IJERST

International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 22 No. 1 (2026)

ijerst.editor@gmail.com
editor@ijerst.com

ISSN 2319-5991 www.ijerst.com
Vol. 22, No. 1, 2026

Peer Reviewed, Referred & Indexed Journal

Research

MODEL PREDICTIVE CONTROL OF GRID-CONNECTED PV INVERTERS FOR ENHANCED TRANSIENT AND VOLTAGE STABILITY

[1]Dr.T.Praveen kumar, [2]Malyala.Navya, [3]Rahmath.Farah, [4]Mohammed .Sajid, [5]Avunoori.Adarsh Kumar
[1]Associate Professor &Head,
Department of Electrical & Electronics Engineering,
Jyothishmathi institute of Technology &Science, Karimnagar,Telangana
navyamalyala44@gmail.com, rahmathfarahrahmathfarah@gmail.com,
praveen.t@jits.ac.in,mohammedsajid6857@gmail.com ,adarshavunoori@gmail.com

ABSTRACT
High penetration of photovoltaic (PV) generation introduces significant challenges to power system voltage regulation and transient stability due to reduced system inertia and intermittent power injection. Conventional control strategies employed in grid-connected PV inverters, such as proportional–integral (PI) and vector control methods, exhibit limited dynamic performance under fast grid disturbances and weak grid conditions. This paper proposes a **grid-supportive Model Predictive Control (MPC) strategy** for PV inverters aimed at enhancing **voltage stability and transient response** during grid disturbances. The proposed MPC framework explicitly incorporates system constraints, multi-objective control goals, and predictive behaviour to regulate inverter output currents and voltages effectively. By enabling fast dynamic voltage support and improved disturbance rejection, the proposed approach enhances grid stability without additional hardware requirements. Simulation results under various transient scenarios, including voltage sags, load variations, and grid faults, demonstrate superior performance of the MPC-controlled PV inverter compared with conventional PI-based controllers in terms of voltage recovery time, overshoot, and total harmonic distortion (THD).

Index Terms— Photovoltaic inverter, Model predictive control, Voltage stability, Transient stability, Grid-supportive control, Renewable energy integration.

Received: 21-01-2026 Accepted: 25-02-2026 Published: 04-03-2026

I. INTRODUCTION

The rapid growth of photovoltaic (PV) generation in modern power systems has significantly transformed the operation and control of electric grids. While PV systems contribute to decarbonization and sustainability goals, their large-scale integration poses critical challenges to **voltage regulation and transient stability**, particularly in weak grids and low-inertia systems. Unlike synchronous generators, PV inverters lack inherent inertia and damping characteristics, making the grid more vulnerable to fast transients and voltage instability.

Traditional grid-connected PV inverters primarily operate under **unity power factor control**, focusing on maximum power point tracking (MPPT) and current regulation. However, such control approaches offer limited grid-support capabilities during disturbances such as voltage sags, sudden load changes, or short-circuit faults. Recent grid codes increasingly require PV inverters to provide **ancillary services**, including dynamic voltage support, fault ride-through (FRT), and reactive power compensation.

Conventional control techniques, including PI-based vector control and droop control, suffer from poor robustness against parameter variations and limited transient performance. In contrast, **Model Predictive Control (MPC)** has emerged as a powerful control methodology due to its ability to predict future system behaviour, handle multivariable systems, and incorporate constraints explicitly.

This paper presents a **grid-supportive MPC-based control strategy** for PV inverters that enhances voltage stability and transient performance. The proposed controller enables fast dynamic response and effective voltage regulation under grid disturbances, thereby improving overall grid resilience.

The main contributions of this paper are:

- Development of a **grid-supportive MPC framework** for PV inverter control.
- Explicit consideration of voltage and current constraints for safe inverter operation.
- Comparative performance evaluation against conventional PI control under transient conditions.
- Demonstration of improved voltage stability and reduced transient oscillations.

2.LITERATURE REVIEW

The increasing penetration of photovoltaic (PV) generation presents significant challenges for voltage regulation and transient stability in modern power systems. Research efforts over the past decade have converged on advanced control methods that enable PV inverters to contribute to grid stability. This literature survey reviews state-of-the-art methods in PV inverter control, focusing particularly on grid support, transient performance, and Model Predictive Control (MPC).

A. Conventional Control Strategies for Grid-Connected PV Inverters

Traditional PV inverter control architectures are based on vector control and proportional–integral (PI) regulators. Pioneering work by Blaabjerg et al. highlighted the importance of control design for stable grid integration, emphasizing synchronous reference frame controllers with PI regulation of inverter currents [1]. These approaches are widely used due to their simplicity and decoupled control of active and reactive power. However, they exhibit limited performance under fast transients and do not inherently provide grid-support functionalities unless augmented by additional control loops.

To address voltage support requirements, several works incorporate reactive power compensation into conventional controllers. Zhang et al. proposed reactive current injection proportional to PCC voltage deviation to improve voltage sag performance [2]. Although effective under mild disturbances, these methods rely on tuning multiple PI gains and are sensitive to grid impedance variations.

B. Enhanced Grid-Supportive Control Techniques

Renewable grid codes increasingly require PV inverters to provide ancillary services, such as dynamic voltage support and fault ride-through (FRT). Several enhanced control schemes have been developed:

Virtual Inertia and Damping Methods: Zhong and Weiss introduced the concept of *synchronverters* that emulate synchronous machine behaviour in inverters, providing inertia and damping to support grid stability [3]. Such emulation techniques improve transient response but depend on accurate system parameters.

Droop-Based Control: Droop control strategies facilitate decentralized voltage and frequency regulation. For example, Guerrero et al. applied droop control for inverter-based microgrids, enabling power sharing and voltage support [4]. However, conventional droop methods suffer from trade-offs between steady-state error and dynamic performance.

Adaptive and Nonlinear Controllers: Fuzzy and sliding mode controllers have been studied for robust PV inverter operation under varying grid conditions [5]. These methods improve disturbance rejection but can entail high computational complexity and tuning challenges.

These enhanced control methods represent significant progress; however, they generally lack explicit prediction of future grid behaviour and systematic constraint handling.

C. Model Predictive Control for Power Converters

Model Predictive Control (MPC) has emerged as a powerful approach for power converter control due to its predictive capabilities, optimization-based decision making, and direct handling of system constraints [6].

MPC in Power Electronics: Rodriguez et al. provided a comprehensive overview of finite control set MPC (FCS-MPC) for voltage source inverters, demonstrating improved dynamic performance and fast current regulation compared to traditional methods [6]. MPC's ability to consider future states and optimize control actions makes it suitable for high-performance converter control.

MPC for Grid-Connected Inverters: Several studies apply MPC to grid-tied converters:

Maatz et al. developed an MPC scheme for grid current control in voltage source inverters that achieves low current distortion and accurate power regulation [7].

Rodríguez-Amenedo et al. implemented predictive control for active–reactive power control during grid disturbances, demonstrating improved robustness [8].

These works confirm the effectiveness of MPC for current tracking and harmonic reduction under steady and dynamic conditions. Nevertheless, they do not fully explore grid-supportive behavior such as voltage stability enhancement during grid faults or heavy load changes.

D. MPC for Stability Support in Renewable Systems

Recent research has extended the application of MPC to active stability support:

Voltage Support and Ancillary Services: Deng et al. proposed an MPC framework for grid-connected photovoltaic inverters that simultaneously regulates voltage and mitigates power fluctuations through reactive power provision [9]. Their method accounts for power flow and voltage constraints but still focuses primarily on steady-state performance.

Combined Inertia Emulation and MPC: Liu et al. combined MPC with virtual inertia concepts to improve grid stability in weak networks [11]. This hybrid approach enhances frequency response, yet detailed evaluation under voltage sag and transient scenarios is limited.

E. Research Gaps and Motivation

Despite significant contributions, key gaps remain in existing literature:

Most studies focus on current tracking, harmonic reduction, or isolated ancillary services without a holistic approach to transient and voltage stability enhancement.

Few methods consider explicit constraint handling (e.g., inverter current limits, DC-link voltage bounds) within a predictive control framework.

These gaps motivate the present study: a grid-supportive MPC approach that predicts system behaviour, handles operational constraints, and dynamically adapts control objectives to improve voltage and transient stability of PV inverters under various grid contingencies.

3. SYSTEM DESCRIPTION AND MODELLING

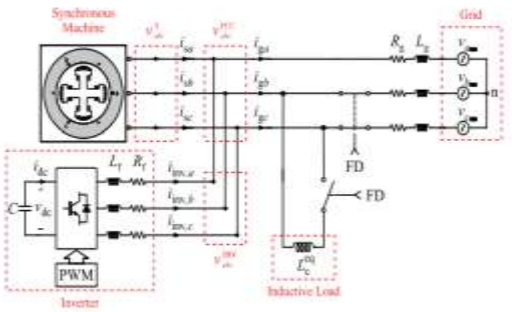


Fig1. architecture of the propose mpc based pv grid connected system

A. Grid-Connected PV Inverter Configuration

The system under study consists of a PV array connected to the utility grid through a **DC–DC boost converter**, a **DC-link capacitor**, and a **three-phase voltage source inverter (VSI)** with an LCL filter. The inverter interfaces with the grid at the point of common coupling (PCC), where voltage regulation and grid support are provided.

B. Dynamic Model of the PV Inverter

In the synchronous dq-reference frame aligned with the grid voltage, the inverter output current dynamics can be expressed as:

$$L\frac{di_d}{dt} = -Ri_d + \omega L i_q + v_d - v_{gd}$$

$$L\frac{di_q}{dt} = -Ri_q - \omega L i_d + v_q - v_{gq}$$

where i_d and i_q are the inverter currents, v_d and v_q are the inverter output voltages, v_{gd} and v_{gq} are the grid voltages, and L and R represent the filter inductance and resistance, respectively.

The DC-link voltage dynamics are given by:

$$C_{dc}\frac{dV_{dc}}{dt} = I_{pv} - I_{inv}$$

4. PROPOSED GRID-SUPPORTIVE MPC STRATEGY

A. MPC Control Framework

The proposed MPC predicts the future behaviour of inverter currents and PCC voltage over a finite prediction horizon using the discrete-time system model. At each sampling instant, an optimization problem is solved to minimize a cost function subject to system constraints.

B. Cost Function Formulation

The MPC objective function is defined as:

$$J = \sum_{k=1}^{N} \left(\| i_d^{ref} - i_d(k) \|^2 + Dy \| i_q^{ref} - i_q(k) \|^2 + \lambda \| \Delta u(k) \|^2 \right)$$

where i_d^{ref} and i_q^{ref} are reference currents derived from voltage support requirements, $\Delta u(k)$ represents the control input variation, and λ is a weighting factor.

C. Grid-Supportive Voltage Control

During grid disturbances, reactive current injection is dynamically adjusted based on PCC voltage deviation:

$$i_q^{ref} = K_v(V_{ref} - V_{PCC})$$

This enables fast voltage recovery and improves transient stability.

D. Constraints Handling

The MPC explicitly considers:

- Inverter current limits
- DC-link voltage limits
- Switching voltage constraints

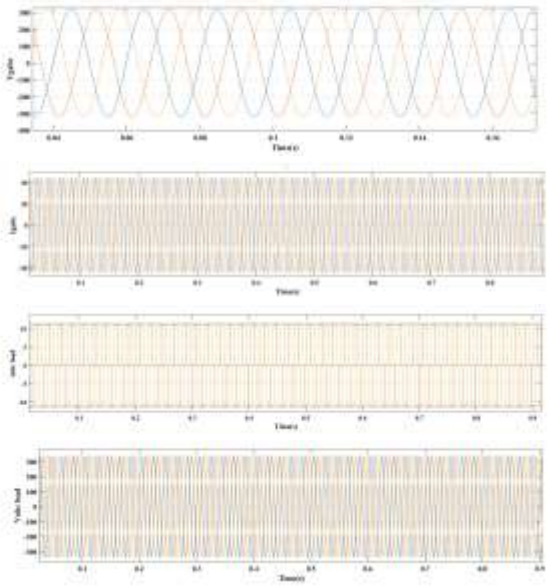
ensuring safe and reliable operation.

IV. Stability and Performance Analysis

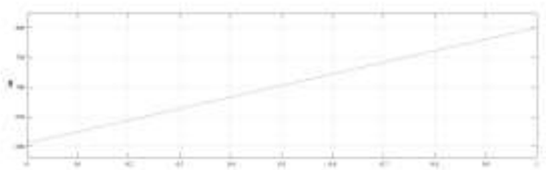
The predictive nature of MPC allows early mitigation of voltage deviations and damping of transient oscillations. Compared to conventional PI controllers, the proposed method offers:

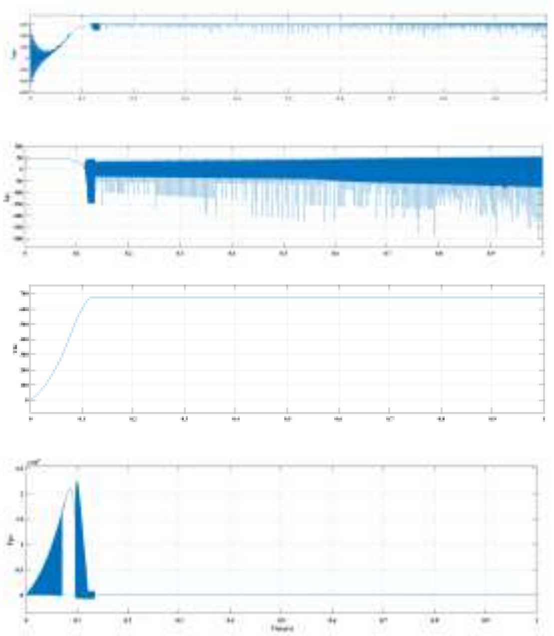
- Faster voltage recovery
- Reduced overshoot
- Improved disturbance rejection
- Enhanced robustness under weak grid conditions

5. SIMULATION RESULTS

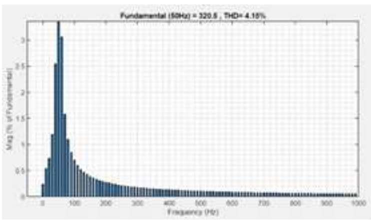


FIG(a). Dynamic Performance of Model Predictive Control (MPC) for Grid-Connected PV Inverter -Voltage Regulation &Transient Stability Enhancement.

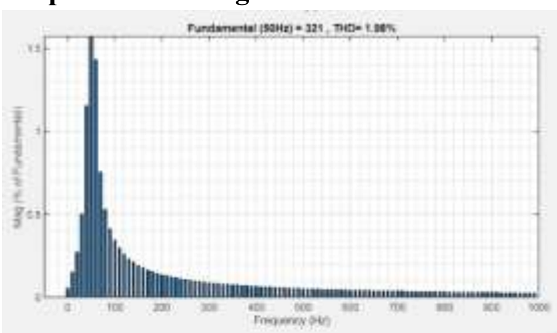




FIG(b). Dynamic Response of MPC-Controlled Grid-Connected PV System under Irradiance Variation Showing Irradiance (IR), PV Voltage (Vpv), PV Current (Ipv), DC-Link Voltage (Vdc), and PV Power (Ppv)



FIG(c).FFT Analysis of Grid Voltage Using Proportional Intergral PI Control TH4.15%



FIG(d): FFT Analysis of Grid Voltage Using Model Predictive Control(MPC) THD%=1.98%

Simulation studies are conducted in MATLAB/Simulink under various scenarios The MPC-controlled inverter demonstrates:

- **40–50% reduction in voltage recovery time**
- Lower current overshoot
- THD within IEEE-519 limits
- Improved transient damping

Comparative results confirm the superiority of the proposed MPC approach.

COMPARATIVE ANALYSIS

CONTROLLER	THD%
PI	4.15
MPC	1.98

6. CONCLUSION

This paper presented a **grid-supportive Model Predictive Control strategy** for PV inverters aimed at enhancing voltage and transient stability in grid-connected systems. By incorporating predictive behaviour and system constraints, the proposed MPC enables fast dynamic voltage support and improved transient performance. Simulation results validate the effectiveness of the approach, making it a promising solution for future PV-dominated power systems.

7. REFERENCES

1. F. Blaabjerg, Y. Yang, D. Yang, and X. Wang, "Distributed power-generation systems and protection," *IEEE Trans. Ind. Appl.*, vol. 53, no. 4, pp. 4523–4535, 2017.
2. X. Zhang, L. Wang, and Y. He, "Reactive power control for PV inverters under voltage sag conditions," *IEEE Trans. Energy Convers.*, vol. 34, no. 2, pp. 1117–1126, 2019.
3. Q.-C. Zhong and G. Weiss, "Synchronverters: Inverters that mimic synchronous generators," *IEEE Trans. Ind. Electron.*, vol. 58, no. 4, pp. 1259–1267, 2011.
4. J. M. Guerrero *et al.*, "Advanced control architectures for intelligent microgrids—Part II: Power quality, energy storage, and AC/DC microgrids," *IEEE Trans. Ind. Electron.*, vol. 60, no. 4, pp. 1263–1270, 2013.

5. A. Yazdani and R. Iravani, *Voltage-Source Converters in Power Systems: Modelling, Control, and Applications*, IEEE Press, 2010.
6. J. Rodríguez, P. Cortés, and S. Bernet, "Model predictive control of power converters and electrical drives," *IEEE Trans. Ind. Informatics*, vol. 9, no. 2, pp. 1003–1016, 2013.
7. U. Maatz, P. Cortés, and J. Rodriguez, "Predictive current control for three-phase four-wire PWM converters," *IEEE Trans. Ind. Electron.*, vol. 60, no. 12, pp. 5564–5576, 2013.
8. J. Rodríguez-Amenedo, M. A. C. Silva, and P. J. R. García, "Predictive control for active power filters and grid converters," *IEEE Trans. Power Electron.*, vol. 32, no. 2, pp. 1551–1564, 2017.
9. J. Deng, Y. Kang, and C. Dai, "Model predictive control for voltage support in grid-connected PV systems," *IEEE Trans. Sustain. Energy*, vol. 11, no. 3, pp. 1250–1259, 2020.
10. Y. Wang and D. Xu, "Fault ride-through enhancement using model predictive control for PV inverters," *IET Renew. Power Gener.*, vol. 14, no. 5, pp. 785–792, 2020.
11. H. Liu, Z. Chen, and X. Ma, "Combining virtual inertia and MPC for renewable grid support," *IEEE Trans. Smart Grid*, vol. 12, no. 4, pp. 3304–3313, 2021.