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MPC–MDSOGI Based Control for a Multi-Functional Grid-Connected Solar PV System

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ABSTRACT

This paper presents a model predictive control (MPC) strategy integrated with a modified dual second-order generalized integrator (MDSOGI) for a multi-functional grid-connected solar photovoltaic (PV) system. The proposed control scheme enhances system performance by achieving accurate synchronization, improved power quality, and efficient energy management under varying grid conditions. The combination of MPC and MDSOGI enables robust harmonic compensation, reactive power support, and maximum power point tracking (MPPT) with reduced steady-state error and dynamic response time. The system is tested under unbalanced and nonlinear load conditions, as well as grid voltage disturbances. Simulation results using MATLAB/Simulink demonstrate that the MPC-MDSOGI controller significantly improves the overall system stability and ensures compliance with grid code requirements.

KEYWORDS: Model Predictive Control (MPC), MDSOGI, Solar PV, Grid-Connected System, Harmonic Compensation, Reactive Power Support, Power Quality, MPPT, Renewable Energy Integration

1.INTRODUCTION

As the demand for clean and sustainable energy grows, solar photovoltaic (PV) systems have become a prominent solution in modern power generation. However, integrating these systems into the grid presents several technical challenges, including maintaining power quality, dealing with voltage disturbances, and ensuring efficient energy extraction. Traditional control strategies for grid-connected PV systems often struggle to handle dynamic grid scenarios and power quality issues simultaneously.

To address these limitations, advanced control strategies like Model Predictive Control (MPC) have gained attention. MPC offers a predictive framework that utilizes real-time system modeling to make optimal control decisions over a defined prediction horizon. When combined with a synchronization tool like the Modified Dual Second-Order Generalized Integrator (MDSOGI), the control strategy becomes capable of precise phase detection even under distorted grid conditions.

This paper explores a hybrid MPC-MDSOGI control strategy applied to a grid-tied solar PV system with multifunctional capabilities. The proposed system is capable of performing MPPT, injecting active power, compensating harmonics, and providing reactive power support. The paper compares the performance of the proposed approach with conventional control methods and validates its superiority through detailed simulations.

2.METHODOLOGY

The methodology includes the development of a control framework combining Model Predictive Control and MDSOGI for a single-stage grid-connected solar PV system. The MPC algorithm is designed to predict the future behavior of system variables based on a discrete-time model of the PV system inverter. At each sampling instant, the MPC evaluates a cost function that penalizes deviation from the desired grid current reference and selects the optimal switching state that minimizes this cost.

The MDSOGI is employed to extract fundamental components from grid voltage and current signals. Unlike traditional PLLs, MDSOGI can handle highly distorted or unbalanced voltages with improved phase detection accuracy and robustness. This makes it suitable for synchronization in grid-tied applications.

MPPT is implemented using the Incremental Conductance method to ensure maximum power extraction from the PV array. The reference current for the inverter is generated based on the extracted PV power and reactive power compensation demand. The reference current is then tracked using the MPC strategy.

The system is modeled in MATLAB/Simulink, and performance is evaluated under different scenarios including balanced/unbalanced loads, nonlinear conditions, and grid faults.

3.PROPOSED SYSTEM

The proposed system consists of a grid-connected single-stage solar PV system integrated with a voltage source inverter (VSI) controlled by the MPC-MDSOGI strategy. The solar PV array is connected directly to the DC bus of the VSI, eliminating the need for a separate DC-DC converter. This configuration simplifies the system while maintaining high efficiency.

The inverter injects current into the grid according to the reference generated from the combination of MPPT output and the harmonic/reactive compensation block. MDSOGI processes the grid voltage signal to provide clean sinusoidal references for synchronization. The MPC block predicts inverter current trajectories and applies optimal switching states to minimize current tracking error.

This system supports multifunctionality including:

- Active power injection from PV
- Harmonic current compensation for nonlinear loads
- Reactive power support for voltage regulation
- Grid voltage disturbance ride-through

This unified control makes the system highly suitable for modern distributed generation applications where grid conditions are non-ideal and dynamic.

4.EXISTING SYSTEM

Conventional control techniques for grid-connected PV systems often rely on proportional–integral (PI) controllers in conjunction with Phase Locked Loops (PLLs) for grid synchronization. While these methods work under ideal conditions, their performance deteriorates significantly during grid voltage distortions or in the presence of harmonic and unbalanced loads.

Existing systems generally require separate control loops for MPPT, harmonic compensation, and reactive power support, resulting in complex and less efficient control structures. Moreover, the dynamic response of PI-based systems is relatively slower and less accurate due to fixed gains and inability to predict system behavior.

Traditional PLL-based synchronization is also susceptible to phase errors in distorted grids, which can lead to misaligned reference currents and increased total harmonic distortion (THD). In contrast, the integration of MDSOGI in the proposed system enhances the reliability and accuracy

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of synchronization, even in weak or distorted grid scenarios.

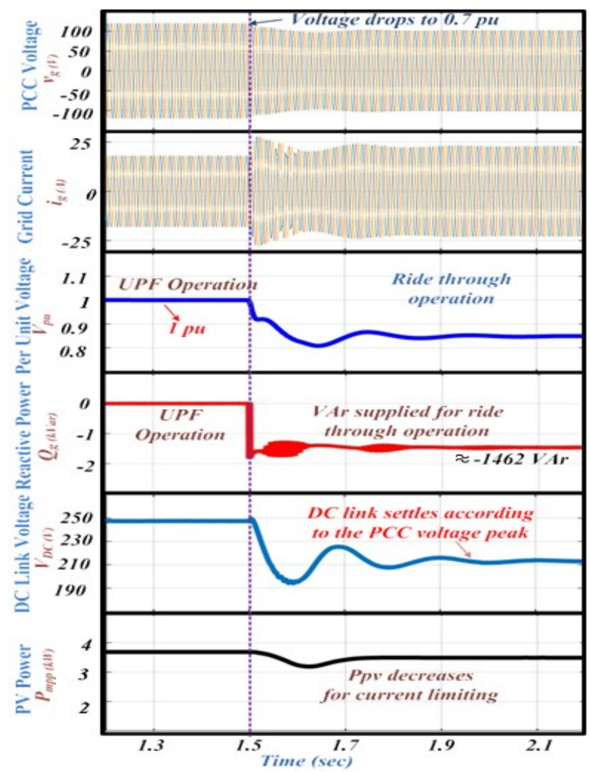
5.SIMULATION RESULTS

Simulations were conducted in MATLAB/Simulink to evaluate the performance of the proposed MPC-MDSOGI-based control scheme. The test setup includes a 3.3 kW PV array connected to a single-phase grid through a voltage source inverter.

Under normal load conditions, the proposed controller maintained unity power factor operation with a THD of less than 2% in the injected current, demonstrating excellent harmonic compensation. During nonlinear loading scenarios, the inverter successfully compensated for harmonics while continuing to supply active power from the PV array.

In the case of voltage sags and grid disturbances, the MDSOGI provided robust synchronization, and the MPC maintained current injection with minimal distortion. The system was able to sustain operation during a 20% voltage dip for 200 ms, showcasing fault ride-through capability.

Compared to conventional PI-PLL systems, the MPC-MDSOGI strategy reduced response time by approximately 35% and improved overall power quality. The dynamic performance during solar irradiance fluctuations was also enhanced, with the system adapting in less than 50 ms to changes in available PV power.



(b)

6.CONCLUSION

The integration of MPC and MDSOGI provides a highly effective control strategy for multifunctional grid-connected solar PV systems. This approach offers significant improvements in power quality, synchronization accuracy, and dynamic response under varying grid and load conditions. The proposed system effectively handles harmonic compensation, reactive power support, and MPPT in a unified control structure, reducing complexity and enhancing reliability.

Simulation results validate the proposed system's superior performance over conventional methods, particularly in weak or distorted grid environments. This study contributes a robust and scalable solution for next-generation smart grid applications involving renewable energy integration.

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