After the RISEnergy Transnational Access, Users are required to submit a User Report. This should be done within 4 weeks after the Access is completed unless otherwise agreed. The User Report will be given to the User(s) by the WP2 leader. The report contains sections related to the work performed, the main results and observations that were achieved.

This document should be completed, signed, and sent by e-mail to risenergy@for.kit.edu.

Summary questionnaire for Users who have been granted Transnational Access (TA) under the RISEnergy project Horizon Europe TA scheme. More information on RISEnergy TA can be found in "General Rules" and in "Access Policy" which can be found on the RISEnergy webpage.

Please complete, sign, and send this form, together with the Cost claim by e-mail to risenergy@for.kit.edu with title: RISEnergy APPXXX - reports.

General information about the project	
Project title (as used in Application)	Power Hardware in Loop Testing for Inertial Support Services Offered by Inverter Based Resources
Project number (APPXXX) and acronym (max 15 characters)	TA2.241 and PHIL-ISS
RISEnergy RI(s) accessed	TA25-ICCS-EES-lab
Keywords (up to five, free text)	Power hardware in Loop, Inertial response, Grid Forming , Grid Feeding
Arrival date (in town where RI is located)	15/02/2026
Departure date (from town where RI is located)	16/03/2026
Starting date of Access (first day at RI)	16/02/2026
Finishing date of Access (last day at RI)	13/03/2026
Number of days not using the RI (during the above period)	09
Reason for not using RI those days (describe)	Weekends and Public Holiday
Number of days using the RI	19 days (4 weeks)
Number of Users granted Access (group size)	1
Comments	
User	
User group leader or sole applicant (user group member 1)	
First name	
Last name	

Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	

Access Summary Report - work performed and initial results

Brief description of the objectives of your project (up to 200 words)

The main objectives of the project are summarized as follows:

1. **Develop Grid-Forming Control Architecture:** Integrating Battery Energy Storage Systems (BESS) with PV and WT systems to enhance synthetic inertia and fast frequency response. Thus, BESS-enabled grid-forming control strategies for both PV and WT will be developed.
2. **Enhancing Inertial and Frequency Support:** Quantifying improvement in grid inertia provided by PV-BESS and WT-BESS hybrid systems under different penetration levels. The share of inertial support from various sources across contingency scenarios will be evaluated.
3. **Validate Performance via Power Hardware-in-the-Loop (PHIL) Testing: The proposal aims to conduct power-hardware-in-the-loop (PHIL) studies to verify the system's dynamic stability under faults, load variations, and** other grid disturbances. It will also determine whether the system satisfies operational reliability and regulatory requirements.

Activities performed (up to 600 words)

1. Development of grid-forming control strategies was taken up as the first task. The energy storage system, primarily a battery, was integrated at the point of common coupling (PCC) with a photovoltaic (PV) and wind turbine (WT) setup. The battery was modeled as a grid-forming source, while the other two inverter-based sources (PV and WT) were modeled as grid-following.
2. The simulation test case for varying contingency conditions was run.
3. Transfer functions corresponding to various components of a PHIL experiment were added to the RSCAD program. This virtual PHIL (VPHIL) program was tested for stability and transient performance. Delays due to transmission and system components were added.
4. Finally, after successfully running VPHIL, PHIL experimentation began.
5. Final experiments focused on integrating PV, WT, and BESS together on a single platform and then quantifying the inertial support services provided by various sources under various contingency conditions.

Scientific results (up to 800 words)

The simulation was carried out on RSCAD. The screenshot of the RSCAD draft case so developed is shown in Fig. 1. It comprises a Battery Energy Storage System (BESS) in a grid-forming mode while the PV is in a grid-following mode. Both of these are connected to a common bus.

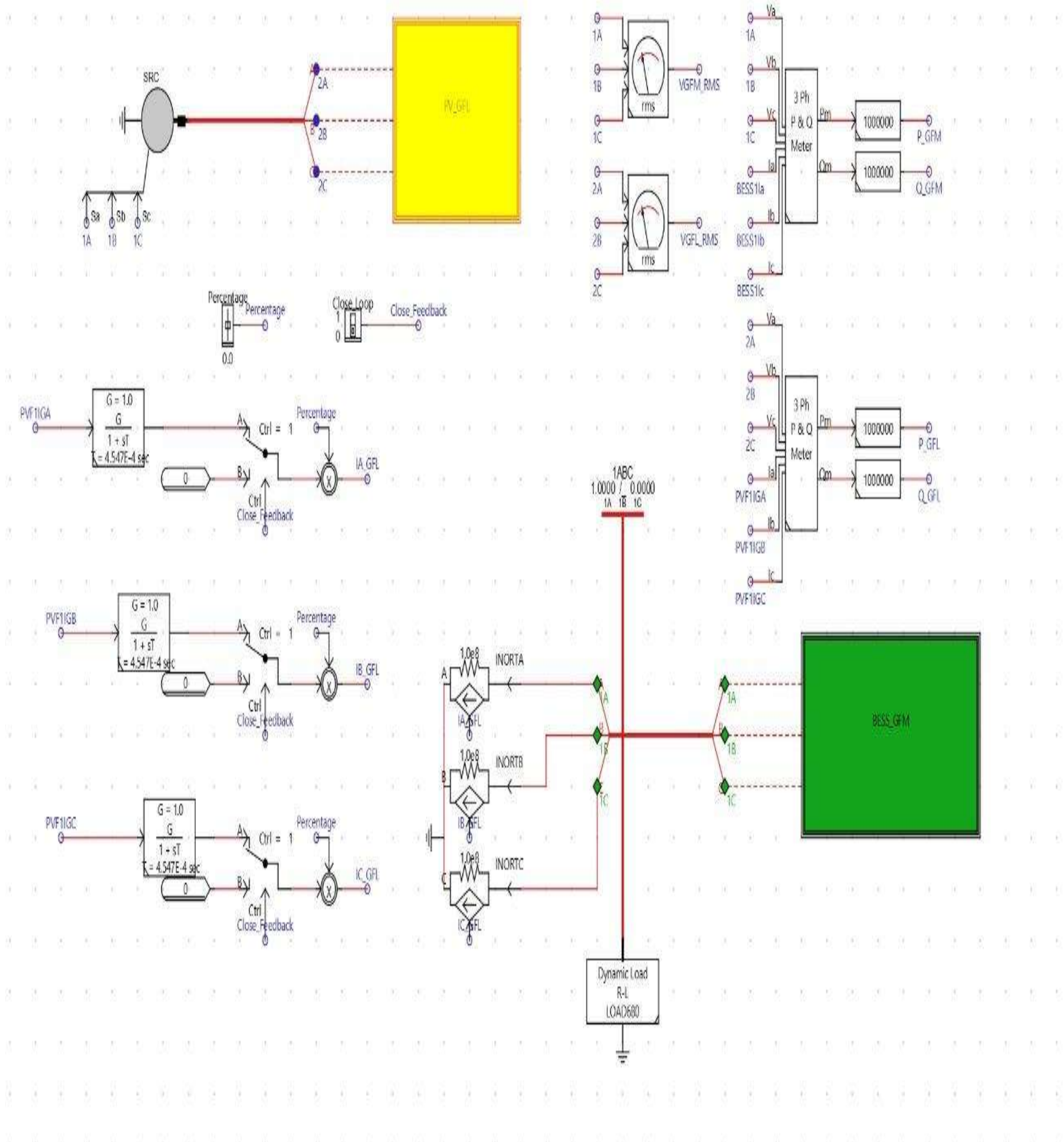

Fig. 1. Screenshot of the developed RSCAD program

The above simulation is subject to load variations while the load connected to the common bus (1A, 1B, 1C) is modeled as a dynamic load. The BESS response, as a GFM, and the PV response, as a GFL, are captured as P_GFM and P_GFL_meas, respectively, as shown in Fig. 2. The voltage at the common bus is recorded as 1A, 1B, and 1C, respectively, while the feedback current of the PHIL setup is captured as INORTA2, INORTB2, and INORTC2, respectively.

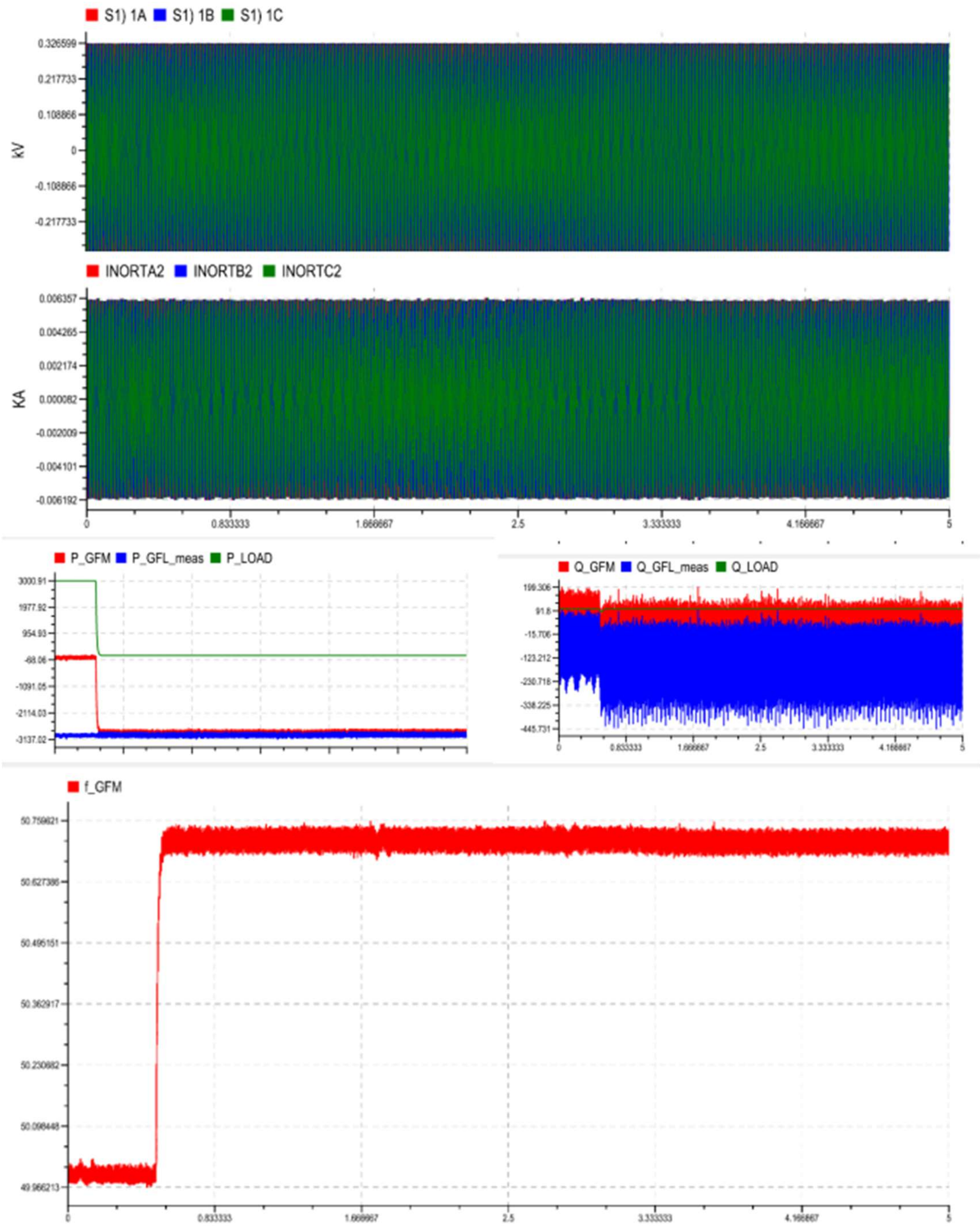

Fig. 2. Response of DERs to load variations

The frequency variation of the grid-forming source, i.e., the battery, is recorded as f_GFM. The PHIL simulation runs successfully with BESS and accommodates load variations.

Fig. 3 shows a screenshot of the second developed case, which corresponds to droop control with a BESS in grid-forming mode while the PV is in grid-following mode.

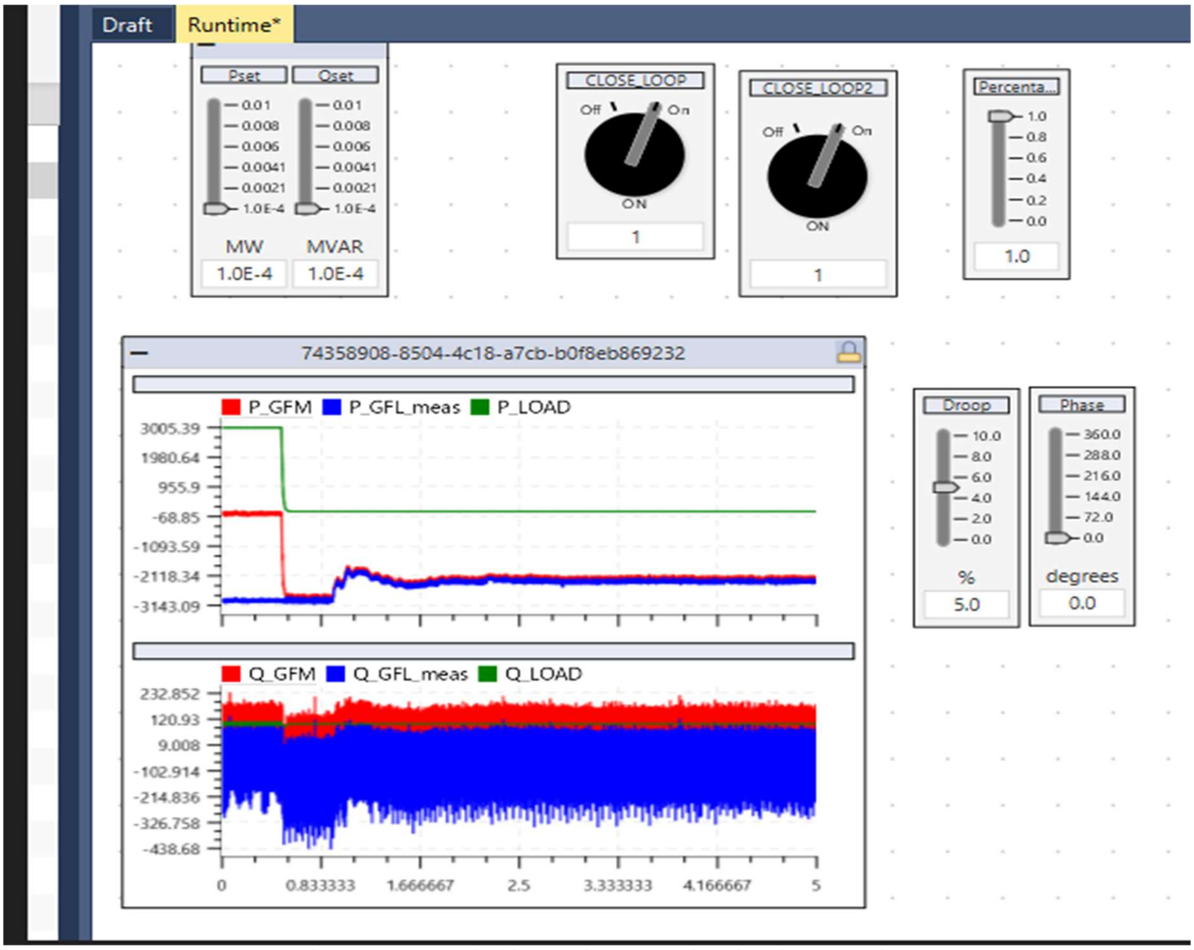

Fig. 3 Droop Control with BESS in GFM mode and PV in GFL mode

Fig. 4 shows the frequency variation corresponding to a 5% droop. The variations in the feedback current of the PHIL simulation are recorded as INORTA2, INORTB2, and INORTC2, respectively. The feedback current corresponds to the current of the hardware PV unit connected in this PHIL setup.

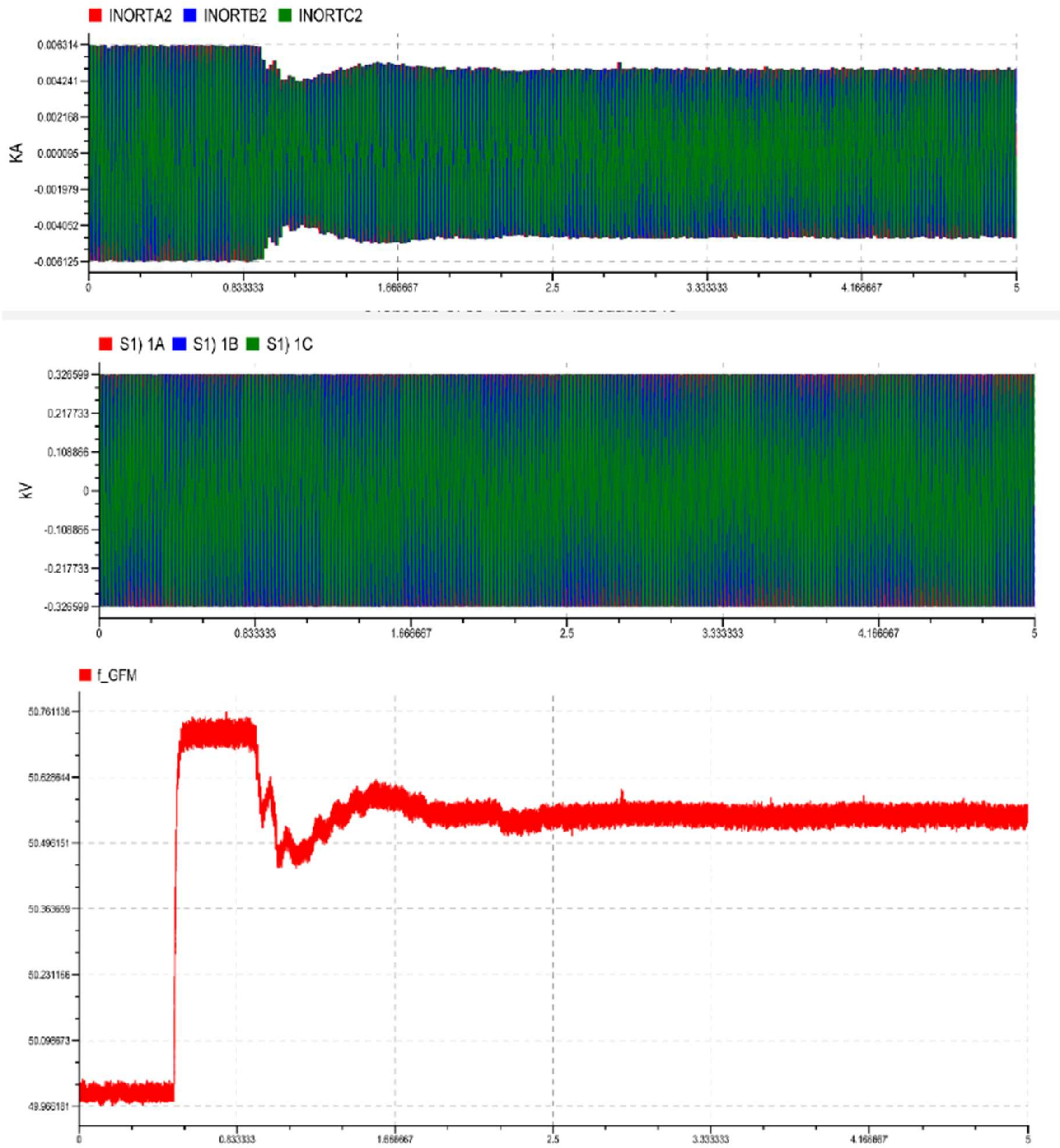

Fig. 4. Response of the PHIL set up to a 5% droop

Interpretation of the results (up to 400 words)

The proposed work summarizes the major takeaways as follows:

1. The close agreement between switching and average models validates the accuracy and reliability of the developed system models.
2. The VPHIL and PHIL simulations demonstrate stable system operation under both PV grid-following and BESS grid-forming operation, confirming the effectiveness of the implemented control strategies.
3. The inertial response analysis indicates that the system can adequately support dynamic conditions, thereby contributing to improved grid stability.
4. The successful extension of simulations to a shipboard microgrid environment highlights the scalability and adaptability of the developed framework.

5. The integration of additional distributed energy resources, such as a fuel cell and propulsion system with loads, was achieved without any adverse impact on overall system performance.
6. Overall, the results confirm the robustness of the proposed methodologies and provide a strong basis for further enhancement and detailed investigation.

Main achievements during the TA-related work (up to 250 words)

The main achievements during the TA-related work are as follows:

1. Development and verification of system models using both switching and average modeling techniques.
2. Implementation of VPHIL and PHIL-based simulations to analyze stable system operation and inertial response, specifically for a PV and WT system operating in grid-following mode and a BESS operating in grid-forming mode.
3. Extension of VPHIL simulations toward the development of a shipboard microgrid, incorporating additional DERs, including a fuel cell and a propulsion system with associated loads.
4. The next phase of the work will focus on further extending these developments by improving control strategies and conducting more detailed performance and stability analyses under diverse operating conditions.

Data Management

The project data primarily consists of simulation programs developed for VPHIL testing, along with supporting .csv and .png files generated during PHIL simulations. The data is securely maintained by the user, Jasdeep Kour, with an additional backup copy retained by Alkistis Kontou at the host institute.

Difficulties during the TA-related work (up to 250 words)

The laboratory was well-equipped with all the necessary instruments and resources required to carry out the proposed work effectively. Additionally, adequate support and guidance were consistently provided throughout the process. As a result, no significant difficulties were encountered during the TA-related work.

Intended publications

The following manuscript has been submitted and is currently under review in *Energies*: P. Kotsampopoulos, G. Saridaki, **J. Kour,** and H. H. Fayek, "Ship Electric Propulsion Based on Hydrogen Fuel Cell, Batteries, PVs, and WASP: Energy Management, Dynamics, and Converter-Driven Stability."

Expected impact

Overall, the work is expected to facilitate the development and validation of a PHIL-based test bench for low-inertia power systems. It experimentally validates advanced control strategies for integrating renewable energy sources, including grid-forming operation of inverter-based resources, thereby improving system stability, frequency response, flexibility, and sustainability of future power networks. The work aligns closely with key European policy frameworks supporting the transition toward low-carbon, resilient power systems. In the European context, the proposed grid-forming control architectures and PHIL-based validation directly contribute to the objectives of the European Green Deal, REPowerEU, and Fit for 55, which target high renewable penetration, enhanced system flexibility, and deep decarbonization of energy systems.

From an Indian perspective, the work supports national priorities under the National Action Plan on Climate Change and the National Solar Mission, which emphasize large-scale renewable integration and reduction in carbon intensity. The integration of battery energy storage systems with PV and wind generation aligns with grid modernization and flexibility requirements identified by the Central Electricity Authority, particularly in addressing stability challenges associated with high renewable penetration and reduced system inertia.

Overall, the proposed work establishes a scalable and experimentally validated framework for grid-forming operation of inverter-based resources, contributing to compliance with evolving grid code requirements, including fault ride-through and reactive power support, and supporting both European and Indian pathways toward sustainable, secure, and resilient energy systems.
Conclusions / additional comments
The proposed work established a framework of grid-forming control architectures that integrate BESS with PV and wind systems. Furthermore, the combined CHIL and PHIL validation approach ensures realistic and reliable performance evaluation, confirming stable system operation under faults, load variations, and contingency scenarios. Overall, the work highlights a scalable, experimentally validated pathway to strengthen modern power systems with high renewable penetration, while laying a strong foundation for future advancements in grid-forming control and real-time implementation. The access also enhanced the technical insights for performing a successful PHIL simulation.
Did you complete the European Commission User questionnaire https://ec.europa.eu/eusurvey/runner/RIsurveyUSERS?
☑ Yes ☐ No

Feedback – HSE, Ethics and Satisfaction

Please rate on a scale from 1 (excellent) to 5 (poor). Feel free to provide additional comments

Practical information on how to apply for Transnational Access and the overall application process

1 (excellent)	2	3 (neutral)	4	5 (poor)
☑	☐	☐	☐	☐

Comment

Information provided, once your project was accepted, on how to proceed

1 (excellent)	2	3 (neutral)	4	5 (poor)
☐	☑	☐	☐	☐

Comment

Support received at the site(s) regarding technical/scientific matters and logistics	Have you got sufficient support from the RI staff during the project? If not, please, specify the problems. ☑Yes ☐ No
Please specify any problems	
RI extension / upgrades required	In your opinion, is the RI needed to be upgraded? If yes, please give an explanation. ☐ Yes ☑No
Please specify	
Problems with local regulations	Have you had any problems with regulations of the visited RI owner (HSE, lab working hours, etc.)? If yes, please, specify

	☐ Yes ☑ No
Please specify	
Health and safety issues	Did you encounter any health or safety issue during your research? Please provide details. ☐ Yes ☑ No
Please provide details	
Environment & Ethics	Did your research involve the use of elements that may cause harm to the environment, to animals or plants? Please provide details. ☐ Yes ☑ No
Please provide details	
Environment & Ethics	Did your research deal with endangered fauna and/or flora and/or protected areas? Please provide details. ☐ Yes ☑No
Please provide details	
Environment & Ethics	Did your research involve the use of elements that may cause harm to humans, including research staff? Please provide details. ☐ Yes ☑ No
Please provide details	
Environment & Ethics – Dual use	Does your research have the potential for military applications? Please provide details. ☐ Yes ☑ No
Please provide details	
Environment & Ethics – Misuse	Does your research have the potential for malevolent /criminal/terrorist abuse? Please provide details. ☐ Yes ☑No
Please provide details	
Environmental issues	Were any potentially dangerous substances (materials / gases etc.) released into the environment (atmosphere, water, or land)? Please provide details. ☐ Yes ☑ No
Please provide details	
Ethics issues	Are there any other ethics issues that should be taken into consideration? Please specify

	☐ Yes ☑ No
Please provide details	
Overall impression of communication and interaction after finishing your TA and related work	1 (excellent): ☑; 2: ☐; 3 (neutral): ☐; 4: ☐; 5 (poor): ☐
Comment	
Suggestions for facilities not included in RISEnergy which you would use for your research	
The host institute was well equipped with all the resources required to conduct the simulation and experiments under the accepted proposal.	
Suggestions how RISEnergy can improve future TA programme, how to make the TA more impactful and how to enable the achievement of high TRL levels	
The RISEnergy TA programme is already effective, and its future impact can be enhanced by strengthening industry collaborations.	

Feedback – Pro-active Innovation Support

Awareness	Did you know about the pro-active innovation support of RISEnergy? ☐ Yes ☑No
[Please specify how you learned about the pro-active innovation support]	
Personal experience	Have you taken advantage of or benefited from the pro-active innovation support? ☐ Yes ☐ No
[Please provide details]	
Information/service provided by the pro-active innovation support?	1 (excellent): ☐; 2: ☐; 3 (neutral): ☐; 4: ☐; 5 (poor): ☐
[Please provide details]	

I declare that the above provided information and especially that information on the number of days visited the RI is correct.

☑I have read the RISEnergy privacy policy for participation in the RISEnergy TA and consent to participation and the associated data processing.

Your full name:

Your signature: