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Optimized Energy Management of a Solar and Wind Equipped Student Residence with an Innovative Hybrid Energy Storage System and Power-to-Heat Solutions

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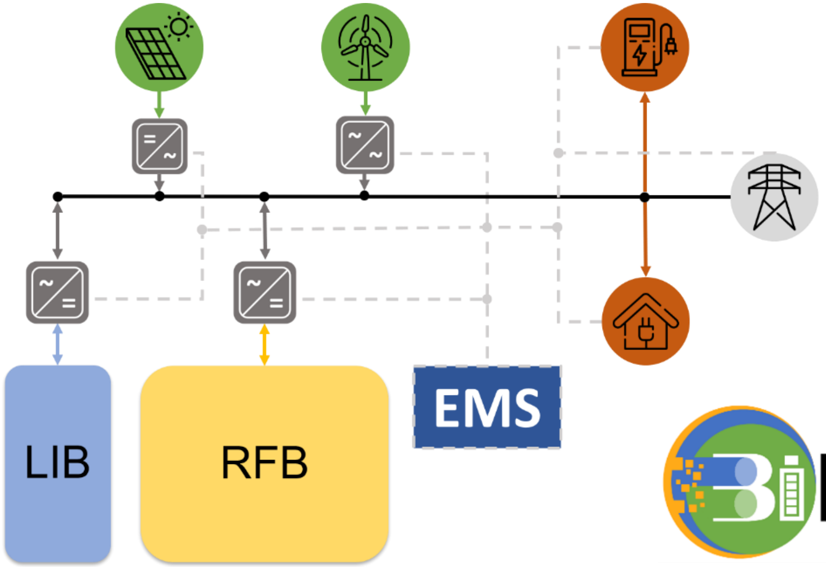
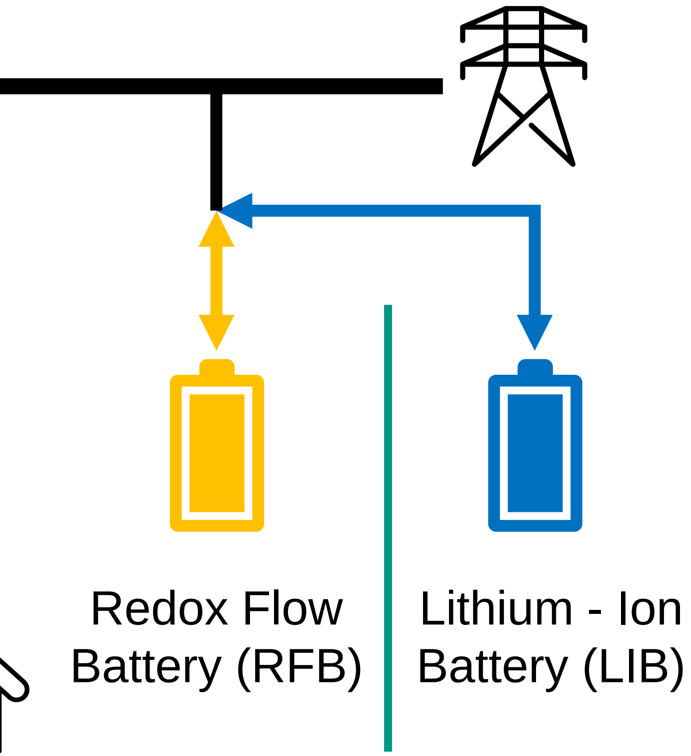
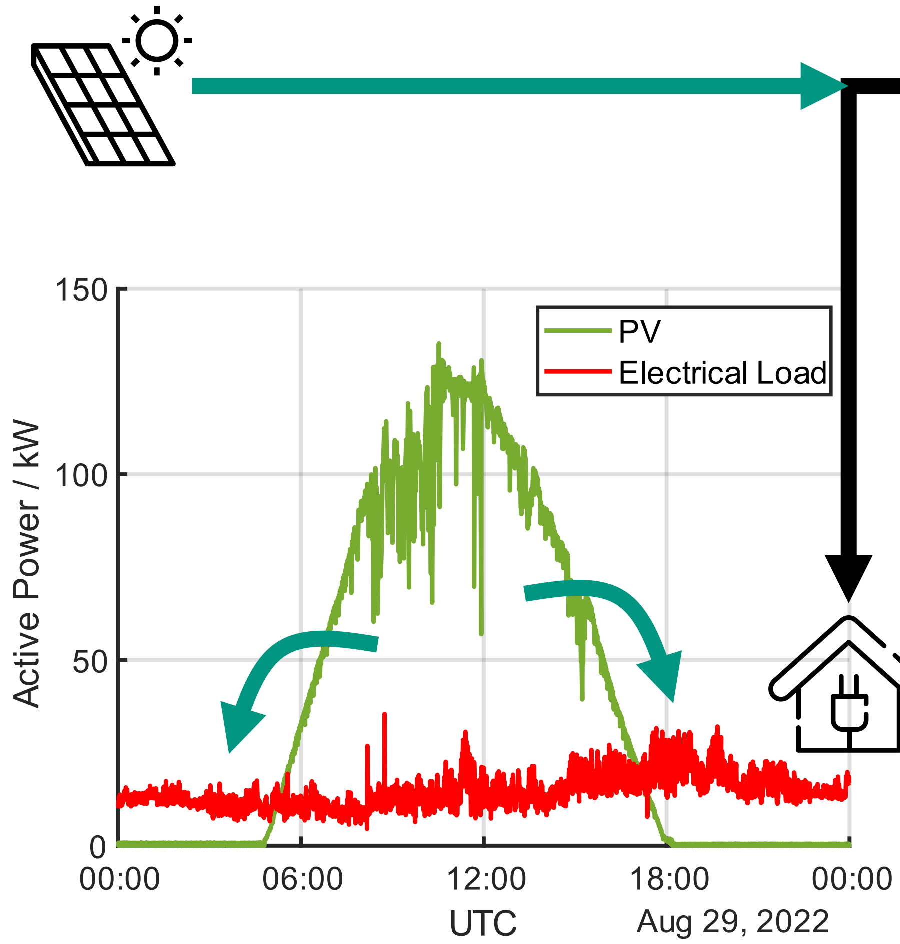


BiFlow

Motivation





Ideal Energy Storage System (ESS) must provide:

- instantaneous high power
- high efficiency
- high cycle lifetime
- long term storage capability
- low cost

Hybrid Energy Storage System (HESS) exploits the advantage of two technologies thus enabling: **efficient, flexible and economical** operation

Contents

System Setup : Basics

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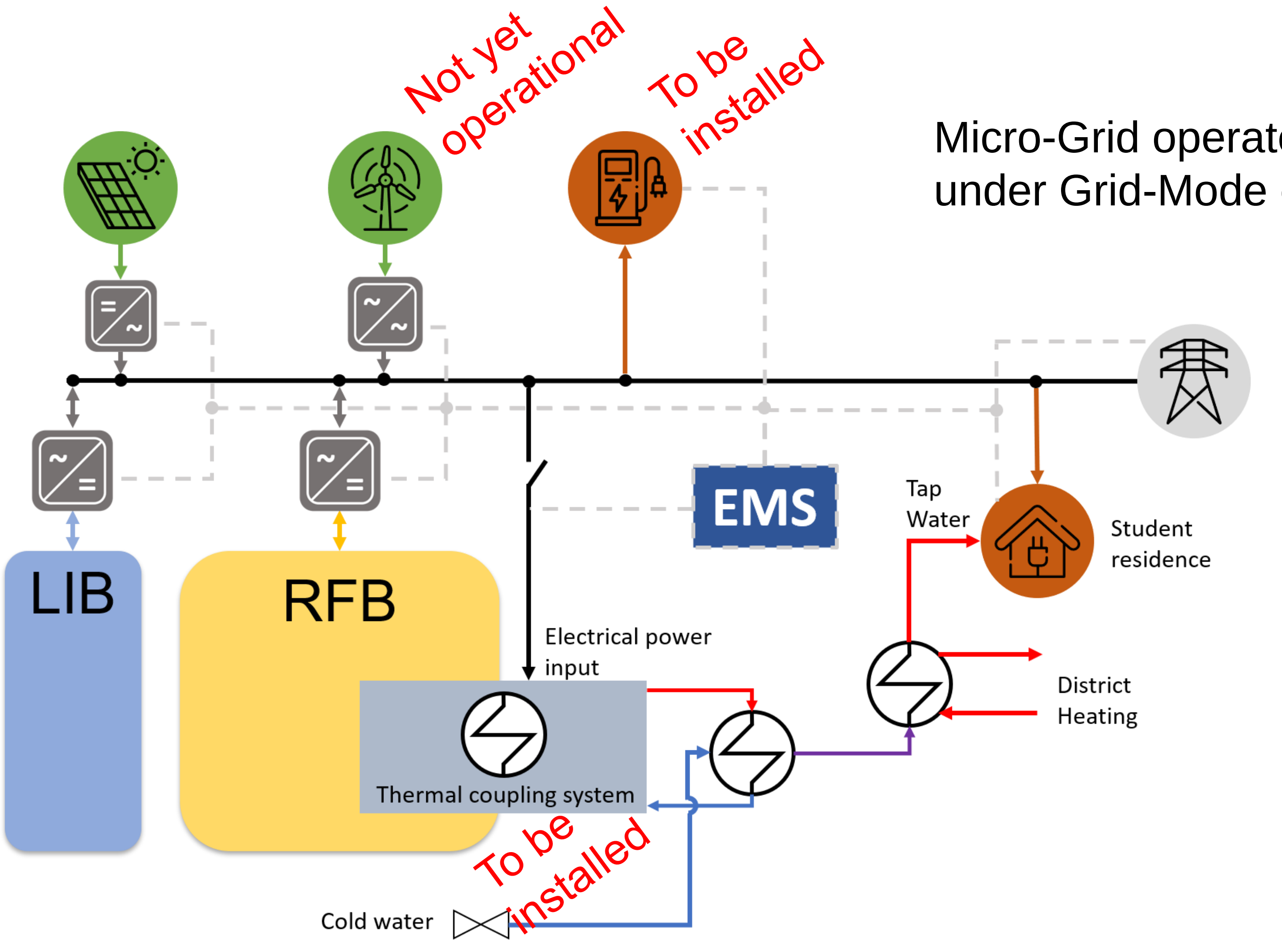
3iFlow

Bruchsal, Germany



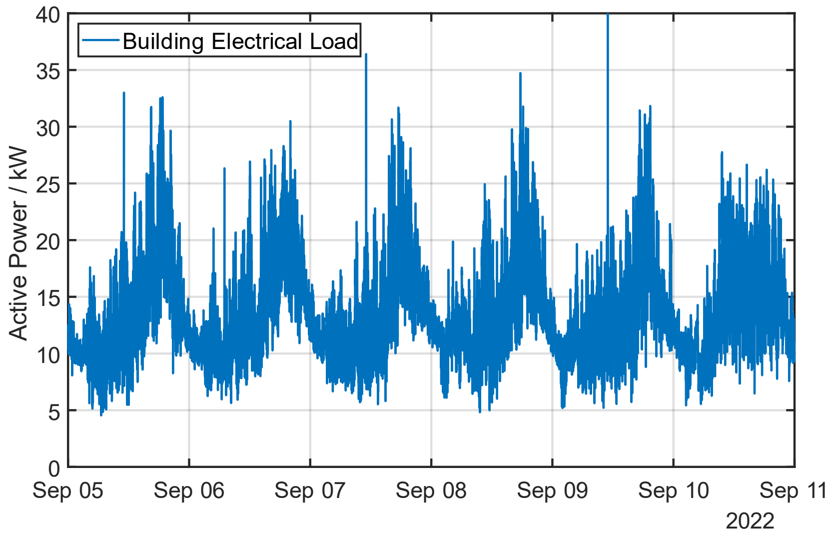
Micro-Grid operated under Grid-Mode only

3 fold optimization problem:

- **When** to charge/discharge
- **Where** to charge/discharge
- **Which** energy form (Heat/Electricity)

Load: Building

- Student residence with capacity for 150 students
- Combination of university students + trainees
- “Moving crowd” – min. rent period 6 months, and max. 3 years

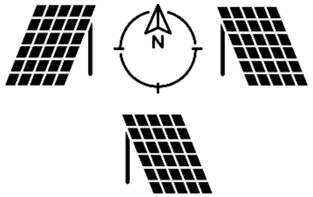


Base Load : **~ 5kW**
Peak Load : **~ 40kW**
Peak time : **17 -21 UTC**

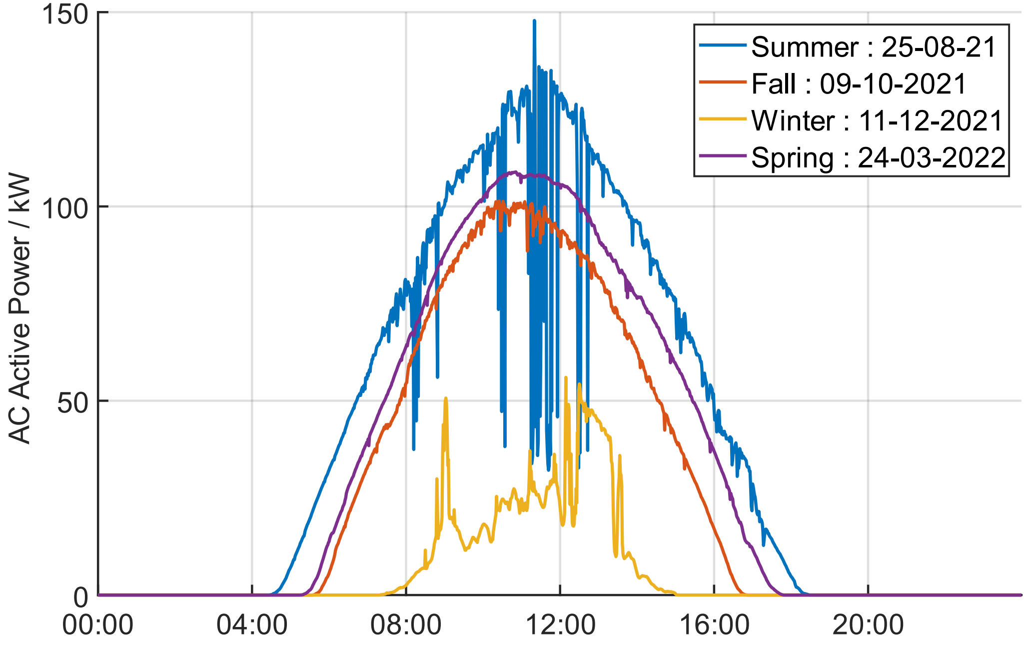
Avg. Energy requirement / day : **320 kWh**

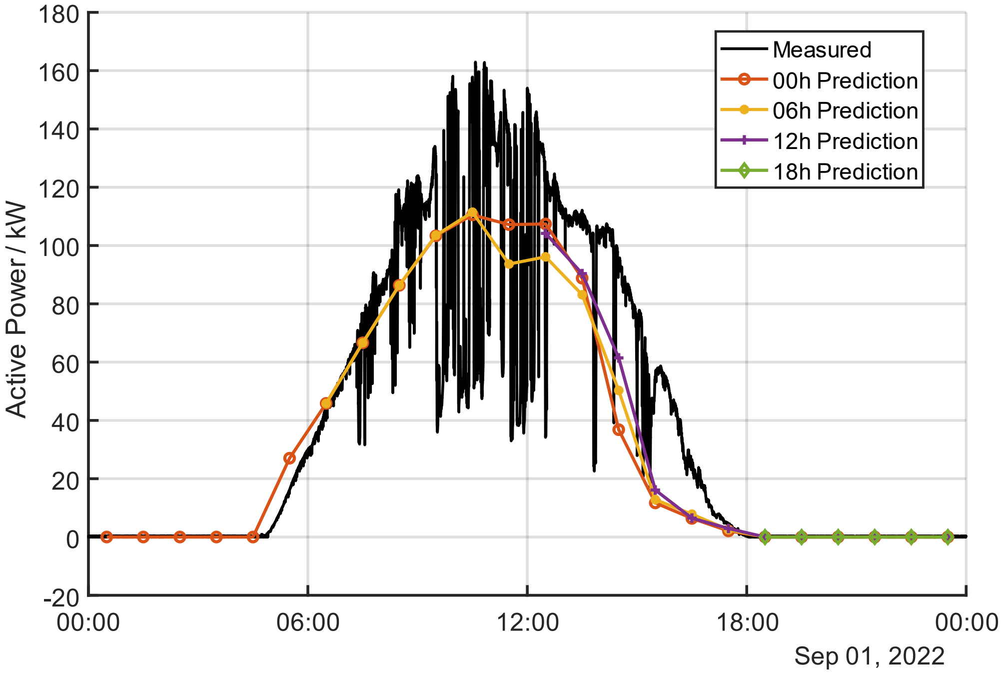
Generation : Photovoltaics

- Installed capacity: 220 kWp DC
  - 76% roof-top
  - 24% wall mounted



- Forecasting based on Numerical Weather Prediction (NWP) data, updated every 6hrs
- 5 day ahead forecasting done by EMS





Ref: A. Starosta, et.al., A Comparative Analysis of Forecasting Methods for Photovoltaic Power and Energy Generation with and without Exogenous Inputs.

HESS: RFB + LIB

- Vanadium Redox Flow
- Operational since March 2022
- Electrical Capacity: 120 kWh @ 14 kW (to be increased to 21 kW)

- Technology: Lithium iron phosphate ($LiFePO_4$)
- Operational since: June 2022
- Electrical Capacity: 60 kWh @ 30 kW

HESS: RFB + LIB

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	Vanadium Redox Flow Battery	*Lithium Ion Battery ($LiFePO_4$)*
Auxiliary requirements / standby consumptions	BMS & Power Electronics, Pumps, Electrolyte mixers, valves	BMS & Power Electronics,
Power loss origin	AC ←→ DC conversion, Loss as heat during discharging	AC ←→ DC conversion, LFP internal losses
Operation efficiency with auxiliary requirements	Charging → **65-80%** Discharging → **60-75%**	Charging → **85-95%** Discharging → **85-95%**
Overall ESS efficiency with auxiliary requirements	**50-70%**	**85-95%**

HESS Optimization: 1. Fixed Priority operation

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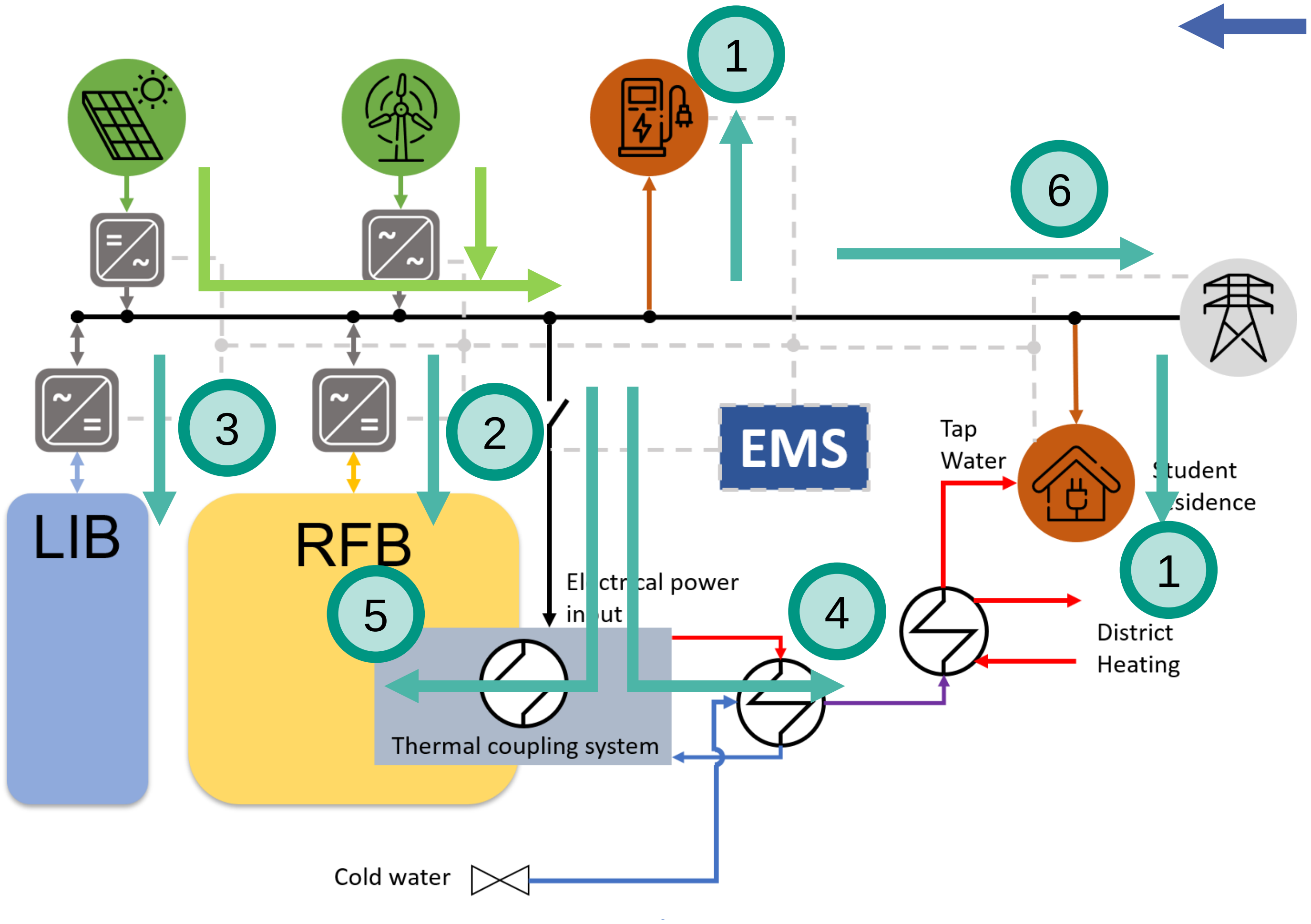

Charging direction priority

Discharging direction vice-versa

RFB not operated between -7kW to 7kW due to low operational efficiency because of high auxiliary requirements.

Aim of the optimization:

- Maintain the grid at 0, thus improve building self sufficiency
- Effectively use available renewable energy
- Improve RFB operation efficiency

HESS Optimization: 1. Fixed Priority operation

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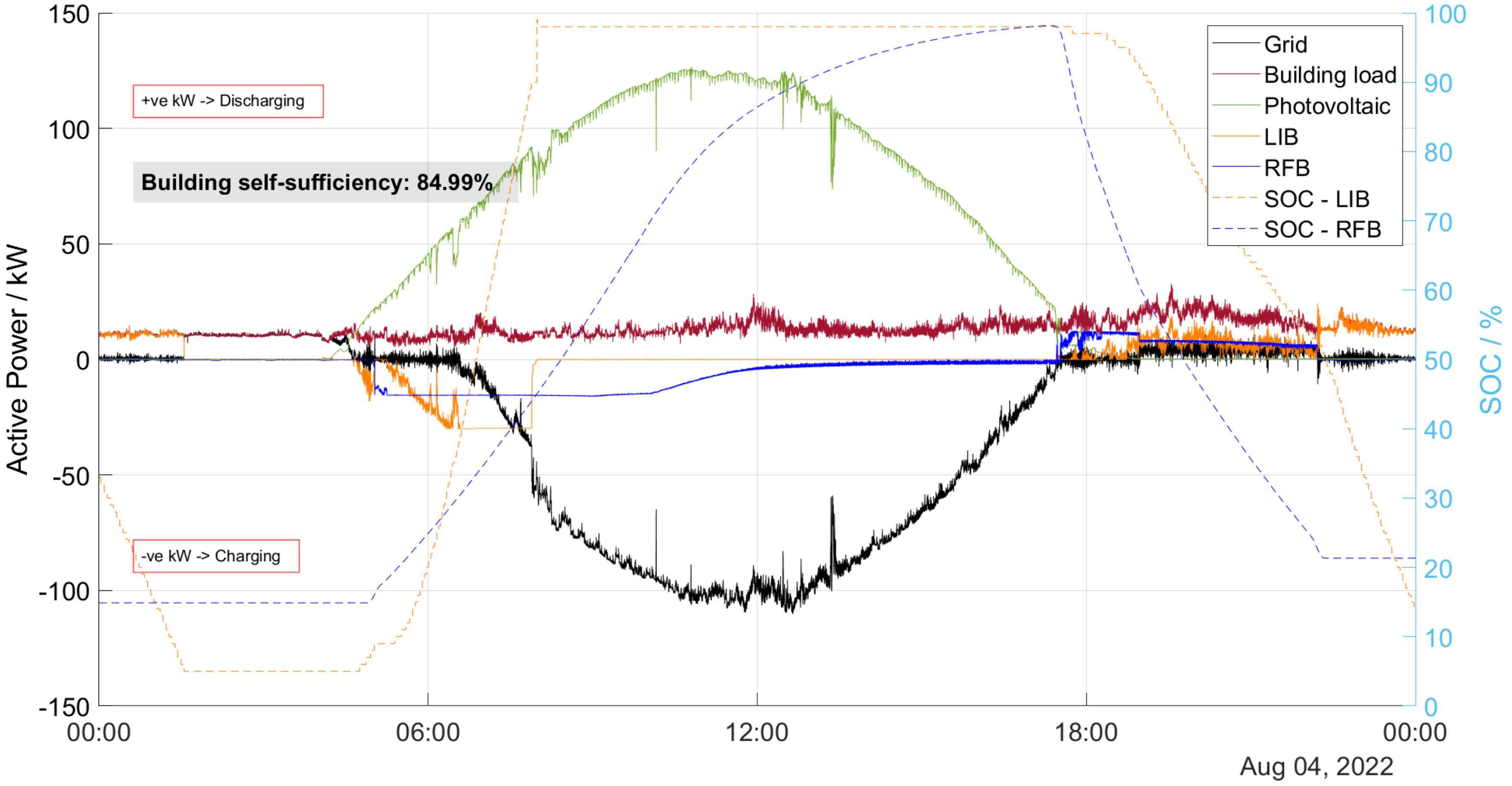
Results:

<u>Clear sky case</u>

- Priority based optimization did not play major role in charging, but was helpful in discharging

- RFB →
  - discharged at a constant rate
  - Stable and efficient operation.
- LIB →
  - dynamic requirements during discharging.



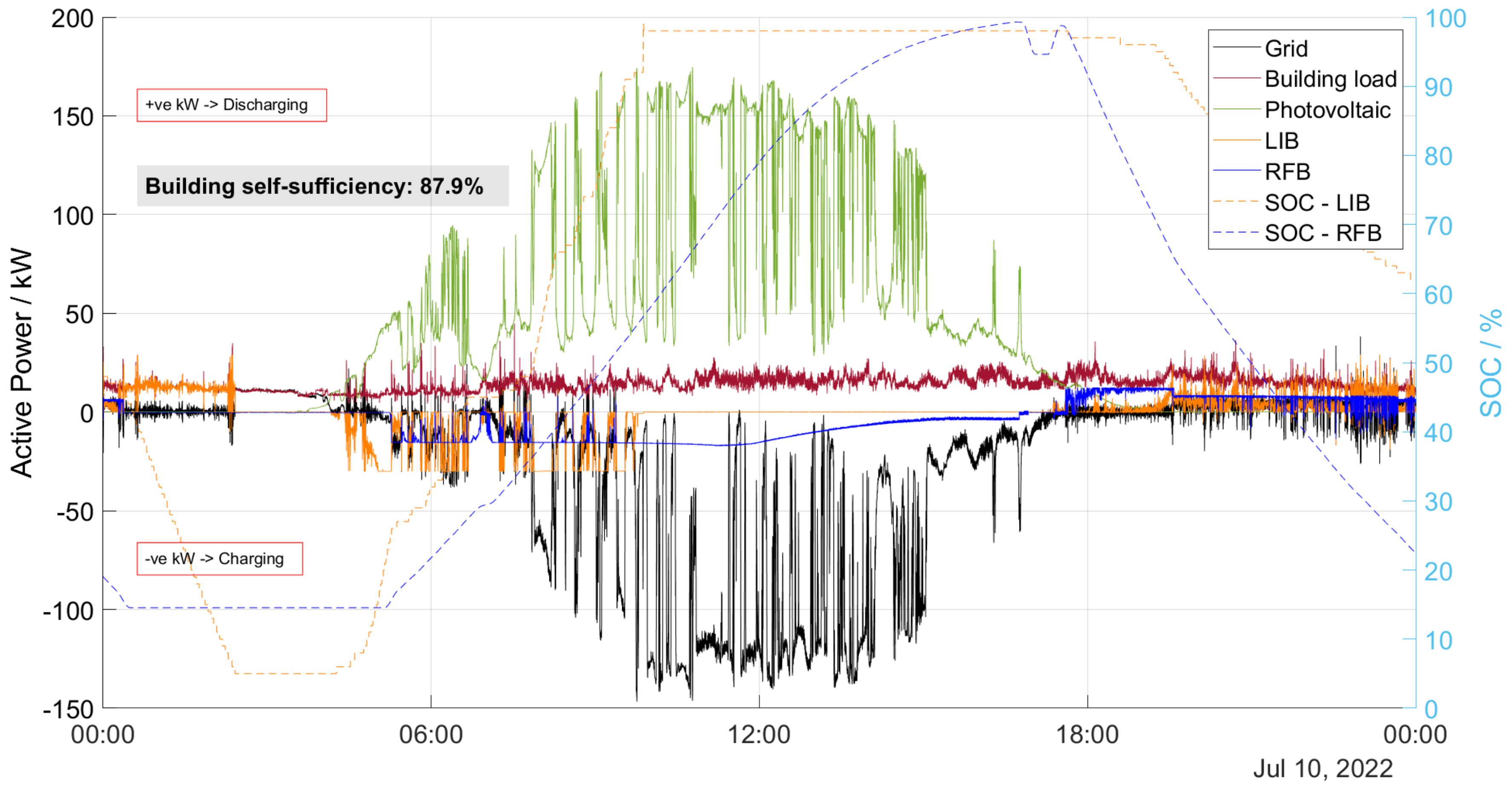
HESS Optimization: 1. Fixed Priority operation

Results:

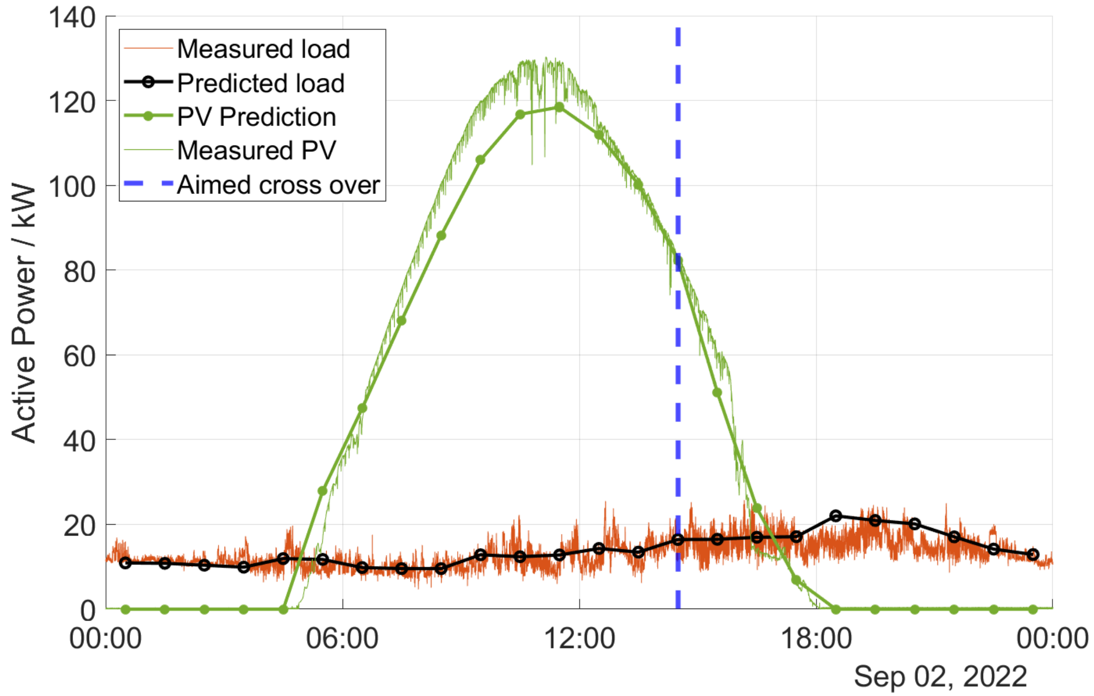
<u>Heavy moving cloud case</u>

- Priority based optimization was helpful in both charging and discharging.

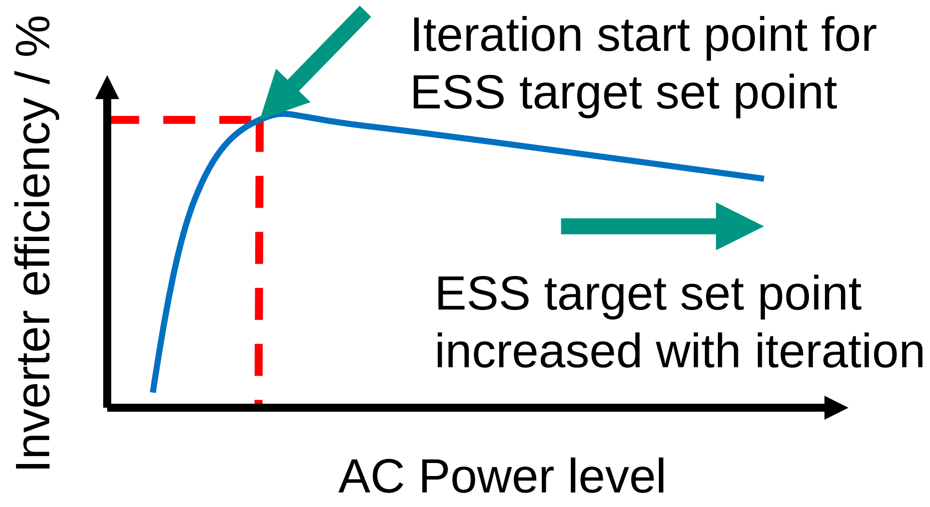
- RFB →
  - charged <u>without</u> disturbance
  - Discharged without disturbance
- LIB →
  - adjusted according moving clouds during charging
  - dynamic requirements during discharging



HESS Optimization: 2. Optimal charging schedule

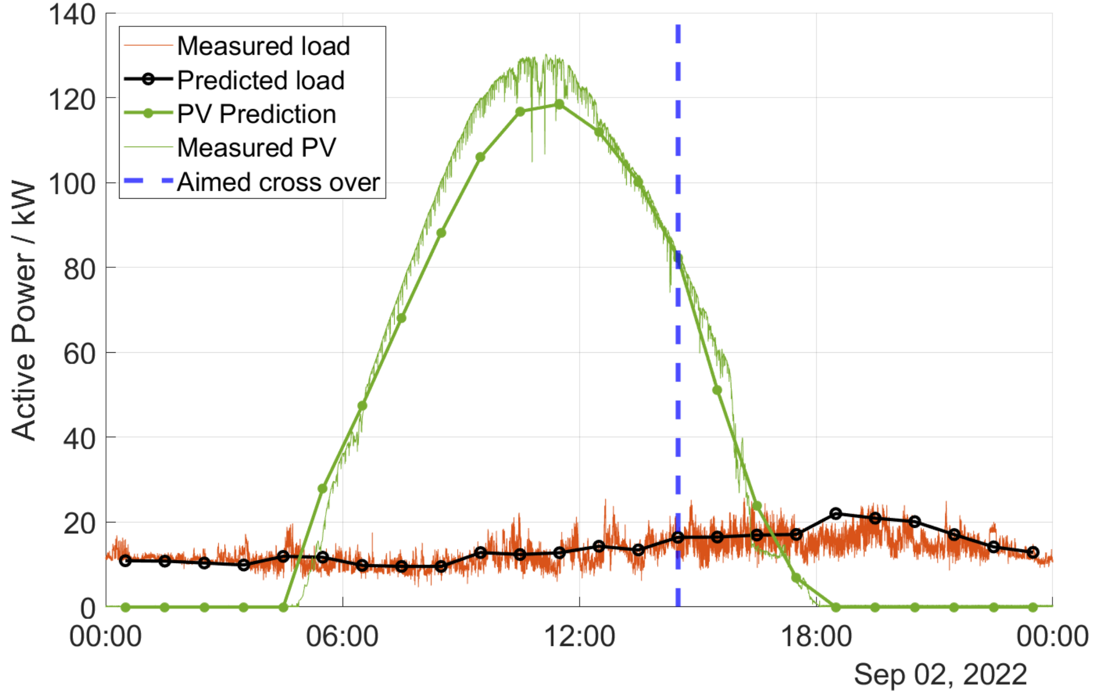


Example intermediate result from the algorithm



Has ESS reached current SOC?
Yes → Scheduled start Time
No → Iterate again with higher power

HESS Optimization: 2. Optimal charging schedule



Example intermediate result from the algorithm

Forecasting based optimization running on top of Priority based optimization.

<u>Aim of the optimization:</u>

- Intelligent scheduling of charging start timepoint and operation point.
- Full charge ESS before aimed crossover
- Improve operation efficiency of not only RFB, but LIB also
- Reduce calendric aging of LIB

HESS Optimization: 2. Optimal charging schedule

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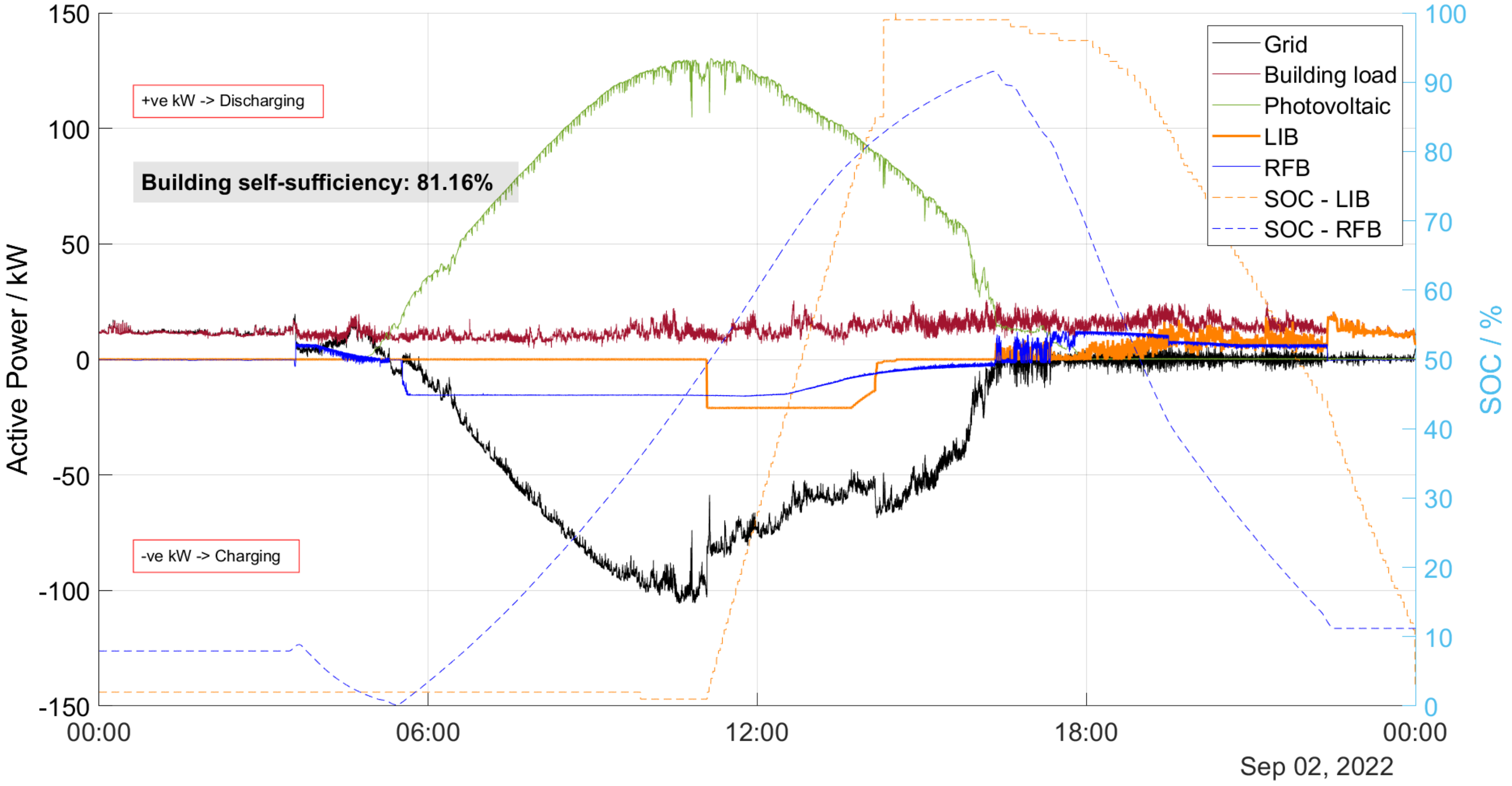
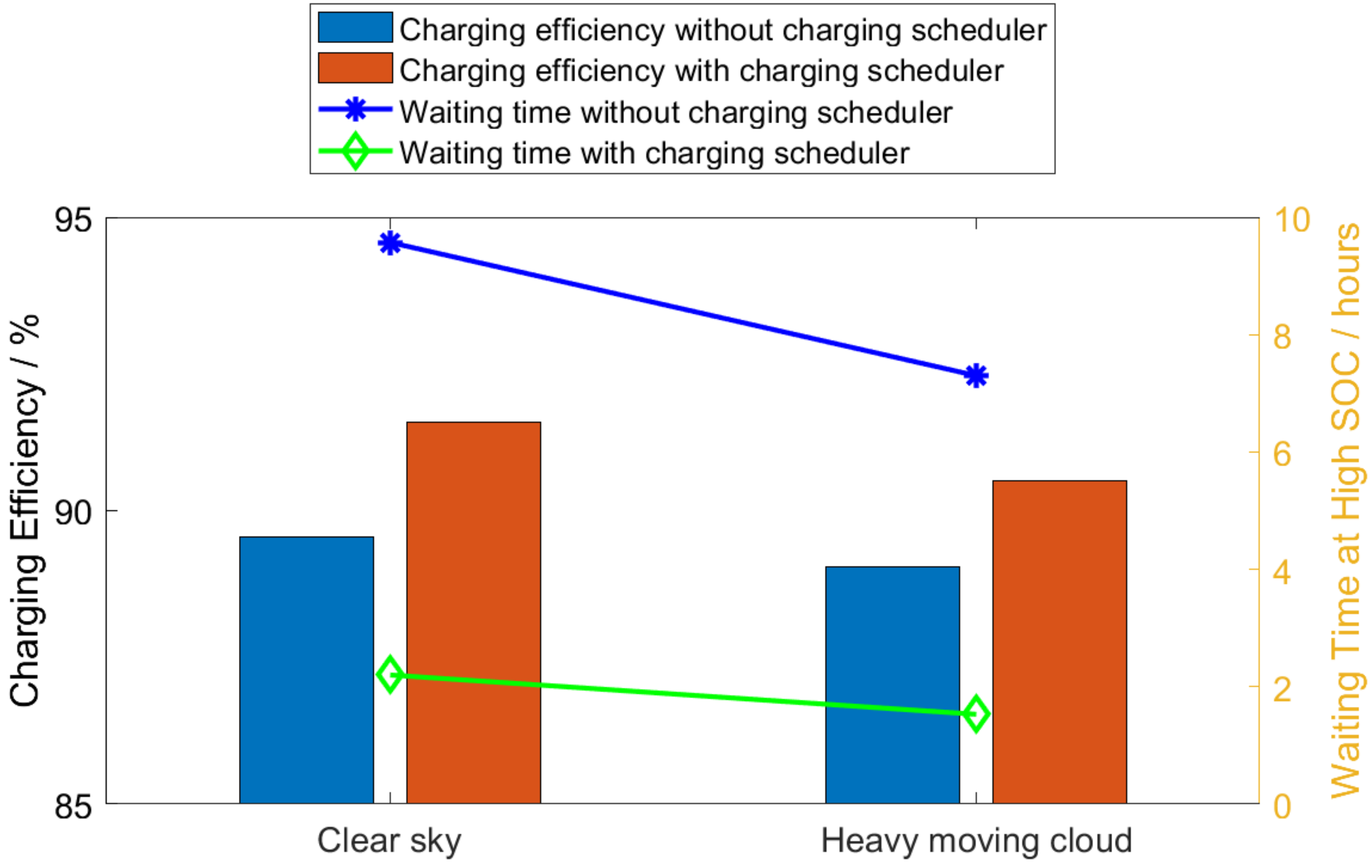
Results:

<u>Clear sky case</u>

- Priority based optimization was helpful in discharging
- Optimal schedule based charging was useful for both RFB and LIB
- Both the ESS were operated stably at its optimum power point.
- LIB has very less waiting time before discharging



HESS Optimization: 2. Optimal charging schedule



LIB charging operation characteristics

- LIB charging efficiency is improved with optimal scheduling
- The wait period of ESS at high SOC is *drastically* reduced, thus reducing calenderic aging.

Note: Data extracted from four actual days with similar but not exactly same weather conditions.

Summary

Setup:
- BiFlow is a living lab project, acting as a microgrid with a Hybrid Energy Storage system.
- The HESS of RFB and LIB act as a High Energy and High Power Duo.
- Novel Power-to-heat has been designed and currently under the process of implementation.

Operation:
- Systems dependent on naturally occurring renewable energy generation.

- A Fixed Priority based operation strategy has been proposed, which improves the operational efficiency of the HESS, mainly RFB.

- To further optimize the system, optimal charging based scheduler has been proposed, which helps improve efficiency of both the ESS, as well as reduces calenderic aging of LIB.

- Optimal charging scheduler is dependent on the forecasting performance.

Outlook

We are just getting started ☺

Operation mechanism:

- More stable controlling methods for the HESS are being researched. This would reduce unwanted losses due to poor control.
- Model Predictive based ~~fixed~~ *dynamic* prioritization mechanism are under development.

Operation strategy:

- Optimization for discharging directions are yet to be developed.
- The optimal scheduler will be updated when Thermal systems are also online.
- Heuristic Long-term (days) and short-term(hours) optimization concept would be researched.

Outlook

Multi-Objective optimization goals

1. RFB:
    - improve round-trip efficiency through reducing pump and inverter losses
    - reduce standby consumption
    - reduced ageing at high temperature
    - maximize waste heat utilization through heat storage

2. LIB:
    - reduced ageing
    - improve efficiency through reduced inverter losses

3. LIB + RFB: improve building self-sufficiency (both electrical and thermal load)

Thank you for your kind attention!

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More about the research project:

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