Final report

1. Project details

Project title	TEST4IEA - ”IEA Harmoniserede Testmetoder til integration af El og Energi Systemer under IEA-ISGAN Annex 5”
File no.	64020-1107
Name of the funding scheme	EUDP
Project managing company / institution	DTU
CVR number (central business register)	30060946
Project partners	DTU
Submission date	01 April 2023

2. Summary

This project aims to strengthen the Danish leadership of IEA-ISGAN-SIRFN[1] Task on Power System Testing (PST). The field of work is **integrated power system testing** which accelerates and de-risks the development of control solutions in electric energy systems. This project will support the consolidation and harmonization of the state of the art in power system integration testing via the PST activity and support the development and dissemination of harmonized testing methods. The project delivered a test planning procedure that accommodate test system design, and an exemplary benchmark test system for electric vehicle integration studies. The developed framework shows promise for further applications and gaps exist in the existence of benchmark systems for inverter-dominated power systems and reference ICT networks to be included in multi-domain test systems. The project organised several workshops with mainly internal participants (as hybrid events in 2022), and disseminated preliminary results at industry-near conferences, both online (CIRED 2021), and on-site (IRED 2022, Adelaide).

Dette projekt har til formål at styrke den danske ledelse af IEA-ISGAN-SIRFN Task on Power System Testing (PST). Arbejdsområdet er integrerede elsystemtest, som accelererer og mindsker risikoen for udviklingen af styringsløsninger i elektriske energisystemer. Dette projekt vil støtte konsolidering og harmonisering af state-of-the-art inden for elsystemintegrationstestning via PST-aktiviteten og støtte udvikling og formidling af harmoniserede testmetoder. Projektet leverede en testplanlægningsprocedure, der rummer testsystemdesign, og et eksemplarisk benchmark-testsystem til undersøgelser af integration af elektriske køretøjer. Den udviklede ramme viser lovende for yderligere applikationer, og der er gaps i eksistensen af benchmark-systemer for

[1] International Energy Agency - International Smart Grid Action Network, Annex 5: Smart grid International Research Facility Network

inverter-dominerede strømsystemer og reference-IKT-netværk, der skal inkluderes i multi-domæne testsystemer. Projektet organiserede adskillige workshops med hovedsageligt interne deltagere (som hybride begivenheder i 2022) og spredte foreløbige resultater på industri-nær konferencer, både online (CIRED 2021) og på stedet (IRED 2022, Adelaide).

3. Project objectives

This project aims to strengthen and further develop the Danish leadership of IEA-ISGAN-SIRFN[2] Task on Power System Testing (PST). The field of work is **integrated power system testing** which accelerates and de-risks the development of essential control solutions in electric energy systems. The validation of such integrated solutions is essential as modern system designs are increasingly modular and rely on soft controls and communications. Such modular approach bears the risk that potentially critical interactions are deferred to testing in the field. Power system integration testing promises the alternative of assessing actual system solutions (e.g. control hardware) on risk-free laboratory environment, as well as testing, updating and validating simulated development test platforms with relevant features, such as the ability to emulate communication and interactions of modular solutions.

This project will support the consolidation and harmonization of the state of the art in power system integration testing via the PST activity, and particularly emphasize on the dialogue with Danish Industry to bring their expertise and commercial interest into the international harmonization activities.

This project aims to support the development and dissemination of harmonized testing methods for state-of-the-art smart grid and energy systems integration solutions, that are based on algorithms, electronics and communication, not on passive electrical equipment.

Examples of applications that fall under this scope of system testing include: coordinated dispatch of storage and flexibility/ storage (aggregators), ancillary services from renewable sources (wind farms hybrid power plants), inertia services from renewable power plants, microgrids, coordinated protection.

4. Project implementation

The tasks outlined in the project description, especially the technical work progressed initially as planned. The collection of test cases was successful. After a while, the effect of the lack of in-person meeting became apparent, as the necessarily more challenging discussions among researchers could not take place due to travel and meeting restrictions in the project period.

Several delays were incurred during the project execution, but overall the project proceeded in the direction that was planned for. The project plan had to be updated a few times, as large delays were incurred and can be attributed to the pandemic context.

A key unforeseen issue was the COVID-19 pandemic which hit this project at the outset. It meant that for two years no in-person meetings were held.

[2] International Energy Agency - International Smart Grid Action Network, Annex 5: Smart grid International Research Facility Network

5. Project results

With respect to the original aims, the following was achieved:

- support the consolidation and harmonization of the state of the art in power system integration testing via the PST activity,
  - A range of relevant test cases and types of testing was identified and documented
  - A definition for power system testing was formulated and published
- with emphasis on the dialogue with Danish Industry to bring their expertise and commercial interest into the international harmonization activities
  - Danish industry cases were included in the collection of test cases that formed the basis for the harmonisation attempt
  - One joint paper with Dansk Energi (now GPD) was published
  - The dialogue was maintained with SIEMENS Wind Power (one of the original support letters), who perform the considered type of testing at an advanced level, but it broke off with the others – for the other existing contacts the task results remained too much at a conceptual level
- to support the development and dissemination of harmonized testing methods for state-of-the-art smart grid and energy systems integration solution
  - A joint journal paper on state of the art testing methods was published, and two separate industry conference papers on system testing at DTU were published
  - Based on the mentioned definition for power system testing, a *test development* procedure was formulated, and published
  - The consolidation of the system testing definition and procedure included a new emphasis on benchmark systems, which was not anticipated in the project aims.
  - Instead of a harmonized testing procedure, the project developed a specific benchmark system as a reference case (described in a poster). The final publication of this reference case is close to completion.

Overall, the project results were in line with the stated objectives, however, the maturity achieved by the end of the project was lower than expected. The originally plan which used technology clusters to drive the harmonisation was not practical (possibly due to the pure web-based communication/lack of face-to-face meetings, possibly due to too much diversity within the defined clusters), so that the approach was shifted. Eventually, results were obtained by a two-level approach: a methodology-oriented working group and a single testing-technology area.

The results at this point help the consolidation of existing technology; specifically testing labs see added value in the test development procedure and the new opportunities to develop system reference tests. Follow-up project work will aim at utilizing the consolidated procedure in new testing applications, and aim to demonstrate an acceleration effect of the integration testing on the TRL escalator.

The dissemination of results to Danish stakeholders remained limited to direct dialogue with a) members of the Danish standard subcommittee to TC57, and b) SIEMENS Wind Power. The intended workshop has not been organized (yet – there is one in planning, but delayed till Q3-Q4/2023).

The other planned non-academic dissemination activities could not be implemented fully, partly because non-academic staff resigned and could not be replaced. The videos remained in script form, a press release in draft form, and the case story for PowerLabDK was abandoned during the department restructuring process. As all of the above activities were not concluded, also the associated budget was returned to the funding agency.

6. Utilisation of project results

The strategic outcome of the project is adopted by ISGAN-SIRFN, and will be used as part of the current re-organisation of the SIRFN work programme. The power system testing methodology and developed benchmark will be treated as assets of the SIRFN working group. DTU (project lead), also adopts the results as methodology to shape further development projects. Since the dialogue with DK stakeholders is ongoing, some adoption in this area can be expected, but is subject to future initiatives. Specific initiatives together with Japanese collaborators have been inquired (from Japanese), but currently lack a suitable Danish or European funding model.

The key aim of the proposed methods is to assist in accelerating technology development and technology maturity escalation for system-based technologies in energy. Since SIRFN and the task led here are international, with participation from around the globe (e.g. Japan, India, US, Australia, many EU countries) Since Danish leadership in energy technology and facilitating its export is sought after, maintaining a visible footprint on the ISGAN-SIRFN activities appears to be in line with Danish energy policy objectives. The carbon emission reduction potential of international collaborations, for example. through knowledge and technology exchange with Indian researchers, is considerable.

7. Project conclusion and perspective

The concrete project results were achieved by leveraging the workforce from all the SIRFN participants, which both increased the impact of the project and the set scope. The concrete project outcomes, a test design framework and a concrete new benchmark system are summarized by the two IRED posters (see appendices).

The main insights and learnings from the project were generated in two workshops during the last project year (both organized as hybrid events): one workshop hosted in Denmark in May 2022, the other in Adelaide as a side event to the IRED conference.

In short, the insights can be summarized as “Power system testing – there is still work to do”.

Of the many research questions and next steps in the researched technology area which have been identified, only few can be mentioned. A clear need is to demonstrate the full testing methodology on the test system/benchmark which has been developed. Both the developed benchmark system and the methodology can be further extended. The methodology can be made more specific for types of testing, e.g. to distinguish controller testing from component-system integration testing procedures and needs. The developed benchmark/test system can also be ‘advanced’ to represent with higher accuracy a range of dynamic interaction phenomena, or to include a reference communication system, etc. A closely related field of study is that of the dynamics of inverter-dominated power systems, and it will be relevant to extend the existing testing methods for inverters to more system-oriented test cases.

It appears that benchmark systems, as promoted by the developed methodology, have a role as technology development accelerator. In the power systems field, there is a wide array of “classical” benchmark test systems that facilitated lifting of conceptual solutions from TRL2-TRL4. In context of systems integration testing and with modern (remote) Hardware in the loop testing methods, this ‘test system’ role can be extended with emulated test systems, up to TRL6 as evidenced in several reported test cases. Further exploring the potential of systems integration testing with benchmark test systems, there is a chance to extend the validation methods

to include automated screening tests on a wide range of test scenarios. Especially for testing AI-based solutions in the energy sector, such screening tests are going to be relevant to increase the trustworthiness of AI-based solutions.

Two new avenues of further development have been uncovered by this project and may be pursued:

1. To identify significant test cases and associated test system candidates to develop and solidify benchmark test systems
2. To further develop the methods for generating edge test cases (worst case scenarios) for testing.

One technology for the first avenue may be test systems for inverter-dominated power systems (when conventional generators are almost fully phased out); for the second avenue on testing method development is currently difficult to fund directly, but may be included as part of technology research projects. These avenues will also influence the reorganization of the IEA ISGAN SIRFN working group and determine related future initiatives.

8. Appendices

- Homepage: https://www.iea-isgan.org/our-work3/wg_5/research-topics-of-sirfn/pst/
- Journal article:
  - Montoya, J., Brandl, R., Vishwanath, K., Johnson, J., Darbali-Zamora, R., Summers, A., Hashimoto, J., et al. (2020). Advanced Laboratory Testing Methods Using Real-Time Simulation and Hardware-in-the-Loop Techniques: A Survey of Smart Grid International Research Facility Network Activities. *Energies*, *13*(12), 3267. MDPI AG. Retrieved from http://dx.doi.org/10.3390/en13123267
  - https://www.mdpi.com/1996-1073/13/12/3267
- CIRED(2021a):
  - Gehrke, O., Ziras, C., Heussen, K., Jensen, T. V., & Bindner, H. W. (2021). Testbeds for active distribution networks: case experience from SYSLAB. In *Proceedings of 26th International Conference and Exhibition on Electricity Distribution* [1077] Cired.
  - link
- CIRED(2021b):
  - Clavijo, J. I. P., Douglass, P. J., Heussen, K., & Prostejovsky, A. M. (2021). Loss-of-mains detection in a household PV inverter: Test of the effect of active and reactive power balance. In *Proceedings of 26th International Conference and Exhibition on Electricity Distribution* [577] Cired.
  - link
- IRED poster (PST)
  - Heussen, K., Obusevs, A., Stanev, R., Pombo, D., Gehrke, O., O'Donnell, T., Strasser, T. I., & Johnson, J. (2022). *Sirfn Power System Testing: A Cyber-Physical Power System Testing Framework for Power System Transformation*. Poster session presented at 9th International Conference, Integration of Renewable & Distributed Energy Resources, Adelaide, South Australia, Australia.
  - Link
- IRED poster (VEHICLE)
  - Obusevs, A., Mächler, A., Korba, P., Pellegrino, L., Varghese, S., Ninad, N., Syed, M., Heussen, K., & Gehrke, O. (2022, October 24). Development of benchmark system for charging control Investigation. *9th International Conference, Integration of Renewable & Distributed*

Energy Resources (IRED), Adelaide, Australia, 24-26 October 2022. https://doi.org/10.21256/zhaw-26561

- link