MULTIPORT CONVERTERS FOR LV APPLICATIONS

The rising popularity of dc systems in residential and commercial settings has prompted a reassessment of conventional approaches to grid interfacing. Traditionally, each dc system would utilize a dedicated converter for connection to the grid, a practice that often leads to larger system sizes and higher costs. In response to these challenges, multiport converters (MPCs) have emerged as promising and efficient solutions. MPCs offer an effective approach by integrating multiple energy ports into a single hub, thereby providing a more streamlined and potentially cost-effective solution. Figure 1 depicts the proposed concept of using a single MPC to interface the utility grid with multiple dc microgrids.

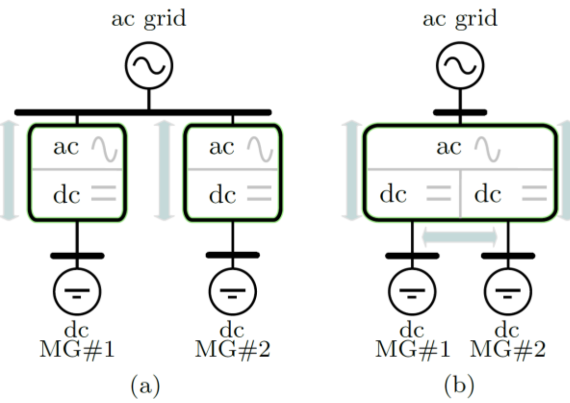

Fig. 1: Integration of two dc microgrids with the ac grid: (a) utilizing two-port converters; (b) utilizing a multiport converter

INNOVATIVE TOPOLOGIES

Two novel single-stage non-isolated MPCs have been proposed to interface the three-phase AC grid with DC systems. These MPCs enable direct power sharing between DC systems, minimizing dependence on the AC grid and enhancing the efficiency and power density of the power electronic interface compared to using multiple two-port converters. The motivations for the proposed converters include their single-stage power conversion across different ports, potentially leading to higher efficiency and power density. Furthermore, the absence of bulky intermediate DC-link capacitors and transformers in the proposed topology contributes to improved power density and reduced costs. Additionally, the proposed MPCs feature buck-boost capability and bidirectional power flow at all ports, independent of the DC ports' voltage, providing the flexibility to directly interface with a wide range of DC systems.

The proposed converters build upon the two-port Y-converter, transforming it from a two-port configuration into a multi-port one capable of connecting multiple DC systems to a three-phase AC grid. In its original form, the two-port Y-converter comprised three four-switch buck-boost modules, as shown in Figure 2.

To develop the multi-port converter, the four-switch buck-boost converter is expanded into a six-switch buck-boost converter formed with a shared buck half-bridge and two boost half-bridges. This can be developed in a symmetric or asymmetric configuration. In the symmetric configuration, displayed in Figure 3, the extension from a four-switch to a six-switch buck-boost converter is applied to all three modules. In the asymmetric configuration, the extension is applied only to one of the modules.

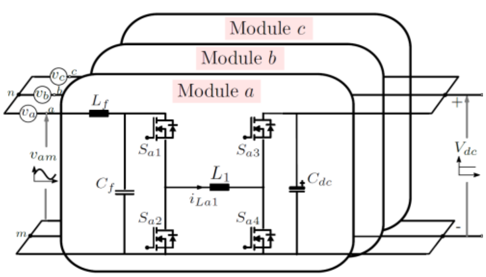

Figure 2: Two-port Y-converter

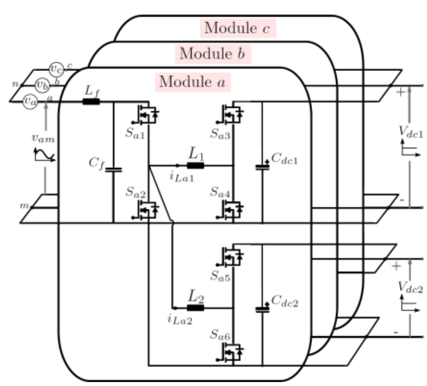

Figure 3: Symmetric multiport Y-converter

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The asymmetric multi-port Y-converter, denoted as AY-MPC and shown in , displayed in Figure 4, offers a reduced structure with fewer semiconductor devices and inductors compared to the symmetric multi-port Y-converter, denoted as Y-MPC. For the case study where the two DC systems have different power levels, the AY-MPC enables the integration of the lower power DC system into the three-phase IC with a minimum number of components, resulting in a simpler structure and compact size. However, a challenge in the AYMPC is to maintain balanced AC-grid currents.

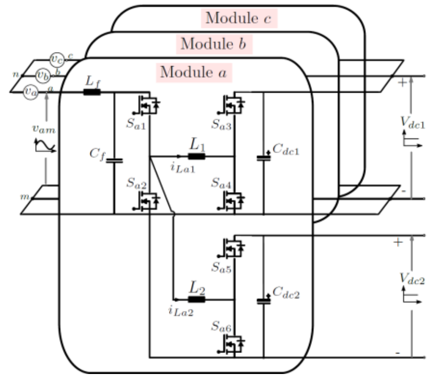


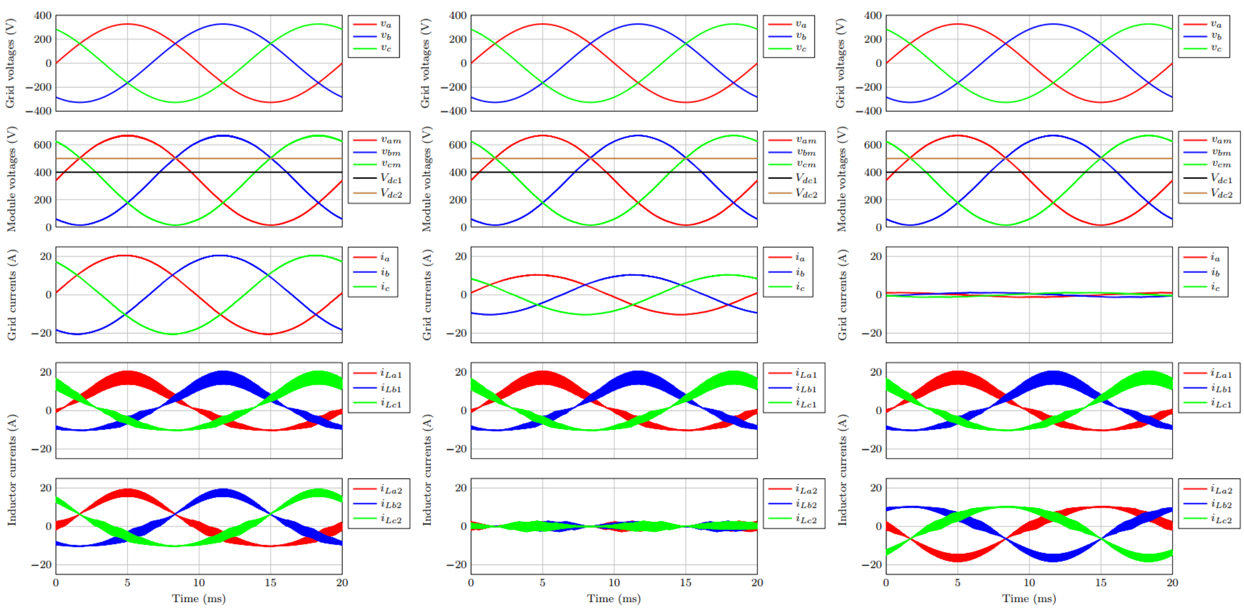
Figure 4: Asymmetric multiport Y-converter

SIMULATION RESULTS

Different operating conditions are presented in simulation results to highlight the performance of the proposed converter. In the first operating condition, demonstrated in Figure 5a, *Pdc2* is set to 5 kW, indicating that both DC systems are absorbing power from the AC grid. As evident from the waveforms, these simulation results match the waveforms discussed in the analysis section, exhibiting pure sinusoidal AC grid currents and positive AC module voltages.

In Figure 5b, *Pdc2* is set to 0 kW. In this case, power flows only from the AC grid to *Vdc1*, and the average current flowing in the *L2* inductors is controlled to zero, with only a high frequency ripple current flowing through *L2*.

The third operating condition is displayed in Figure 5c where *Pdc2* is set to -5 kW. In this case, both DC systems are directly exchanging active power through the proposed converter, and hence no active power is drawn from the AC grid. The AC grid currents are minimized, and only the current due to the reactive power drawn by *Cf* flows.



(a) P_{dc2} equal to 5 kW (b) P_{dc2} equal to 0 kW (c) P_{dc2} equal to −5 kW

Figure 5: Simulation results of the proposed converter under *Pdc1* equal to 5 kW and different values of *Pdc2*

MULTIPORT CONVERTER SIZING AND LOCATION OPTIMISATION-BASED METHODOLOGIES

Planning of modern distribution systems is a challenge, as they can involve several energy sources, energy storage, management, and power electronics. In general, the lack of optimum design usually leads to systems which are oversized or not properly planned, and therefore with higher costs. Furthermore, their design should include sizing of the assets, optimal operation, and economic analysis of the system.

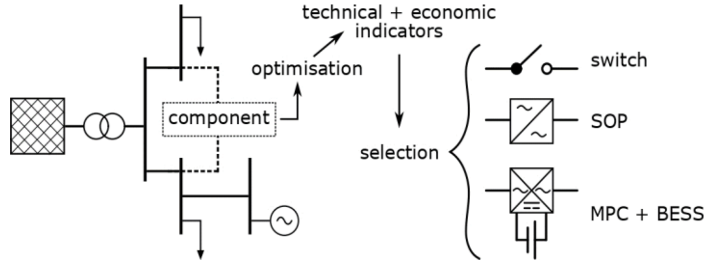


Figure 6: Framework of the methodology

This work proposes optimisation-based methodologies to size and locate multiport power converters, with and without AC power flow as shown in Figure 6. Regarding the scope, only steady-state analysis is performed, and historical data of the loads and renewable sources availability represent a perfect forecast for the years studied.

As inputs, generation and demand profiles for a year and with hourly resolution are required. The technical parameters of the grid and the assets contained in the system are also needed. Moreover, cost parameters of the grid reinforcements such as storage and several interconnection options must be provided. As a result, the nominal power of each multiport converter terminal and optimal system operation are obtained. Moreover, several economical and technical indicators are provided to evaluate the advantages of installing a multiport converter. These indicators can be also employed to compare different interconnection configurations. Different elements can be included in the general multiport converter sizing optimisation: the network, generators and loads, external grid connection, battery energy storage, and multiport converter. Each of those elements is modelled separately with the set of variables and constraints, ensuring active and reactive power balance in each bus. Additionally, several indicators can be defined, such as the multiport converter cost, annual renewable generation and curtailment, and line losses. The multiport converter is introduced to improve the system operation without an excessive additional cost. Therefore, the optimisation will minimise the multiport converter cost while optimising other indicators that will depend on the case study.

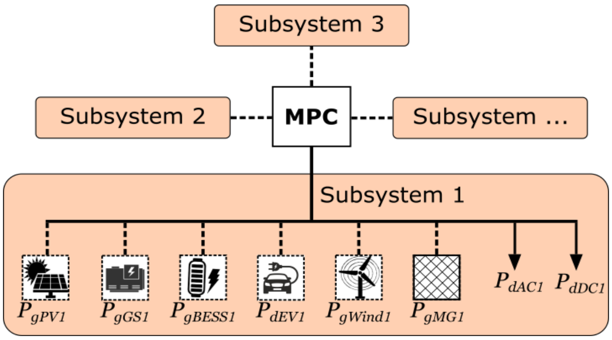


Figure 7: General energetic layout of a system

Also, an energy-based multiport converter sizing optimisation has been developed as a simplification of the previous optimization as shown in Figure 7, considering only active power and without grid constraints, to analyse network constraints impact on multiport converter sizing. In this case, there is no need to use representative days as full-year optimisation is fast enough to solve, also BESS size can be optimised.

Additionally, several configurations can be simulated to find the best location. A configuration is defined by the location of the multiport converters and switches. Then, the multiport converter sizing optimisation is performed for each configuration separately. Comparing the results of the different configurations, the configuration with lower objective function value is the optimal.

GIS-BASED RESILIENCY ANALYSIS FOR DISTRIBUTION GRIDS

Until now, reliability has been considered an essential concept in the development, management, and improvement of networks. However, traditional reliability metrics tend to underestimate low-probability events, which can have significant impacts on networks. In this context, resilience has emerged as a more holistic approach that accounts for both the network's characteristics and the hazards to which it is exposed. Although the definition of resilience is still under debate, it is commonly understood as the ability to anticipate, operate during, and recover from disruptive events while learning from them.

This work introduces a GIS-based approach to address resilience in network planning. The specific circumstances of a network's environment significantly influence the disruptive events that may affect it. Therefore, a resilience approach must effectively consider both the system's technical characteristics and the particularities of its location. Consequently, resilience is closely linked to risk assessment evaluations. Geographical Information Systems (GIS) enable the management and analysis of large amounts of geolocated data. The GIS-based approach proposed in this work evaluates resilience by considering hazards—disruptive events that may impact infrastructure and are beyond control—and vulnerabilities, which are weaknesses in the infrastructure characterized by their likelihood of occurrence and potential impact when a hazard is present.

This work proposes developing a comprehensive hazards database, requiring contributions from various local and regional institutions. Subsequently, an investigation of the network identifies its primary vulnerabilities and their potential impacts on the system. By combining data on hazards, vulnerability likelihood, and impact, a resilience measurement is proposed. Through the proposed methodology, which is summarized in Figure 8, the resilience of the network can be evaluated, including the introduction of specific technologies such as the Multiport, from a resilience perspective.

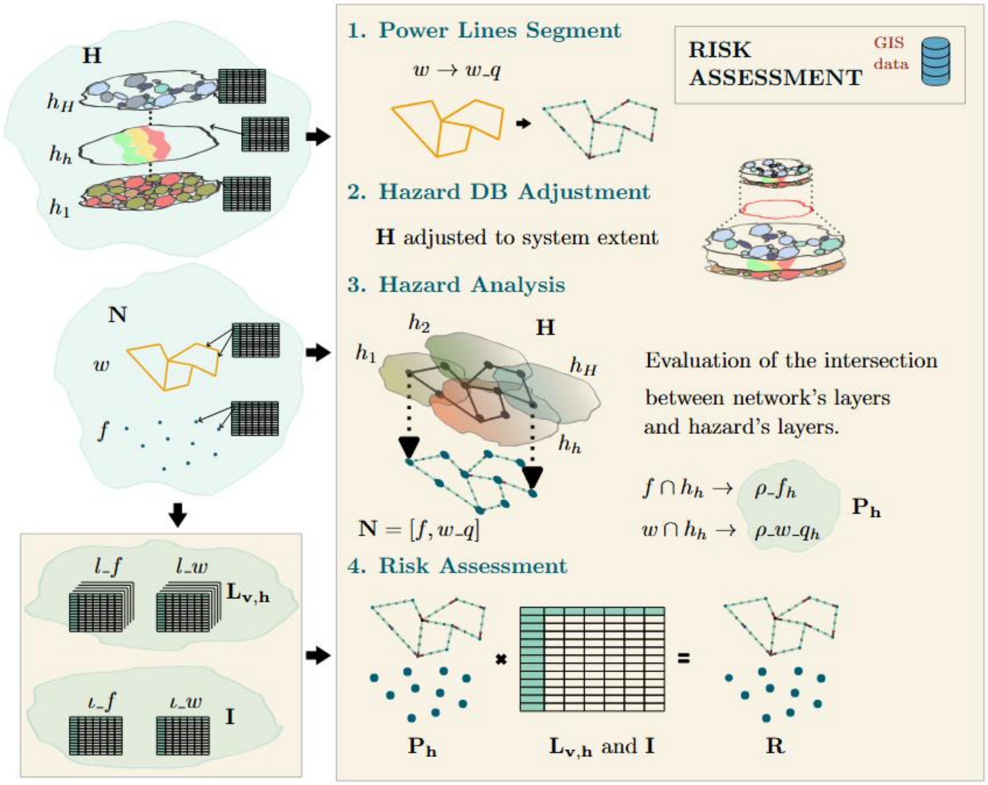


Figure 8: Resiliency methodology with GIS data

EVENTS

04 GENERAL ASSEMBLY

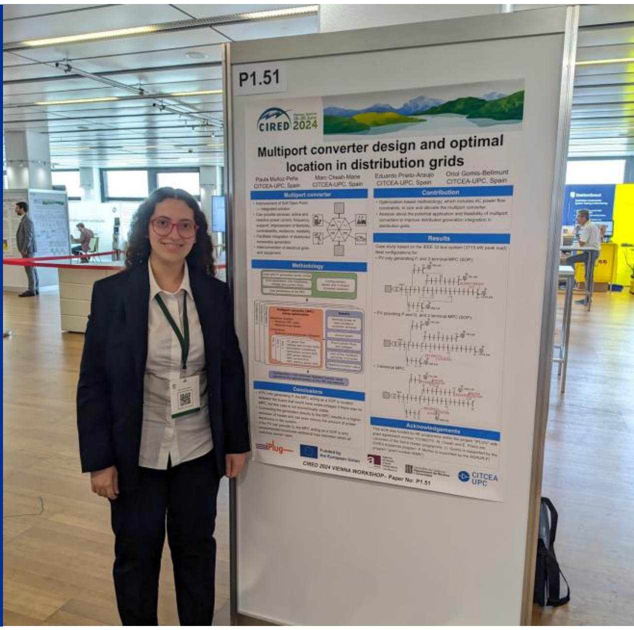
In September 2024, the fourth General Assembly of the project iPLUG was hosted by Chalmers University of Technology in Gothenburg, Sweden. During the first day at Chalmers University of Technology, there was an extensive review of the Work Packages and technical discussions regarding Multiport Converters sizing and topologies for medium voltage applications. Later on, during the day, we had the opportunity to visit Chalmers University of Technology – EPE Division Lab facilities. After the visit a dinner was organized by Chalmers University of Technology were all the participants had the opportunity to network and share their experiences so far during the implementation of the project iPLUG. On the second day at Chalmers University of Technology discussions and sessions regarding WPs were held by IREC – Institut de Recerca en Energia de Catalunya and Anell. 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.

PEMD 2024

Our project was represented by our colleagues from UNIPD held at the PEMD International Conference on Power Electronics, Machines and Drive in Nottingham (UK). Our colleagues from UNIPD presented a comprehensive study which evaluates semiconductor device stresses, losses, total chip area and magnetic element size. The main objective of this study was to validate the superior performance of the proposed converter compared to the conventional approach of interconnecting DC-DC and AC-DC converters in a cascaded connection. The PEMD 2024 conference provided a great opportunity not only to present our work, but also to engage with fellow experts working in this field, creating synergies and being updated with the latest developments for the multiport converters.

CIRED VIENNA WORKSHOP 2024

Our project was represented by CITCEA-UPC colleagues at the CIRED 2024 – International Community on Electricity Distribution in Vienna (Austria), focused on increasing distribution network hosting capacity. This work presented an optimization-based methodology to size and locate multiport power converters together with a techno-economic comparison to other conventional approaches. This methodology includes AC power flow constraints and is evaluated in a case study based on IEEE 33 bus system to identify the best scenarios where multiport converters can be considered as a potential solution to improve distributed generation integration in distribution grids. This event provided a great opportunity to share our research, present iPLUG work, and exchange ideas with other researchers and industry professionals in the field.



CIRED CHICAGO WORKSHOP 2024

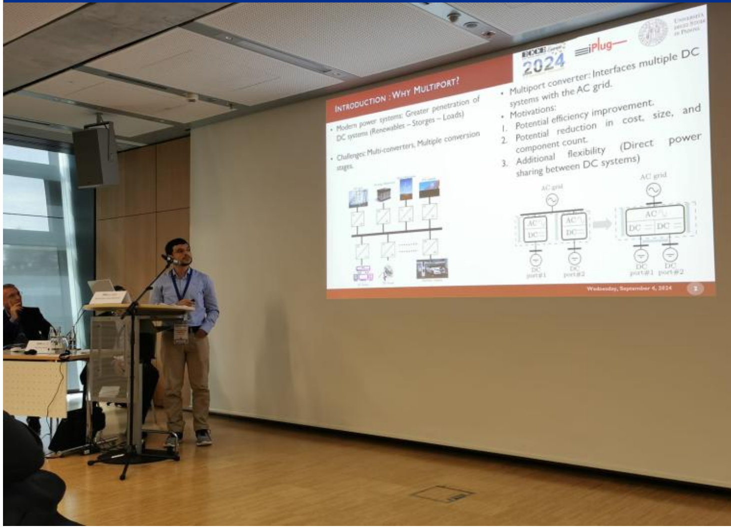
Our colleagues from CITCEA-UPC and UoS attended the CIRED – International Community on Electricity Distribution and presented their work in two poster sessions. This conference focused on the resilience of distribution grids, presenting various methods for evaluating grid resilience and technologies for enhancing it. In particular, multiport converters where suggested as a potential technology solution.

INDEL 2024

Our project was represented by our colleagues from IREC at the INDEL2024 and presented their latest work for the project iPLUG in Banja Luka (Bosnia and Herzegovina).

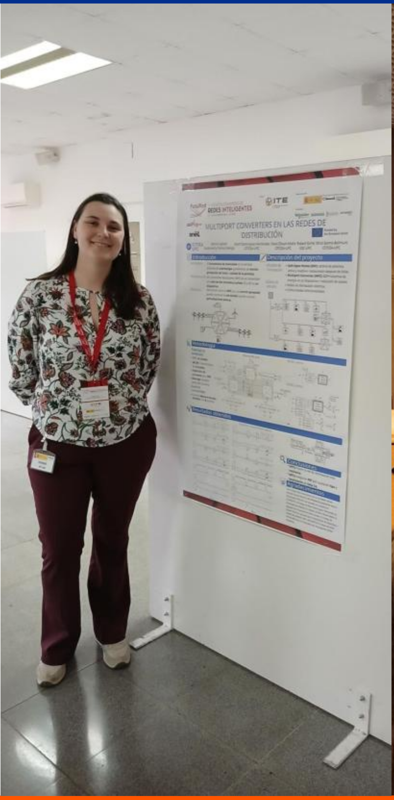
ECCE 2024

Our project was represented by our colleagues from UNIPD at the ECCE 2024 held at Darmstadt (Germany) presenting his latest work.



FUTURED 2024

Our project represented by our colleagues from ANELL presenting a poster at the III Congress of Futured Spanish platform of Electrical Networks held at CIEMAT 2024 in Madrid (Spain).



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