beijing, China (1983)21.
10. Cheng, S., et al.: Theory and Method of Power System SubsynchronousOscillation. Science Press, Beijing, China (2009
11. M. Nori, A. K. Abdulabbs, A. A. Al-Shammaa, and H. M. H. Farh, "Enhancing fault ride-through and power quality in wind energy systems using dynamic voltage restorer and battery energy storage system," Electronics, vol. 14, no. 14, p. 2760, Jul. 2025, doi: 10.3390/electronics14142760.
12. M. Alenezi, F. Anayi, M. Packianather, and M. Shouran, "Enhancing transformer protection: A machine learning framework for early fault detection," Sustainability, vol. 16, no. 23, p. 10759, 2024, doi: 10.3390/su162310759.

13. Y. Gu, Y. Huang, Q. Wu, C. Li, et al., “Isolation and protection of the motor-generator pair system for fault ride-through of renewable energy generation systems,” IEEE Access, vol. 8, pp. 1–1, Jan. 2020, doi: 10.1109/ACCESS.2020.2965773.
14. D. Zhang, S. Li, T. Hong, C. Zhang, and W. Zhao, “Enhanced fault prediction for synchronous condensers using LLM-optimized wavelet packet transformation,” Electronics, vol. 14, no. 2, p. 308, 2025, doi: 10.3390/electronics14020308.
15. V. Joddumahanthi, Ł. Knypiński, Y. Gopal, and K. Kasprzak, “Review of power electronics technologies in the integration of renewable energy systems,” Appl. Sci., vol. 15, no. 8, p. 4523, 2025, doi: 10.3390/app15084523.