Renewable Energy Monitoring System for Microgrid Using Novel Model Predictive Control

Sagar Shahaji Kambale, Dr. P. V. Paratwar
Department of Electrical Engineering, Dattakala College of Engineering, Savitribai Phule Pune University (SPPU), Pune, India

Abstract: This paper presents a Renewable Energy Monitoring System (REMS) for a hybrid microgrid using a Model Predictive Control (MPC) technique implemented in MATLAB/Simulink. The proposed microgrid integrates a solar photovoltaic (PV) array, wind turbine with Permanent Magnet Synchronous Generator (PMSG), Battery Energy Storage System (BESS), DC-link, and grid-connected inverter for efficient renewable power management. The developed MPC controller continuously predicts system behavior and regulates the power flow between renewable sources, storage units, and load demand under varying operating conditions. A real-time monitoring framework is designed to observe renewable generation, DC-bus performance, inverter output, battery charging/discharging condition, and grid power exchange. Simulation results obtained from the developed Simulink model show stable operation under variable solar irradiance and wind speed conditions. The proposed MPC-based system achieves improved DC-link voltage regulation, reduced power fluctuations at the Point of Common Coupling (PCC), faster transient response, and enhanced renewable energy utilization compared to conventional control approaches. The obtained output waveforms and grid power analysis also demonstrate effective load sharing and reliable microgrid operation in both grid-connected and standalone modes. The overall results confirm that the proposed REMS with MPC provides an efficient, intelligent, and scalable solution for hybrid renewable microgrid applications with improved system stability, monitoring capability, and energy management performance.

Keywords: Microgrid, Renewable Energy Monitoring System (REMS), Model Predictive Control (MPC), Solar Photovoltaic (PV), Wind Turbine, Battery Energy Storage System (BESS), MATLAB/Simulink, Hybrid Renewable Energy System, DC-Link Control, Energy Management System (EMS).

I. INTRODUCTION

The rapid increase in global energy demand and the depletion of conventional fossil-fuel resources have accelerated the development of renewable energy–based power systems. Among the available renewable energy sources, solar photovoltaic (PV) and wind energy have emerged as the most promising alternatives due to their sustainability, environmental friendliness, and wide availability. However, the intermittent and unpredictable nature of renewable energy sources creates significant challenges in maintaining stable and reliable power delivery in modern microgrid systems. A microgrid is a localized power network that integrates Distributed Energy Resources (DERs) such as solar PV systems, wind turbines, battery energy storage systems (BESS), and controllable loads. Microgrids can operate either in grid-connected mode or islanded mode depending on operating conditions and grid availability. The integration of multiple renewable sources into a common DC or AC bus improves energy reliability and flexibility, but it also introduces issues related to voltage regulation, frequency stability, power quality, and energy balancing.Traditional control methods such as Proportional–Integral–Derivative (PID) and droop controllers are widely used in renewable energy systems. However, these controllers are based on fixed control parameters and are unable to respond effectively to rapid variations in solar irradiance, wind speed, and load demand. As renewable penetration increases, conventional controllers become less efficient in maintaining dynamic stability and optimal power management in hybrid microgrids. To overcome these limitations, advanced predictive and optimization-based control techniques have gained considerable attention in recent years. Model Predictive Control (MPC) is one of the most effective modern control approaches for microgrid applications because it can predict future system behavior over a defined prediction horizon and generate optimal control actions while considering system constraints. MPC provides fast dynamic response, efficient energy utilization, reduced power fluctuations, and improved voltage and frequency regulation under varying operating conditions.

A Renewable Energy Monitoring System (REMS) for a hybrid solar–wind microgrid using a Novel Model Predictive Control (MPC) strategy is proposed and implemented in MATLAB/Simulink. The proposed system integrates a solar PV array, wind turbine with Permanent Magnet Synchronous Generator (PMSG), Battery Energy Storage System (BESS), DC-link, and inverter-based grid interface into a unified microgrid architecture. A real-time monitoring framework is also developed to supervise renewable power generation, battery state of charge, DC-link voltage, inverter output, and grid interaction. The proposed MPC controller continuously predicts system conditions and optimizes the power flow between renewable sources, storage systems, and load demand. Simulation studies are carried out under variable irradiance, wind speed, and load conditions to analyze the performance of the proposed system. The obtained results demonstrate improved DC-link voltage regulation, enhanced renewable energy utilization, reduced power fluctuations at the Point of Common Coupling (PCC), and better overall microgrid stability compared to conventional control methods.

II. LITERATURE SURVEY

Recent advancements in renewable energy–based microgrids have focused on intelligent energy management, predictive control strategies, and real-time monitoring systems. Among various control techniques, Model Predictive Control (MPC) has gained significant attention due to its capability to predict future operating conditions, handle system constraints, and optimize multi-variable control actions. Several researchers have investigated MPC-based microgrid energy management systems for improving voltage stability, frequency regulation, renewable energy utilization, and battery coordination. A summary of the latest research contributions related to renewable microgrid control and monitoring is presented in Table I.

Sr. No.	Author(s) / Year	Technique / Method	Major Contribution	Limitation
1	J. Sichlau et al. (2025)	Hierarchical MPC	Improved energy coordination in hybrid microgrids	High computational burden
2	S. Kaur et al. (2025)	MPC Frequency Regulation	Enhanced frequency stability in islanded mode	Requires accurate prediction
3	E. Yaghoubi et al. (2025)	MPC Review Study	Comprehensive review of MPC applications	Limited real-time validation
4	C. Liu et al. (2025)	Economic MPC	Reduced operational cost and converter stress	Complex optimization
5	H. He et al. (2025)	Intelligent EMS	Improved energy scheduling and demand response	Increased implementation complexity
6	T. Cao et al. (2025)	Forecast-Based MPC	Renewable uncertainty handling	Heavy data dependency
7	Rehman et al. (2024)	Multi-objective MPC	Battery-aware energy management	Limited scalability
8	Veni et al. (2025)	Dynamic Power Control	Stability improvement in hybrid AC/DC microgrids	No hardware testing
9	Malik et al. (2024)	Distributed EMS	Efficient DER coordination	Communication dependency
10	Sharma et al. (2024)	Adaptive MPC	Improved transient response under load variation	Parameter tuning required
11	Zhang et al. (2024)	Stochastic MPC	Robust operation under renewable uncertainty	High computational time
12	Kumar et al. (2023)	Fuzzy-MPC Hybrid	Better voltage regulation and THD reduction	Increased controller complexity
13	Singh et al. (2024)	ANN-Assisted MPC	Improved prediction accuracy	Training data requirement
14	Li et al. (2025)	Real-Time EMS	Fast response in grid-connected mode	Limited battery optimization
15	Ahmed et al. (2023)	IoT-Based Monitoring	Real-time renewable monitoring	Cybersecurity concerns

16	Patel et al. (2024)	Smart Grid Integration	Enhanced renewable utilization	Grid synchronization issue
17	Wang et al. (2025)	Deep Learning + MPC	Improved renewable forecasting accuracy	High implementation cost
18	Rao et al. (2024)	Battery Energy Optimization	Improved battery life and charging control	Limited renewable forecasting
19	Choudhary et al. (2025)	Hybrid Renewable EMS	Reduced voltage and frequency deviation	Complex mathematical modeling
20	Elavarasan et al. (2024)	Intelligent Microgrid Control	Enhanced stability and reliability of hybrid microgrid	Real-time hardware validation not performed

III. PROPOSED SYSTEM

The system architecture of the proposed Renewable Energy Monitoring System (REMS) using Model Predictive Control (MPC) is shown in Fig. 1. The proposed hybrid microgrid integrates solar photovoltaic (PV) generation, wind energy conversion system, Battery Energy Storage System (BESS), DC-link architecture, inverter, and AC load/grid interface within a unified energy management framework. The entire system is controlled and monitored through a centralized MPC-based supervisory controller for efficient renewable power utilization and stable microgrid operation.

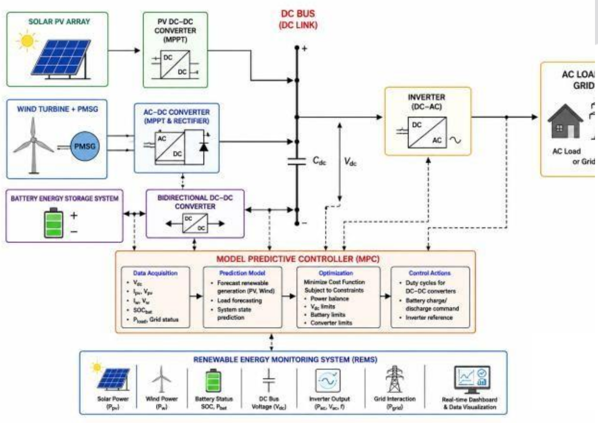

Fig.1. Proposed System Architecture

Solar PV Subsystem: The solar PV array converts solar irradiance into DC electrical energy. A DC–DC boost converter integrated with a Maximum Power Point Tracking (MPPT) controller is used to extract maximum available power from the PV array under varying irradiance conditions. The regulated DC output is connected to the common DC bus for further power distribution.

Wind Energy Conversion System: The wind energy subsystem consists of a wind turbine coupled with a Permanent Magnet Synchronous Generator (PMSG). The generated AC power is converted into regulated DC power through an AC–DC converter with MPPT and rectification control. This subsystem continuously supplies renewable power to the DC-link based on wind speed variations.

DC Bus (DC-Link): The DC bus acts as the central power coupling point of the hybrid microgrid. Both solar and wind subsystems are connected to the DC-link to maintain common voltage regulation and power balancing. The DC-link ensures smooth power transfer between renewable sources, storage systems, inverter, and load demand.

Battery Energy Storage System (BESS): A Battery Energy Storage System is connected to the DC bus through a bidirectional DC–DC converter. The battery stores excess renewable energy during high generation periods and supplies power during renewable deficiency or sudden load changes. The bidirectional converter controls battery charging and discharging operations based on the control signals generated by the MPC controller.

Inverter and AC Load/Grid: The inverter converts the regulated DC-link voltage into AC power suitable for AC loads and utility grid integration. The inverter maintains synchronization with the grid and ensures stable voltage and frequency regulation during both grid-connected and islanded operating conditions.

Model Predictive Controller (MPC): The Model Predictive Controller acts as the intelligent energy management unit of the proposed system. The MPC receives real-time sensor data such as solar irradiance, wind speed, DC-link voltage, load demand, and battery state of charge (SOC). Based on future prediction and optimization algorithms, the controller generates optimal duty cycles and control signals for converters and inverter operation. The main objectives of the MPC are:

- DC-link voltage stabilization
- Optimal power sharing
- Reduction of renewable power fluctuations
- Improved energy utilization
- Battery charging/discharging management

- Stable microgrid operation under dynamic conditions

Renewable Energy Monitoring System (REMS): The Renewable Energy Monitoring System continuously monitors system parameters including renewable power generation, battery SOC, inverter output, load demand, and grid interaction. The monitoring framework enables real-time visualization and performance analysis of the hybrid microgrid using MATLAB/Simulink dashboards.

IV. Experimental Results and Performance Analysis

The proposed Renewable Energy Monitoring System (REMS) using Model Predictive Control (MPC) was modeled and simulated in MATLAB/Simulink to evaluate the performance of the hybrid renewable microgrid under different operating conditions. The simulation model integrates a solar photovoltaic (PV) array, wind turbine with Permanent Magnet Synchronous Generator (PMSG), Battery Energy Storage System (BESS), DC-link, inverter, and AC load/grid interface. The performance of the proposed MPC controller was analyzed under varying solar irradiance, wind speed, and load demand conditions. The main objective of the experimental analysis is to verify the effectiveness of the MPC controller in maintaining DC-link voltage stability, improving renewable energy utilization, reducing power fluctuations, and ensuring reliable microgrid operation during dynamic operating conditions. The simulation studies were carried out using MATLAB/Simulink R2023a with Simscape Electrical and MPC Toolbox.

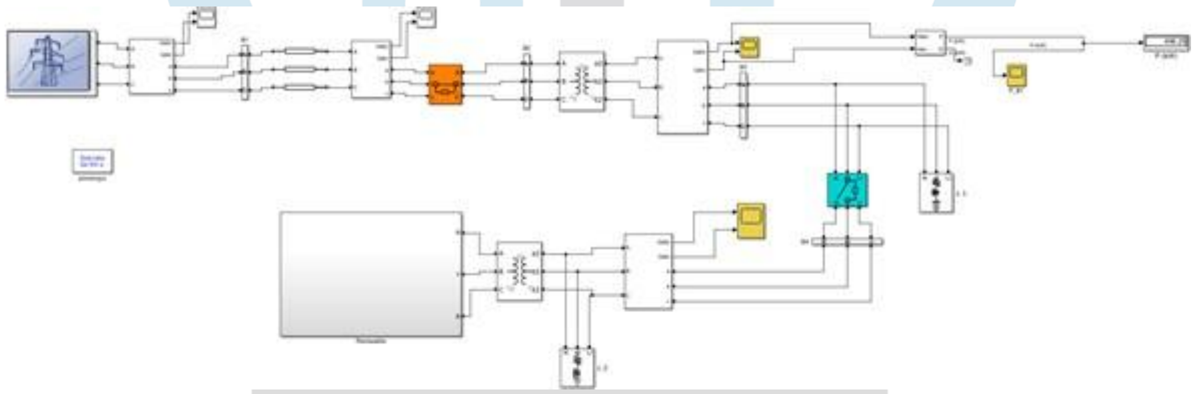

Fig. 2. Simulink

The figure shows the three-phase voltage and current waveforms obtained from the MATLAB/Simulink simulation of the proposed hybrid microgrid system. The waveforms become stable and sinusoidal after a short transient period, indicating effective voltage regulation and balanced power flow using the proposed MPC controller.

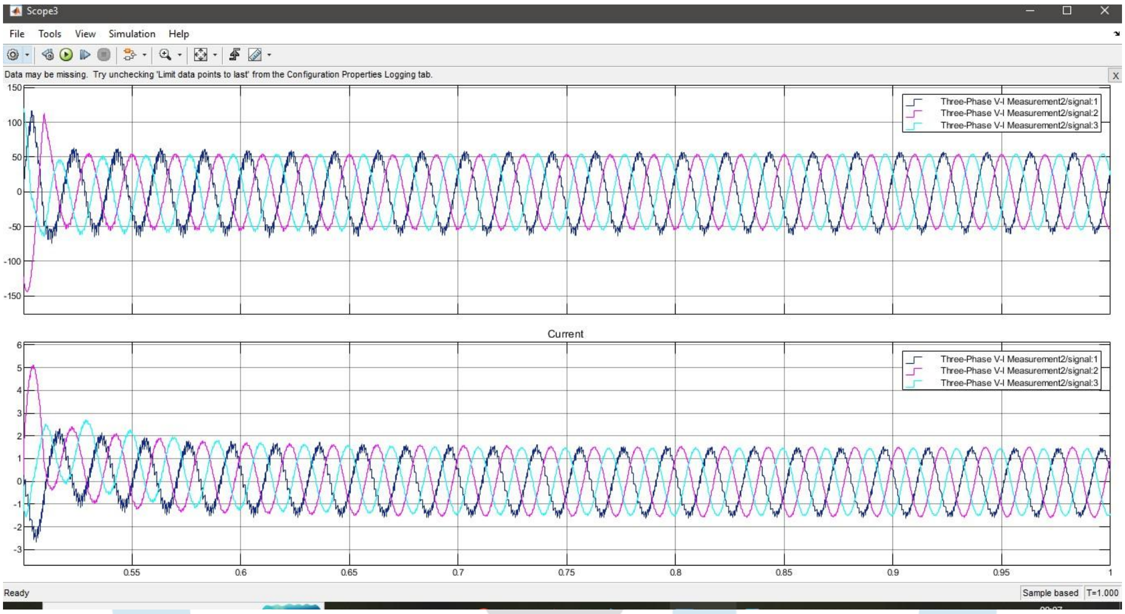

Fig. 3. Renewable O/P

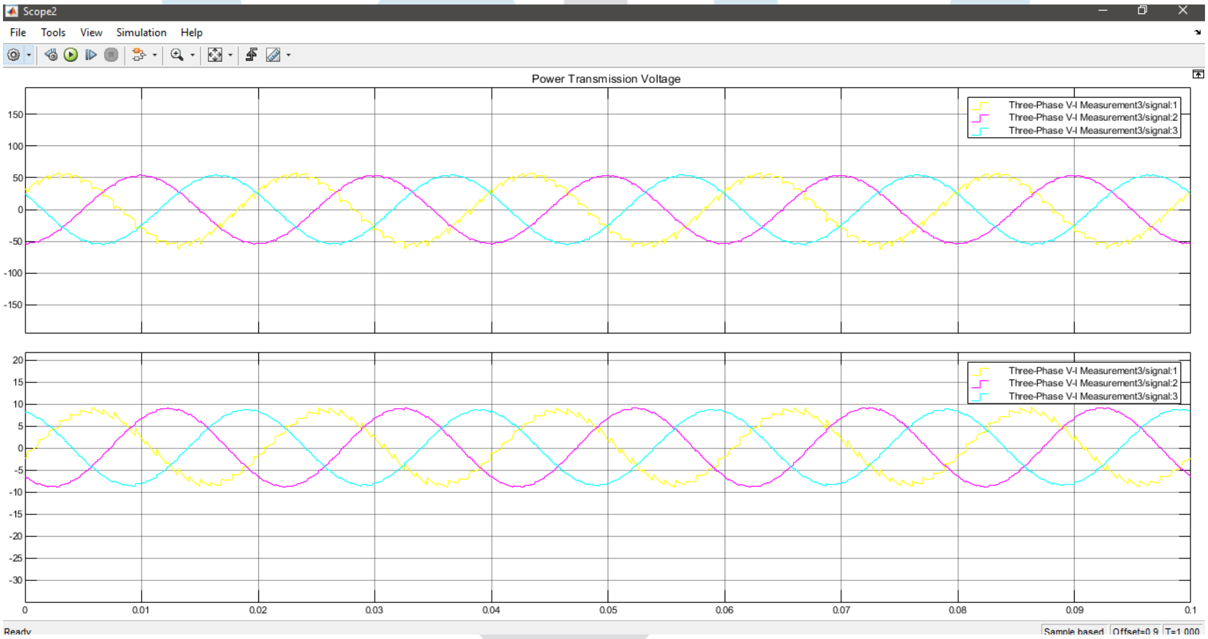

Fig.4. Optimised O/p at PCC point

The figure shows the three-phase transmission voltage and current waveforms of the proposed microgrid system obtained from MATLAB/Simulink simulation. The balanced sinusoidal waveforms indicate stable power transmission, proper inverter synchronization, and effective operation of the MPC-based control strategy.

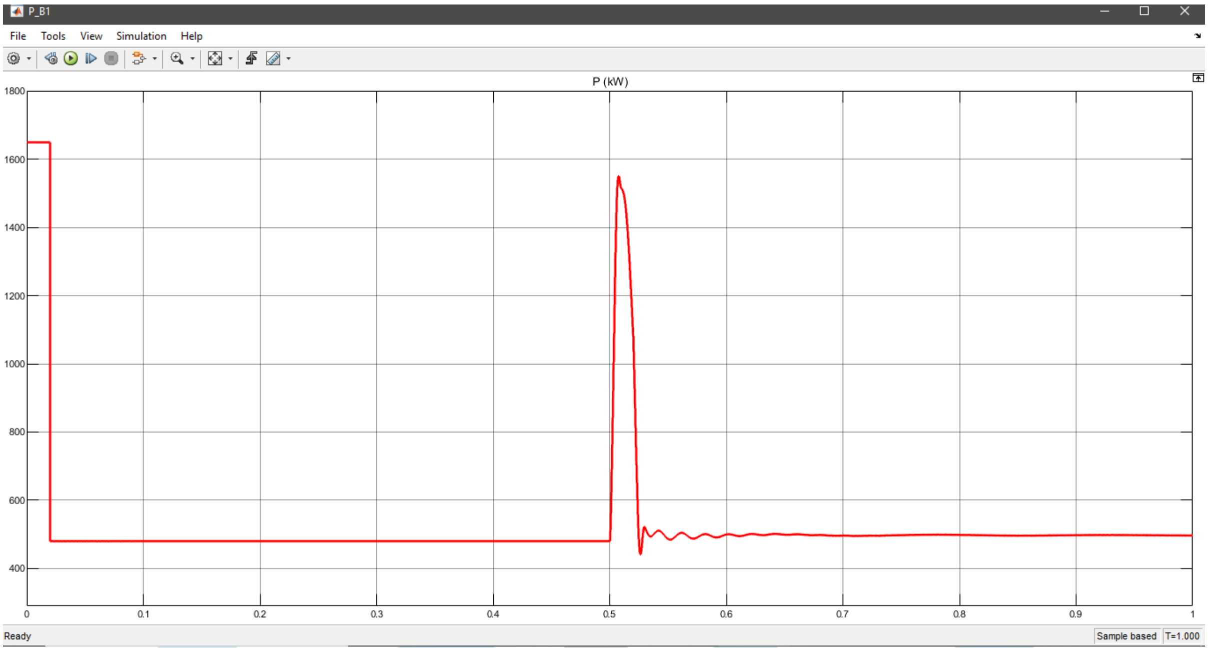

Fig. 5. -O/p Power

The figure illustrates the active power response PPP of the proposed hybrid microgrid system under dynamic operating conditions. A transient disturbance occurs around 0.5 s, causing a temporary power overshoot; however, the MPC controller quickly stabilizes the system and restores the power to its steady-state value.

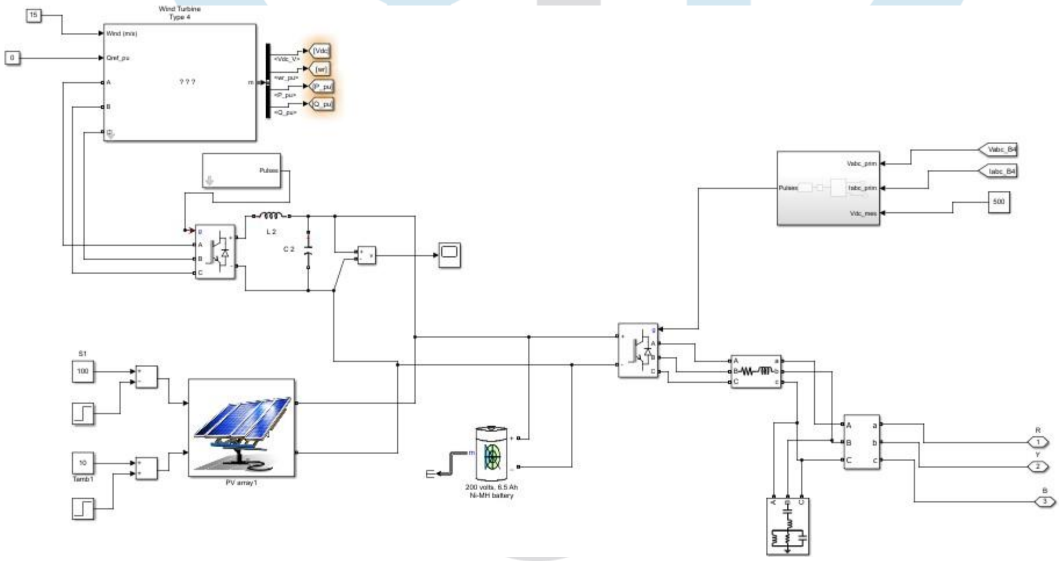

Fig. 6. - Renewable design

The figure shows the MATLAB/Simulink model of the proposed hybrid renewable microgrid integrating a solar PV array, wind turbine system, battery energy storage system, inverter, and AC load/grid connection. The renewable sources are connected through a common DC-link and controlled using converter circuits for stable power transfer and energy management.

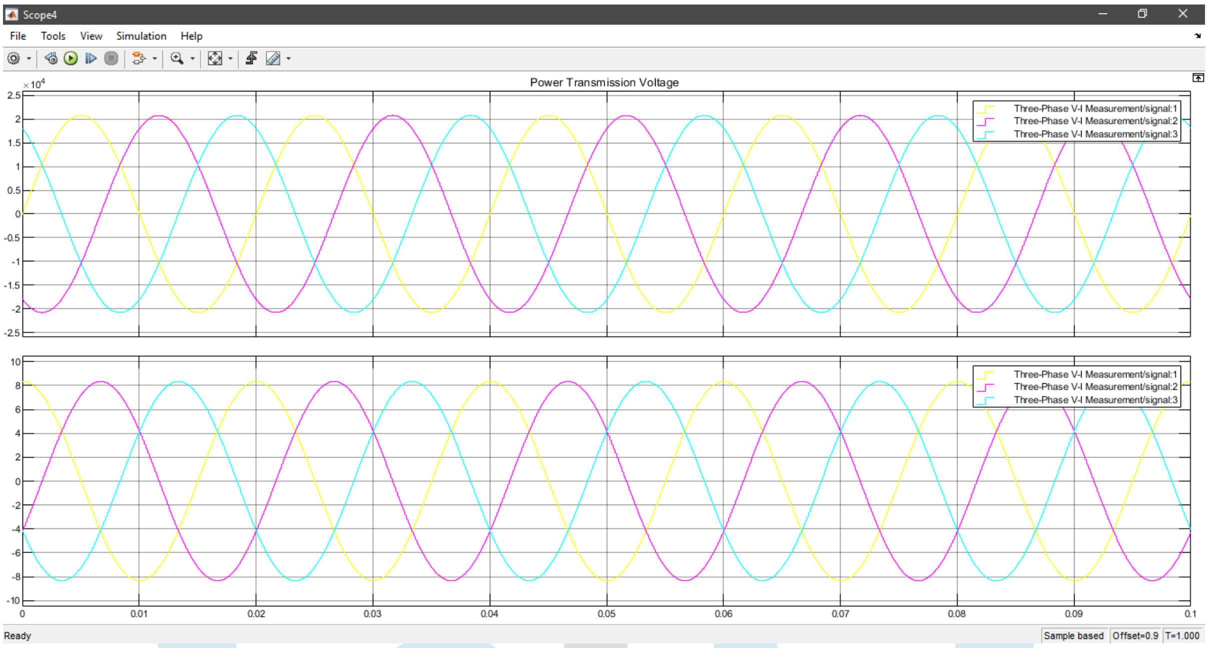

Fig. 7. -Grid o/p

The figure shows the three-phase transmission voltage and current waveforms of the proposed hybrid renewable microgrid system. The balanced sinusoidal waveforms indicate proper inverter operation, stable power transmission, and effective synchronization between the renewable sources and the grid.

V. PERFORMANCE ANALYSIS WITH BASE PAPER AND PROPOSED SYSTEM

The performance of the proposed Renewable Energy Monitoring System (REMS) using Model Predictive Control (MPC) is compared with the conventional microgrid control methods discussed in the base paper. The comparison is carried out based on important performance parameters such as voltage stability, dynamic response, renewable energy utilization, power fluctuation reduction, monitoring capability, and system reliability. The base paper mainly focuses on conventional microgrid energy management techniques such as PID control, droop control, fuzzy logic control, and traditional monitoring systems. Although these methods provide acceptable operation under normal conditions, they suffer from slower transient response, limited adaptability to renewable fluctuations, and reduced prediction capability under dynamic operating conditions. In the proposed system, a Novel Model Predictive Control (MPC) framework is integrated with a Renewable Energy Monitoring System (REMS) to improve overall microgrid performance. The MPC controller predicts future operating conditions and optimizes converter and inverter control signals in real time, resulting in improved DC-link voltage regulation, reduced power oscillations, and enhanced renewable power utilization. The MATLAB/Simulink results demonstrate stable three-phase voltage/current waveforms, fast transient recovery, and efficient battery energy management under varying solar irradiance and wind speed conditions.

Table III

Performance Comparison between Base Paper and Proposed System

Parameter	**Base Paper System**	**Proposed MPC-Based System**
Control Technique	PID / Droop / Fuzzy Control	Model Predictive Control (MPC)
Renewable Source Integration	Solar and Wind	Solar, Wind, and BESS
Dynamic Response	Moderate	Fast
Voltage Stability	Moderate	Excellent
Frequency Regulation	Limited	Improved
Power Fluctuation Reduction	Medium	High
DC-Link Voltage Control	Conventional Regulation	Predictive Optimization
Renewable Energy Utilization	Moderate	High
Battery Energy Management	Basic Control	Intelligent Bidirectional Control
Monitoring Capability	Limited Monitoring	Real-Time REMS Dashboard

Grid Synchronization	Moderate	Stable and Smooth
THD Performance	Higher	Reduced
System Reliability	Moderate	Improved
Prediction Capability	Not Available	Available
Computational Intelligence	Low	High

VI. CONCLUSION

This paper presented a Renewable Energy Monitoring System (REMS) for a hybrid renewable microgrid using a Novel Model Predictive Control (MPC) strategy implemented in MATLAB/Simulink. The proposed system integrates solar photovoltaic (PV) generation, wind turbine with Permanent Magnet Synchronous Generator (PMSG), Battery Energy Storage System (BESS), DC-link architecture, inverter, and AC load/grid interface within a unified energy management framework. The developed MPC controller successfully predicted future operating conditions and optimized the power flow between renewable sources, battery storage, and load demand under varying environmental and operating conditions. Simulation results demonstrated that the proposed system achieved improved DC-link voltage regulation, stable three-phase voltage and current waveforms, reduced power fluctuations, faster transient response, and enhanced renewable energy utilization compared with conventional control methods.

The Renewable Energy Monitoring System provided continuous real-time supervision of renewable generation, battery status, inverter output, and grid interaction, enabling efficient monitoring and operational analysis of the hybrid microgrid. The comparative performance analysis also confirmed that the proposed MPC-based system offers better voltage stability, improved dynamic performance, lower harmonic distortion, and enhanced overall system reliability than traditional PID and fuzzy-based controllers. Therefore, the proposed REMS integrated with MPC provides an efficient, intelligent, and scalable solution for modern hybrid renewable microgrids and future smart-grid applications. Future work may include real-time hardware implementation, IoT-enabled cloud monitoring, artificial intelligence–based forecasting techniques, and hardware-in-the-loop (HIL) validation for practical deployment of the proposed system.

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