WORK SUMMARY

IRP10: ENERGY MANAGEMENT SYSTEMS FOR RESIDENTIAL MICRO-GRIDS WITH INTEGRATED ENERGY STORAGE

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ESR BIO & ACTIVITIES

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SmartGYsum training period: 01 Nov 2023 – 30 June 2025

Secondment: 23 January 2026-23 March 2026

Senergy Products and Services SL / University of Extremadura

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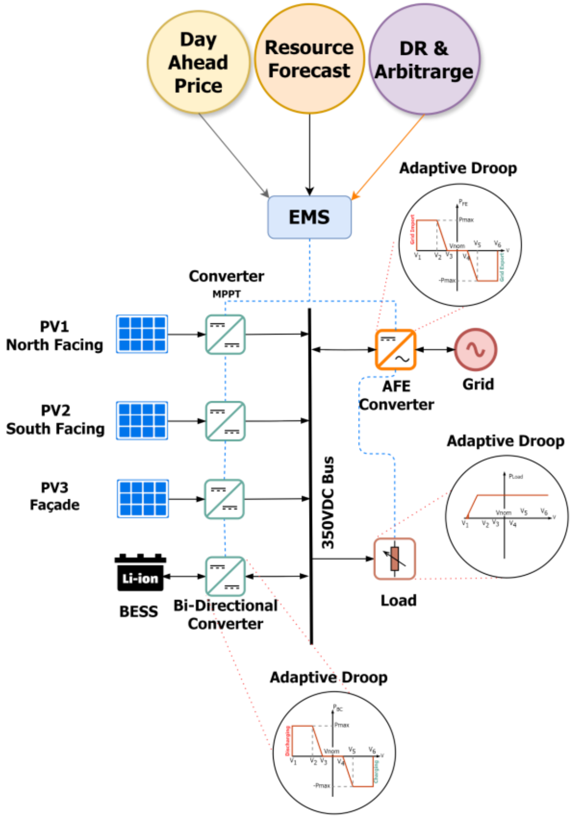
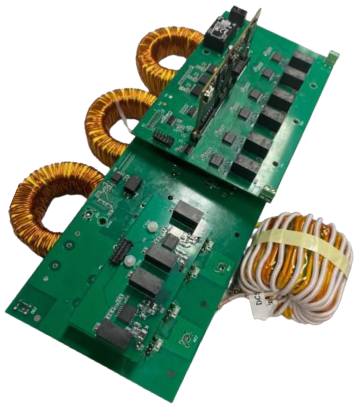
IRP SUMMARY & OBJECTIVES

IRP10: Energy management systems for Residential micro-grids with integrated energy storage

Optimization of building energy performance by integration of energy storages and their coordinated control

1. **Design resilient and efficient power electronic converters and energy routers for the DC Residential Energy Management System(EMS)**
2. Design and implementation **of Energy Management System** for the **DC Residential Microgrid** (e.g. *Data Curation, Visualization*, and *Coordinated System Control*)
3. Design business models for Smart Buildings and Prosumer Communities (Energy trading and Arbitrage)
4. Verification in the living lab – **TalTech Residential DC Innovation Hub**
5. Testing and Verification of the designed **EMS** in **RT-HIL** Platform





Single Stage Active Front End Converter

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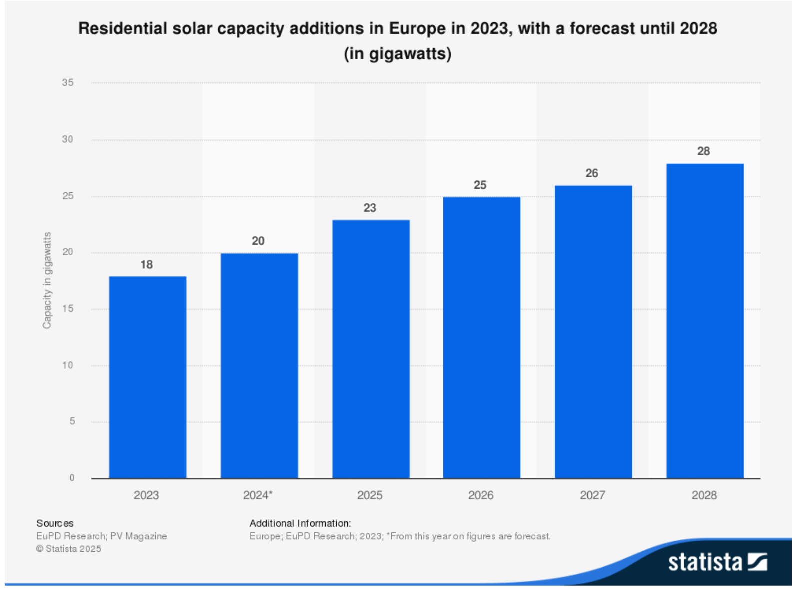
BACKGROUND

- **EU Green Deal** and government subsidy boost the adoption of renewables in residential buildings
- Furthermore, to reach **A-class energy efficiency in buildings**, homeowner are installing PV in their houses
- Most European countries have **high renewable penetration**, which leads to **lower feed-in tariffs**, **grid sales fees**, and renewable subsidy payments
- In the future, selling surplus may not be possible due to **inadequate grid capacity**, and may not be effective to **break even**



https://www.statista.com/statistics/1615988/residential-solar-capacity-additions-forecast-europe/

SOLUTION: DC MICROGRID WITH ENERGY MANAGEMENT SYSTEM & PROMOTING SELF-CONSUMPTION

- In a DC Residential Microgrid, issues like phase imbalance, low efficiency, and multi-stage losses are eliminated.
- Droop-controlled converters and EMS enable effective asset control for higher self-consumption.
- An active front-end converter allows grid support, energy trading, and arbitrage.

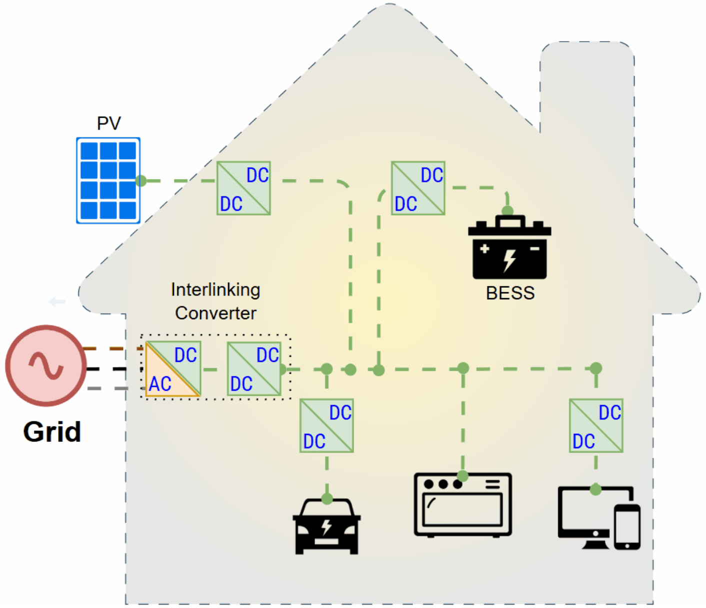


Fig: House with **DC converter** and **appliances**

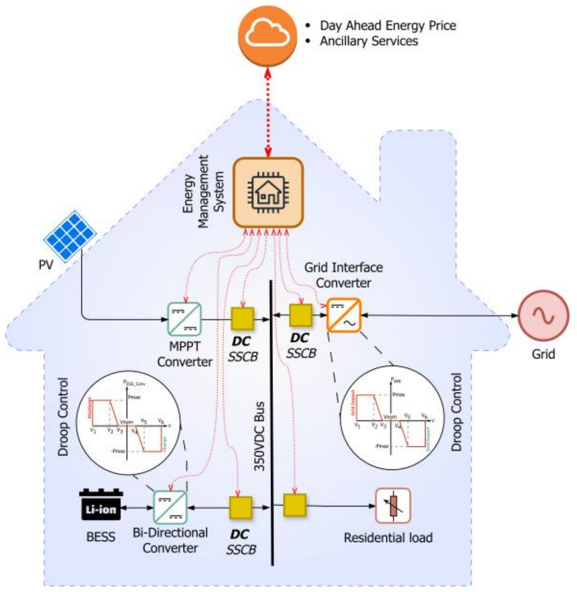


Fig: DC residential microgrid with **energy management system**

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OUTCOMES

- Design of efficient **grid-interface converters** for DC residential microgrids.
  - A single-stage active front-end converter was designed and demonstrated
  - Softstart, Blackstart, and fault-tolerant methodologies were demonstrated
  - Reactive power control methodology was demonstrated

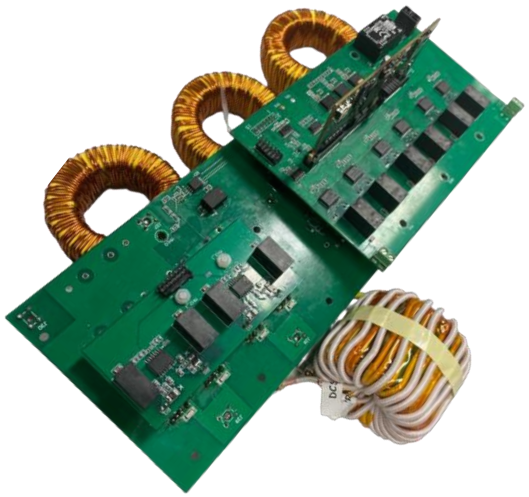


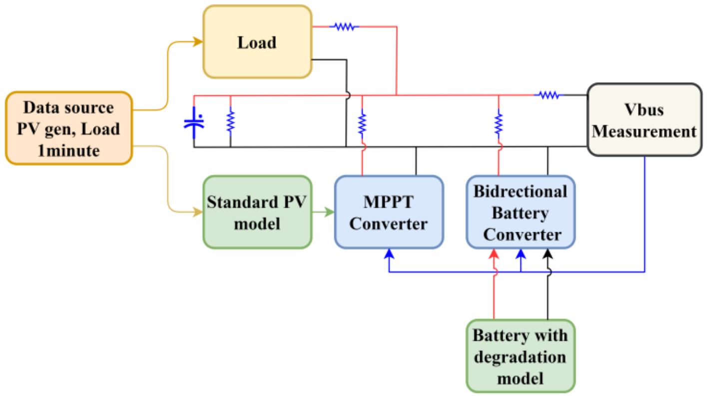
Fig: Single-stage AC-DC Converter

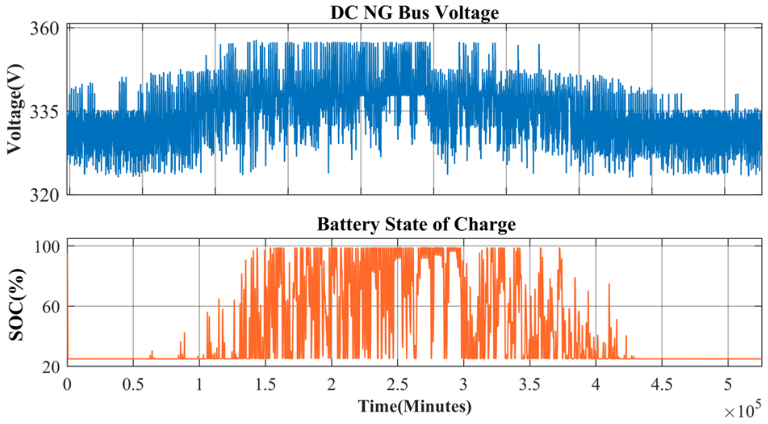
OUTCOMES

- Design and implementation of the **Energy Management System** for the DC Residential Microgrid (e.g., Data Curation, Visualization, and Coordinated System Control)
  - Modeled DC residential microgrid in SIMULINK/PLECS
  - Proposed two different battery management strategies based on adaptive droop
  - Worked on sensor correction, and voltage deviation prediction.
  - Additionally, worked on integration of other ESS (Supercap, HESS)
  - Implemented software and hardware solutions for DC uGrid test bed(for EMS testing and others.)
  - Contributed to other research activities, dissemination activities.

OUTCOMES

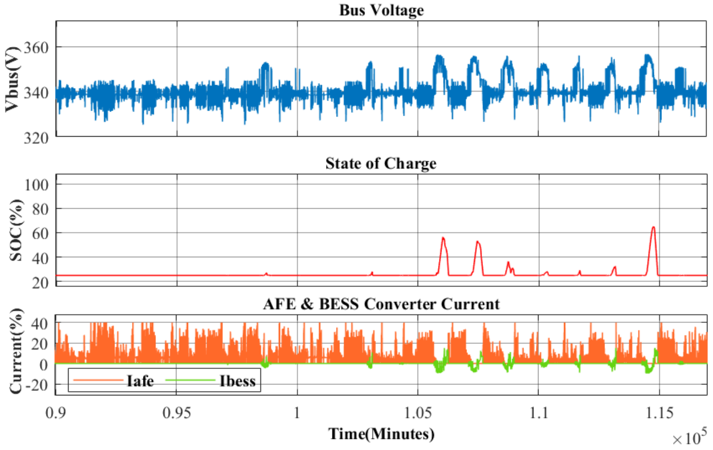
DC residential microgrid in SIMULINK/PLECS



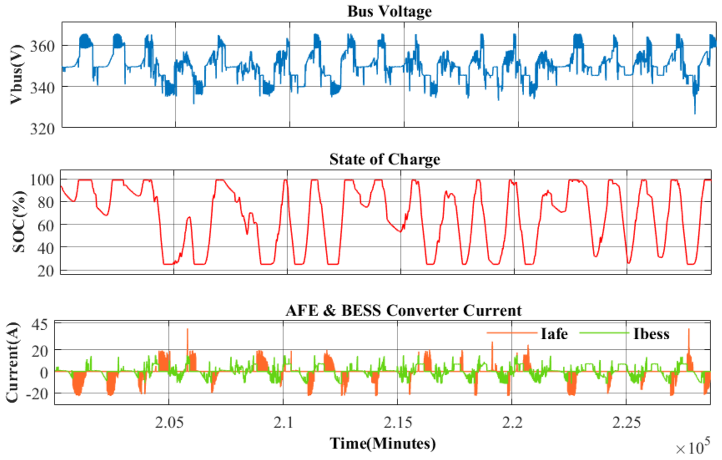


DC bus voltage and battery SOC state for the whole year.

DC bus voltage and battery SOC state for the whole year.



Bus voltage, SOC, and converter currents for 20 winter days.



Bus voltage, SOC, and converter currents for 20 summer days.

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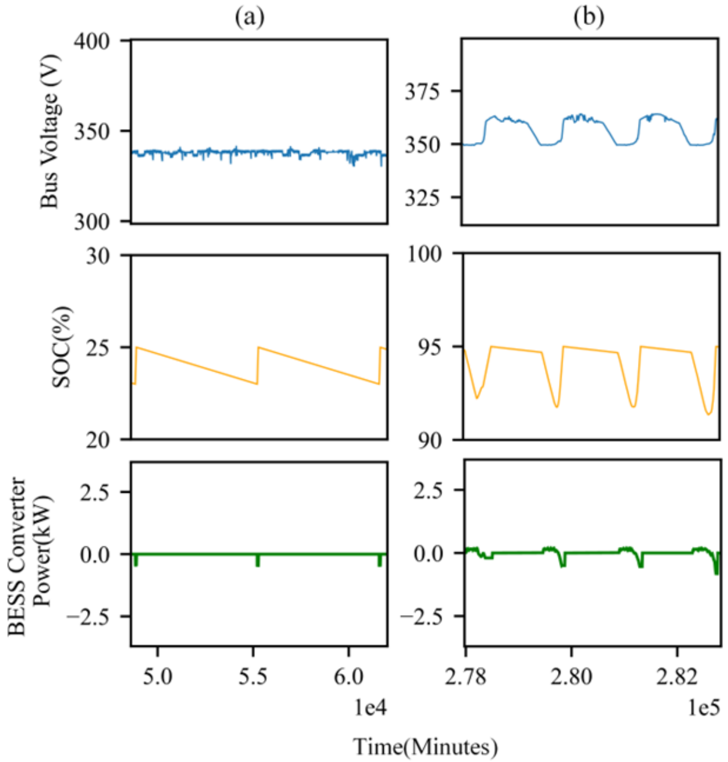
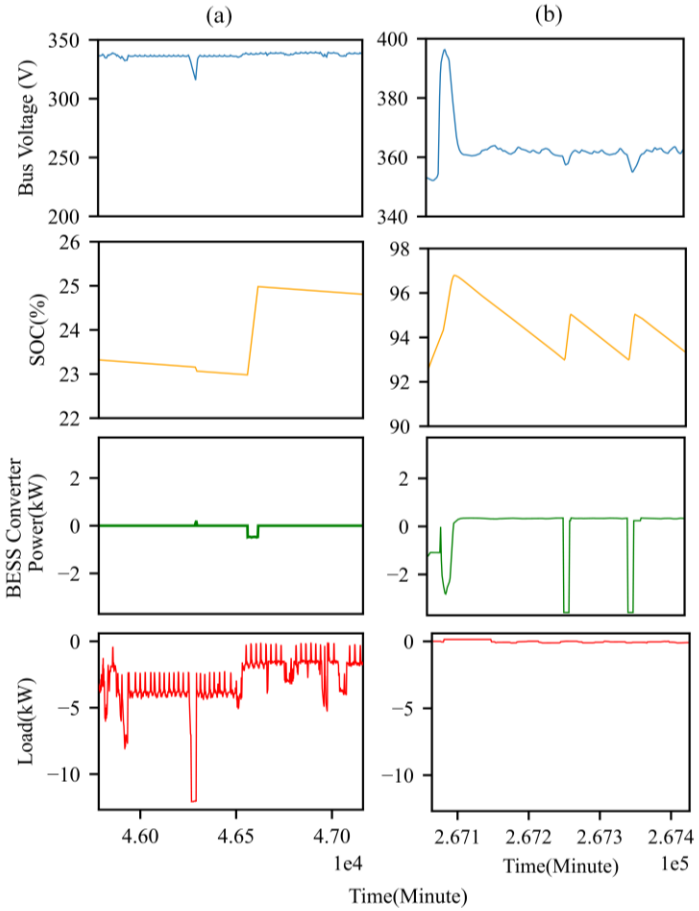
OUTCOMES

- Two Proposed battery management strategies based on adaptive droop
  - **Hysteresis control**
  - Continuous Compensation

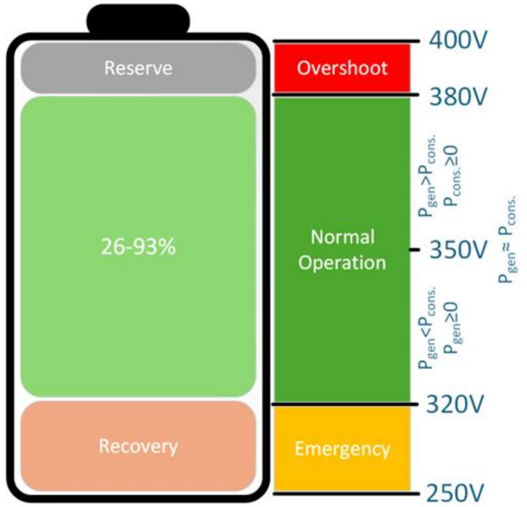


Normal operation with BESS mgmt.



Emergency and transient with BESS mgmt.

DC grid operating band, Vnom= 350V



ESS allocation based on condition

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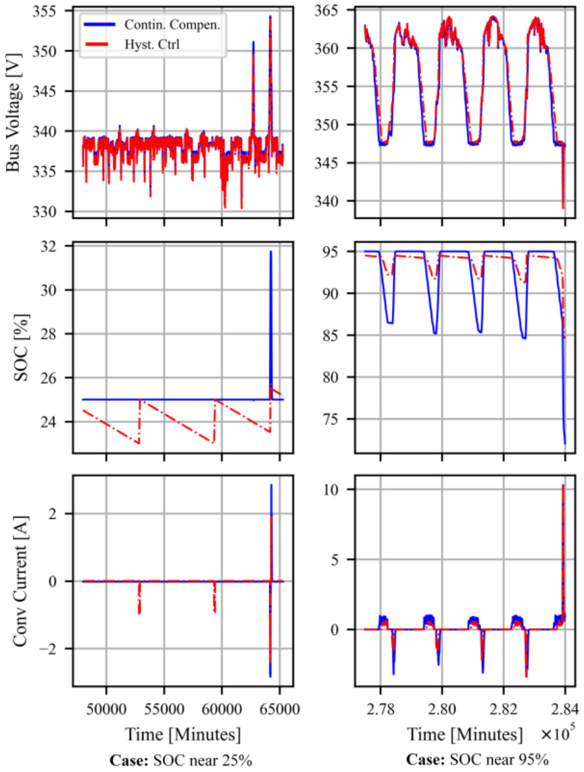
OUTCOMES

- Two Proposed battery management strategies based on adaptive droop
  - Hysteresis control
  - **Continuous Compensation**



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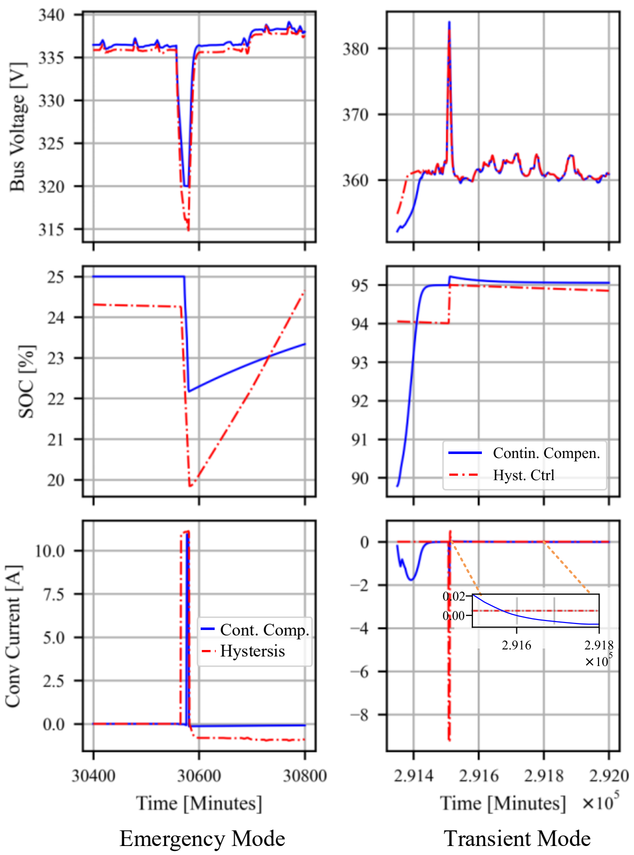
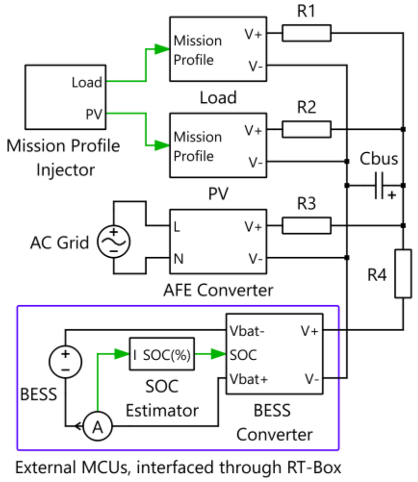
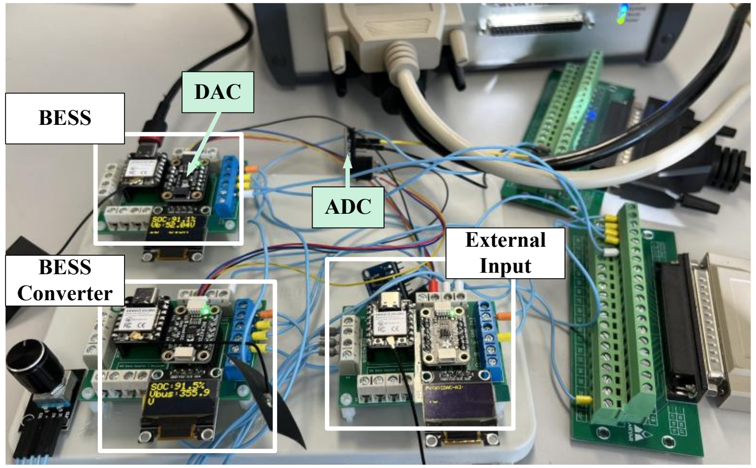


Emergency and transient with BESS mgmt.



HIL Setup Schematic

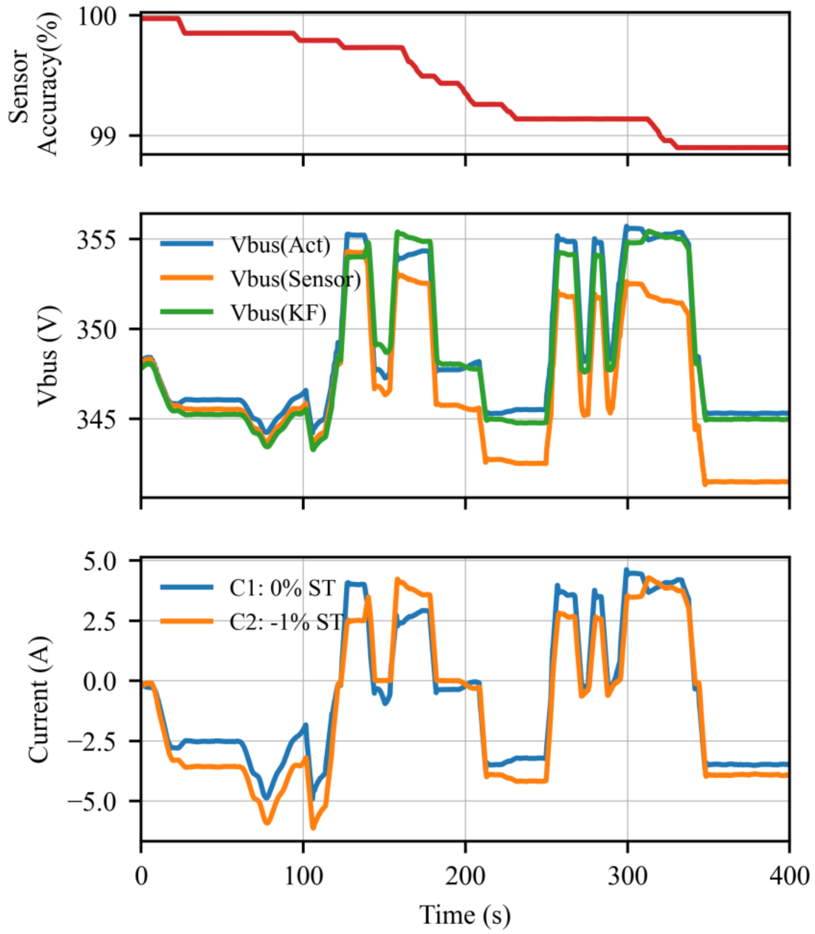


HIL Setup

OUTCOMES

Sensor correction, and voltage deviation prediction.

- Deadband/Droop curve inclination-based approach,
- **Separate sensor correction submodule (UKF based)**

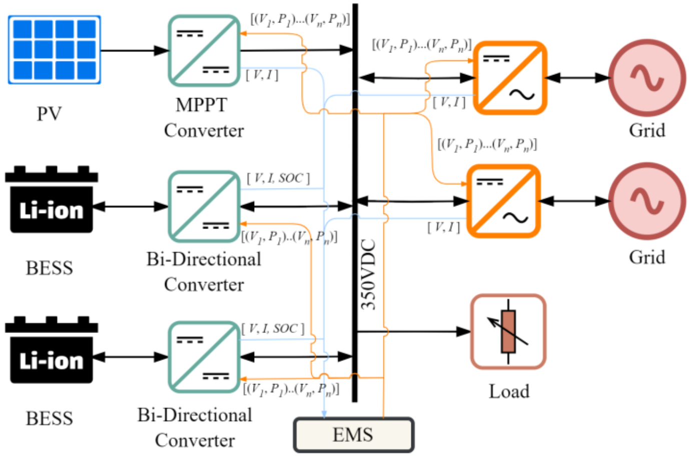


Sensor bias/drift correction using UKF and current sharing between two identical converters, one with 0% tolerance and the other has gradually added tolerance up to -1%.

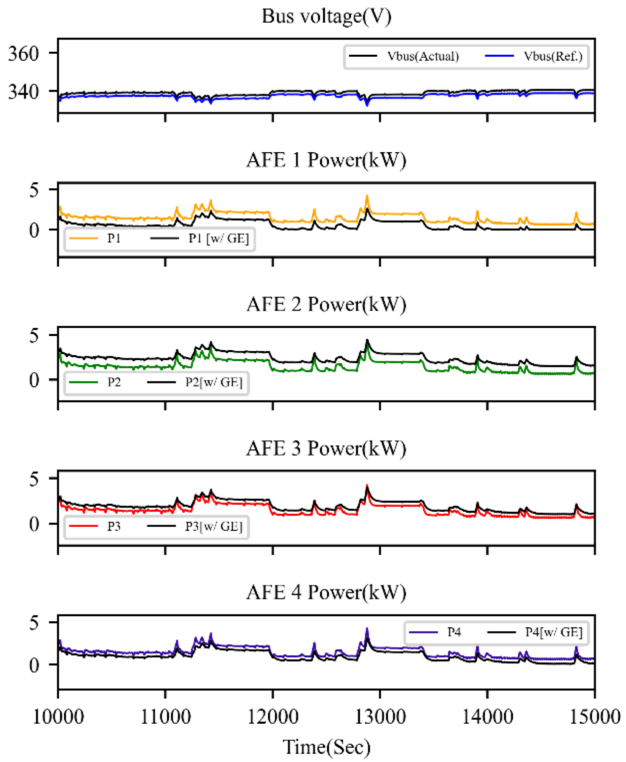
OUTCOMES

SmartGY SUM

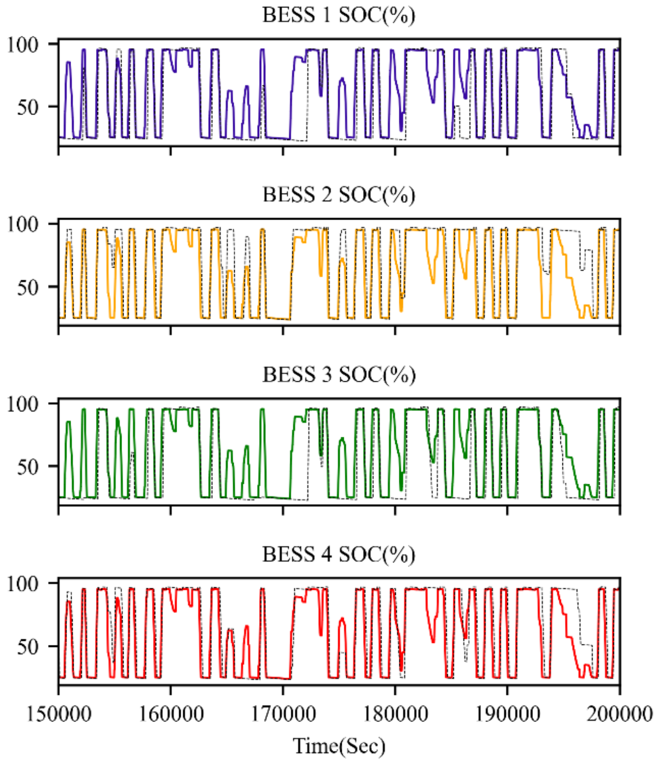
Simulation of centralized uGrid for power and SOC balancing similar converters



Multi-asset DC nanogrid with centralized EMS.



Power balance through Droop curve shifting.



SOC balance through Droop curve shifting.

OUTCOMES

- Design and implementation of the **Energy Management System** for the DC Residential Microgrid (e.g., Data Curation, Visualization, and Coordinated System Control)
  - A visualization and logging platform was set inside the DC Innovation Hub
  - Analysis of BESS integration in DC grid and BESS management methods were studied.
  - Price-based centralized microgrid EMS was demonstrated.

Fig: Live demo of proposed price-based EMS in DC Hub

Fig: DC Microgrid monitoring platform

OUTCOMES

- Testing and Verification of the designed EMS in the RT-HIL Platform / Verification in the living lab
- Run two simulation models of a DC residential microgrid with price-based adjustment and battery management on HIL Platform (PLEXIM RT BOX-1)

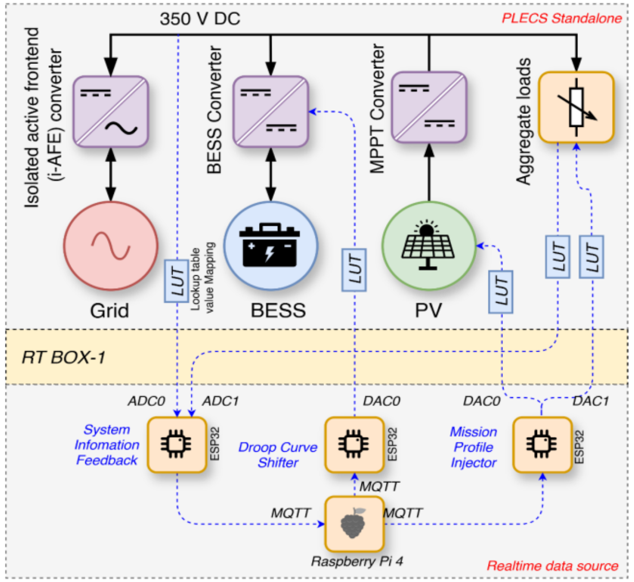


Fig: Microgrid with EMS model for RT-HIL Simulation

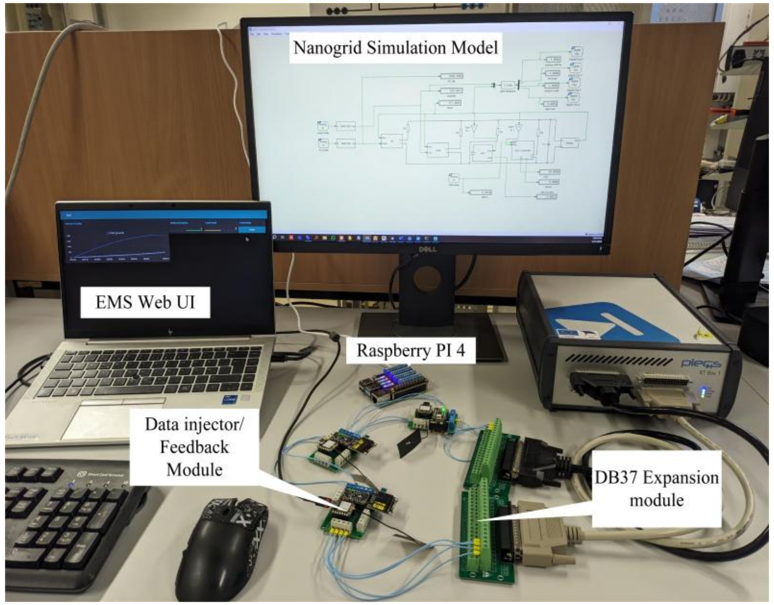


Fig: EMS simulation setup

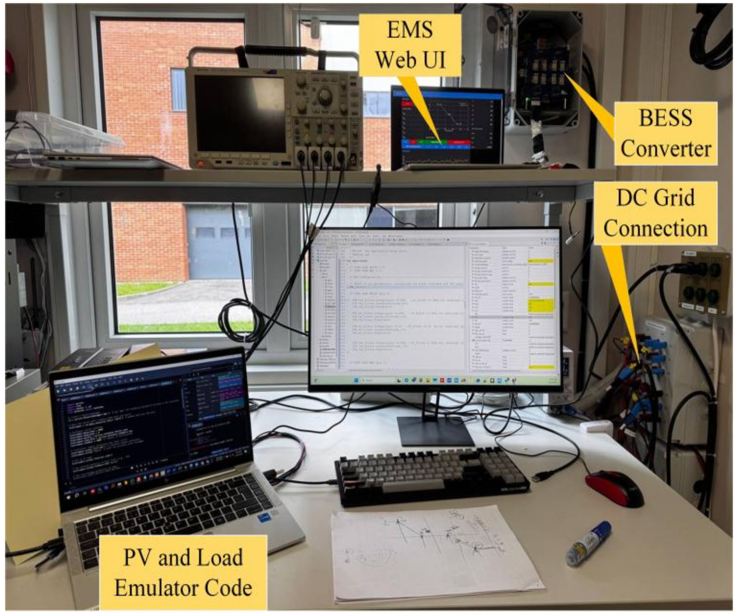


Fig: Actual system test in living lab

OUTCOMES

SmartGY SUM

Design business models for Smart Buildings and Prosumer Communities (Energy trading and Arbitrage)

- Attended Doctoral Schools related to business models and Business pitches.
- 2nd Runners-up, Business canvas pitch-competition, 6th Doctoral School of SmartGYsum

Awards

- 1st runner-up (Group) - Development work of the year 2024, Tallinn University of Technology
- 2024 TalTech Green Action award (Group)
- Best Student Paper-2nd Place, 7th International Conference on DC Microgrids (ICDCM 2025)
- IEEE IES Student and Young Professionals Paper Assistance

Publications

- 2 Published journal articles (SH:2)
- 2 Book chapter (SH:1)
- 10 Conference proceedings (SH:6)
- 1 Dataset (SH:1)

	Journal	Conf. paper/ Book chapter	Dataset
ETIS Classification	1	3	6
Subclass	1.1	3.1	6.7
Publications	***2***	**15**	**1**
Total		***17***	

OUTCOMES

Journal Article

1. Hasan, **Sayeed**; Blinov, Andrei; Chub, Andrii; Vinnikov, Dmitri (2025). Solar PV Generation and Consumption Dataset of an Estonian Residential Dwelling. Scientific Data, 12, #481. DOI: 10.1038/s41597-025-04747-w.
2. Sibiński, M.; Chub, A.; **Hasan**, S.; Rogowski, S. (2025). Enhancement of residential PV energy storage system by supercapacitor battery – high spatial resolution data analysis. Proceedings of the Estonian Academy of Sciences, 74 (2S), 269–280. DOI: 10.3176/proc.2025.2S.01.

Book Chapter

1. Blinov, A.; Roasto, I.; Chub, A.; Emiliani, P.; Vinnikov, D. (2023). Electric Power Management and Control in DC Buildings — State-Of-The-Art and Emerging Technologies. In: Power Quality: Infrastructures and Control. (67–96). Springer. (Studies in Infrastructure and Control). DOI: 10.1007/978-981-19-7956-9_3.
2. S. **Hasan**, N. Yadav, A. Chub, A. Blinov, and D. Vinnikov, “A Centralized Energy Management System for Droop Controlled DC Nanogrids Using Binary Setpoint Shifting,” in Compilation of selected SMARTGYsum project scientific results, in Smart and Green Energy Systems. , pp. 165–179. Book Chapter Published ISBN: 978-84-09-81019-2

Conference Proceedings

1. Emiliani, P.; Blinov, A.; Peftitsis, D.; Giannakis, A.; Vinnikov, D. (2022). Reactive Power Control for Bidirectional Isolated High-Frequency Link Converter. 2022 International Symposium on Power Electronics, Electrical Drives, Automation and Motion, SPEEDAM 2022. IEEE, 372–376. DOI: 10.1109/SPEEDAM53979.2022.9842131.

OUTCOMES

Conference Proceedings

2. Emiliani, P.; Blinov, A.; Chub, A.; De Carne, G.; Vinnikov, D. (2022). Black Start and Fault Tolerant Operation of Isolated Matrix Converters for dc Microgrids. IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society: 48th Annual Conference of the IEEE Industrial Electronics Society, Brussels, Belgium, 17-20 October 2022. IEEE, 1−5. DOI: 10.1109/IECON49645.2022.9968735.
3. Emiliani, P.; Blinov, A.; Chub, A.; De Carne, G.; Vinnikov, D. (2022). DC Grid Interface Converter based on Three-Phase Isolated Matrix Topology with Phase-Shift Modulation. IEEE 13th International Symposium on Power Electronics for Distributed Generation Systems (PEDG): Kiel, Germany, 26-29 June 2022. IEEE, 1−6. DOI: 10.1109/PEDG54999.2022.9923256.
4. Verbytskyi, I.; Blinov, A.; Emiliani, P.; Galkin, I. (2022). Digital Control of PFC Rectifier with Combined Feedforward and PI Regulator. IECON 2022- 48th Annual Conference of the Industrial Electronics Society: Brussels, Belgium, 17-20 October 2022. IEEE, 1−6. DOI: 10.1109/IECON49645.2022.9968509.
5. Arena, G.; Vinnikov, D.; Chub, A.; De Carne, G. (2022). Accuracy Analysis of Dual Active Bridge Simulations under Different Integration Methods. 2022 AEIT International Annual Conference, AEIT 2022: AEIT 2022, Rome, Italy, 03-05 October 2022. IEEE, 1−6. DOI: 10.23919/AEIT56783.2022.9951711.
6. Arena, Gabriele; Emiliani, Pietro; Chub, Andrii; Vinnikov, Dmitri; De Carne, Giovanni (2023). DC Fast Charging of Electric Vehicles: A Review on Architecture and Power Conversion Technology. 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG): 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Tallinn, Estonia, Jun. 14-16, 2023. IEEE, 1−6. DOI: 10.1109/CPE-POWERENG58103.2023.10227492.
7. Emiliani, Pietro; Blinov, Andrei; De Carne, Giovanni; Arena, Gabriele; Vinnikov, Dmitri (2023). Three-Phase Four Wire High-Frequency Link Converter for Residential DC Grids. 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG): Tallinn, Estonia, June 14-16 2023. IEEE, 1−5. DOI: 10.1109/CPE-POWERENG58103.2023.10227416.

OUTCOMES

Conference Proceedings

8. Emiliani, Pietro; Blinov, Andrei; De Carne, Giovanni; Arena, Gabriele; Vinnikov, Dmitri (2023). Predictive Control for Isolated Matrix Rectifier Without Current Distortion at Sector Boundary. 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG): Tallinn, Estonia, June 14-16 2023. IEEE, 1–6. DOI: 10.1109/CPE-POWERENG58103.2023.10227405.
9. Hassanpour, Naser; Chub, Andrii; Blinov, Andrei; Yadav, Neelesh; Hasan, **Sayeed**; Vinnikov, Dmitri (2024). Protection of Bidirectional Step-Up/Down Partial Power Converter Against Short Circuit and Open Circuit Faults and Mode Transition Issues. 2024 IEEE 18th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG): 18th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-PowerENG 2024), Gdynia, Poland, June 24 - 26, 2024. Gdynia, Poland: IEEE, 1–6. DOI: 10.1109/CPE-POWERENG60842.2024.10604315.
10. Hasan, **Sayeed**; Chub, Andrii; Vinnikov, Dmitri; Blinov, Andrei (2024). Study of Battery Energy Storage Operation in Droop-Controlled Residential DC Nanogrid. 2024 IEEE 18th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG): 18th International Conference on Compatibility, Power Electronics and Power Engineering, Gdynia, Poland, June 24 - 26, 2024. Gdynia, Poland: IEEE, 1–5. DOI: 10.1109/CPE-POWERENG60842.2024.10604364.
11. Rogowski,Szymon; Hasan, **Sayeed;** Chub, Andrii; Sibiński,Maciej (2024). Assessment of Mixed Energy Storage System Considering High Spatial Resolution Data from a Real PV Installation. 2024 19th Biennial Baltic Electronics Conference (BEC): 19th Biennial Conference on Electronics and Embedded Systems, Tallinn, Estonia, October 2-4, 2024. Tallinn, Estonia: IEEE, 1–6. DOI: 10.1109/BEC61458.2024.10737964.

OUTCOMES

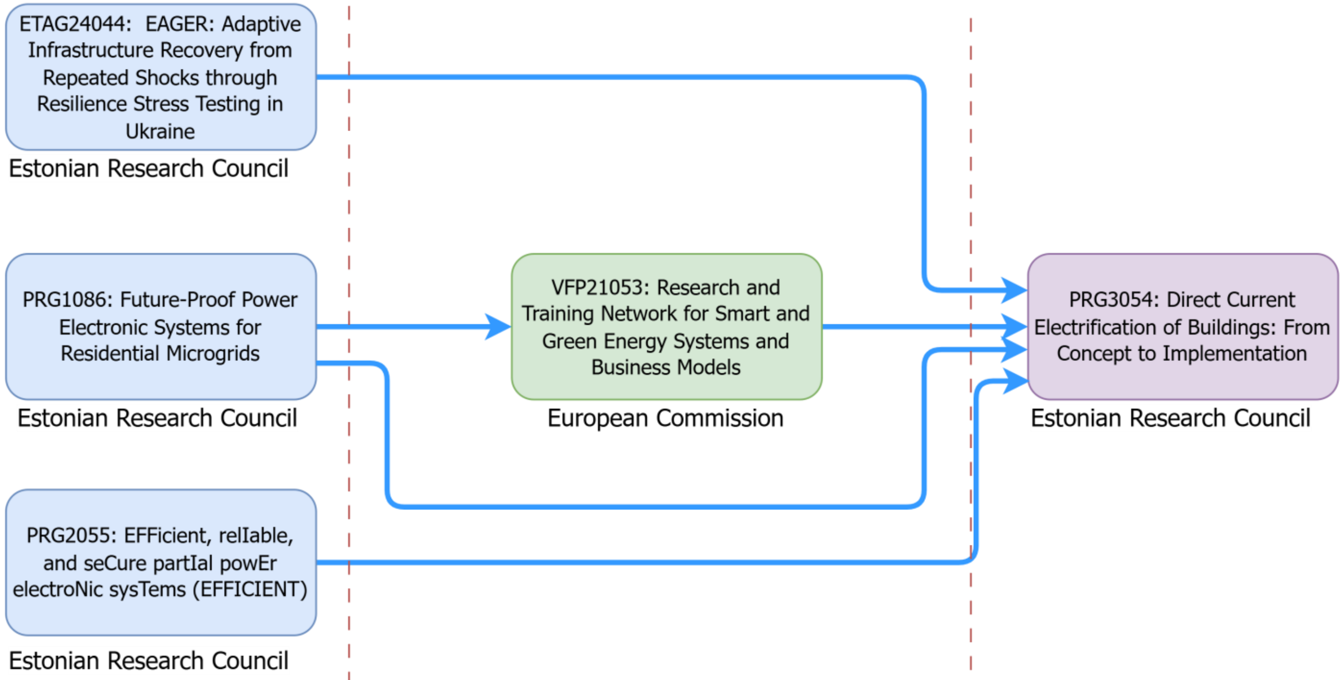
Conference Proceedings

13. Hasan, **Sayeed**; Chub, Andrii; Blinov,Andrei; Vinnikov, Dmitry; (2024). Implementation Issues of Droop Controlled DC Nanogrids: State of Charge Management of Battery Energy Storage and Impact of Sensor Gain Tolerance. 2024 IEEE 65th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON): Riga, Lativa, 10-12 October 2024. Riga, Latvia: IEEE, 1−6. DOI: 10.1109/RTUCON62997.2024.10830832.
14. Hasan, **Sayeed**; Chub, Andrii; Yadav, Neelesh; Blinov, Andrei; Kurnitski, Jarek; Vinnikov, Dmitri (2025). Energy Management Implementation Approach for Droop-Controlled Residential DC Nanogrids. 7th IEEE International Conference on DC Microgrids (ICDCM 2025): 7th IEEE International Conference on DC Microgrids (ICDCM 2025), Tallinn, Estonia, June 4 - 6, 2025. Tallinn, Estonia: IEEE, 1−5. DOI: 10.1109/ICDCM63994.2025.11144665.
15. Yadav, Neelesh; Hasan, **Sayeed**; Galkin, Ilya; Chub, Andrii (2025). Performance Analysis of Partial Power Converter in DC Microgrid with Active Front-End Converter. 7th IEEE International Conference on DC Microgrids (ICDCM 2025): 7th IEEE International Conference on DC Microgrids (ICDCM 2025), Tallinn, Estonia, June 4 - 6, 2025. Tallinn, Estonia: IEEE, 1−5. DOI: 10.1109/ICDCM63994.2025.11144718.

Dataset

1. Hasan, **Sayeed**; Blinov, Andrei; Chub, Andrii; Vinnikov, Dmitri (2024). PV Generation and Consumption Dataset of an Estonian Residential Dwelling. DOI: 10.48726/6hayh-xoh25.

FUTURE WORK



- Development of high efficiency DC-DC converters for DC grids(TMC, PPP, FTC)
- Fault tolerant contol and self healing uGrid concepts

- Design of Grid interface converters
- Design of energy management systems for DC microgrids based on the prototypes from PRG1086, PRG2055 and EAGER

- Implementation of congnitive control in DC microgrids
- control of multi scale microgrid systems
- Centralized and decentralized micorgid approach with Adaptive droop control(ADrC)

ACKNOWLEDGEMENT

TALTECH

Prof. Dmitri Vinnikov

Dr. Andrii Chub

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Dr. Neelesh Yadav

Dr. Indrek Roasto

Dr. Tanel Jalakas

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SmartGY SUM

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QUESTIONS??

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