OPERATION AND CONTROL OF DISTRIBUTION GRIDS WITH MULTIPORT CONVERTERS

WP4 explores the integration of multiport converters (MCs) into distribution grid operation, focusing on system models, real-time control strategies, and advanced grid functionalities. The developments are validated through hardware experiments and control-in-the-loop setups.

Grid Modelling and Simulation

The modelling and simulation work of iPLUG is structured around two representative case studies that explore the impact and control of multiport converters in realistic distribution grid environments. These case studies serve as the main testbeds for developing and validating both local and coordinated control strategies. Each case includes a detailed network configuration, realistic load and generation profiles, and integration of multiport converters at strategic locations in the grid.

Case Study 1 represents the Anell LV grid employed in WP1 but without simplification of the feeders (see Figure 1). Therefore, this is a suburban low-voltage distribution network with three feeders and varying load conditions. This scenario is designed to analyse the flexibility potential of multiport converters installed at the feeder level. In particular a MC based on triple active bridge topology is considered (see Figure 2). Within Case Study 1 simulations are used to evaluate the steady state operation with the introduction of MC and how different controller settings of the MC (such as voltage or power control modes) affect local and feeder-wide performance. The inclusion of realistic DER behaviour and load variability ensure that the converter responses are tested under dynamic conditions. The outcomes demonstrate that the converter can support both local voltage stability and system-level objectives, depending on how the control strategy is configured.

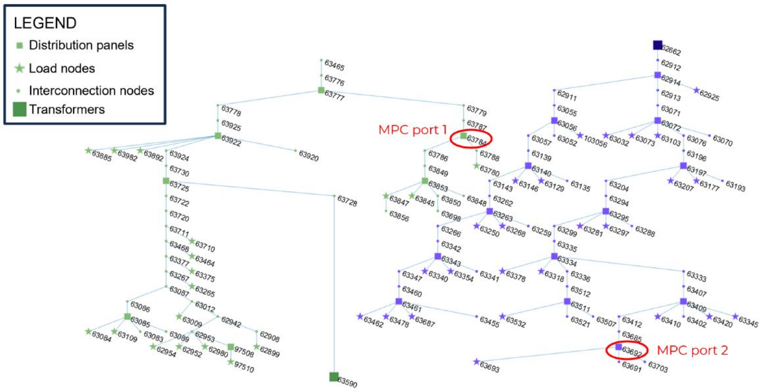

Figure 1: Complete topology of Anell LV grids. MC ports connections are highlighted by red circles.

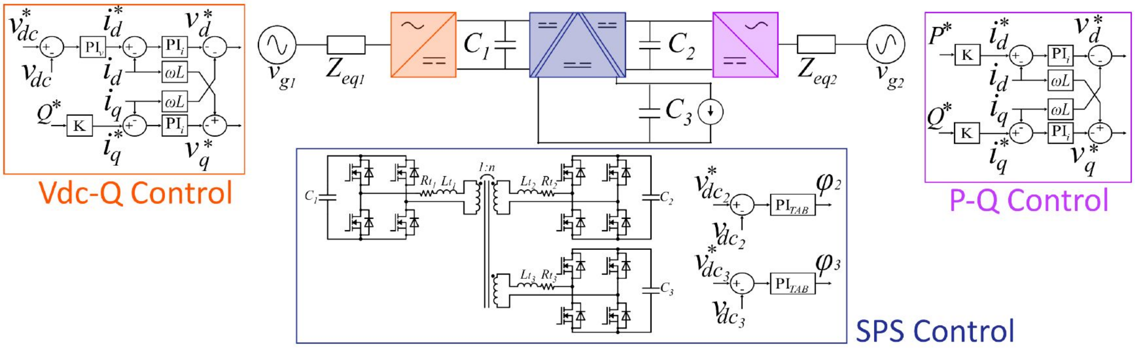

Figure 2: Model and control scheme of multiport converter based on the triple active bridge

Case Study 2 represents the IEEE 33 bus system, which is a rural medium-voltage network with long radial lines and significant penetration of renewables. In this case, the DERs are placed closer to the end of feeders, where voltage sensitivity is higher. The analysis of Case Study 2 first explores the impact of different control modes from DERs in the dynamic stability conditions. Then, the inclusion of a non-isolated MC is analysed (see Figure 4). This case confirms the strategic value of deploying multiport converters in weak or remote grid areas, where they can significantly improve stability conditions.

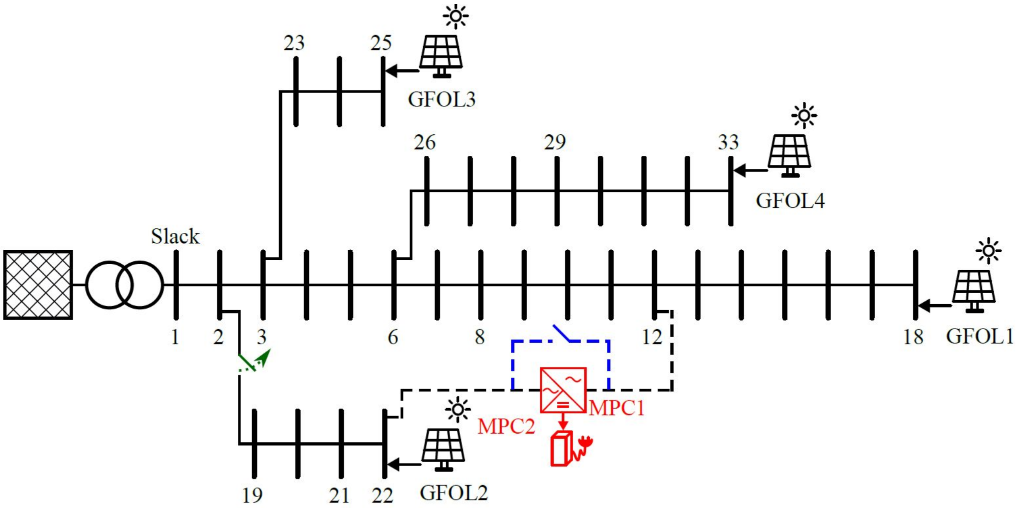

Figure 3: IEEE 33 bus system with potential MC inclusion

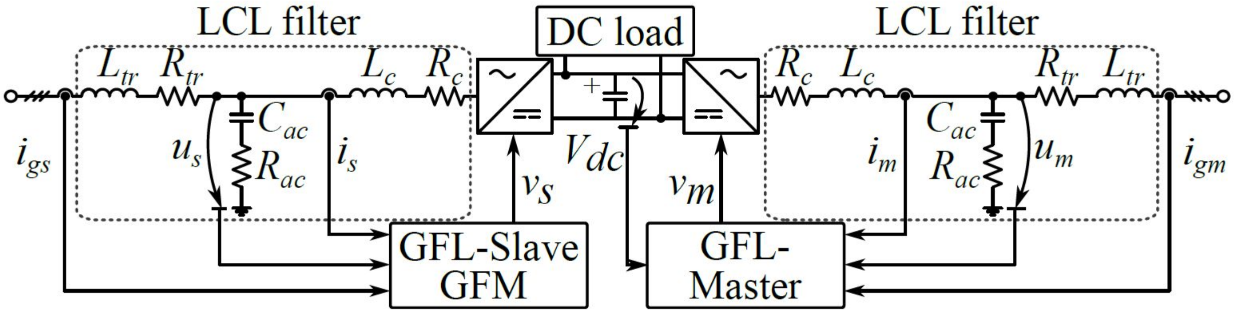

Figure 4: Model and control scheme of non-isolated multiport converter.

These two case studies collectively provide a robust and versatile simulation framework to validate the performance of both local and coordinated control strategies. The insights gained from these scenarios form the foundation for the controller designs and coordination methods developed throughout the rest of the project.

Local Controllers

The first part of the local controller development focuses on isolated Multiport Converters (MCs), particularly those based on the Triple Active Bridge (TAB) topology. These converters, due to their galvanic isolation and multiple ports, are highly suitable for applications requiring strong control decoupling and bidirectional power flow. The section explores both linear and non-linear control strategies to manage power transfer among ports while ensuring system stability. Special attention is given to the dynamic behaviour of these systems when implemented as Soft Open Points (SOPs), and stability analyses are carried out to validate the controllers' effectiveness under realistic grid conditions. Figures 5 shows an example of eigenvalue analysis where the impact that the AC current loop has on the stability is observed.

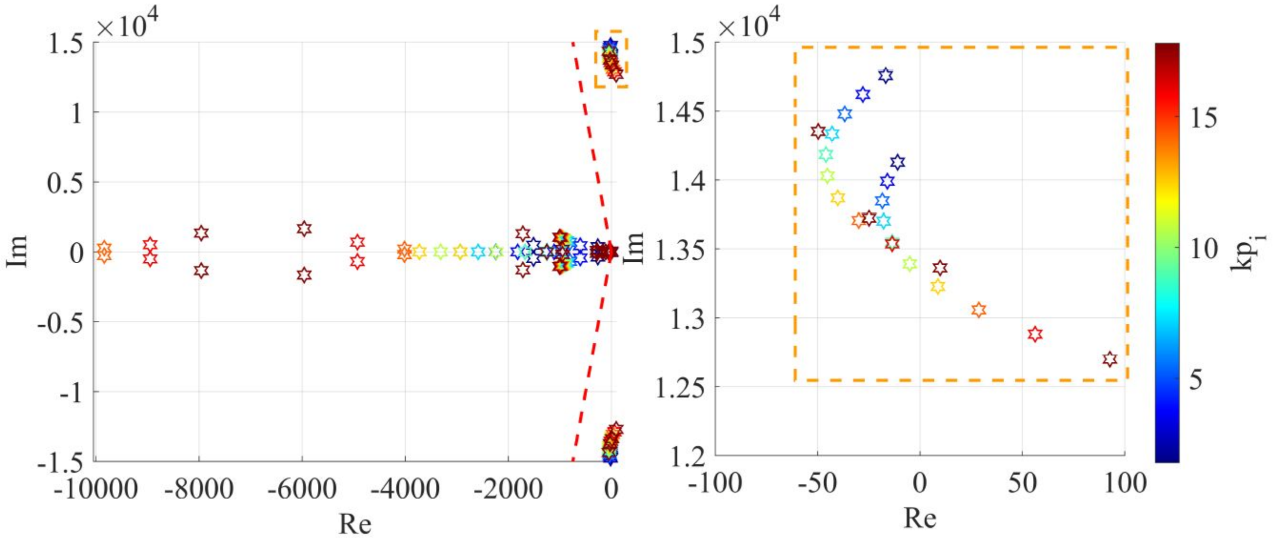

Figure 5: Eigenvalue sensitivity analysis for the proportional gain of the AC current controller.

The second part of the study addresses non-isolated MCs, focusing on their control under normal and abnormal operating conditions. These converters typically rely on back-to-back structures or shared DC links and are more sensitive to disturbances such as voltage sags, fault currents, or fast load variations. The control design aims to maintain reliable operation even during transient events, incorporating current limitation strategies and fault-handling mechanisms. Simulation results highlight how these converters can support voltage regulation and continue to deliver power during adverse conditions, reinforcing their role as flexible assets within the grid. Figure 6 shows the simplified test system and the fault location that have been considered, while Figure 7 shows an example of results to test fault and islanded operation of the non-isolated MC.

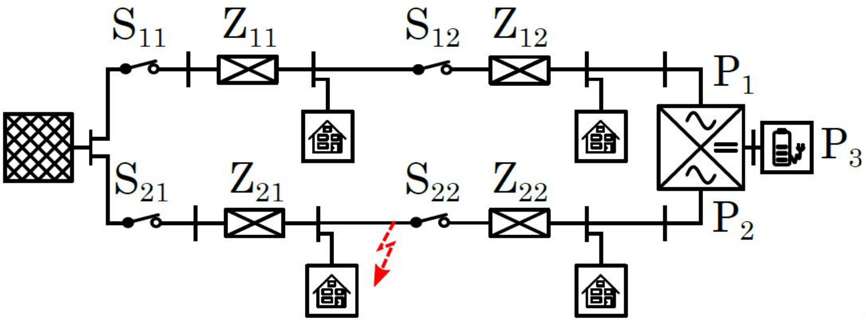

Figure 6: Scenario with 3-port MC

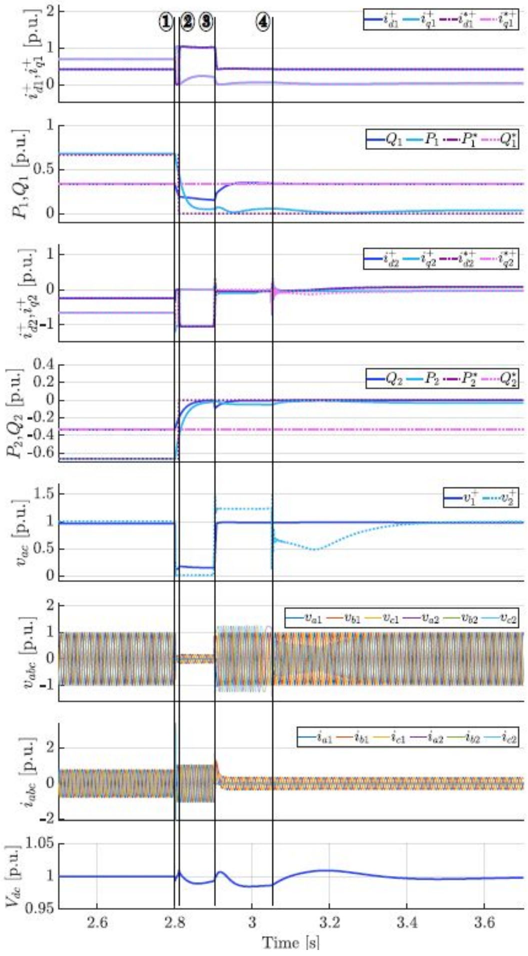

Figure 7: Simulation results for an AC balanced permanent fault without battery and switches S21 and S22 opened after the fault is detected.

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Lastly, advanced control approach based on Virtual Oscillator Control (VOC) are analysed (see Figure 8), enabling grid-forming (GFM) capabilities in MCs. Unlike traditional grid-following methods, VOC enables MCs to synchronise naturally with the grid and provide essential services such as inertia emulation, voltage and frequency regulation, and islanding support. This approach positions MCs not just as interface devices, but as active grid participants capable of stabilising weak networks and supporting the transition to converter-dominated grids. The integration of VOC opens new possibilities for decentralised and autonomous control in low-inertia distribution systems.

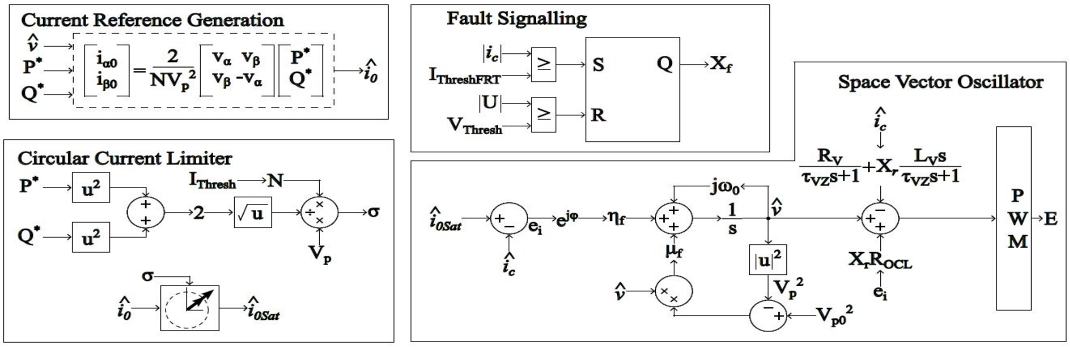


Figure 8: Control scheme of unified Virtual Oscillator Controller.

System-wide Coordination

A central focus of the iPLUG control framework is the optimal dispatch of MCs across the distribution grid to enhance system performance. This section formulates the coordination problem as an optimal power flow (OPF), aiming to minimise network losses and voltage deviations. By incorporating network constraints and converter capabilities, the OPF calculates the optimal active (P) and reactive (Q) power setpoints for each MC. The flexibility of the formulation allows adapting the objective function to different operational goals, such as reducing congestion or improving voltage profiles. The optimal dispatch of the MC has been tested in the IEEE bus system (see Figure 9). Simulation results demonstrate how optimally dispatching MCs enables more efficient operation of the grid, maximising the value of their controllability across multiple points of connection. Figure 10 shows an example where voltage profile is improved with the MC introduction.

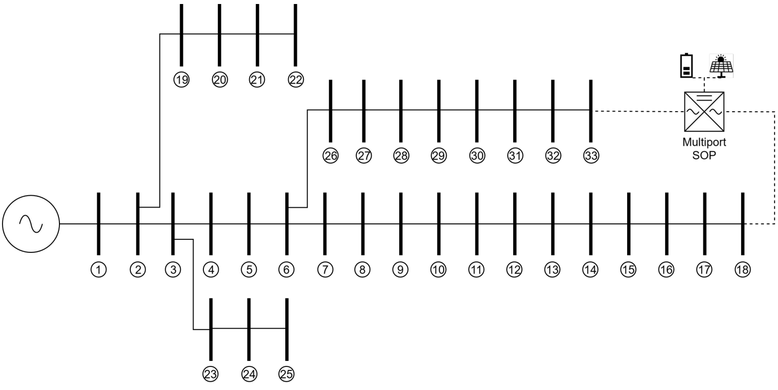


Figure 9: MC location in IEEE 33 bus system

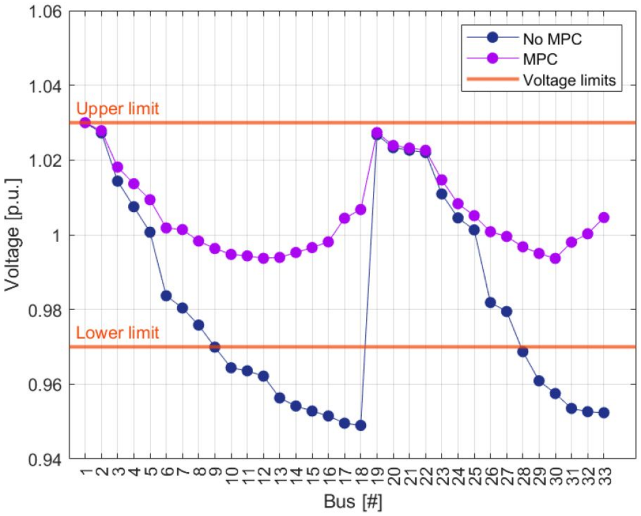
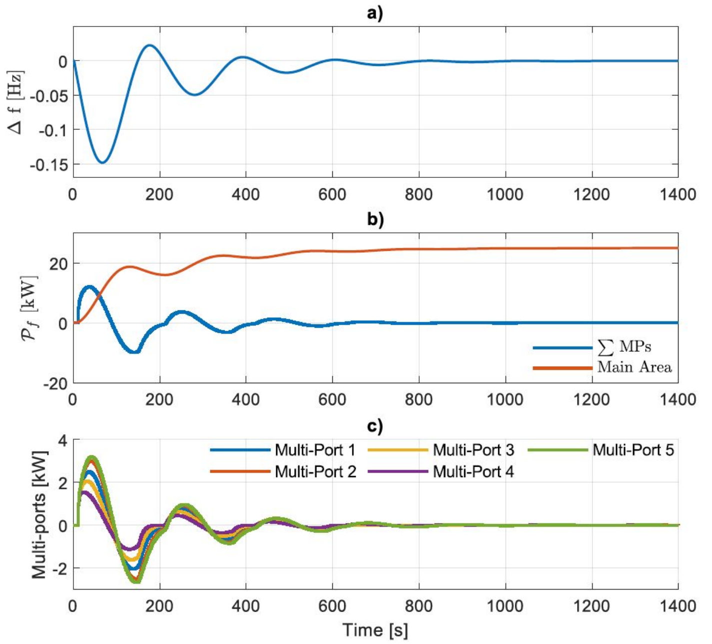


Figure 10: Voltage profile of the IEEE 33 bus system with and without MC between bus 18 and 33.

The next part of the coordination strategy leverages Model Predictive Control to manage interactions between multiple MC units and connected energy assets. This predictive control approach is especially suited for scenarios involving distributed systems such as interconnected microgrids. By forecasting system dynamics and disturbances, the controller adjusts the setpoints of each MC in real time, ensuring coordinated behaviour over a defined time horizon. This strategy enables the converters to contribute actively to grid stability services, particularly frequency regulation, even in the presence of high renewable penetration or sudden changes in demand. Figure 11 shows and example of how MPC can be used to provide frequency support from several MCs.



Overall, the coordination layer transforms MCs from locally controlled devices into system-wide optimisation agents. Through OPF-based dispatch and predictive control mechanisms, the system ensures that converter actions align with broader grid objectives. These results highlight the key role MCs can play in supporting efficient, stable, and flexible operation of modern distribution networks, especially as these grids evolve toward higher shares of decentralised and converter-based generation.

Figure 11: Evolution of the controller's response in providing frequency support. (a) System frequency evolution in response to a load disturbance, (b) Restoring frequency contributed by the combined multiport converters and the main area, and (c) Power distribution across individual multiport converters.

Validating Control and Operation of Multiport Converters

The final step is to validate the MC in laboratory and hardware-in-the-loop (HIL) setups. This validation confirms the robustness of the proposed MC control architectures and paves the way for the deployment of flexible, smart distribution networks. The validation stages, from simulation to real hardware, highlight iPLUG's commitment to bridging theory and practical implementation.

The validation process was structured around three main HIL stages:

- Digital Real-Time Simulation

This phase involved developing and testing a simulation model of an isolated triple active bridge (TAB) converter using the Typhoon HIL platform. The chapter covers the operational principles, switching model, and implementation of a decoupled power flow control strategy. Both open-loop and closed-loop tests validate the proposed control method.

- Control Hardware-in-the-Loop (CHIL) Validation

The next stage shifts focus to real-time control validation using laboratory hardware. A PI controller implemented on a commercial microcontroller is tested through a CHIL setup (see Figure 12). The same strategy is applied to a TAB-based SOP, confirming controller performance under realistic hardware conditions

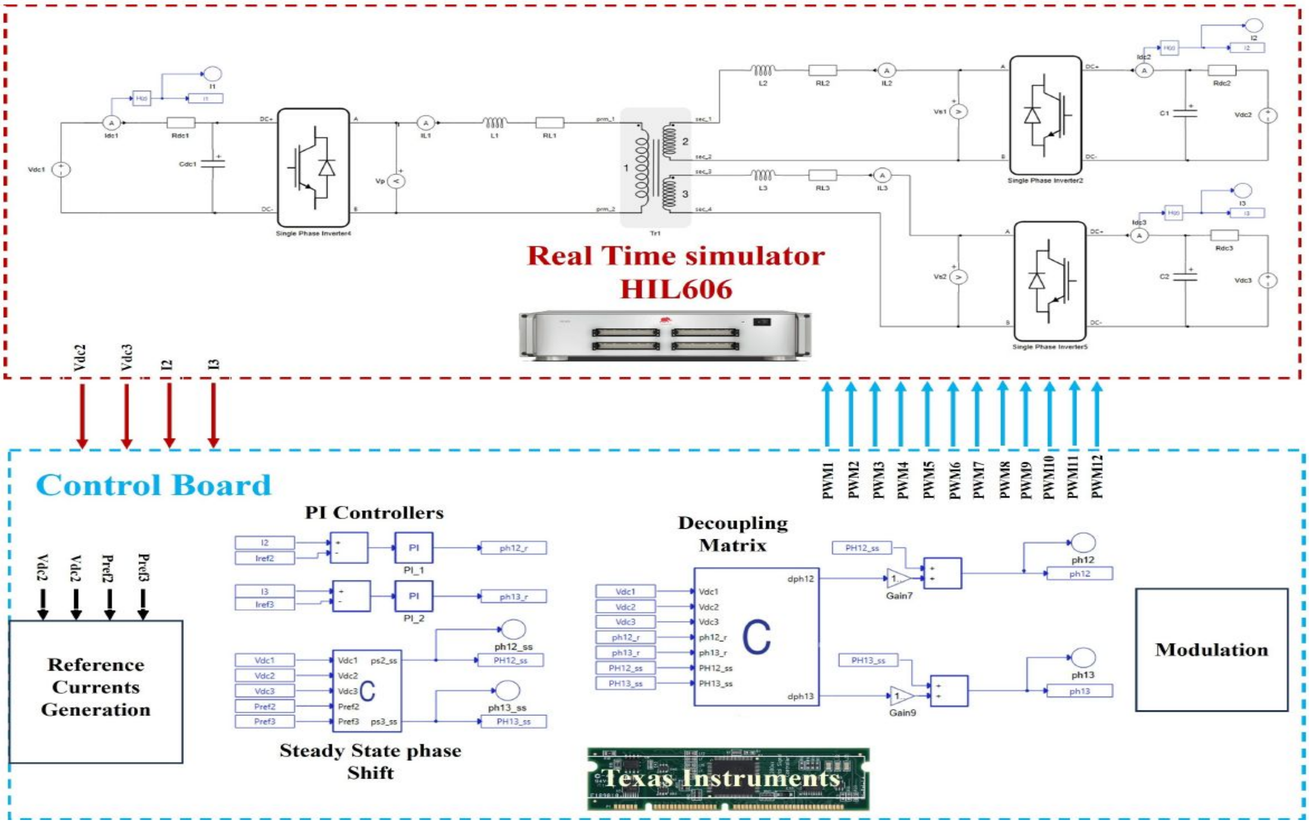
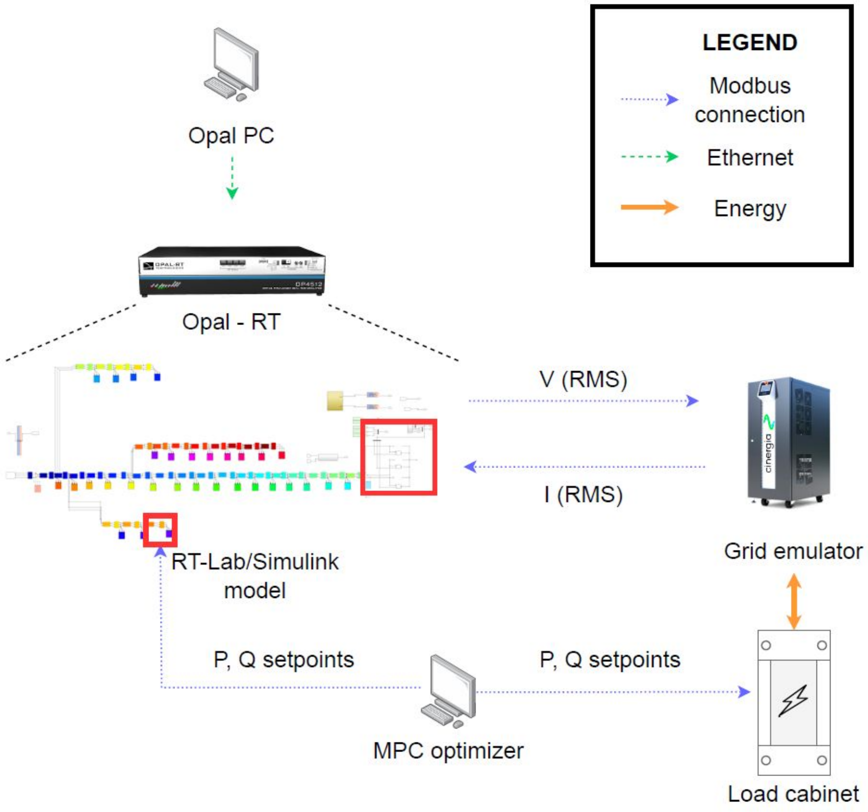


Figure 12: CHIL test setup for the TAB converter validation



- Power Hardware-in-the-Loop (PHIL) Validation

Finally, the testbed at IREC's Energy Laboratory (see Figure 13) enabled validation of centralized coordination strategies via high-level optimization. The testbed setup, model adaptation for PHIL testing, and successful demonstration of the control strategy was addressed.

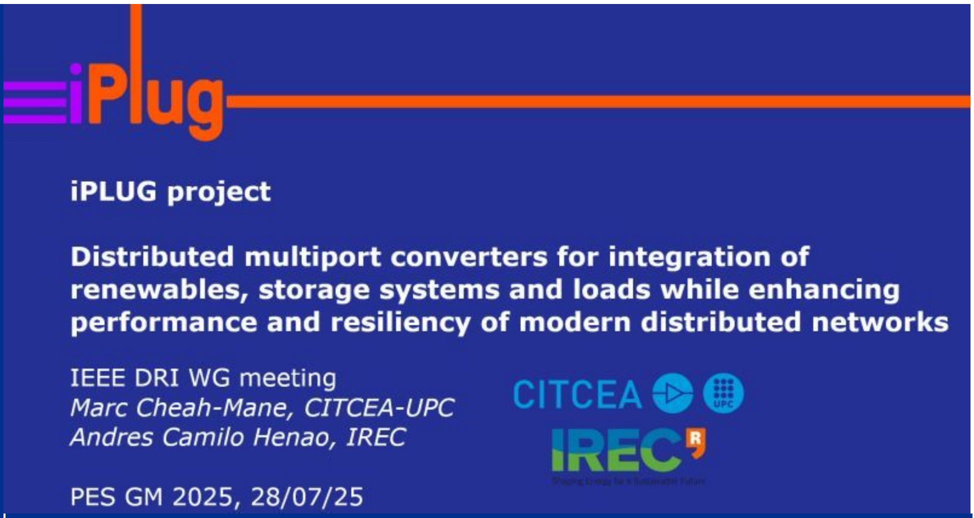
Figure 13: Integration of MPC-based SOP optimizer with Opal-RT and physical equipment

EVENTS

SUMMARY OF THE IPLUG PROJECT

Our project was represented by our colleagues Marc Cheah Mañé and Camilo Henao during the IEEE Distributed Resources Integration Working Group Meeting, held at the PES General Meeting. They presented a summary of the iPLUG project outcomes, sharing key results and insights with the IEEE PES community.

This meeting offered an excellent opportunity to showcase the progress of our project, engage with professionals in the field, and exchange ideas on the integration of distributed energy resources



iPLUG project

Distributed multiport converters for integration of renewables, storage systems and loads while enhancing performance and resiliency of modern distributed networks

IEEE DRI WG meeting

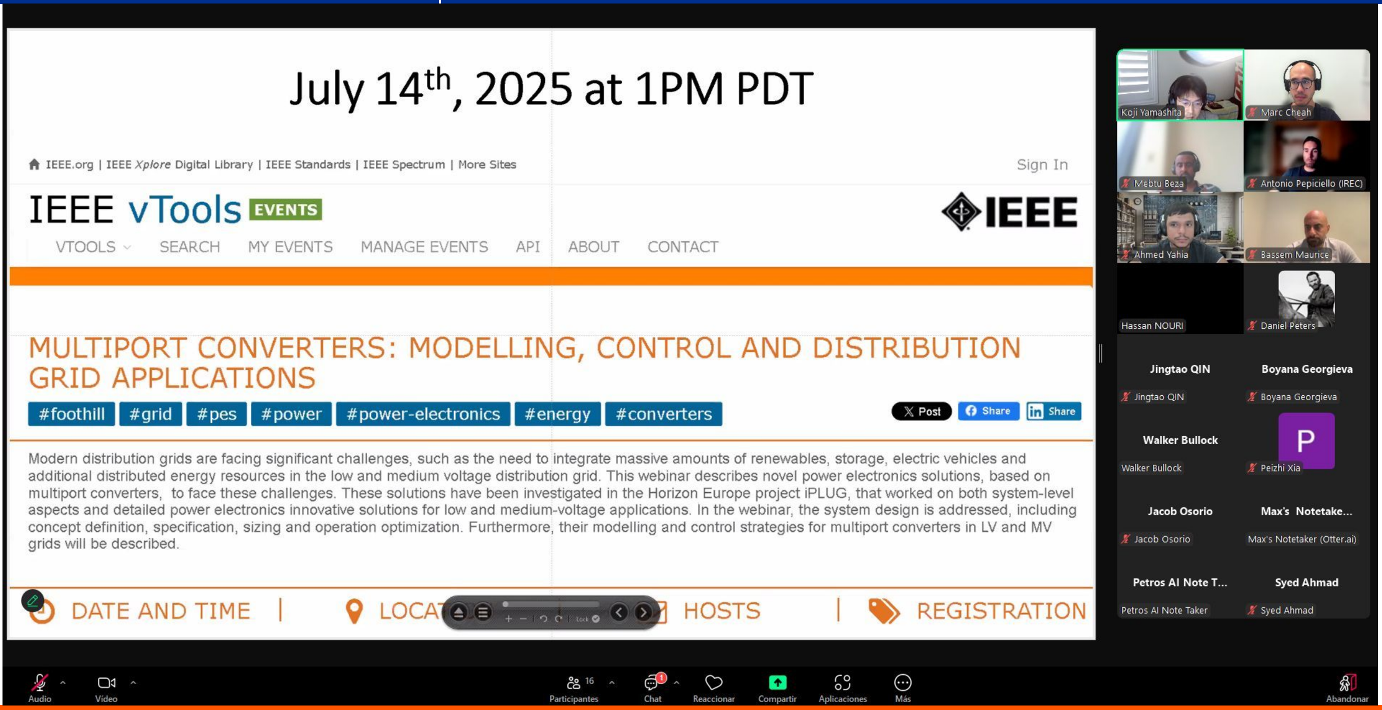
Marc Cheah-Mane, CITCEA-UPC

Andres Camilo Henao, IREC

PES GM 2025, 28/07/25

PES WEBINAR – MULTIPORT CONVERTERS FOR DISTRIBUTION GRID APPLICATIONS

On 14th July 2025, the IEEE Foothill Section hosted a webinar on multiport converters, focusing on their modelling, control, and application in modern distribution grids. Speakers from the iPLUG-HE project — Ahmed Yahia Farag, Antonio Pepiciello, Marc Cheah Mañé, and Mebtu Bihonegn Beza — shared insights on advanced converter topologies and system-level design for low and medium voltage networks. The session highlighted the importance of coordinated control, robust modelling, and European innovation in supporting resilient and flexible grids.



July 14th, 2025 at 1PM PDT

MULTIPORT CONVERTERS: MODELLING, CONTROL AND DISTRIBUTION GRID APPLICATIONS

#foothill #grid #pes #power #power-electronics #energy #converters

Modern distribution grids are facing significant challenges, such as the need to integrate massive amounts of renewables, storage, electric vehicles and additional distributed energy resources in the low and medium voltage distribution grid. This webinar describes novel power electronics solutions, based on multiport converters, to face these challenges. These solutions have been investigated in the Horizon Europe project iPLUG, that worked on both system-level aspects and detailed power electronics innovative solutions for low and medium-voltage applications. In the webinar, the system design is addressed, including concept definition, specification, sizing and operation optimization. Furthermore, their modelling and control strategies for multiport converters in LV and MV grids will be described.