

CASE STUDY APPLICATIONS OF MULTIPOINT CONVERTER SIZING AND RESILIENCE ANALYSIS

WPI explored the potential of Multiport Converters (MPCs) across diverse use cases, applying optimisation-based methodologies to determine optimal sizing, location, and operation. Three complementary use case families were analysed: **building integration**, **distribution-level interconnection**, and **resilience-driven network upgrade**

Application of multiport converter sizing methodology

The **building case studies** (Castelló d'Empúries Health Centre, Garrotxa Regional Hospital, and ICAT Headquarters) integrated PV, EV charging, and battery storage through a single MPC. Hourly demand, generation, and market price data from 2023–2024 were used in an energy-based optimisation minimising MPC, storage, and energy exchange costs. The scenarios presented in Figure 1 were compared, where Scenario C represents the conventional configuration without MPC. Figure 2 shows the areas where MPC and separated converter options are more convenient based on the total cost for the three building case studies. Compared to separate converters, MPC integration reduced total investment by 43–55% and improved PV self-consumption, with EV presence amplifying the benefits. PV capacity and MPC terminal cost emerged as key sizing drivers.

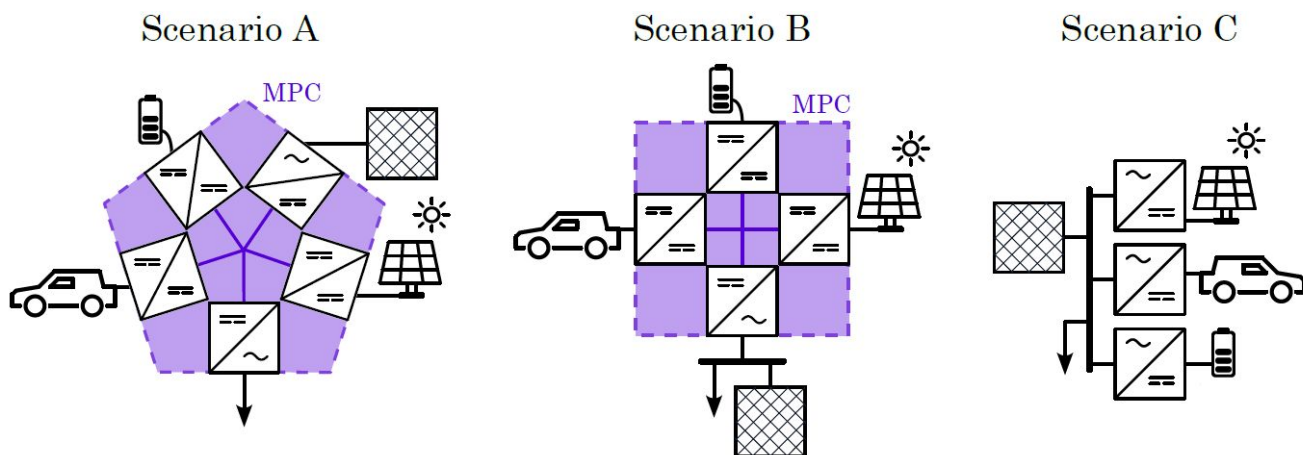


Figure 1: Building case studies scenarios

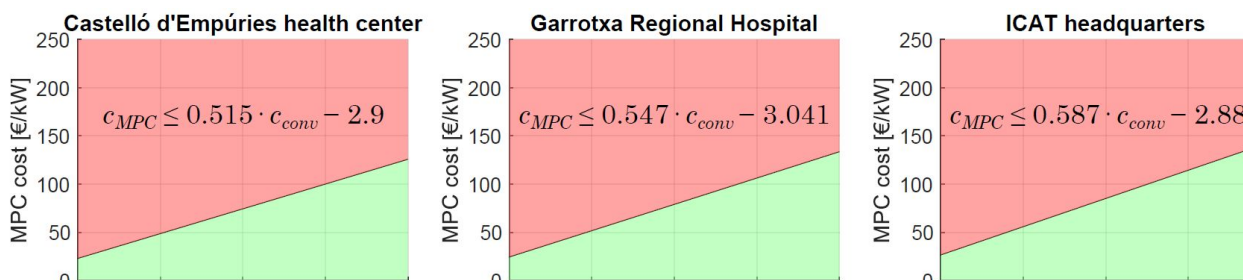


Figure 2: Relationship between MPC and separated converter costs

The **LV case study** modelled two interconnected LV feeders in Anell’s network, with varying PV and EV penetration scenarios (“Extreme PV”, “Extreme EV”). Figure 3 shows the simplified grid configuration that is considered. An AC power-flow optimisation determined optimal terminal ratings while maintaining voltage and current limits. In high-PV scenarios, MPCs reduced grid imports and eased line congestion; in high-EV scenarios, they enabled peak-shaving and voltage stabilisation without breaching feeder limits. Figure 4 shows an example of the powers of each port for the extreme PV scenario.

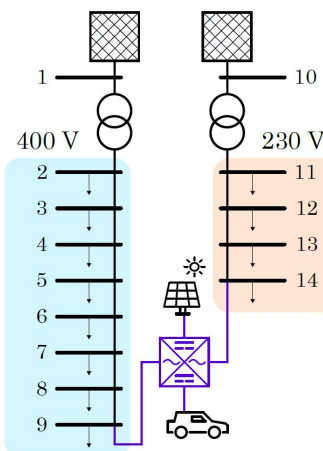


Figure 3: Simplified topology of Anell LV grids with potential MPC

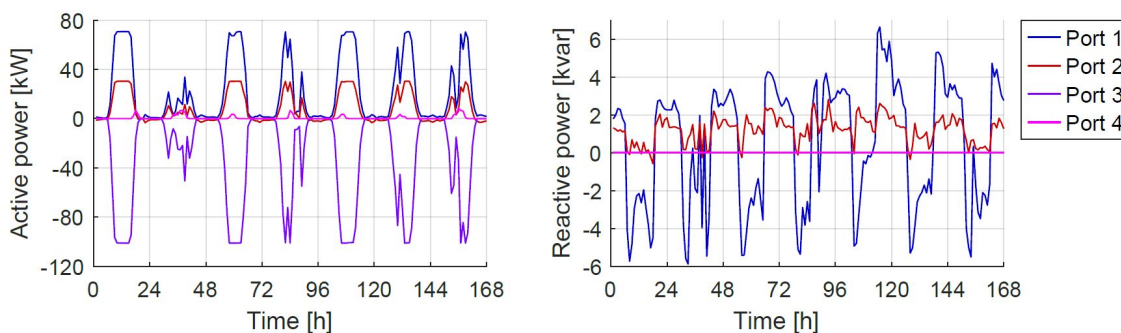
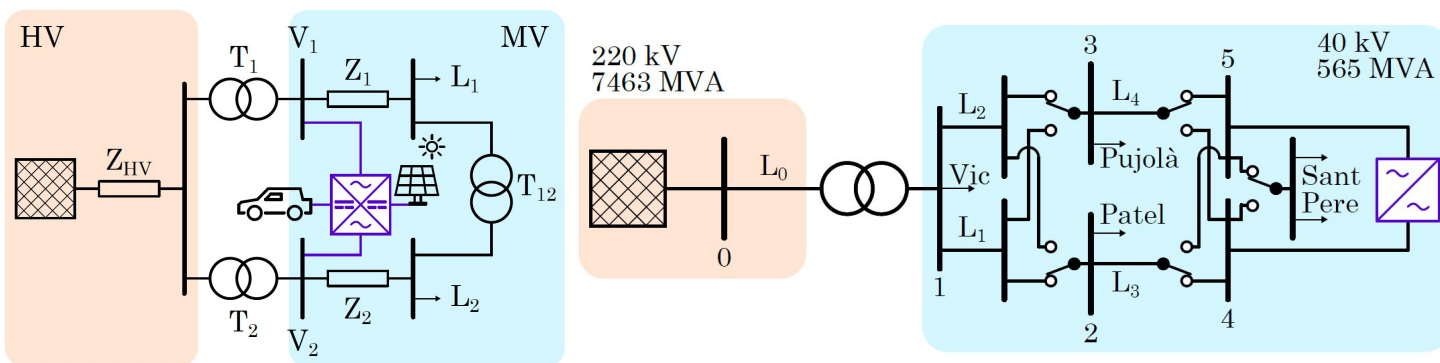


Figure 4: Active and reactive power of the MPC terminals for LV case study in the extreme PV scenario

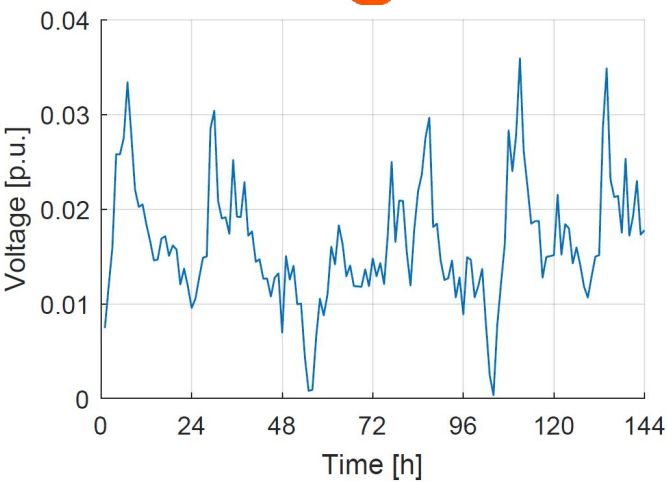
The **MV case study** analysed both a simplified two-bus interconnection (Figure 5a) and a real MV distribution system (Figure 5b). For the simplified case, the influence of pre-connection voltage difference on optimal MPC sizing and power factor was quantified. In the real network, MPC operation improved voltage profiles and relieved loading on constrained lines, especially under high renewable injection. Figure 6 shows an example of how the MPC can support balance the voltage differences between two buses of the same substation.



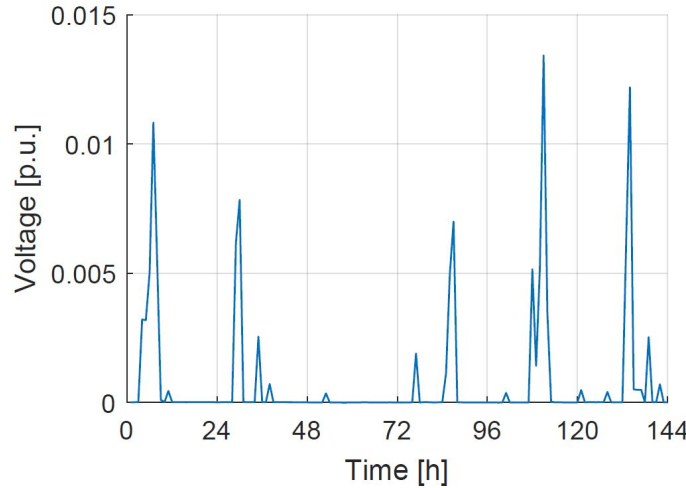
(a) Simplified two-bus interconnection

(b) Simplified topology of the MV grid use case provided by Anell

Figure 5: Subtransmission grid case study



(a) Initial scenario



(b) Scenario with introduction of MPC

Figure 6: Voltage difference between bus 4 and 5 for the Anell MV use case with increased Sant Pere load

Resilience evaluation with multiport converters

Finally, the **resilience-driven use case** applied a GIS-based hazard and vulnerability assessment to a rural MV network. Baseline resilience indices were calculated from historical incident data (floods, wildfires, wind, lightning, equipment failures). Figure 7 shows a summary of all the information sources that have been considered to create the hazards and vulnerability database. Adding an MPC between two MV feeders, with an additional DC port connected to a BESS, increased the resilience index by enabling alternative supply routes and local backup. Risk maps before and after MPC deployment showed significant reductions in customer exposure to outages. Figure 8 shows an example of the risk assessment results (as power demand under risk) when the MPC is introduced

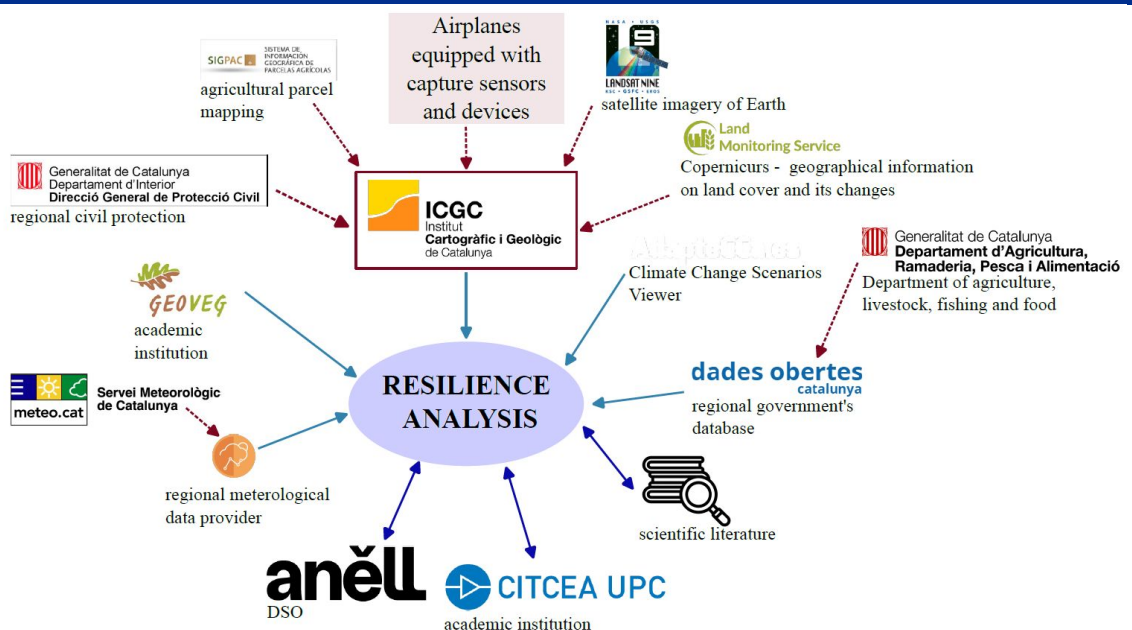


Figure 7: Resilience analysis network.

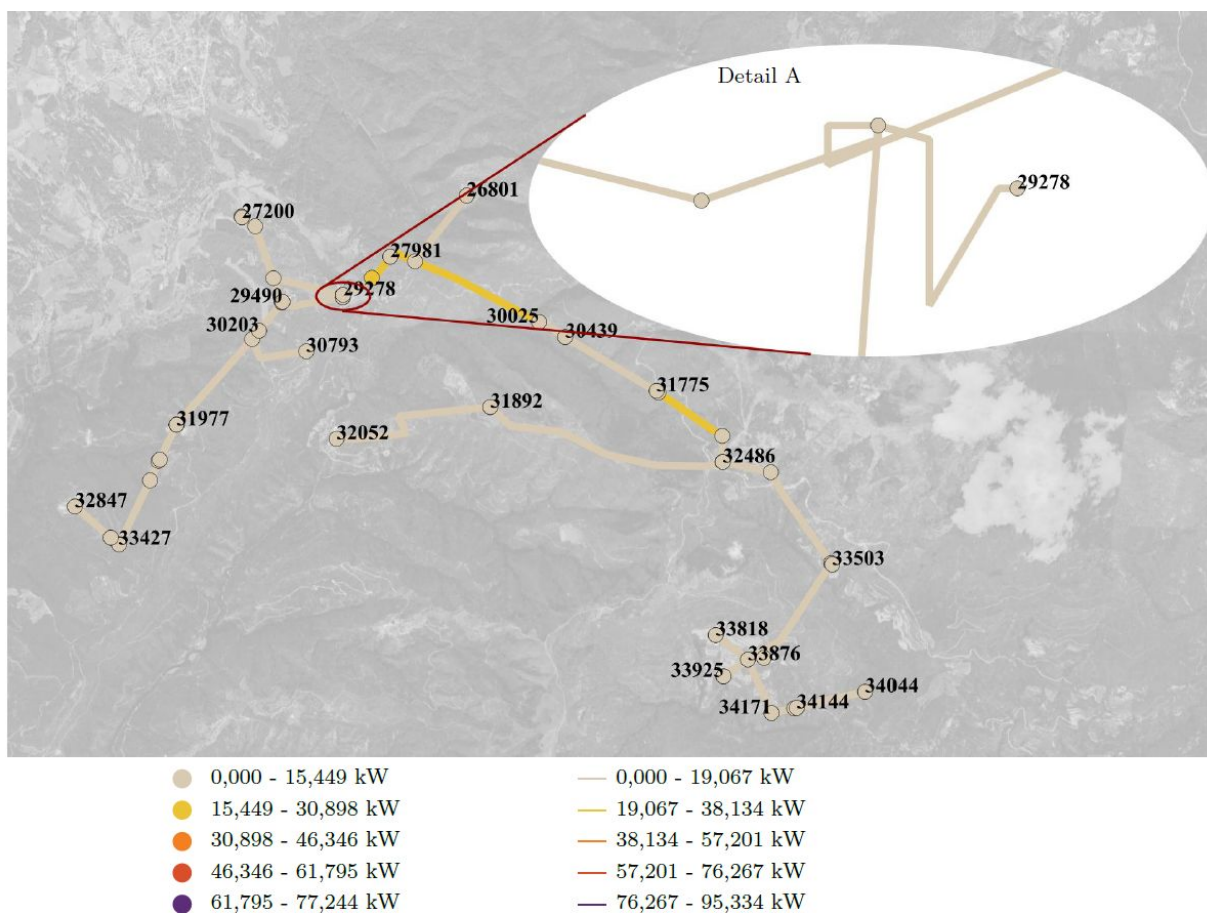


Figure 8: Network's risk assessment for an average autumn hour after including the MPC. Map scale: 1 : 100 000, Detail A: 1 : 75.

TOPOLOGY SELECTION AND EXPERIMENTAL VALIDATION OF MV MULTIPOINT CONVERTERS

The selection of the most suitable medium-voltage MPC topology in WP2 was followed by a sequence of complementary experimental validations carried out in three stages, each with a distinct setup and objective.

Qualitative topology selection

A structured comparison was undertaken to identify the most suitable MV MPC topology for an Enhanced Soft Open Point (ESOP) application interconnecting two MV AC feeders with a LV DC energy storage port. The evaluation considered performance in normal and fault conditions, scalability for different voltage levels, component count, and operational flexibility.

Two topology families were shortlisted:

1. **Partially-isolated** – Back-to-back full-bridge Modular Multilevel Converter (MMC) linked to the DC port via an Input-Series Output-Parallel (ISOP) Dual Active Bridge (DAB) stage.
2. **Fully-isolated** – Cascaded H-bridge MMC interfaced to all ports via a Multi-Active Bridge (MAB) stage.

Figure 9 shows the results of the qualitative comparison between the previous selected topologies. The partially-isolated option was chosen as it combined high efficiency, reduced component count, and fault-ride-through capability while keeping port decoupling. Its ISOP DAB stage allowed scalable integration of large voltage differences and provided galvanic isolation for the LV port. Figure 10 shows the scheme considered for the selected semi-isolated topology.

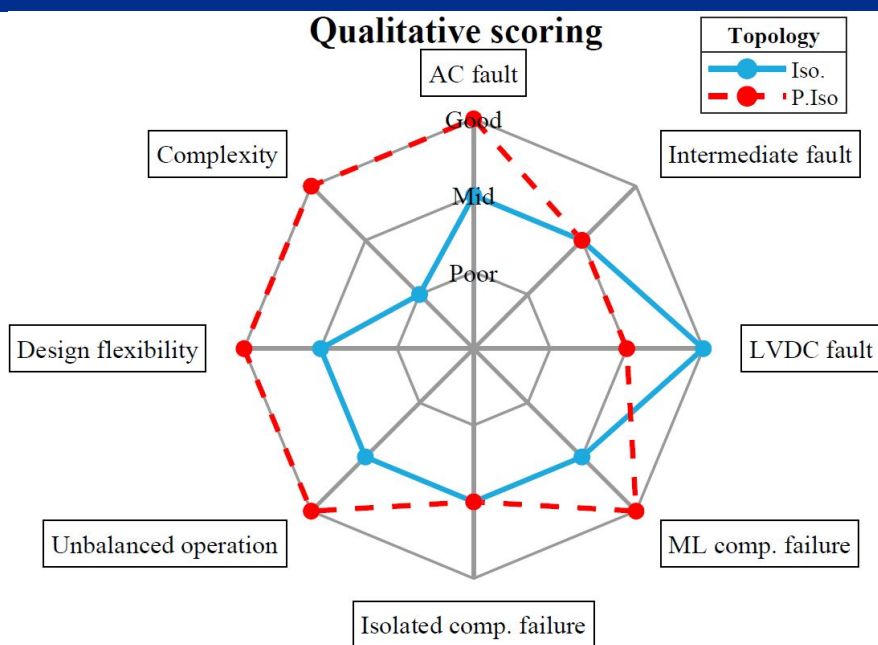


Figure 9: Comparison of qualitative feature scoring.

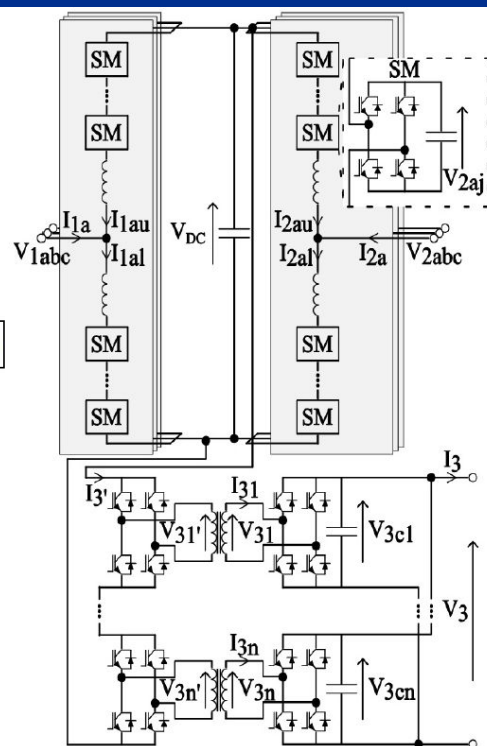


Figure 10: Schematic of the selected semi-isolated topology

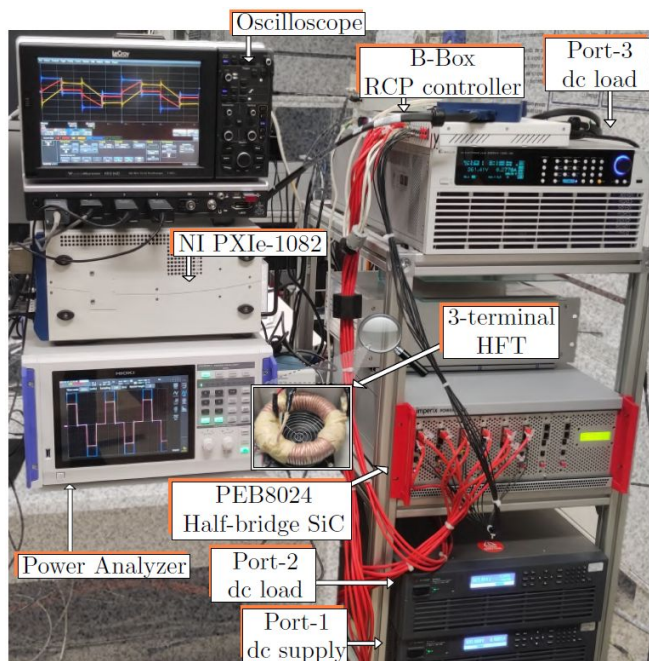


Figure 11: TAB experimental prototype

High-frequency isolation stage optimisation and validation

The first setup focused on the triple-active-bridge (TAB) DC-DC isolation stage, a key building block of the partly-isolated topology. The aim was to find an optimal trade-off between zero-voltage switching (ZVS) and reduced RMS currents, both of which impact efficiency, EMI, and component lifetime. A multi-dimensional ripple correlation control (MD-RCC) algorithm was implemented for online, model-free optimisation of modulation parameters. This approach was validated in both simulation and hardware (see Figure 11), showing that slight increases in RMS current can significantly reduce hard-switching currents, improving overall performance.

CHIL validation of control strategies for a non-isolated MV-MPC

The second setup assessed control robustness using a Control Hardware-in-the-Loop (CHIL) platform with a non-isolated full-bridge MMC topology (see Figure 12). Three control strategies—classical, crossed, and combined—were compared under normal operation, AC faults, and DC faults. Classical control maintained total energy balance, while crossed control ensured DC voltage stability and STATCOM capability during DC faults. The combined strategy merged these strengths, achieving improved fault performance. Typhoon HIL modelling with a Texas Instruments F28379D microcontroller running the centralised control confirmed the feasibility of deploying these strategies in real hardware.

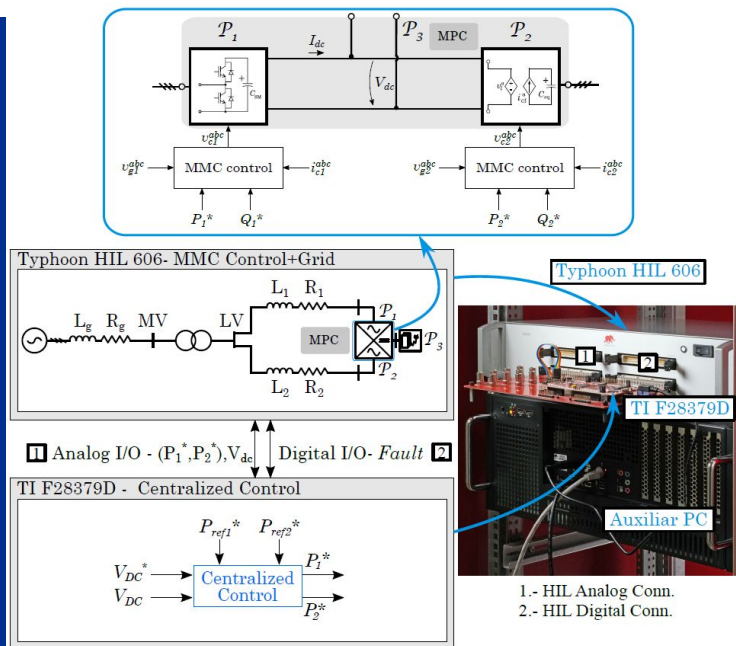


Figure 12: Schematic of the CHIL setup for non-isolated MMC-MPC validation

Laboratory validation of the selected partly-isolated topology

The third setup implemented a down-scaled laboratory prototype of the selected partly-isolated topology, comprising two MV AC ports (one realised with a two-level converter, the other with a full-bridge MMC) and a LV DC port as seen in Figure 13. In the lab version, the high-frequency isolation stage was omitted for simplicity, with the DC port connected directly to the DC link. The testbed included a grid emulator, passive AC loads, and configurable DC loads/sources. The control system featured PLL-based synchronisation, PI-controlled outer loops for power, energy, and DC-link voltage, negative-sequence compensation, and circulating current suppression. Dynamic tests demonstrated stable operation under reactive power steps, load changes, voltage dips, and port disconnections, confirming the topology's suitability for MV distribution integration. Figure 14 shows an example of the experimental results.

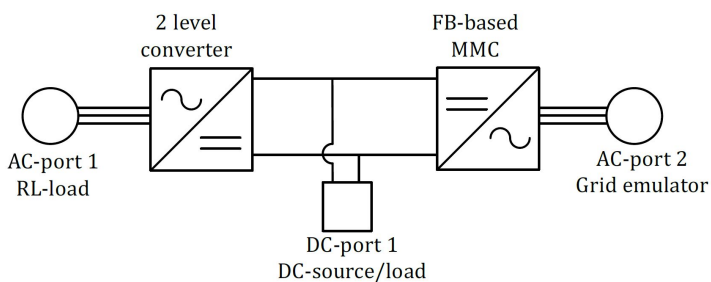


Figure 13: Block diagram of the laboratory setup.

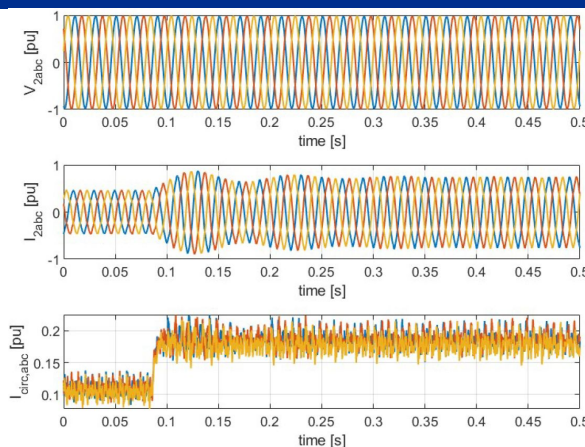


Figure 14: Three-phase grid voltages (top), three-phase grid currents (middle) and three-phase circulating currents inside MMC phase legs at port 2 (bottom); a load step-up happens around 0.1 s at the DC-port.

TOPOLOGY SELECTION AND EXPERIMENTAL VALIDATION OF LV MULTI-PORT CONVERTERS

WP3 focused on developing and validating two innovative single-stage LV Multiport Y-converter topologies: the **symmetric Y-MPC** and the **asymmetric Y-MPC**, both designed to interconnect two DC ports with a three-phase AC grid, offering bidirectional buck-boost capability. Finally, a multi-objective optimisation using a renewable mission profile was used to compare the MPC approaches with a conventional two-port-plus-interlinking configuration.

Experimental verification of the symmetric Y-MPC

The symmetric Y-MPC (see Figure 15) extends the traditional two-port Y-converter by adding a second DC port to each of the three phase modules, creating a uniform structure where both DC ports have equal capability. The prototype used six commercial Imperix PEB8024 half-bridge modules for the boost stages and three custom half-bridge modules for the buck stages, optimised for low conduction losses and adjustable DC-link capacitance. As a result the experimental setup is presented in Figure 16. Tests under various steady-state conditions confirmed accurate power flow control between AC and DC ports, balanced three-phase AC currents, and low total harmonic distortion (THD). Transient tests demonstrated fast response when power references were changed, with minimal overshoot. Efficiency measurements showed high performance across a wide load range, validating the suitability of the symmetric Y-MPC for balanced DC-port applications.

Experimental verification of the asymmetric Y-MPC

The asymmetric Y-MPC (see Figure 17) modifies only one of the three phase modules to add the second DC port, reducing the number of semiconductor devices and inductors. This results in a more compact and cost-effective design for cases where the secondary DC port operates at lower power. Experimental results confirmed correct operation in both steady-state and transient modes, with AC currents kept balanced through specific current-ripple reduction strategies. Tests with different average inductor current waveforms (original, DC, clamped) demonstrated the impact on low-frequency voltage ripple at the DC ports and overall efficiency. The converter maintained stable operation even when large step changes in power occurred at either DC port. Figure 18 shows an example of the experimental results.

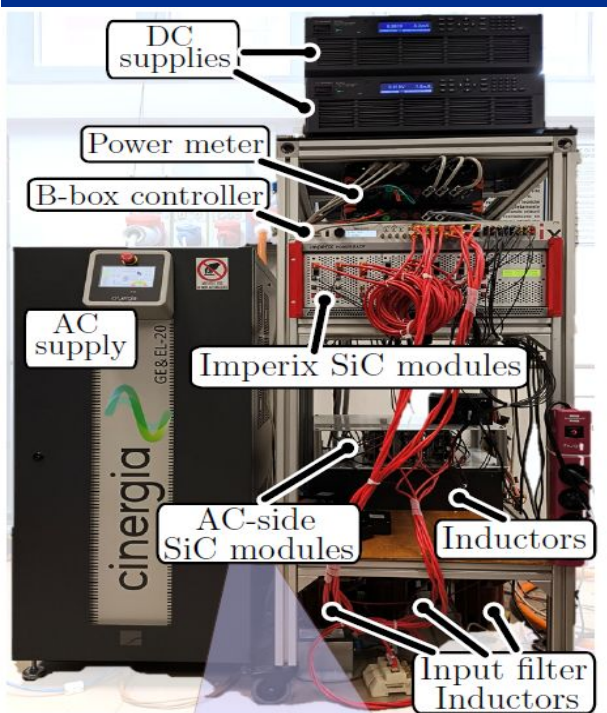


Figure 15: A schematic of the symmetric Multiport Y-converter.

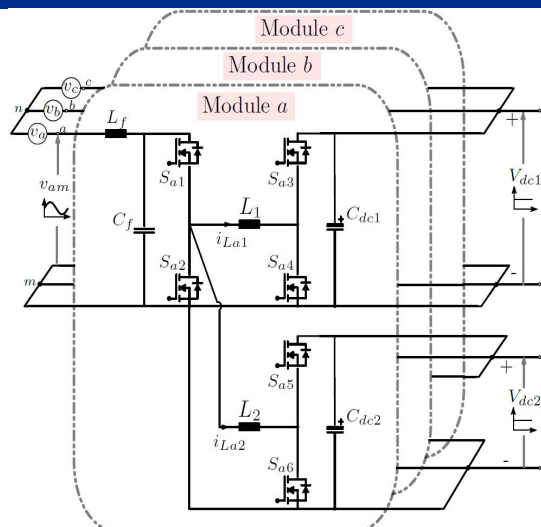


Figure 16: Picture of the experimental prototype of the proposed converter.

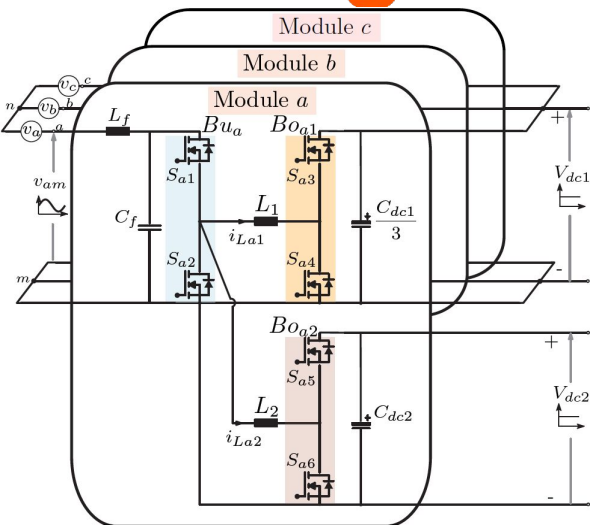


Figure 17: A schematic of the symmetric Multiport Y-converter.

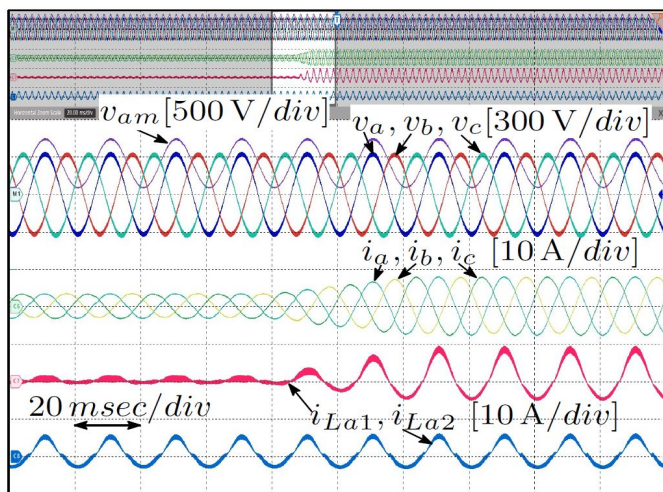


Figure 18: Experimental waveforms illustrating the transient behavior of the proposed converter when port 1 power is increased from 1 kW to 3 kW

Performance evaluation under renewable mission profile

Both symmetric and asymmetric Y-MPCs were assessed under a mission profile emulating renewable generation and storage interaction with the AC grid (see example in Figure 20). A multi-objective optimisation approach compared the Y-MPC with a conventional arrangement using two separate two-port Y-converters (2Y). Results showed that the Y-MPC achieved higher average efficiency by avoiding additional AC conversion stages during DC-to-DC transfer. Pareto-front analysis (see example in Figure 19) revealed that for the same efficiency, the Y-MPC offered higher power density, while for the same power density, it delivered superior efficiency. Loss and volume breakdowns confirmed that the reduction in magnetic components and semiconductor count directly contributed to performance gains.

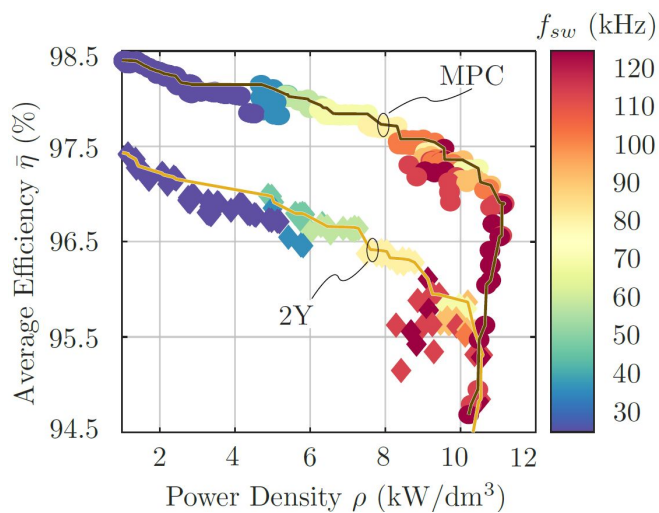


Figure 19: Pareto-front evaluation of both designs considering average efficiency.

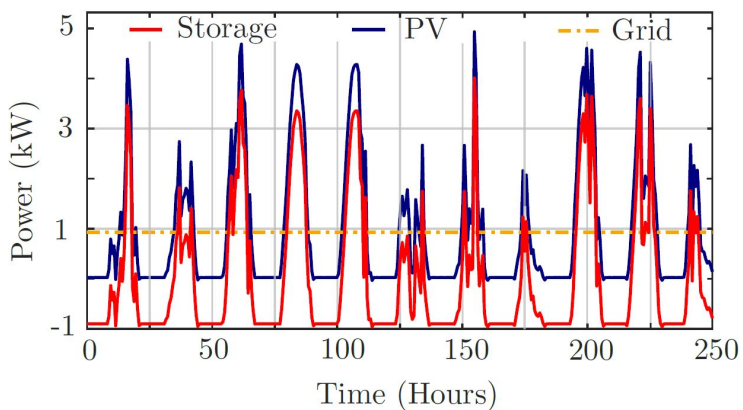


Figure 20: Mission-profile based evaluation for converter configurations

EVENTS

05 GENERAL ASSEMBLY

In April 2025, the fifth General Assembly of the iPLUG project was hosted by the University of Padua in Padua, Italy. During the first day at Università degli Studi di Padova (UNIPD) / University of Padua in Vicenza, there was an extensive review of the Work Packages and technical discussions regarding hashtag#MultiportConverters sizing and topologies for hashtag#mediumvoltage applications. Later on, during the day, we had the opportunity to visit Power Electronics Labs in Vicenza. After the visit a dinner was organized by Università degli Studi di Padova (UNIPD) / University of Padua where all the participants had the opportunity to network and share their experiences so far during the implementation of the project. On the second day at Università degli Studi di Padova (UNIPD) / University of Padua in Padova, discussions and sessions regarding WPs took place. Later on, the attendees had the opportunity to work in groups regarding the value proposition and competitor analysis where a representative of each group presented their work.



RESILIENCE EVENT

Our team participated in the iPLUG-HE #ResilienceEvent, which took place on May 28th, 2025, at the Aula Capella of ETSEIB - Escola Tècnica Superior d'Enginyeria Industrial de Barcelona - UPC. The event was hosted by CITCEA-UPC and focused on key aspects of resilience in future power systems. A highlight of the event was the keynote lecture by Professor Pierluigi Mancarella, Chair Professor of Electrical Power Systems at the University of Melbourne, who presented an insightful session on “Security, Reliability and Resilience in Low-carbon Power Systems”.

Supported by IEEE PES Spain, the event gathered experts from academia and industry, offering a platform to exchange perspectives on how resilience will shape the development of tomorrow’s energy systems. It served as an excellent opportunity to engage with leading voices in the field and to stay aligned with current research and innovation priorities in power system resilience.

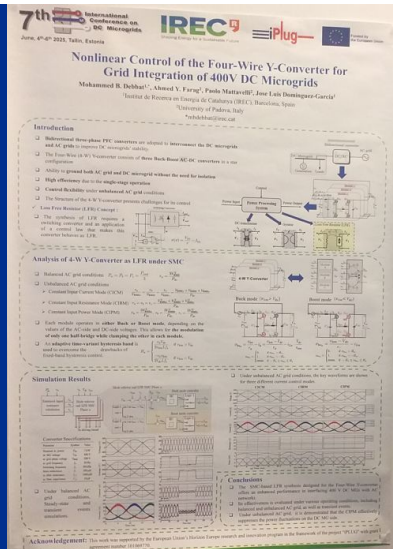


ICDCM 2025

iPLUG-HE presented new research at ICDCM 2025, held June 4-6 in Tallinn, Estonia. The paper, authored by Mohamed Debbat and colleagues, focuses on the nonlinear control of the Four-Wire Y-Converter for integrating 400V DC microgrids with the European low-voltage AC grid.

The proposed Sliding Mode Control based on Loss-Free Resistor synthesis (SMC-LFR) simplifies control, improves performance under unbalanced conditions, and reduces DC-side power fluctuations. An adaptive hysteresis band ensures smooth mode transitions with stable switching frequency.

This work contributes to the development of resilient and efficient microgrid systems.

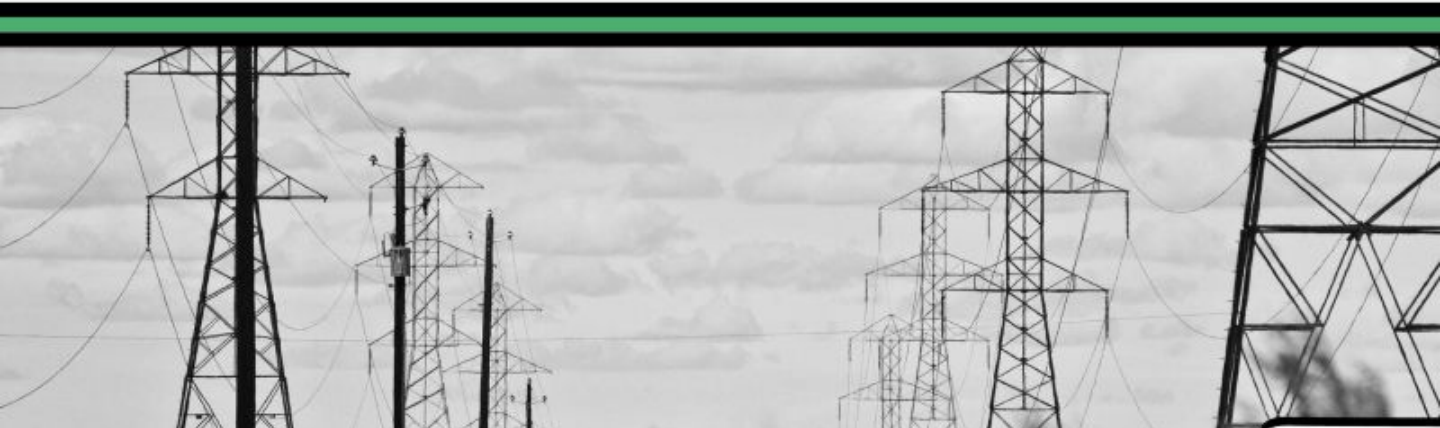


ConNetEU Webinar Highlights

On May 8th, 2025, our team participated in the ConNetEU Cluster webinar titled “Advancing Power Electronics in Distribution Networks”, which brought together key stakeholders involved in Europe’s energy transition.

During the session, the iPLUG-HE and SSTAR projects presented innovative solutions aimed at improving energy efficiency and supporting the integration of sustainable technologies into power distribution systems. The webinar provided a valuable platform to highlight how EU-funded initiatives are driving technological progress and contributing to the development of a more resilient and sustainable energy landscape across Europe.

ConNetEU Webinar Highlights: Driving the Future of Power Electronics in Europe’s Energy Grids



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PUBLICATIONS

ARTICLE IN JOURNAL

- M. Domínguez-Hernández, M. Cheah-Mane, R. Griñó, and O. Gomis-Bellmunt, “Centralized DC Voltage Control for a Multiport Converter in Distribution Grids,” *International Journal of Electrical Power and Energy Systems*, under review, 2025, pp. 1–34, doi: 10.5281/zenodo.16631038

OTHER PUBLICATIONS

- J. Perez-Noguera, P. Muñoz-Peña, and M. Cheah-Mane, “Data analysis and evaluation of multiport converter optimization in different scenarios,” Master’s Thesis, Universitat Politècnica de Catalunya (UPC), published on UPCommons, Mar. 2, 2025, pp. 1–88, doi: 10.5281/zenodo.14803754

