SmartGY SUM

D3.5. Innovative Business Models in Smart Energy Distribution Systems

WP3 – Smart Energy Distribution, Microgrids and Grid of Microgrids

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Table of Contents

List of abbreviations

BEN	Beneficiary
Dn	Deliverable (number)
DoA	Description of Action
DS	Doctoral School
ESR	Early Stage Researcher
ETN	European Training Network
GA	Grant Agreement
IRP	Individual Research Project
ITN	Innovative Training Network
MSn	Milestone (number)
MSCA	Marie Sklodowska-Curie Actions
PC	Project Coordinator
REC	Research Ethics Committee
RSC	Recruitment and Secondment Committee
WPn	Work Package (number)

1. Executive summary

The present deliverable provides the report about the developed business models, related with the implementation of IRPs in WP3 of the SMARTGYSUM project.

WP3 (Smart energy Distribution. Microgrids and grid of microgrids) aims to explore the possibilities of microgrids for energy management to address the challenges of secure energy routing and power quality control, as well as advanced distribution grid management and the use of radial grids. In particular, the objectives of WP3 are to identify and demonstrate new ways of collaborative distributing electric energy and new operation strategies as well as operating in connected and islanding modes; to design converters and strategies to control microgrids (as optimal operational parts of distribution grids) to manage energy flows and minimize transportation losses; to coordinate the production of different generators with the consumption of different consumers to match generation and consumption in a safety and optimize way; finally to analyse the new opportunities of storage system in microgrids and conventional grids. This research is addressed by IRPs identified by 5 to 8.

The ESRs involved in this WP3 are indicated below with a brief description of the initial targets of their IRPs:

- ESR05 (Mohammadreza Azizi), recruited and coordinated by Chernihiv Polytechnic National University (CNTU). The individual research project is entitled "Energy Router for Hybrid Microgrids for efficient and robust energy and power management". The IRP objectives are linked to research on the communication performance requirements in wireless networks, as well as to advance in the grid intelligence to understand the energy distribution in the grid and allow real-time decision-making.
- ESR06 (Mykola Lukianov), recruited and coordinated by Politechnika Gdanska (GUT). The individual research project is entitled "EV chargers, developing an active bidirectional charger able to provide anciallary services". The IRP objectives are linked to develop new power electronics facilities for energy transfer system with improved efficiency and power density and analyse future energy system including wireless charge system for electric vehicles.
- ESR07 (Mahyar Hassanifar), recruited and coordinated by Christian-Albrechts-Universitaet Zu Kiel (CAU). The individual research project is entitled "Reliability and availability of Smart Transformers for cost effective and high quality of services in the grid". The IRP objectives are linked to create smart devices in the grid, aimed at enabling autonomous grid management increasing the reliability and the availability of grid services.
- ESR08 (Gabriele Arena, followed by Danilo Di Bernardino), recruited and coordinated by Karlsruhe Institut für Technologie (KIT). The individual research project is entitled "Real-time modelling and validation of Distributed Energy Storage Systems and Integration strategies". The IRP objectives are linked to generate and analyse real-time models of Distributed Energy Sustems, to optimize distributed REES through the integration of actual and simulated components, controls and networks, under a wide variety of scenarios, to optimize the computation efforts for the obtention of the models.

1.1. Objectives of the deliverable

The contents of this deliverable are based on the reports made by ESRs. The objective is to collect the proposals of business models provided by each ESR for making profitable the research work they conducted in the SMARTGYSUM project for achieving the WP3 objectives. To develop such business models ESRs exploited competencies acquired during the courses of the doctoral schools delivered in the frame of the SMARTGYSUM project.
The parts carried out by ESRs are reported in the following sections and identified with this topics:

- IRP05 – Energy Router for Hybrid Microgrids for efficient and robust energy and power management
- IRP06 – EV chargers, developing an active bidirectional charger able to provide anciallary services
- IRP07 – Reliability and availability of Smart Transformers for cost effective and high quality of services in the grid
- IRP08 – Real-time modelling and validation of Distributed Energy Storage Systems and Integration strategies

The developed business models, one for each activity, are reported in section 3 and detailed in the subsections indicated with BM.1, BM.2 BM.3 and BM.4 respectively.

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2. General progress of the action

2.1. WP3 Objectives and tasks

WP3 (Smart Energy Distribution, Microgrids and Grid of Microgrids) objectives are:

i. To identify and demonstrate new ways of collaborative distributing electric energy and new operation strategies as well as operating in connected and islanding modes;
ii. To design converters and strategies to control microgrids (as optimal operational parts of distribution grids) to manage energy flows and minimize transportation losses.
iii. To coordinate the production of different generators with the consumption of different consumers to match generation and consumption in a safety and optimize way
iv. To analyse the new opportunities of storage system in microgrids and conventional grids

WP3 (Smart Energy Distribution, Microgrids and Grid of Microgrids) tasks are:

- Task 3.1: Development of Energy Routers for Hybrid Microgrids enhancing efficiency and robustness (USA-CNTU).
- Task 3.2: Development of an Active Bidirectional Energy Charger for providing Ancillary Services. (USA-GUT).
- Task 3.3: Research on the reliability of smart transformers to ensure cost-effective and high-quality services. (USA-CAU).
- Task 3.4: Real time modelling of energy storage system technologies with low computation effort (KIT-OPAL).
- Task 3.4: Elaboration of partial and final scientific reports on Smart Energy Distribution (USA).

2.2. WP3 – IRP progress

ESR#	Starting date	General evaluation	Status
5	1/08/2022	ESR05, Mohammadreza Azizi has successfully completed his research work, and all major deliverables have been achieved. The designed system fully aligns with the objectives of developing efficient and robust power electronics solutions for intelligent energy management in microgrids and residential applications. No major deviations occurred. The only modification from the initial plan was the prioritization of the experimental validation of the power electronics hardware and control strategy over the wireless communication implementation, to ensure a fully functional and stable prototype within the project timeline. This adjustment was made in agreement with the supervisors. In conclusion, the project successfully delivered a functional single-cell three-phase energy router prototype, achieving high dynamic performance, safety, and flexibility, meeting the intended research and development objectives.	• Design completed. • Prototype fully assembled and tested. • Experimental verification completed under various operating scenarios. • Communication interface defined to be tested
6	1/06/2022	ESR06, Mykola Lukianov carried out his research workflow: from conceptual development to the realization of a small-scale hardware prototype of the bidirectional multi-terminal EV charging station.	• Completed
7	1/08/2022	ESR07, Mahyar Hassanifar, successfully carried out his research and studies on the defined tasks and topics at the Chair of Power Electronics, Kiel University. His work primarily focused on the investigation and development of control strategies with particular emphasis on the control of insertion and charging of redundant submodules (SMs) for Modular Multilevel Converters (MMCs). In parallel, he developed a hardware test bench specifically tailored for experimental validation, enabling the testing and analysis of various MMC control scenarios under realistic operating conditions. The	• Completed

		developed setup provides a flexible platform for evaluating converter behavior, assessing dynamic performance, and verifying the effectiveness of the proposed control approaches. The outcomes of this work have been presented through conference presentations and journal publications, in alignment with the overall research objectives of the project.	
8	1/04/2022	ESR08, Gabriele Arena, performed extensive review studies on DC applications, in particular on electric vehicle fast-charging stations. These studies were carried out together with the TalTech group, and a journal contribution has been published. As a follow-up work, an experimental setup for flexible electric vehicle fast-charging stations has been designed and assembled at the KIT. He targeted a re-configurable 400V/800V system, that was able to achieve high efficiency across the full voltage range. The next step would have been to model this system in a real time simulator and validate the results with the developed setup. Mr. Arena left the PhD at the end of 2024 to pursue a career in the industry as software developer, where is currently working.	• On-time with the initial plan. Terminated.
8	2/04/2025	ESR08, Danilo Di Berardino, is currently taking over the modelling and business plan tasks of Mr. Arena with a slightly modified focus. He is developing scenarios for integration of DC Hydrogen in micro- and off-grids, focusing on the technical and economic feasibility. Mr. Di Berardino performed a cost analysis of the single hydrogen components, considered the provision of services to the grid, and analyzed the return of investment for hydrogen storage plants. Currently, a specific off-grid scenario has been chosen, and he is going to implement it in a real time simulator. The next step will entail the validation of the model with the hydrogen experimental plant at KIT "H2-in-the-loop" and the development of control algorithms for grid services provision.	• On-going

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3. Deliverable description

3.1. Preliminary information about deliverable

In this section the scientific work and the context where the activities of each ESR have been carried out are described briefly.

IRP05 – Energy Router for Hybrid Microgrids for efficient and robust energy and power management

This research work has been conducted from August 2022 to July 2025, under general supervision of Chernihiv Polytechnic National University (CNTU) at premises of University of Extremadura (Spain) as the host institution and a research secondment at Gdańsk University of Technology (Poland). The overall objective was the research and development of power electronics facilities to enable efficient and robust energy and power management in microgrid environments, focusing on the realization of an Energy Router (ER) suitable for residential and small-scale applications.

The energy router prototype has been designed, assembled, and experimentally validated. It integrates all key functionalities, including single-phase AC input/output, PV and battery interfaces, and DC grid terminals, forming a 5-kW multiport converter suitable for residential or small-scale microgrid applications. The implemented topology adopts a common-ground inverter structure, ensuring safety and eliminating leakage current paths without the need for isolation, which also reduces cost and complexity.
The control system has been developed based on Flatness-Based Control (FBC) theory for the DC-link voltage, combined with a Proportional Resonant (PR) controller for the grid current regulation. The FBC approach ensures a highly stable DC-link under dynamic load variations, as demonstrated through experimental testing. Tests under grid-forming and grid-following conditions, including dynamic load steps (e.g., 59 Ω), confirmed the robustness and rapid response of the proposed control scheme.
Additionally, reliability and protection aspects were addressed through analysis of grounding configurations and leakage current mitigation, in accordance with the research objectives. The use of common-ground topology has proven effective in enhancing system safety and simplifying protection design. Regarding communication capabilities, the system architecture and control framework were designed to be compatible with wireless communication interfaces for future integration into smart microgrids. While a complete implementation of the wireless communication layer was outside the primary hardware validation phase, its structure and interface points have been defined for future work.
The work progressed through three main phases:

- Preliminary phase (University of Extremadura):
- During the initial stage, the research focused on reviewing and analyzing the state-of-the-art in Energy Routers, grounding techniques, and dc-ac interlink topologies. This phase provided a comprehensive understanding of integration challenges between dc systems and the ac grid, including issues of leakage current, isolation, and safety.
- Design and simulation phase (University of Extremadura and Gdańsk University of Technology): The theoretical findings were followed by detailed modeling and simulation in PLECS software. The author developed and compared various converter structures, proposed a common-ground three-phase ER topology, and designed its control strategy based on flatness-based control (FBC) theory to ensure a fast and robust response under dynamic conditions.

The author visited Gdańsk University of Technology three times to perform specialized research activities:

- First visit (November–December 2023): Simulation and analysis of leakage currents, grounding configurations, and protection mechanisms at the dc–ac interface.
- Second visit (May 10 – July 10, 2024): Development and implementation of the control system using FBC theory for dynamic condition improvement.
- Third visit (April – July 2025): Assembly and experimental testing of the 5 kW ER prototype, including verification under multiple operating modes and dynamic load transitions.

Experimental validation phase (Gdańsk University of Technology):
The assembled prototype was tested under dc-mode, grid-forming, and grid-following scenarios. Extensive dynamic tests were conducted to validate the robustness of the proposed topology and control method.
Throughout the project, four conference papers and two journal articles were published, with an additional journal paper submitted, including the final experimental results. All publications acknowledge funding from the Horizon Europe programme.
The business model was initially conceived during the 5th Doctoral School event in Pärnu, Estonia, and later refined through collaboration with academic and industrial partners. The model focuses on the commercial production of a

compact residential Energy Router, emphasizing cost-effective integration of renewable energy sources, dc microgrids, and conventional ac household systems.

IRP06 – EV chargers, developing an active bidirectional charger able to provide ancially services

The research was primarily conducted at the facilities of Gdańsk University of Technology (GUT), Poland, within the research team led by Prof. Ryszard Strzelecki. At GUT, the complete research workflow was executed — from conceptual development to the realization of a small-scale hardware prototype of the bidirectional multi-terminal EV charging station.
Parts of the work were also carried out during secondments at the University of Extremadura (UEX) in Spain, under the co-supervision of Prof. Enrique Romero-Cadaval and his research group. At UEX, the charging station simulation model was developed in PLECS and subsequently validated through hardware-in-the-loop testing using RT BOX 1.
The results of this research form the foundation of the business model, demonstrating the system's functionality, application suitability and competitiveness in the current market. Key references related to the developed system are listed in the References section.

IRP07 – Reliability and availability of Smart Transformers for cost effective and high quality of services in the grid

The work was performed between August 2022 and July 2025 under the supervision of the Chair of Power Electronics at Christian-Albrechts-Universität zu Kiel (CAU), Germany, with additional input from secondments and collaborations with both academic and industrial partners within the SMARTGYSUM project. The research was developed under the Individual Research Project (IRP) entitled "*Reliability and Availability of Smart Transformers for Cost-Effective and High-Quality Services in the Grid.*"
The core of this work focuses on the development of a Real-Time Model-Assisted Modular Multilevel Converter (MMC) Emulator. This test bench integrates an actual MMC submodule (SM) with a fully detailed real-time model of the MMC running on a real-time simulator. The hybrid setup enables safe, accurate, and flexible investigation of complex test cases such as AC/DC faults, overcurrent conditions, and submodule failures, which are difficult, expensive, or dangerous to reproduce in full-scale or even scaled-down laboratory prototypes. Moreover, the presence of real hardware in the loop makes this setup particularly valuable, as it allows the evaluation of the converter real world behaviour under conditions that closely replicate practical operating scenarios, ensuring highly realistic and reliable hardware-validation results.
The scientific background supporting this work builds upon previous and ongoing research at the Chair of Power Electronics and within the SMARTGYSUM. These studies explore converter control strategies, submodule hardware validation, and real-time simulation methods for advanced power electronic systems. The Power Electronics Laboratory at CAU, equipped with OPAL-RT real-time simulator and small-scale MMC prototype hardware, provided the experimental infrastructure necessary to validate the concept and gather representative results.
In parallel with the technical development, the business and commercialization aspects of the research were refined through a series of Horizon Results Booster (HRB) initiatives conducted between 2023 and 2025. These included Business Plan Development, Go-to-Market coaching, and Exploitation Options workshops facilitated by the META Group. Over the course of approximately 12 months, continuous technical refinement and expert feedback guided the formulation of this business model. The final outcomes and recommendations are intended to be reviewed and further developed in collaboration with CAU's Technology Transfer Office (TTO) to support future exploitation and implementation strategies.

IRP08 – Real-time modelling and validation of Distributed Energy Storage Systems and Integration strategies

The business model has been developed through the individual research work of the ESR, focusing specifically on the feasibility assessment of hydrogen applications. This scientific work was conducted over a period of six months, drawing primarily on scientific literature, technical reports and publicly available data from relevant companies and industrial stakeholders.
The research approach began with a broad investigation of potential hydrogen-use scenarios, aiming to identify the most feasible applications from a commercial perspective. This included a review of potential competitors, allowing for a clear understanding of current market possibilities and prevailing limitations within the sector. Following the technological and competitive assessment, the revenue model was developed in alignment with the identified limitations and market conditions

3.2. Business model (BM.1) presentation

IRP05 – Energy Router for Hybrid Microgrids for efficient and robust energy and power management

3.2.1. Executive Summary

The proposed business model is centered on the development and potential commercialization of a residential single-cell three-phase (SC-TP) Energy Router (ER), a compact, safe, and cost-efficient hardware platform designed for next-generation smart and sustainable homes. The prototype enables direct integration of photovoltaic panels, battery storage, and AC/DC loads through a common-ground inverter structure, eliminating the need for galvanic isolation and significantly reducing both system complexity and cost. The mission of this business model is to make advanced energy routing technology accessible for residential and small-scale microgrid applications, contributing to the realization of net-zero energy buildings (NZEBs). The vision is to create a universal and modular energy hub capable of hosting any intelligent energy management algorithm in the future, thus bridging the gap between hardware innovation and digital energy services.
The key goals include:

- Advancing the prototype toward a commercially viable TRL level, ensuring compliance with safety and reliability standards.
- Demonstrating high efficiency and robustness of the ER in real dynamic operating conditions.
- Establishing the foundation for future integration with IoT-based monitoring and control systems.

Main success metrics are defined by experimental performance indicators (voltage stability, power balance, and dynamic response), scalability toward industrial design, and cost competitiveness compared to existing inverter-based systems. The strategic priorities of the business model are focused on technology validation, prototype optimization, and the exploration of commercialization pathways through academic–industrial collaboration under the Horizon Europe framework.

3.2.2. Value Proposition & Competitive Advantage

The proposed business model is centered on the development and commercialization of an experimentally validated prototype of a Single-Cell Three-Phase (SC-TP) Energy Router (ER). This hardware platform provides an efficient, safe, and cost-effective interlink between residential dc and ac systems, representing a breakthrough in the power electronics domain for microgrid and smart home applications.
The key value proposition lies in the unique single-cell three-phase structure, which enables access to all grid phases and phase balancing without the need for multiple conversion cells, thereby significantly reducing cost, weight, and system complexity. Additionally, the common-ground inverter topology ensures inherent safety by mitigating leakage currents and eliminating galvanic isolation, addressing one of the most critical technical challenges in dc–ac integration.
From a control perspective, the system incorporates an innovative Flatness-Based Control (FBC) method to enhance dynamic performance under transient operating conditions. Experimental results, published in peer-reviewed journals and international conference papers, have confirmed that the proposed control strategy provides fast response, high reliability, and robustness, outperforming conventional methods such as PI, PR, or sliding-mode controllers in dynamic conditions.
Beyond the hardware advantages, the prototype has been designed with a modular and communication-ready architecture, allowing future integration of intelligent energy management algorithms and wireless monitoring systems. This flexibility positions the system as a scalable and future-proof solution compatible with evolving smart-grid standards and energy community infrastructures.
In summary, the competitive advantage of the proposed solution includes:

- Simplified and cost-effective topology (single-cell three-phase configuration).
- Enhanced safety via common-ground structure and reduced leakage currents.
- Superior control dynamics based on FBC theory.
- Experimental validation confirming efficiency and reliability.
- Compatibility with future digital and communication-based EMS solutions.

The current prototype has achieved Technology Readiness Level (TRL) 5, having been successfully validated in relevant laboratory environments under various operating and dynamic conditions. The next development stage will focus on extending the system toward TRL 6–7, enabling semi-industrial demonstration and preparation for pilot commercialization in collaboration with industrial partners.

3.2.3. Market & Customer Segments

The primary market focus of the developed Energy Router (ER) technology lies in the renewable energy and power electronics industry, particularly targeting companies involved in solar energy systems, battery storage solutions, and power converter manufacturing. These industrial partners represent the key customers capable of integrating the ER hardware into their own product lines, enabling large-scale production and commercialization.

In the medium term, the product is also aimed at residential and small-scale microgrid applications, where the ER can operate as a compact and intelligent interlink device managing energy flows among PV panels, storage systems, and local ac/dc loads. This semi-commercial version is designed to contribute to the growing demand for efficient, safe, and flexible energy management solutions in Zero-Energy Buildings (ZEBs) and smart homes.
From a geographic perspective, the initial market entry is planned within Spain, leveraging the research infrastructure and industrial connections around the University of Extremadura, before scaling to the broader European market. Europe provides a favorable regulatory and technological environment, driven by the EU Green Deal, the rapid growth of distributed renewable generation, and the rising number of prosumers adopting dc microgrid technologies.
The prototype, validated experimentally under different operating conditions, demonstrates the potential for real-world implementation. Furthermore, given the flexible hardware architecture and integrated communication capabilities, the developed ER can in the future, support innovative energy management and digital optimization layers, aligning with the ongoing transition toward intelligent, grid-interactive energy systems.

Market Segment	Description & Target Customers	Current Pain Points / Needs	ER Competitive Advantage
Solar Energy Integrators	Companies developing residential or commercial PV systems with storage	Complexity and high cost of managing multiple energy sources	Single-Cell Three-Phase design reduces conversion stages and cost while improving efficiency
Power Electronics Manufacturers	Producers of inverters, converters, and hybrid controllers	Need for flexible hardware adaptable to ac/dc environments	Modular and scalable hardware, compatible with various EMS platforms
Residential & Microgrid Installers	Installers of hybrid ac/dc microgrids and smart homes	Lack of compact, safe, and interoperable energy routers	Experimentally validated, common-ground structure ensures safety and dc/ac interconnection
Energy Research & Development Centers	Universities, research labs, and pilot projects	Need for testbeds supporting innovative control and management algorithms	Open hardware and control platform, ready for integration with advanced EMS solutions
European Smart Grid Market	National utilities and grid operators in the EU	Integration of distributed generation and real-time grid balancing	Future-ready design allowing SEMA integration and real-time phase balancing

3.2.4. Channels & Customer Relationships

The commercialization strategy of the Energy Router (ER) prototype relies on a dual approach that combines academic–industrial dissemination with direct collaboration channels toward commercialization.

Channels

1. Research and Innovation Networks
   The ER was developed within a Horizon Europe project framework, providing direct visibility through European research networks. Participation in EU research clusters, doctoral schools, and conferences serves as the first step toward building recognition and credibility in both academic and industrial domains.
2. Industry Collaboration and Technology Transfer Offices
   Cooperation with solar energy companies, inverter manufacturers, and grid-technology developers is planned through joint R&D projects and technology transfer agreements.
   The University of Extremadura and Gdańsk University of Technology will act as facilitators for collaboration, prototyping, and patenting processes.
3. Professional Exhibitions and Technical Workshops
   Presentation of the experimentally validated prototype at energy and smart grid exhibitions (e.g., Intersolar Europe, Smart Energy Expo) will enable direct contact with potential adopters and investors.
   Technical workshops and demonstration sessions will be organized to showcase the system's flexibility, control performance, and modular structure.
4. Digital and Academic Dissemination
   Publications in high-impact journals and open-access repositories serve as a continuous visibility channel. The system's modular control infrastructure allows the creation of demo videos and simulation platforms that can be shared with R&D centers and companies through institutional websites and LinkedIn networks.

Customer Relationships

1. Collaborative and Long-Term Partnerships
   Early customers (mainly universities, R&D centers, and innovative SMEs) will be engaged through joint pilot programs and customized prototype adaptations.
   These relationships are based on knowledge exchange, technical support, and co-development rather than standard sales.

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2. Technical Support and Co-Design Services
   The ER team will provide technical documentation, training, and integration support for customers who aim to embed the hardware into larger hybrid energy systems.
   Feedback loops from early adopters will directly contribute to the next design iterations.
3. Future Customer Retention Strategy
   Once TRL ≥ 6 is achieved, customer retention will rely on offering:
   - Firmware and software updates for advanced energy management integration.
   - Optional consultancy for system optimization and compliance with grid codes.
   - Continuous access to the ER research community for innovation sharing.

3.2.5. Revenue Model & Cost Structure

Revenue Model

At the current stage (TRL 5), the Energy Router (ER) functions primarily as a research-driven prototype. However, its modular design and validated experimental performance establish a strong foundation for future commercialization.

The revenue generation pathway is envisioned in three main phases:

Phase	Stage Description	Revenue Sources	Target Clients / Partners
Phase 1 – Research & Prototyping (2022–2025)	Horizon Europe–funded R&D phase; design, assembly, and experimental validation of the prototype	- EU project funding - Research collaborations - Conference presentations and workshops	Universities, research groups, public R&D projects
Phase 2 – Semi-commercial & Pilot Deployment (2025–2026)	Limited pilot production for residential and microgrid demonstrators	- Prototype sales - Technical consultancy - Licensing of control algorithms and topology	Solar and storage companies, inverter manufacturers
Phase 3 – Full Commercial Expansion (Post-2026)	Mass production and deployment in the EU market	- Direct hardware sales - Licensing agreements - Subscription services for smart control - Training programs	Renewable energy providers, residential installers, SMEs in power electronics

Pricing Strategy

While the current prototype is research-oriented, cost analysis shows that the proposed ER can achieve lower system costs compared to conventional multi-stage inverters.

This is primarily due to:

- The SC-TP topology, which reduces hardware complexity by eliminating two extra conversion stages.
- The common-ground structure, removing isolation components and simplifying protection.

In future commercialization, a value-based pricing strategy will be applied — emphasizing efficiency, compactness, and system reliability as key differentiators.

Cost Structure

Category	Description	Current Cost Drivers	Optimization Approach
Hardware components	Semiconductors, magnetics, sensors, control board, mechanical parts	High – due to limited prototype scale	Bulk purchasing, design standardization
Testing & validation	Experimental verification, measurement equipment, TRL progression	Moderate	Shared use of university labs and joint facilities
Software & control development	Flatness-based control design, firmware, wireless interface	Moderate	Modular software and reusability across systems
Assembly & logistics	Prototype assembly, wiring, thermal design	Low–Moderate	Outsourcing assembly to specialized SMEs
Certification & compliance	CE/IEC standards for grid connection	High (in commercialization phase)	Early-stage compliance planning and simulation-based pre-certification

Financial Flow Overview

Phase	Estimated TRL	Main Funding Source	Revenue Type	Cost Intensity
Phase 1	TRL 4–5	Horizon Europe Grant	Research-based	Medium
Phase 2	TRL 6–7	Institutional and Industrial Partnerships	Prototype sales & Licensing	High
Phase 3	TRL 8–9	Commercial Partners & Investors	Product sales & Subscriptions	Moderate

The project's funding through Horizon Europe ensured the financial feasibility of the research and prototype development phase. As the experimentally validated prototype demonstrates robust operation and scalability, the business model naturally transitions from grant-supported research to commercially viable hardware production, with future potential for integration of intelligent energy management services.

This structured evolution ensures a sustainable transition from a publicly funded R&D project to a self-sustaining commercial venture. The experimentally validated prototype (TRL 5) serves as a tangible bridge between the scientific phase and market-oriented development, supported by published research results and proven control performance under dynamic conditions.

3.2.6. Key Resources & Activities

The development of the proposed energy router prototype has been carried out under the supervision of the project's academic supervisors and the researcher. The work utilized the laboratory facilities of the University of Extremadura (Spain) and the Gdańsk University of Technology (Poland). Experimental validation was performed using advanced laboratory equipment, including bidirectional power supplies used as battery and PV emulators, precision power analyzers, programmable loads, and data acquisition systems.

Key resources supporting this development include:

- Human resources: The PhD researcher and academic supervisors specializing in power electronics and energy management systems.
- Physical resources: Laboratory setups in both universities, equipped with converters, control platforms, and real-time testing infrastructure.
- Intellectual resources: Simulation models developed in PLECS and MATLAB/Simulink, along with the experimental prototype validated under real operating conditions.

The core activities of the project comprise:

1. Design and development of a 5 kW single-cell three-phase (SC-TP) energy router, integrating PV, BSS, ac/dc loads, and grid interfaces.
2. Assembly and testing of the prototype using both open-loop and closed-loop configurations, including grid-forming and grid-following operation modes.
3. Implementation and evaluation of the flatness-based control (FBC) to ensure robust dc-link performance in dynamic conditions.
4. Validation using existing energy management platforms, demonstrating interoperability and readiness for integration with digital EMS solutions.

In future commercialization stages, small and medium-sized enterprises (SMEs) are expected to participate in hardware production and pilot deployment phases, leveraging the existing prototype design and control framework developed within this project.

3.2.7. Key Partnerships

The development of the proposed energy router was supported through collaborative research within the Horizon Europe framework, involving strong partnerships between academia and industry. The main academic partners include:

- University of Extremadura (Spain): Lead host institution, responsible for the system design, preliminary assembly, and initial prototype validation.
- Gdańsk University of Technology (Poland): Focused on advanced simulations, grounding and protection analysis, and final-stage experimental testing under various operating and dynamic conditions.

These collaborations allowed for a seamless transition from simulation and modeling to hardware implementation, leveraging the complementary laboratory infrastructures of both institutions. Bidirectional power supplies were used as battery and PV emulators, ensuring realistic testing scenarios for multi-port energy management.

In the next development phases, the project envisions active collaboration with small and medium-sized enterprises (SMEs) specializing in power electronics manufacturing, energy storage systems, and converter production. These industrial partners will be essential for:

- Scaling up hardware production and improving manufacturability.
- Standardizing modules for residential and microgrid applications.
- Ensuring cost-effective and high-efficiency designs suitable for mass production.

Furthermore, future partnerships are expected with companies and research groups developing Energy Management Systems (EMS) and smart home automation platforms. Given that the hardware infrastructure is already compatible with advanced digital interfaces, integrating innovative EMS solutions will enable smart energy scheduling, wireless monitoring, and predictive control in residential and microgrid environments.
This partnership structure ensures a balanced ecosystem combining academic innovation, industrial expertise, and digital intelligence, paving the way from a validated prototype (TRL 5) to a scalable, commercially viable energy router platform.

3.2.8. Sustainability & Scalability

The proposed Single-Cell Three-Phase Energy Router (SC-TP ER) was designed with long-term scalability and sustainability in mind. Its modular architecture allows straightforward adaptation for different power levels, making it suitable for residential, microgrid, and small industrial applications.

From a sustainability perspective, the solution directly supports the transition toward Zero-Energy Buildings (ZEBs) and renewable-based smart grids, aligning with the European Green Deal and Horizon Europe objectives. By efficiently integrating renewable sources such as photovoltaic panels and battery storage, the system minimizes conversion losses and reduces dependency on fossil-based energy. The common-ground topology further contributes to environmental sustainability by lowering material usage through the elimination of bulky isolation transformers and reducing system weight and cost.

In terms of scalability, the design is inherently adaptable:

- The hardware platform can be scaled up by paralleling converter modules for higher power levels.
- The embedded control structure is flexible and can incorporate advanced energy management algorithms and wireless communication protocols without hardware modification.
- The validated prototype (TRL 5) serves as a foundation for moving toward semi-commercial pilot production (TRL 6–7) through collaboration with SMEs.

Additionally, the system provides a solid base for future integration with cloud-based energy management, IoT connectivity, and smart home ecosystems. This adaptability ensures relevance in evolving energy markets that demand intelligent, distributed, and user-interactive power management solutions.
By emphasizing modularity, renewable integration, and software compatibility, the proposed ER ensures long-term sustainability not only in energy efficiency but also in its potential for technological evolution and market scalability.

3.2.9. Financial Overview (Optional)

At the current stage (TRL 5), the Single-Cell Three-Phase Energy Router (SC-TP ER) remains a research-oriented prototype developed under the Horizon Europe funding framework, which fully supported the R&D phase, laboratory testing, and mobility activities between the University of Extremadura (Spain) and Gdańsk University of Technology (Poland).

Funding and Cost Structure
The project's financial resources have primarily covered:

- Hardware development and laboratory materials, including power converters, control boards, and safety components.
- Testing equipment and facilities, utilizing existing university laboratories and shared resources.
- Researcher mobility and collaboration costs, through the Horizon program.

Future cost structures will depend on the transition to semi-commercialization, which includes:

- Manufacturing and assembly of small pilot batches (with SMEs).
- Integration of embedded wireless communication and software-based energy management systems.
- Certification and compliance testing according to EU electrical safety and EMC standards.

Revenue and Market Potential
The initial revenue model is based on direct hardware sales of modular ER units for residential and microgrid applications. Additional revenue streams are envisioned in:

- Licensing of the design and control algorithms to inverter and power-electronics manufacturers.

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- Collaborative projects with renewable energy system integrators for pilot deployments.
- Future subscription-based services for cloud and energy management platforms once the communication layer is fully developed.

Funding Requirements and Future Outlook

To advance from TRL 5 to TRL 7, an estimated €200,000–€300,000 would be required for pilot-scale production, certification, and extended field validation. Funding is expected to be sought through European innovation grants, public-private partnerships, and potential collaborations with SMEs in renewable technology manufacturing.
The long-term financial vision aims for sustainable growth through low-cost, scalable production, leveraging the system's modular design and alignment with EU green energy policies to attract both public funding and industrial partners.

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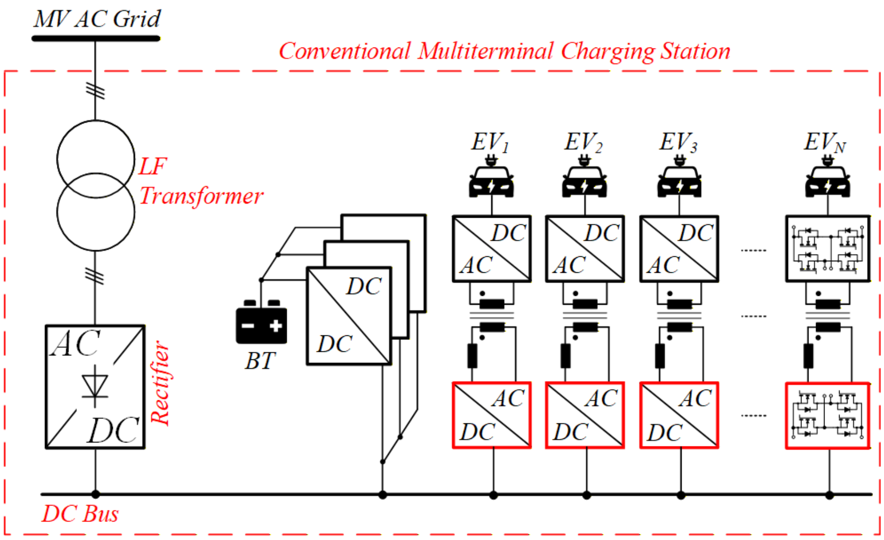
3.3. Business model (BM.2) presentation

IRP06 – EV chargers, developing an active bidirectional charger able to provide anciallary services

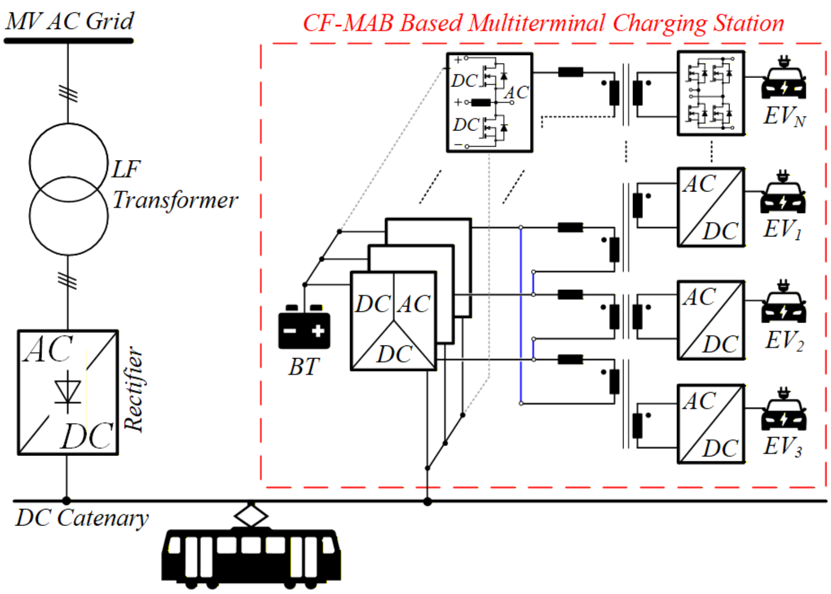
3.3.1. Executive Summary

This business model targets the deployment of multiterminal fast EV charging stations using a Current-Fed Multi-Active Bridge (CF-MAB) converter connected to low-voltage DC (LV DC) traction grids (trams/trolleybuses). The solution is designed for high efficiency (>96%), scalable architecture and reduced installation costs by utilizing existing DC traction infrastructure.

- **Mission:** Accelerate urban EV adoption by providing cost-effective, high-power, scalable fast-charging solutions.
- **Vision:** Enable large-scale integration of EV chargers into urban traction networks while providing ancillary services such as voltage stabilization and reactive power compensation for the LV DC grids.
- **Goals:** Deploy multi-port stations (3×50 kW EV ports + 250 kW BES), achieve energy efficiency >96%, reduce installation costs by ~25% compared to conventional MV AC-connected chargers and scale to major European cities by 2030.
- **Success Metrics:** Number of deployed stations, average utilization rate, reduction in installation cost, efficiency, regulatory approvals obtained.



Existing solution



Proposed Solution

3.3.2. Value Proposition & Competitive Advantage

- **Problem Addressed:** Rapid EV adoption demands high-power fast chargers. Existing solutions require independent converters per EV and costly MV AC infrastructure. LV DC traction grids remain underutilized for EV charging.
- **Proposed Solution:** Multiport CF-MAB converter connects multiple EVs and BES to LV DC traction grid, allowing independent charging. Uses SiC devices, high-frequency isolation and scalable port count.
- **Differentiation:**
    - ~25% reduction in silicon area due to shared switches.
    - Eliminates AC-DC rectifier and low-frequency transformer.
    - Enables bidirectional V2G operation.
- **Customer Advantage:** Reduced CAPEX (~€270k for 3 EV ports + BES in comparison to existing solution with ~€357k), scalable deployment and compatibility with existing urban infrastructure
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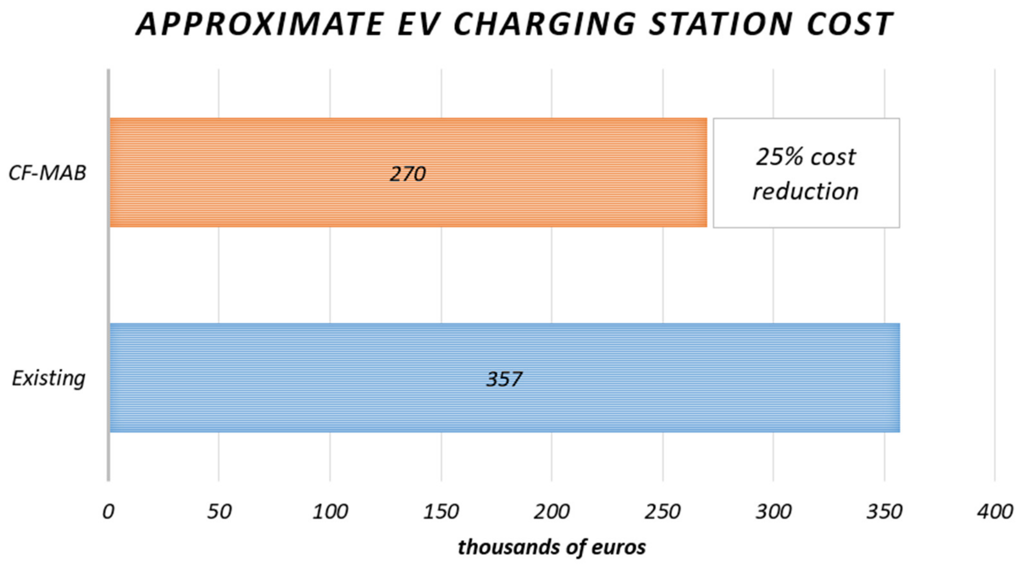

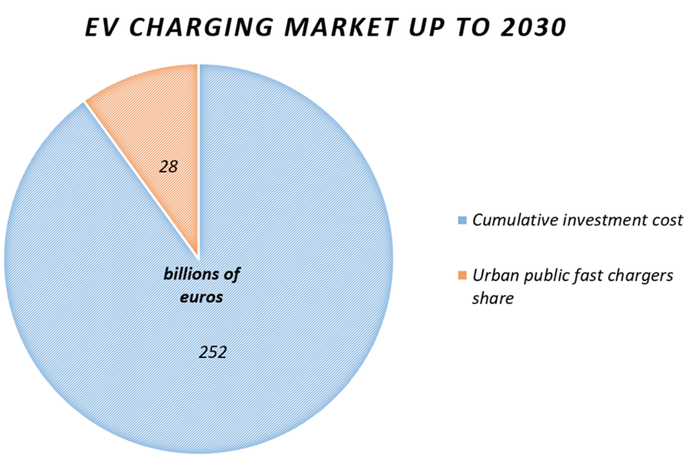

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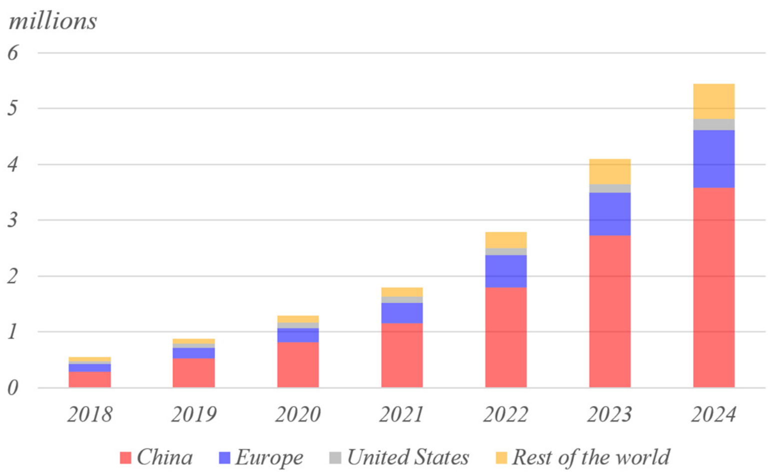
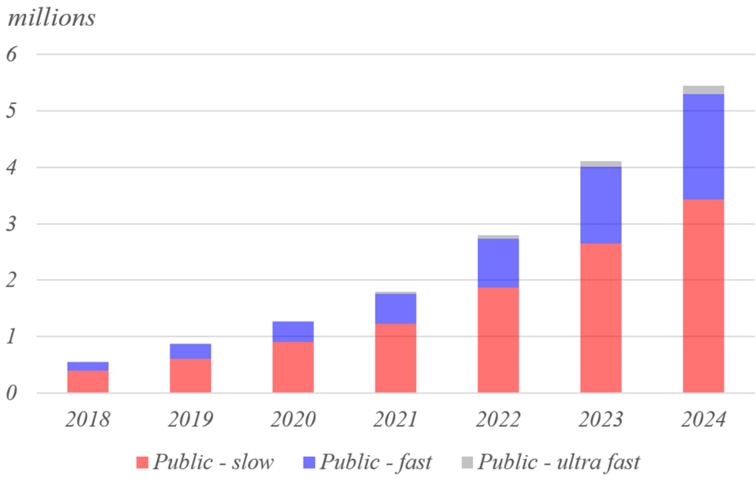
3.3.3. Market & Customer Segments

- **Target Customers:** Utilities, public transport authorities, government agencies, private integrators responding to tenders.
- **Customer Needs:** Cost-efficient high-power fast chargers, modular deployment, V2G capability, compliance with standards (IEC 61851-23, ISO 15118-20), reduced permitting hurdles.
- **Market Overview:** European EV fast-charging infrastructure is growing rapidly; >1.3 million new points in 2024 globally, ~60% are slow chargers. Studies estimate that cumulative investment cost necessary to install charging points, enhance power grid and expand renewable energy capacity for EV charging is 280 billion euros by 2030 year in Europe and UK. Estimating 10% of that infrastructure is urban fast chargers, located close to traction grids, market size is 28 billion euros
- **Competitors:** ABB, Siemens, Schneider Electric, Ingeteam, Heliox.
- **Our technical edge:** multiport CF-MAB with lower installation cost, high efficiency and ancillary service potential.



Global stock of public charging points by region



Share of public fast chargers

3.3.4. Channels & Customer Relationships

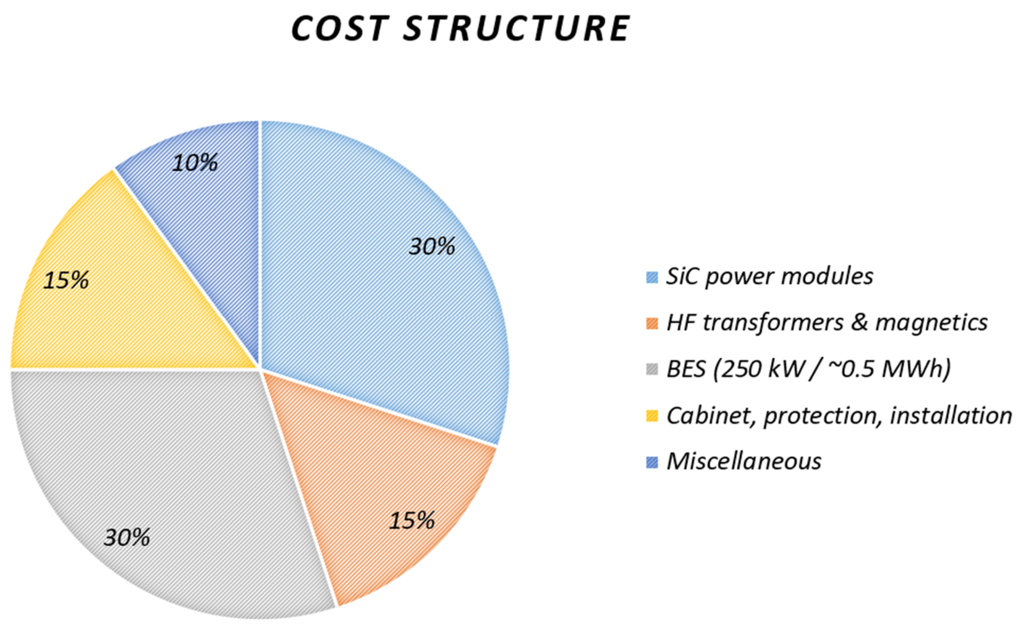
- **Channels:** Direct tender responses to municipalities and utilities; strategic partnerships with transport authorities; technical workshops and demonstrations.
- **Customer Relationships:**
  - Technical consulting and co-design support.

- Automated monitoring and remote management platform.
- On-site installation support and after-sales service.

- Retention Strategy: Performance guarantees, regular firmware updates for CF-MAB converters, predictive maintenance and optional BES upgrade modules.

3.3.5. Revenue Model & Cost Structure

- Revenue Source: Direct sale of multiterminal EV fast-charging stations; additional revenue from maintenance contracts.
- Pricing Strategy: Competitive tender pricing (~€270k per 3 EV + BES system).
- Cost Structure:
  - SiC power modules & drivers: ~30% of BOM.
  - HF transformer & magnetics: ~15% of BOM.
  - BES (250 kW / ~0.5 MWh): ~30%.
  - Cabinet, protection, installation: ~15%.
  - Miscellaneous: ~10%.
  - Expected efficiency losses <4%, resulting in <16 kW for a 400 kW station.



3.3.6. Key Resources & Activities

- Resources:
  - Human: Power electronics engineers, control software developers, installation/commissioning teams.
  - Physical: Production facilities, testing labs, urban deployment sites.
  - Intellectual: CF-MAB topology patents, control algorithms, design documentation.
  - Financial: Working capital for prototypes, initial production batch.
- Activities: Converter design, system integration, HV/LV testing, tender management, deployment, operation monitoring.

3.3.7. Key Partnerships

- Strategic partnerships with city transport authorities and utilities.
- Component suppliers for SiC modules, inductors, transformers, and BES cells.
- Research institutions for optimization of control algorithms and grid interaction studies.
- Outsourcing options: manufacturing of cabinets, assembly of magnetics or modular BES integration.

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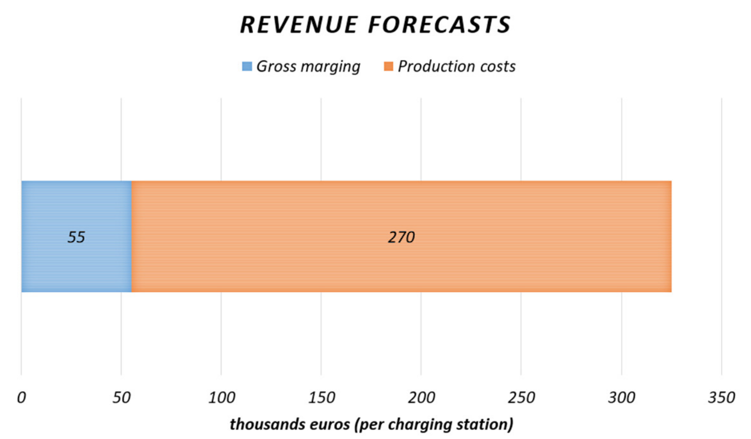
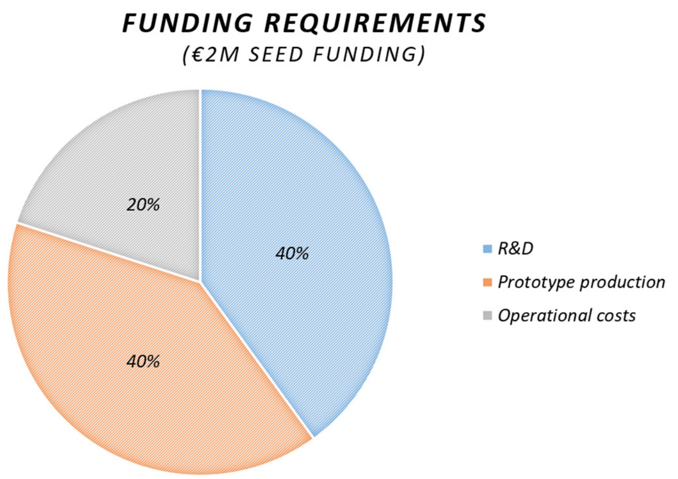
3.3.8. Sustainability & Scalability

- **Growth Plan:** Start with urban centers in Poland, scale to European cities with dense tram/trolleybus networks. Modular CF-MAB allows easy scaling from 3 to 5 EV ports.
- **Environmental Responsibility:** Supports renewable integration via DC traction grids; reduces need for new AC transformers and substations.
- **Scalability:** Converter architecture allows additional ports with minimal incremental cost (~€25k per 50 kW EV port). Efficiency remains >96% with increased ports and HF magnetics scale ~0.8× per new port.

3.3.9. Financial Overview (Optional)

- **Revenue Forecasts:** For initial deployment of 20 stations (3×50 kW + 250 kW BES each):
  - Revenue: 20 × €325k ~ €6.5M.
  - Gross margin ~15–20%.
- **Key Expense Assumptions:** BOM, installation, R&D amortization.
- **Funding Requirements:** €2M seed funding to cover initial prototypes and development, testing and tender participation. Use of funds: 40% R&D, 40% prototype production, 20% operational costs.





3.4. Business model (BM.3) presentation

IRP07 – Reliability and availability of Smart Transformers for cost effective and high quality of services in the grid

3.4.1. Executive Summary

- *Business Idea:*
  Develop and commercialize a real-time model-assisted test bench for modular multilevel converters (MMCs), which can be used in Smart Transformer applications. This platform allows safe, cost-effective, full-dynamic testing of converter submodules under realistic operating and fault conditions without requiring a complete high-power prototype.
- *Mission:*
  To enhance the safety, reliability, and performance of future Smart Transformers and renewables-based power grids through innovative hybrid testing methodologies that bridge the gap between simulation and hardware validation.
- *Vision:*
  To become a leading provider of integrated real-time testing and validation solutions for power conversion systems, serving universities, R&D centers, and manufacturers worldwide.
- *Strategic Goals:*
  - Validate and standardize the hybrid MMC test bench by 2026.
  - Establish initial collaborations with research institutions and converter manufacturers (2025–2026).
  - If possible, secure EU or national funding to bring the technology from proof-of-concept (TRL 5–6) to market-ready system (TRL 8–9).
- *Key Success Metrics:*
  - Number of contracts or collaborations with early adopters.
  - Reduction in test costs and risks for clients.
  - IP licensing revenues or product sales.
  - Recognition as a reference platform for hybrid real-time converter testing.

3.4.2. Value Proposition & Competitive Advantage

- *Problem:*
  Full-scale converter testing is expensive, risky, and time-consuming. Simulation-only studies fail to capture all physical behaviours (electromagnetic, electrothermal, and failure dynamics) and therefore cannot reliably reproduce the complexity of real operating scenarios, especially under disturbed or faulty conditions.
- *Solution:*
- A hybrid test bench combining real-time simulation and real submodule hardware, enabling detailed converter behaviour analysis, including fault and transient conditions, without endangering full systems.
- *Unique Selling Proposition (USP):*
  - Risk-free failure scenario testing (AC/DC faults, over currents, internal SM failures).
  - Real-time integration of hardware and simulated environment.
  - Reduced cost and time compared to full-scale high-voltage prototypes.
  - Scalability: easily adaptable to different converter topologies or voltage levels.
- *Differentiation:*
- Existing real-time simulator providers (e.g., OPAL-RT) do not offer integrated physical submodule interfacing. This hybrid physical-virtual setup offers a unique competitive edge bridging industrial validation and academic research.

3.4.3. Market & Customer Segments

- Primary Markets:
  Converter and Solid State Transformer manufacturers, research labs, universities, and real-time simulator providers.
- Early Adopters:
  Research institutes working on MMC (joint testing or contract services).
- Trends:
  Expansion of hybrid AC/DC grids; growth in hardware-in-the-loop (HIL) demand; global shift to high-efficiency converter testing.

- Customer Needs:
  Greater safety, reduced costs, faster prototyping, access to realistic case testing.

3.4.4. Channels & Customer Relationships

- Channels:
  Direct B2B outreach, joint research projects, technical conferences (ECCE, ISIE), academic publications, licensing to simulator firms.
- Relationship Type:
  Initially collaborative (R&D partnerships); evolving to structured B2B sales/support.
- Retention & Support:
  Software updates, modular hardware upgrades, ongoing service agreements.

3.4.5. Revenue Model & Cost Structure

- Revenue Sources ➔ Contract-based testing services, modular test-bench sales, IP licensing.
- Pricing ➔ Manufacturing ≈ €7000 / unit → sale ≈ €10 000 / unit (≈ 30 % margin).
- Costs ➔ Hardware components, simulator units, R&D personnel, IP/legal, maintenance.
- Optimization ➔ Modular design, co-funded grants, lean production chain.

3.4.6. Key Resources & Activities

- Resources:
  - Skilled researchers and engineers (CAU ESRs).
  - Real-time simulators & MMC hardware.
  - Grants and institutional funding.
- Core Activities:
  Design & validation of prototype, market testing, IP management, dissemination, and training.

3.4.7. Key Partnerships

- Technology Transfer Office (IP strategy and licensing).
- Real-Time Simulator Companies (product integration partners).
- Research Institutes / Universities (co-development and benchmarking).
- Industrial Stakeholders (field validation and feedback).

3.4.8. Sustainability & Scalability

- Growth Plan:
  Extend hybrid methodology to DC-DC and EV-drive converters.
- Sustainability:
  Reduces energy and material waste, aligns with EU Green goals.
- Scalability:
  Modular platform replicable across laboratories; compatible with commercial real-time systems.

3.4.9. Financial Overview (Optional)

Unit cost	€7 000	Materials + labour
Sale price	€10 000	Target retail
Target sales (3 yrs)	10–20 units	Research institutions
Revenue (3 yrs)	€100 000 – €200 000	Conservative
Funding needs	€150 000 – €250 000	For scale-up & IP

Main sources	Horizon Europe / Nat. grants / private investors

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3.5. Business model (BM.4) presentation

IRP08 – Real-time modelling and validation of Distributed Energy Storage Systems and Integration strategies

3.5.1. Executive Summary

- Brief overview of the business idea.
  The business idea is a company that designs and delivers customized energy solutions for off-grid communities, combining renewable energy generation with hydrogen-based storage to reduce electricity costs and minimize emissions.
- Mission, vision, and key goals.
  The company's mission is to provide off-grid communities with sustainable, cost-effective, and reliable energy solutions. Its vision is to become a leading provider of innovative energy systems for off-grid and remote communities worldwide, supporting a global transition to clean and resilient energy networks. To achieve this, the company aims to build a robust network of partnerships worldwide and to develop its own design tools and modular solutions to optimize the process.
- Main success metrics and strategic priorities.
  Key performance indicators include revenue growth and profit margins, number of installed systems, reduction in electricity costs and emissions for client communities and customer satisfaction. Operational efficiency, such as time and cost required for design and installation, will also be monitored. Strategic priorities focus on expanding the company's presence in off-grid communities and building strong local and international partnerships.

3.5.2. Value Proposition & Competitive Advantage

- What problem solve the proposed solution
  An off-grid microgrid, which relies exclusively on renewables, must be able to store for long time the energy produced during high-energy-production season. Batteries are not suitable for this purpose due to self-discharge and degradation phenomena. Conversely, the use of traditional generators based on fossil fuels entails a high environmental impact, so it is no longer sustainable.
- Unique solution or offering
  For long-term storage applications in off-grid systems, hydrogen offers an effective way to store large amounts of energy from renewable sources, whose production is intermittent. Its adoption reduces emissions compared to traditional fossil fuel generators and requires fewer critical materials than battery-only solutions. Hydrogen-based storage ensures that renewable energy is available year-round with minimal environmental impact, representing a superior economic and ecological investment compared to conventional fossil fuel-based generation.
- Why customers will choose this solution — differentiation, innovation, or entry barriers
  Hydrogen storage systems have proven to be a reliable and cost-effective alternative to traditional energy generators; however, their adoption to store energy is still limited. The proposed technology is innovative, so on one hand it entails several benefits in terms of performances, offering enhanced efficiency, scalability and environmental sustainability. On the other hand, some skepticism may arise by due to the limited familiarity with hydrogen-based storage, especially concerning safety issues. This, in particular, may constitute the main barrier to market adoption.

3.5.3. Market & Customer Segments

- Target markets and customer profiles
  The target market consists of all the off-grid communities worldwide, which are geographically located in areas where connection to the main grid is either technically unfeasible or not economically convenient, for example for islands or in remote rural regions. The proposed solution specifically targets the existing communities which currently rely on fossil fuels to produce electricity. The potential customer, the community authority, should have interest in addressing environmental problems.
- Customer needs, behaviours, and pain points

The typical community authority customer needs to reduce the cost of electricity in the community and the emissions associated with energy generation. Ideally, it already utilizes the renewable sources for energy production and aims to rely only in clean energy. The community should have enough financial capacity, as upfront capital investment for hydrogen-based systems can be significant.

- Industry overview, market trends, and competitive positioning
  The hydrogen-based off-grid storage market is still emerging, with a few companies offering solutions for remote communities and industrial sites. Current trends indicate growing interest in renewable-based microgrids, particularly in regions where connection to the main grid is challenging. Many existing companies focus primarily on supplying equipment. For example, HPS Home Power Solutions' Picea system is a hydrogen-based, all-season electricity storage unit for buildings: it integrates a battery, an electrolyser, a hydrogen storage tank, and a fuel cell to reliably supply electricity and heat year-round. Some other companies provide full design and installation of the energy system. A notable case is Symbase Hydrogen Energy, which offers fully equipped, modular off-grid hydrogen fuel cell installations in containerized form. However, many of these providers still primarily target medium-to-large installations or industrial clients, leaving smaller off-grid communities underserved. The proposed solution differentiates itself by focusing specifically on these smaller communities, offering a modular and scalable plant design. Additionally, it fosters close collaboration with customers to ensure they acquire the right knowledge to operate, maintain, and monitor the system independently.

3.5.4. Channels & Customer Relationships

- How you reach and deliver value to customers (sales and marketing channels)
  The primary channel for reaching customers is direct engagement with government and community authorities, initiating contact with potential communities personally. Moreover, a dedicated website provides information for other prospective customers, showcasing case studies and completed projects. Marketing efforts emphasize the environmental, economic and technical benefits of the hydrogen storage system, as well as the tailored design and support.
- Type of customer relationships (personal, automated, self-service)
  Customer relationships are personal and consultative, combining direct interactions for key discussions with online channels for ongoing communication. Some digital monitoring tools are available too, to enable remote system management and provide continuous support, ensuring quick response to any operational issues.
- Retention, loyalty, and customer support strategies
  Retention and loyalty are fostered by continuous technical support and training programs for local operators, ensuring sustainable use of the system. However, given the long-term investment and the specialized nature of the technology, in this kind of business customer retention is less critical and once a community has chosen the operator and installed the system, it is unlikely to switch providers.

3.5.5. Revenue Model & Cost Structure

- Revenue sources and monetization model (sales, subscriptions, commissions, etc.)
  The main sources of revenue can be categorized into short-term payments and long-term payments. Short-term payments cover the construction and equipment costs, which are incurred at the beginning of the project and can be structured into multiple instalments according to the customer's financial capacity and needs. Long-term payments correspond to system design and operations and maintenance (O&M) costs, which are distributed over the lifetime of the plant, with pricing that may vary over time depending on service requirements and system state.
- Pricing strategy
  The capital investment for this type of plant can be significant, so short-term payments are set at the minimum feasible level to cover the first costs, with a small profit margin. Subsequent payments related to system design and operations and maintenance (O&M) are structured as follows:
  - Fixed component to cover basic expenses.
  - Variable component proportional to the savings generated, to enhance economic attractiveness.
  - Small variable component covering extraordinary activities, if they occur.
- Major cost drivers and cost optimization approach
  The main cost drivers are construction and equipment costs, system design and O&M. Construction and equipment can be optimized thanks to strategic partnerships with devices suppliers of hydrogen system

components as well as through special agreements with local providers for renewable energy technologies. Cost efficiency in system design is achieved by applying standardized approaches based on modular configurations, which allow for scalable and replicable solutions across different communities. O&M costs are minimized through training programs for local operators, enabling them to manage and maintain the systems effectively and reducing reliance on external technical support.

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3.5.6. Key Resources & Activities

- Core resources (human, physical, intellectual, financial)
  The core resources required are:
  - The human resources comprise several teams, according to their expertise. The main teams are the design and technic team, the construction team and administration team. In addition, complementary teams, such as the training team and the R&D team, can be established at a later stage
  - Physical resources include office spaces for design and coordination activities, along with dedicated areas to build and test specific system configurations when required and to eventually train new personnel.
  - Intellectual resources involve expertise in energy and electrical engineering, plant design and legal and administrative knowledge for contract development and regulatory compliance. Strong project management and coordination skills are also essential to manage complex installations in remote areas.
  - Financial resources must be sufficient to cover startup, personnel and working spaces. The initial revenues are reinvested to scale up operations and expand service capabilities.
- Main business operations that create and deliver value (production, marketing, R&D, service)
  Value is created and delivered through the design, construction and maintenance of off-grid hydrogen storage systems tailored to each community's needs. Core operations include system engineering, system construction and R&D, aimed at developing structured procedures and digital tools to simplify and accelerate the design process. Marketing focuses on demonstrating the environmental and economic benefits of the technology, while ongoing technical support, training programs and remote monitoring.

3.5.7. Key Partnerships

- Strategic partners, suppliers, or distributors
  Strategic partners include providers of renewable energy generation technologies, particularly local suppliers, to optimize costs and facilitate installation. Suppliers of hydrogen technologies are also crucial, as these solutions are relatively new and maintaining competitive pricing is essential. Additionally, partnerships with software providers are important for designing and monitoring tools of the plants.
- Outsourcing or alliances that reduce risk or cost
  Equipment manufacturing, components supply and software tools are outsourced to specialized companies, ensuring devices availability without the need for in-house production facilities. Software tools for system design, monitoring, and predictive maintenance are also provided through partnerships with specialized providers, eliminating the need to develop them internally. Alliances with local renewable energy developers and producers, research institutions allow the company to share technical expertise and lower installation and logistics costs.

3.5.8. Sustainability & Scalability

- Long-term growth and expansion plans
  The company's growth strategy is gradual. It will begin by offering consulting and design services to build expertise and customer trust. As capabilities expand, activities will expand to include the full construction and commissioning of off-grid hydrogen storage plants, as well as R&D and dedicated training programs initiatives. it could develop proprietary software tools for design, control, and monitoring, which could eventually be offered commercially. Over time, key production activities, such as the manufacturing of components or devices, may be progressively integrated into the company to reduce dependence on external suppliers.
- Environmental or social responsibility initiatives (if relevant)
  The company is committed to minimizing its environmental impact and promoting sustainable development. Although the hydrogen-based systems are designed to operate with zero emissions during use, residual emissions related to plant construction and logistics can be offset through targeted initiatives. In particular, the company plans to collaborate with specialized environmental organizations to effectively neutralize the carbon impact associated with each installation. In addition, training programs will promote knowledge transfer within the community and partnerships with local suppliers will foster local economy.
- How the model adapts as the business scales

As the business scales and internal and device costs decline, the model will extend its solutions to other microgrid configurations, including grid-connected systems, and can be expanded to industrial applications, enabling fully integrated hydrogen-based energy systems in factories that already utilize hydrogen for industrial processes. Over time, the gained knowledge may also be applied to systems that do not involve hydrogen use.

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4. Conclusions

Overall, the proposed business models are in line with what was expected and large part of activities have been done. Also accounting that some of ESRs already concluded their three years of fellowship.
In the following a summary for the four specific topics.

IRP05 – Energy Router for Hybrid Microgrids for efficient and robust energy and power management

The conducted research and development activities have led to the successful design, modeling, and experimental validation of a novel Single-Cell Three-Phase Energy Router (SC-TP ER) — an advanced power-electronic interface enabling efficient and safe energy exchange between residential DC networks and the AC grid. Through a systematic approach, the project has progressed from conceptual studies to a validated hardware prototype (TRL 5), tested under various static and dynamic operating conditions.
The scientific contributions include the introduction of a new ER topology that reduces system complexity and cost by eliminating redundant conversion cells, as well as novel insights into grounding, leakage current behavior, and safe connection schemes between isolated DC systems and the AC grid. Moreover, the application of Flatness-Based Control (FBC) demonstrated significant improvement in dynamic response and robustness compared to conventional methods.
The project's experimental validation confirmed the practicality and reliability of the proposed architecture, using shared laboratory facilities in the University of Extremadura (Spain) and Gdańsk University of Technology (Poland).
The collaboration between the two institutions enabled complementary expertise, from initial assembly and open-loop testing to final implementation and performance evaluation under real-world scenarios.
From the business perspective, the developed prototype represents a promising foundation for a scalable and sustainable product aimed at solar energy companies, energy storage providers, and power electronics manufacturers. The hardware-centric design allows future integration of innovative software-based energy management systems, enabling the Energy Router to evolve into a multifunctional, intelligent interface for residential and microgrid applications.
Overall, the project outcomes contribute both to the academic advancement of power electronic interface technologies and to the European vision of smart, sustainable, and decentralized energy systems. The next phase will focus on advancing the TRL level through pilot production with SME partners, system certification, and the exploration of commercialization pathways supported by EU innovation frameworks.

IRP06 – EV chargers, developing an active bidirectional charger able to provide anciallary services

The CF-MAB based fast-charging architecture offers a decisive technical and economic advantage in the rapidly expanding EV infrastructure sector. By consolidating multiple EV outputs and a high-power BES port into a single current-fed multi-active-bridge converter, the system achieves substantial reductions in silicon area (~25%), magnetics volume (~20–25%) and total installation cost (~20–35%) relative to conventional multi-converter designs. These gains are enabled by the inherent strengths of the CF-MAB topology—shared power paths, high-frequency isolation, efficient current regulation and scalable multiport operation, while maintaining excellent performance, with system efficiency expected to exceed 96% in real-world operating conditions.

The business plan accompanying this technology is equally strong. It aligns precisely with market needs in urban environments: lower CAPEX, compatibility with existing LV DC traction grids and integrated BES support for peak shaving, continuity of service and future V2G functionality. The financial model is supported by realistic BOM assumptions, competitive tender pricing and healthy target margins demonstrates a commercially sustainable path to early deployments and subsequent scale-up across European cities.

In summary, the CF-MAB solution represents far more than an incremental improvement in converter design. It is a platform that enables a new generation of modular, high-efficiency, cost-optimized fast-charging stations. The strategy laid out in this plan provides a clear, actionable roadmap for transitioning the concept from validated research into a market-ready product with strong long-term growth potential.

IRP07 – Reliability and availability of Smart Transformers for cost effective and high quality of services in the grid

The conducted research and development activities have led to the development of a real-time model-assisted test bench for modular multilevel converters (MMCs), which can be used in Smart Transformer applications. This platform allows safe, cost-effective, full-dynamic testing of converter submodules under realistic operating and fault conditions without requiring a complete high-power prototype. A possible commercialization of this platform allows to enhance the safety, reliability, and performance of future Smart Transformers and renewables-based power grids through innovative hybrid testing methodologies that bridge the gap between simulation and hardware validation. The proposed business model is focused on using the research results to become a leading provider of integrated real-time testing and validation solutions for power conversion systems, serving universities, R&D centers, and manufacturers worldwide.

IRP08 – Real-time modelling and validation of Distributed Energy Storage Systems and Integration strategies

The proposed business offers an innovative solution to the energy challenges faced by off-grid communities worldwide. By integrating renewable energy generation with hydrogen-based storage, the company provides an approach that is both environmentally sustainable and economically viable, ensuring year-round energy availability while minimizing emissions and reducing dependence on fossil fuels. This dual focus on clean generation and efficient long-term storage directly addresses one of the most critical limitations of renewable-based microgrids: the need for clean, reliable, long-duration energy storage.

Unlike traditional battery systems, hydrogen-based storage offers superior scalability and long-term efficiency. Although the technology is still emerging and may face initial scepticism due to limited familiarity, the company's consultative approach and emphasis on direct engagement with community authorities help foster trust among target customers. By prioritizing collaboration and training, the company empowers local stakeholders to operate and maintain their systems independently, strengthening long-term relationships and ensuring sustainable project outcomes.

The business model effectively combines short-term and long-term revenue streams, balancing upfront capital costs with ongoing fees that are structured to promote cost savings and maximize value creation for clients. Strategic partnerships with local suppliers, modular system designs and comprehensive training programs for community operators further optimize costs and enhance operational efficiency.

Sustainability and scalability are fundamental elements of the company's long-term vision. The initial focus on consulting and system design will gradually evolve into full construction, commissioning and the development of proprietary software tools for system control and monitoring. Complementing this growth, the company is committed to offsetting residual emissions and supporting local economic development through collaborations with environmental organizations and local suppliers. As operations expand and expertise deepens, the business model can be adapted to serve industrial applications and other microgrid configurations, extending the benefits of hydrogen-based energy systems to broader markets.

Overall, this venture integrates an approach to off-grid energy provision, through innovative technology, a well-structured operational model and social responsibility. It has the potential to contribute significantly to the global transition toward clean and resilient energy systems.

5. References

List of publications related to BM.1 for ESR05 – Energy Router for Hybrid Microgrids for efficient and robust energy and power management

[1]. M. Azizi, O. Husev, C. Roncero-Clemente, O. Veligorskyi and R. Strzelecki, "Fast and Robust Energy Router Control in Dynamic Conditions Using Flatness-Based Control Theory," 2025 IEEE 19th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Antalya, Turkey, 2025, pp. 1-6, doi: https://doi.org/10.1109/CPE-POWERENG63314.2025.11027260. Flatness-based control theory is developed to enhance the dynamic performance of a multiport energy router. The presented method controls the grid-side current and regulates the dc-link voltage. The simulation results confirm the proper performance of this method, and the comparisons made validate the high speed and accuracy of the system responses compared to conventional solutions. Keywords: Flatness-based control theory, multiport energy router, dynamic conditions, hybrid nanogrid. Conference Paper, indexed in Scopus.

[2]. M. Azizi, O. Husev, R. Mbayed, E. Monmasson, J. Martins and O. Veligorskyi, "Energy Router: A Sustainable Solution for Future Residential Buildings," in IEEE Power Electronics Magazine, vol. 12, no. 1, pp. 75-86, March 2025, doi: https://doi.org/10.1109/MPEL.2024.3525349. This article provides a detailed review of power electronics solutions for ZEBs and offers strategies to address related challenges. By exploring the promising future of the low-voltage dc (LVdc) industry in ZEBs, it presents and compares grid connection scenarios and evaluates their overall efficiencies across hybrid, dc, and ac technologies. Furthermore, it addresses the integration of dc and ac systems in energy resources (ER), proposing solutions for challenges related to protection, grounding, and leakage currents. Finally, it examines the latest EMS solutions, emphasizing the shift to full digitalization through a combination of cloud-based and edge-computing platforms. Keywords: Photovoltaic systems, Renewable energy sources, Energy consumption, Low voltage, Reviews, Buildings, Standardization, Microgrids, Power electronics, Protection. Paper, indexed in Scopus Q2 Journal.

[3]. M. Azizi, O. Husev, O. Veligorskyi, M. Turzvński and R. Strzelecki, "Dc Leakage Current in Isolated Grid-Connected dc Nanogrid - Origins and Elimination Methods," 2024 IEEE 18th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Gdynia, Poland, 2024, pp. 1-6, doi: https://doi.org/10.1109/CPE-POWERENG60842.2024.10604426. This study deals with the leakage current in the galvanically isolated dc nanogrid. Then, it examines the dc leakage current and its relationship with the dc nanogrid grounding and finally provides solutions to remove the dc components in the leakage current. Keywords: Grid-connected dc nanogrid, Isolation, grounding type, dc leakage current, capacitive grounding. Conference Paper, indexed in Scopus.

[4]. Azizi, M., Husev, O., Veligorskyi, O., Rahimpour, S., and Roncero-Clemente, C. (2023). Grounding and Isolation Requirements in DC Microgrids: Overview and Critical Analysis. Energies, 16(23), 7747. https://doi.org/10.3390/en16237747. Dc microgrids, along with existing ac grids, are a future trend in energy distribution systems. At the same time, many related issues are still undefined and unsolved. In particular, uncertainty prevails in isolation requirements between ac grids and novel microgrids as well as in the grounding approaches. This paper presents a critical technical analysis and an overview of possible grounding approaches in dc systems and the feasibility of avoiding isolation between ac and dc grids. Keywords: dc microgrids, isolation requirements, grounding approach. Journal paper, indexed in Scopus Q2.

[5]. M. Azizi, S. Rahimpour, O. Husev and O. Veligorskyi, "Back-to-Back Energy Router Based on Common-Ground Inverters," 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Tallinn, Estonia, 2023, pp. 1-6, https://doi.org/10.1109/CPE-POWERENG58103.2023.10227480. This paper proposes an energy router based on a back-to-back structure with common-ground inverters. Connecting the neutral wire of the ac system to the negative port of the dc link eliminates leakage currents and ensures safety. The operation mode of the common-ground inverter has been investigated, and the simulation results confirm the accuracy of the overall structure and benefits compared to the classical H-bridge inverter. Keywords: Energy router, non-isolated, common-ground inverters, back-to-back structure. Keywords: Energy router, non-isolated, common-ground inverters, back-to-back structure. Conference paper, indexed in Scopus.

[6]. M. Azizi, O. Husev, D. Vinnikov and O. Veligorskyi, "Comparative Evaluation of Isolated dc-dc Converters for Low Power Applications," 2022 IEEE 20th International Power Electronics and Motion Control Conference (PEMC), Brasov, Romania, 2022, pp. 7-12, doi: https://doi.org/10.1109/PEMC51159.2022.9962944. This article examines and evaluates five popular types of isolated dc-dc converters for low-power applications. Using simulations, converters have been evaluated and compared from different perspectives. Keywords: Isolated dc-dc converters, Component design, Flyback, Forward, Push-pull, Full-bridge. Conference paper, indexed in Scopus.

[7]. M. Azizi, O. Husev, and D. Vinnikov, "Single-stage buck–boost inverters: A state-of-the-art survey," Energies, vol. 15, no. 5, p. 1622, Mar. 2022, doi: 10.3390/en15051622. In this paper, the state of the art of single-stage buck–boost inverters is discussed. The advantages and disadvantages of each structure are examined from different perspectives, such as the number of components, losses, and performance. Finally, in a general comparison, the properties of all structures are discussed and summarized in a table. Keywords: single-stage inverter; buck–boost operation; survey, Journal paper, indexed in Scopus Q2.

List of publications related to BM.2 for ESR06 – EV chargers, developing an active bidirectional charger able to provide anciallary services

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[2]. European Commission, A Sustainable Transport Investment Plan. Brussels, Belgium: European Union Publications, 2025. [Online]. Available: https://transport.ec.europa.eu/publications/sustainable-transport-investment-plan-2025. Accessed: Nov. 14, 2025.

[3]. M. Lukianov, I. Verbytskyi, E. R. Cadaval and R. Strzelecki, "Bidirectional EV charger integration into LV DC traction grid," *2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG)*, Tallinn, Estonia, 2023, pp. 1-8, doi: 10.1109/CPE-POWERENG58103.2023.10227489.

[4]. M. Lukianov, I. Verbitsky, R. Strzelecki and E. Romero-Cadaval, "An Overview of Bidirectional EV Chargers: Empowering Traction Grid-Powered Chargers", 2023, pp. 191-230, doi:10.1007/978-3-031-44772-3_9

[5]. M. Lukianov, E. R. Cadaval, G. Arena and R. Strzelecki, "Partially Isolated Multi-Active Bridge DC-DC Converter with Bidirectional EV Charging Ports," *2024 IEEE 18th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG)*, Gdynia, Poland, 2024, pp. 1-7, doi: 10.1109/CPE-POWERENG60842.2024.10604312.

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List of publications related to BM.3 for ESR07 – Reliability and availability of Smart Transformers for cost effective and high quality of services in the grid

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