

Real-time validation of a Robust Intelligent control technique for Grid-Tied Photovoltaic Systems

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INTRODUCTION

The fast growth in the global renewable energy demand has placed photovoltaic (PV) systems as a key solution for sustainable power generation. Grid-tied PV systems (GTPVS) [1] are particularly used due to their efficiency and ability to inject power directly into the electrical grid without requiring energy storage, such as batteries [2]. Despite these advantages, their performance is highly sensitive to environmental variations such as partial shading and grid disturbances, which may affect both power extraction and power quality. These challenges necessitate the development of advanced and intelligent control strategies to ensure efficient maximum power point tracking (MPPT) and high-quality grid integration. To overcome these limitations, robust and intelligent control techniques are required to enhance the GTPVS performance and maintain stable grid synchronization under dynamic operating conditions.

METHOD

A Robust Intelligent Fuzzy Backstepping (RI-FB) control strategy is developed for grid-tied PV systems by combining nonlinear backstepping and fuzzy logic to ensure high MPPT efficiency, fast response time, reduced THD, superior stability, and robust performance under partial shading and grid disturbances. The approach is validated in real time using PIL implementation on the TMS320F28335 platform (Model-Based Design workflow in MATLAB/Simulink).

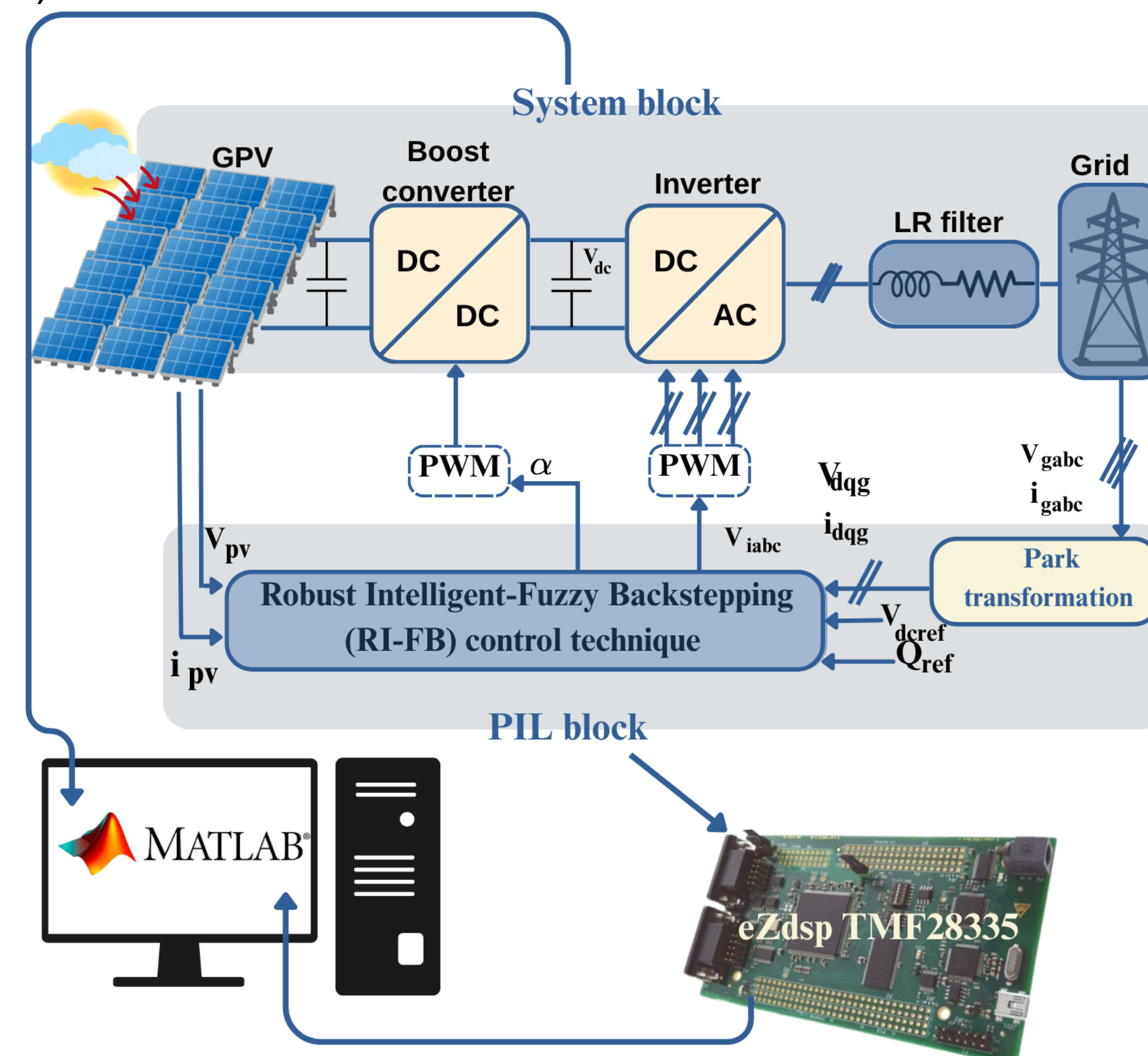


Figure 1. The suggested RI-FB technique for controlling the grid-tied PV system

RESULTS & DISCUSSION

The performance of the proposed Robust Intelligent Fuzzy Backstepping (RI-FB) control technique is evaluated under various operating conditions, including partial shading, and grid disturbances. The obtained results demonstrate a significant improvement in dynamic response and tracking accuracy compared with the conventional Incremental Conductance-Vector oriented Control method. The proposed approach achieves a high MPPT efficiency exceeding 98% with a very fast convergence time, ensuring rapid adaptation to environmental changes. In addition, the system exhibits negligible steady-state oscillations, leading to stable power extraction. Under partial shading conditions and AC load disturbances, the RI-FB controller maintains robust performance, ensuring continuous and stable power injection into the grid. Furthermore, the Total Harmonic Distortion (THD) is maintained below 0.90%, confirming the high quality of the injected current and compliance with grid standards. The Processor-In-the-Loop (PIL) validation confirms the real-time feasibility and effectiveness of the proposed control strategy.

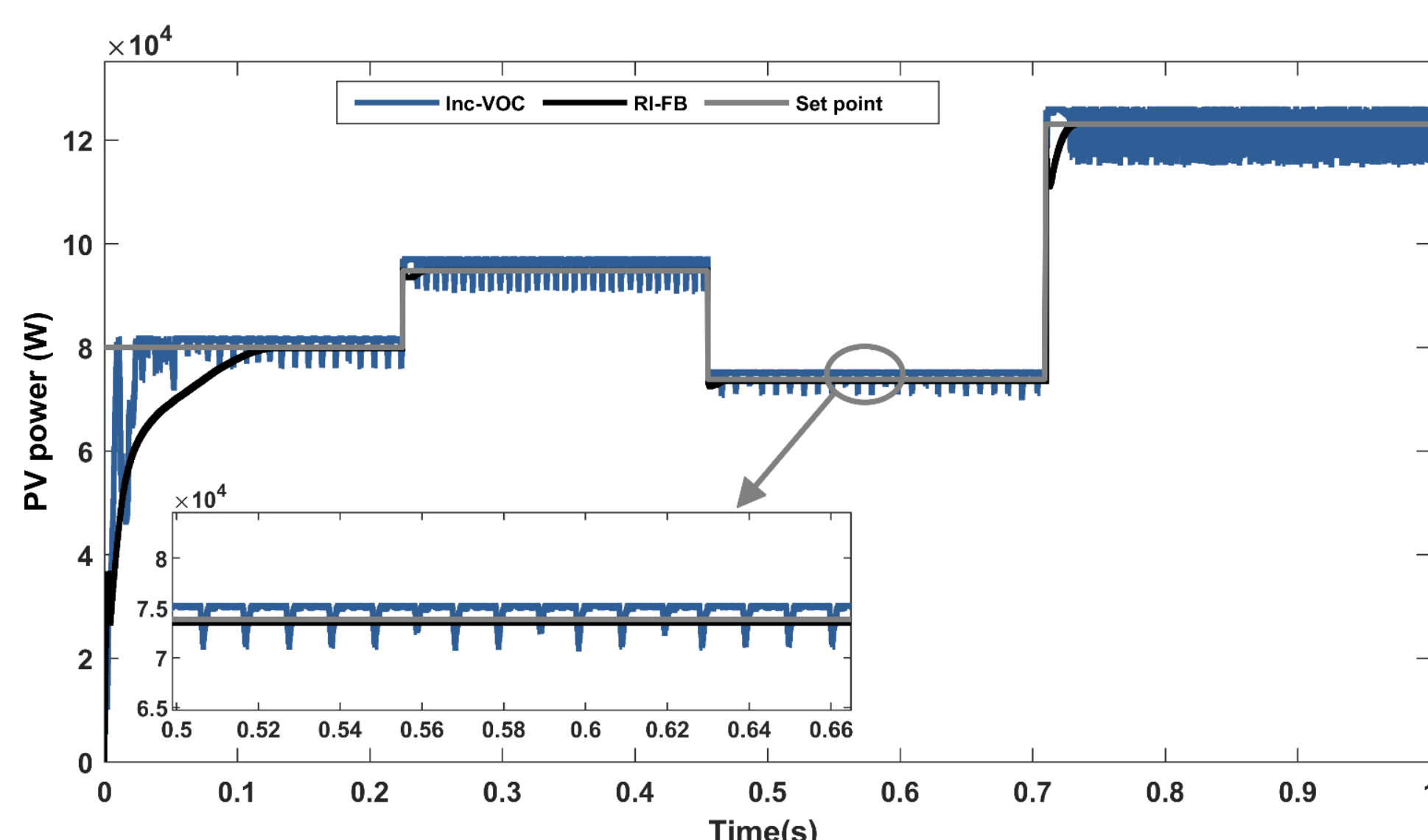


Figure 2. The extracted PV power

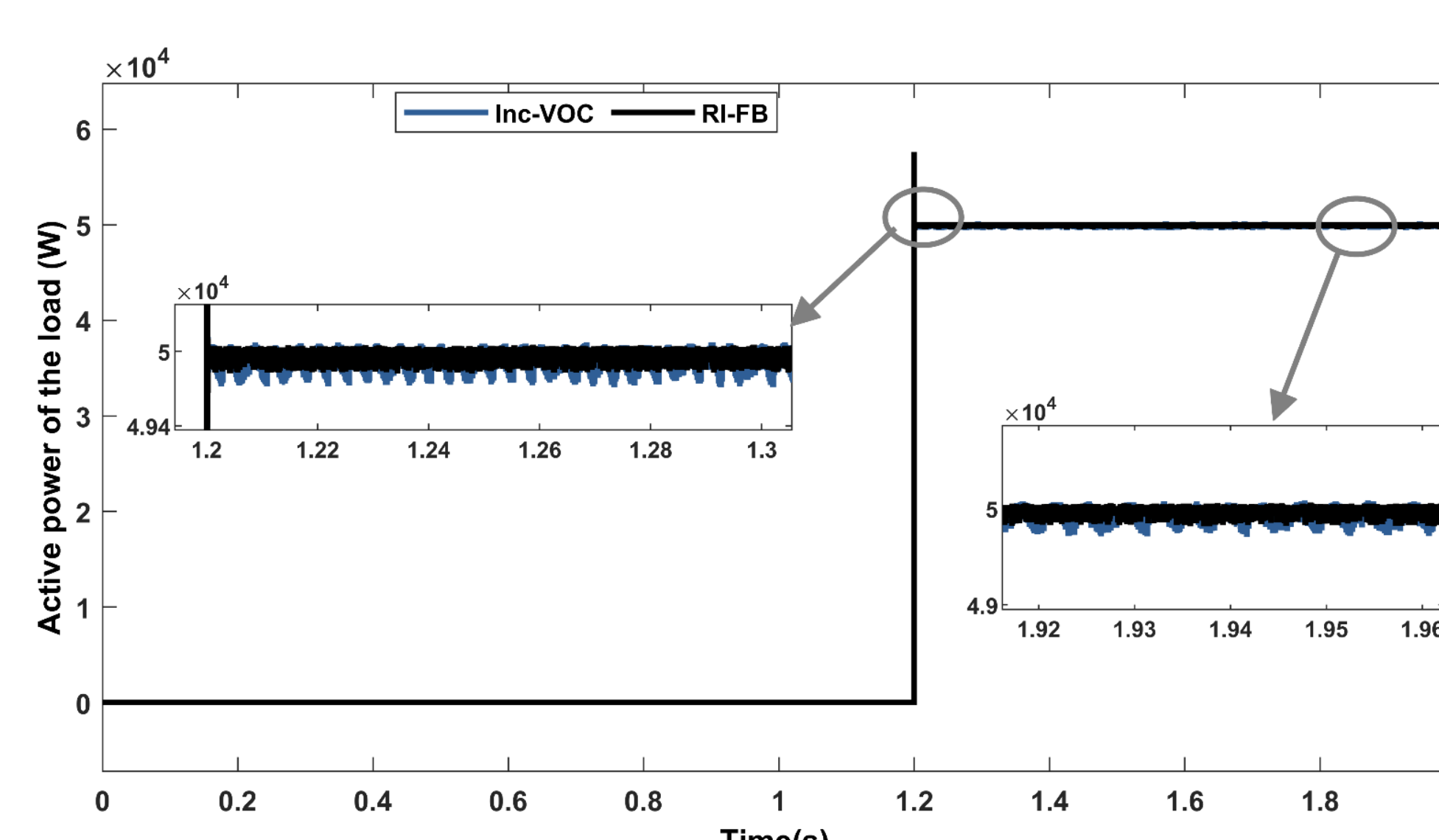


Figure 3. The extracted PV load

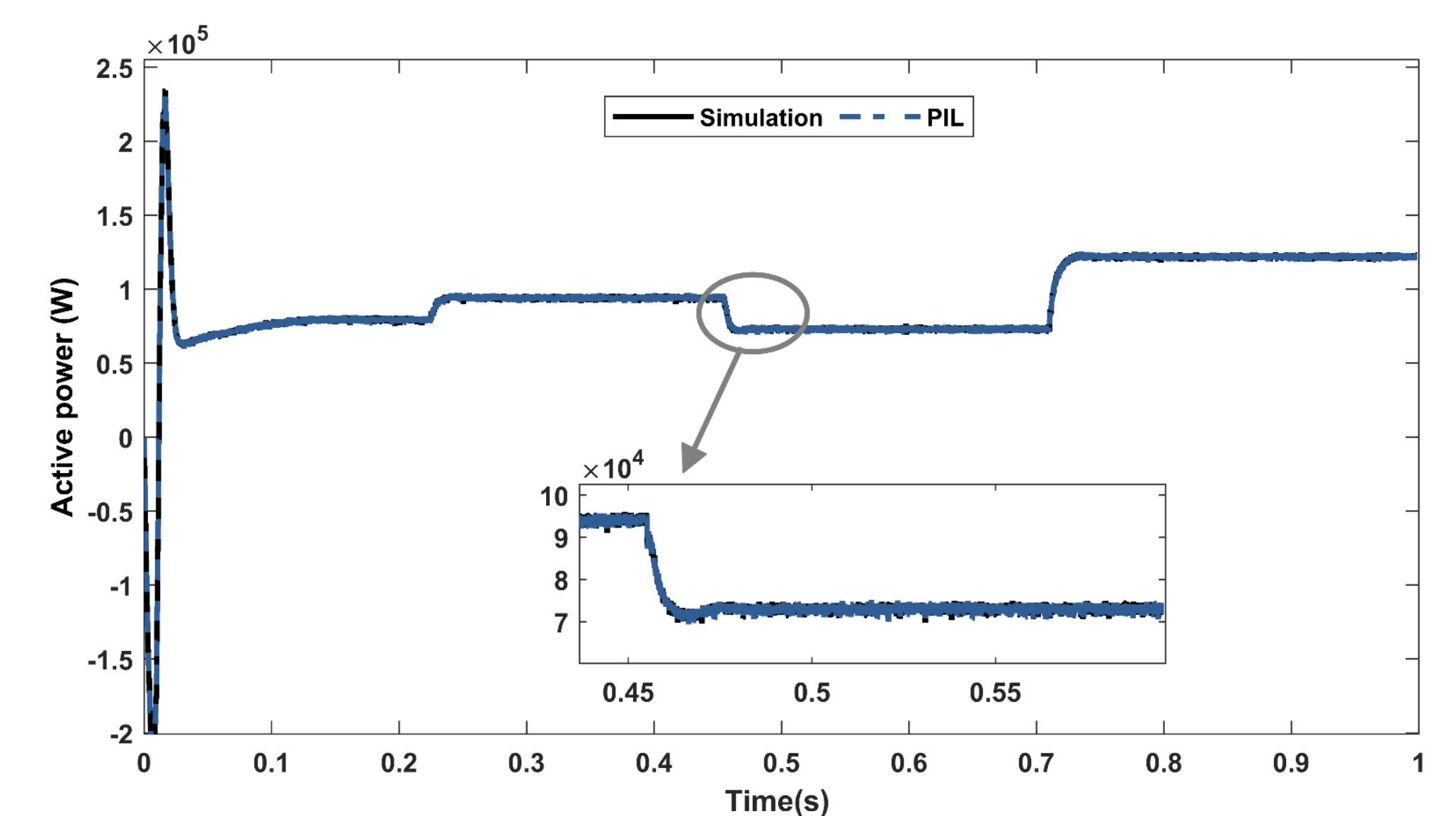


Figure 4. Comparison plots of simulation and PIL implementation

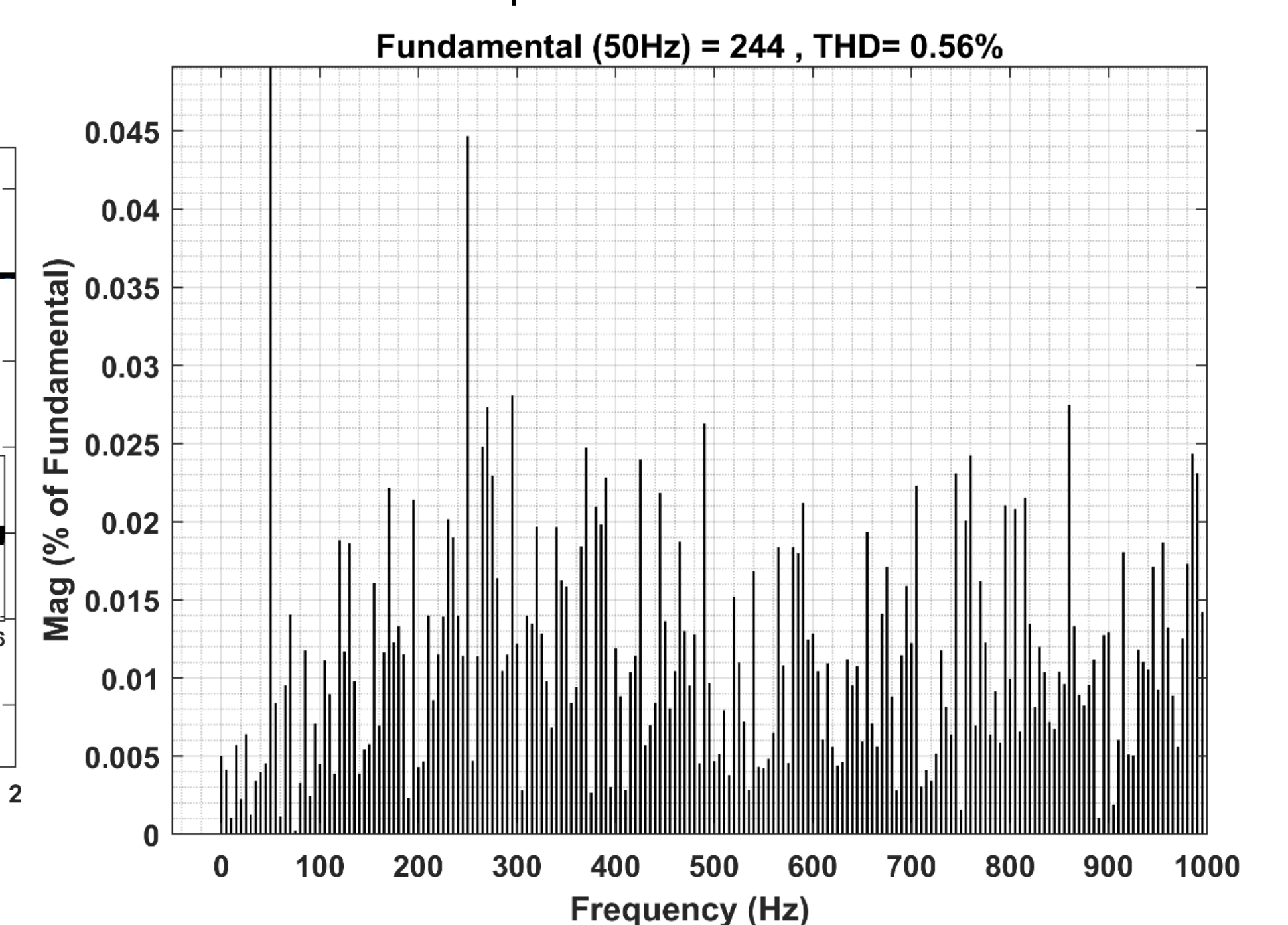


Figure 5. THD result of RI-FB technique

CONCLUSION

The proposed RI-FB control technique is a robust key for Grid-Tied PV Systems, achieving fast MPP tracking of 98% rapidly, minimal THD under 0,90%, and stable grid injection even under disturbances and partial shading. PIL validation on the TMS320F28335 confirms its real-time feasibility and superiority over existing methods. This work contributes a practical, high-performance solution for modern sustainable energy systems.

REFERENCES

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2. Rizki H, Lamzouri FE-z, Boufounas E-M, Amrani AE, Bejjit L. Advanced global MPPT strategy for PV systems using high-order sliding mode control, ABC optimization, and neural network prediction under partial shading conditions. Comput. Electr. Eng 2025;127.