Implementation of a Microgrid Energy Management System Considering E-Mobility, Uncertainties and Contingencies: A Multi-Objective Approach

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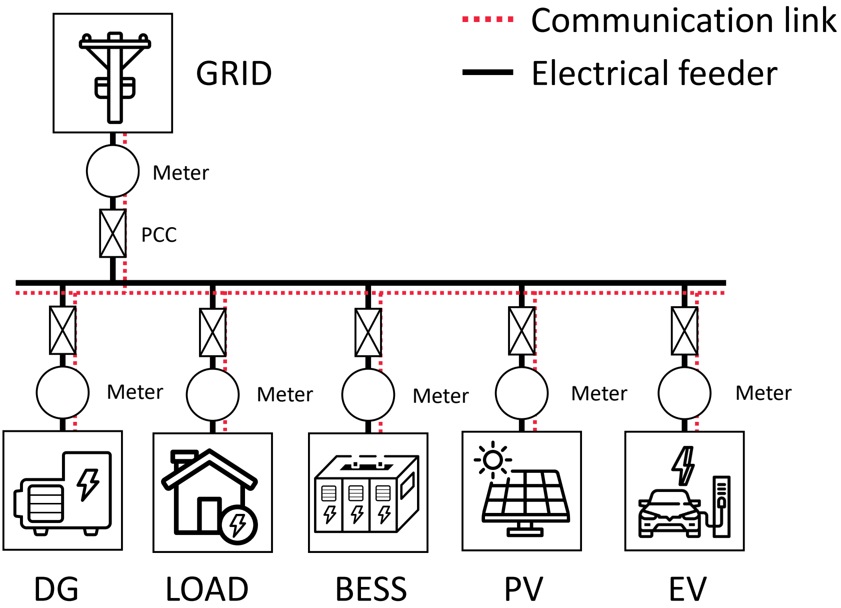
Table of Contents

Introduction



Objectives

- Develop a multi-objective optimization model for the EMS.

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- Integrate a new window of EVs in the IoT-based EMS.
- Validate the EMS in a Hardware-in-the-Loop (HIL) environment.

Methodology

Uncertainty and Contingency Sets

- Uncertainties are addressed using multiple profiles for solar generation and demand, 9 scenarios.
- Contingencies, reflecting all possible occurrences across the 24-hour period.

Methodology

Uncertainty and Contingency Sets

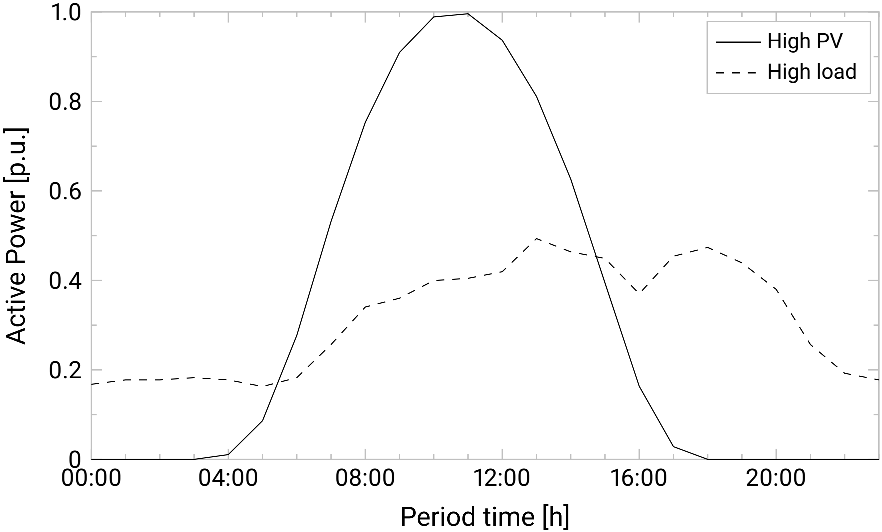
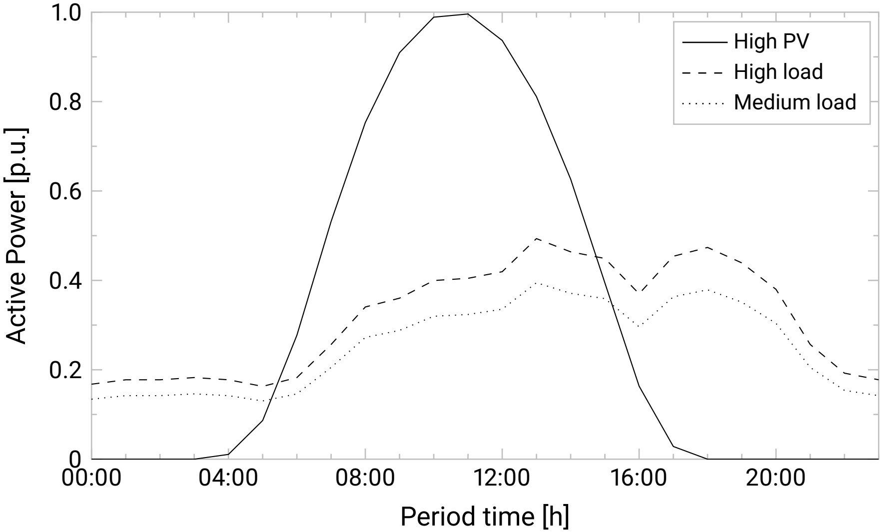


Figure 1: Scenarios for solar generation and demand.

Methodology

Uncertainty and Contingency Sets



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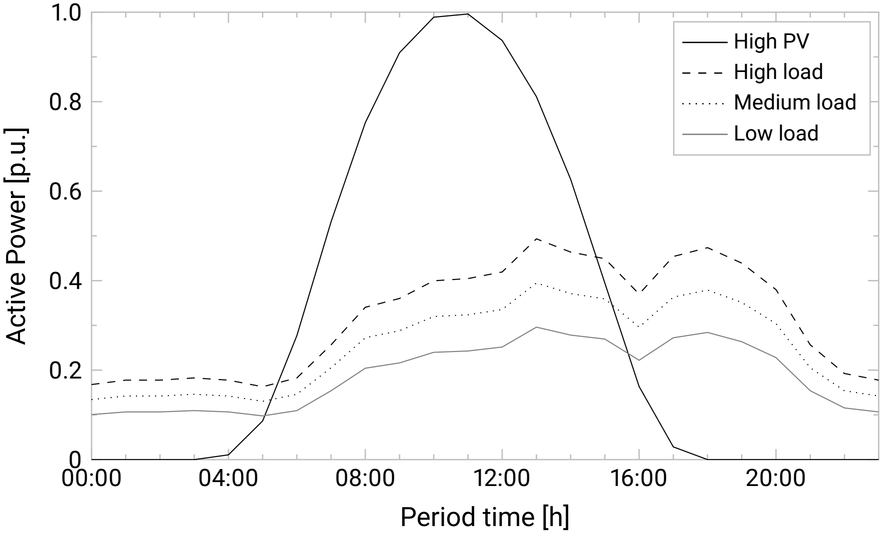

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Methodology

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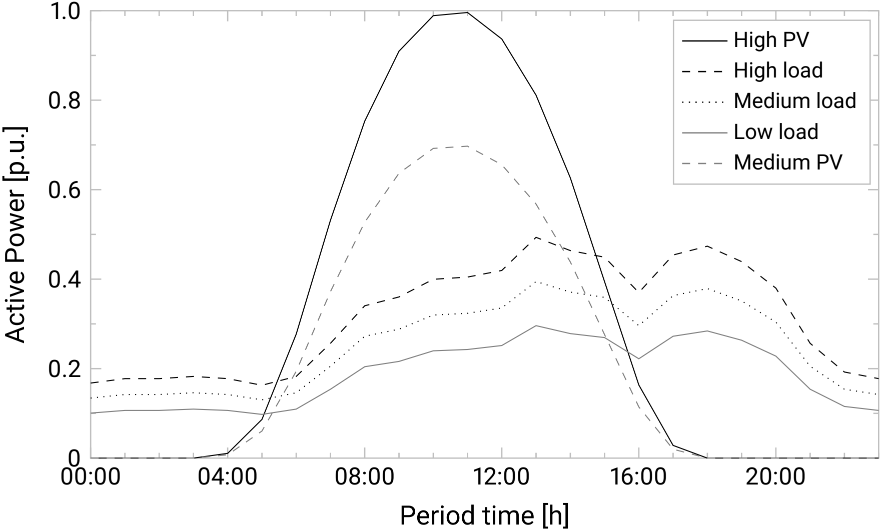

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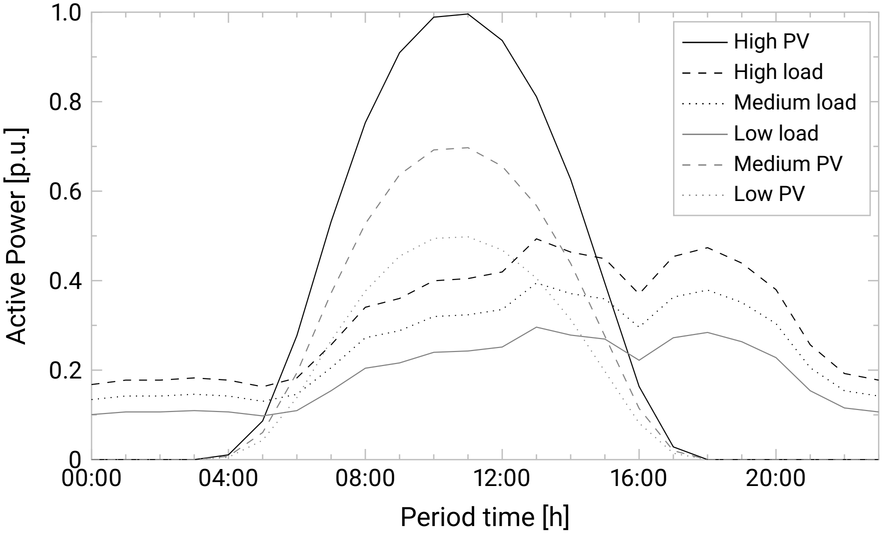

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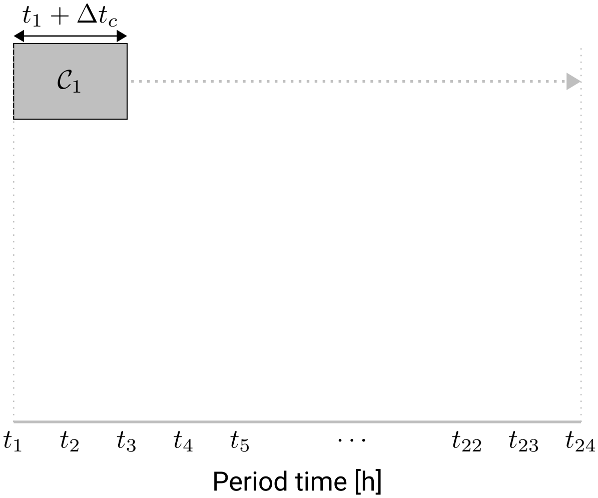
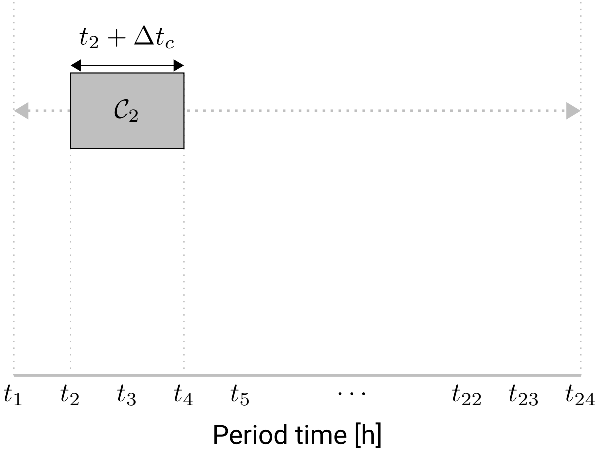


Figure 2: Set of contingencies

Methodology

Uncertainty and Contingency Sets



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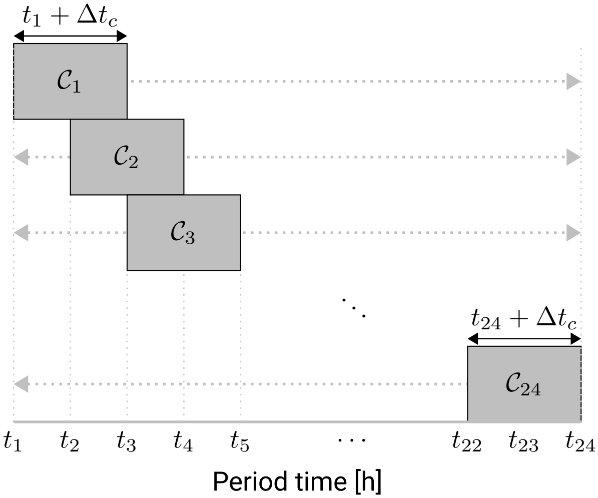


Figure 2: Set of contingencies

Methodology

Mathematical Model for the EMS

- Objective function 1

$$f_{costs} = \min \Delta t \sum_{s \in \mathcal{S}} \Bigg\{ Prob_s \cdot \Bigg[\sum_{i \in \mathcal{N}} \sum_{f \in \mathcal{F}} \sum_{t \in \mathcal{T}} \sum_{c \in \mathcal{C}} \alpha_t^{\mathsf{S}} P_{i,f,t,c,s}^{\mathsf{PCC}} + \sum_{n \in \mathcal{G}} \sum_{t \in \mathcal{T}} \sum_{c \in \mathcal{C}} \left(P_{n,t,c,s}^{\mathsf{G}} \cdot \alpha_n^{\mathsf{G}} \cdot \mu_{n,t,c,s} \right) + \sum_{i \in N} \sum_{f \in F} \sum_{t \in T} \sum_{c \in C} \alpha^{\mathsf{C}} P_{i,f,t}^{\mathsf{D}} (1 - x_{i,f,t,c}) \Bigg] \Bigg\} \quad (1)$$

Methodology

Mathematical Model for the EMS

- Objective function 1

$$f_{costs} = \min \Delta t \sum_{s \in \mathcal{S}} \Bigg\{ Prob_s \cdot \Bigg[\sum_{i \in \mathcal{N}} \sum_{f \in \mathcal{F}} \sum_{t \in \mathcal{T}} \sum_{c \in \mathcal{C}} \alpha_t^{\mathsf{S}} P_{i,f,t,c,s}^{\mathsf{PCC}} + \sum_{n \in \mathcal{G}} \sum_{t \in \mathcal{T}} \sum_{c \in \mathcal{C}} \left(P_{n,t,c,s}^{\mathsf{G}} \cdot \alpha_n^{\mathsf{G}} \cdot \mu_{n,t,c,s} \right) + \sum_{i \in N} \sum_{f \in F} \sum_{t \in T} \sum_{c \in C} \alpha^{\mathsf{C}} P_{i,f,t}^{\mathsf{D}} (1 - x_{i,f,t,c}) \Bigg] \Bigg\} \tag{1}$$

- Objective function 2

$$f_{ens} = \min \sum_{\forall r,t | t = t_d} \left(\overline{E_r^{\mathrm{EV}}} - E_{r,t}^{\mathrm{EV}} \right) \tag{2}$$

Methodology

Mathematical Model for the EMS

Subject to:

- Constraints related to the operation of three-phase distribution systems
- Constraints related to genset operation
- Constraints related to islanded operation
- Constraints related to BESS
- Constraints related to EVs

Methodology

Multi-objective Optimization Problem

To solve MOOP, we employ the ϵ-constraint method

Methodology

Multi-objective Optimization Problem

$$
\left.
\begin{array}{rl}
\textbf{minimize} & f_{costs} \\
\textbf{subject to} & f_{ens} \leq \varepsilon_p, \\
& \text{Operation of three-phase distribution systems} \\
& \text{Islanded operation} \\
& \text{Genset operation} \\
& \text{BESS} \\
& \text{EVs}
\end{array}
\right\} \tag{3}
$$

EMS software architecture

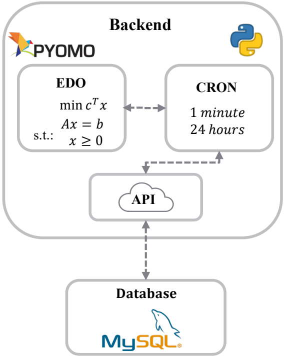
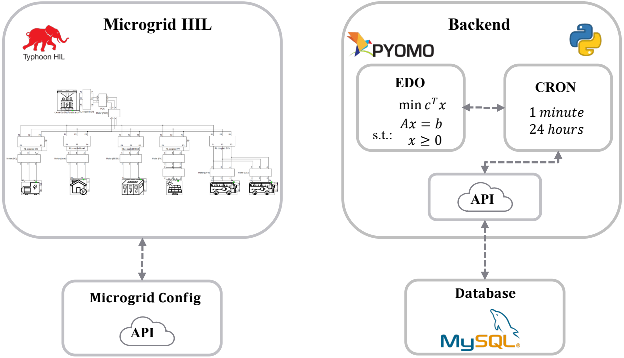


Figure 3: IoT-based for microgrids software architecture.

EMS software architecture



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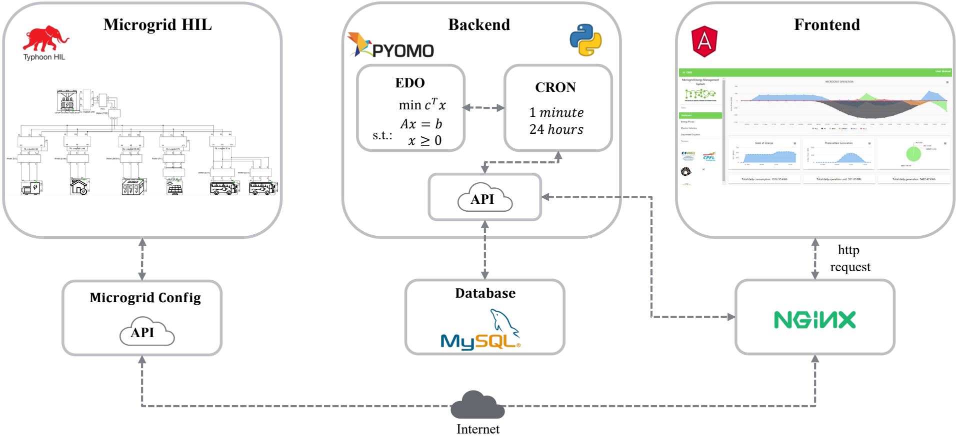

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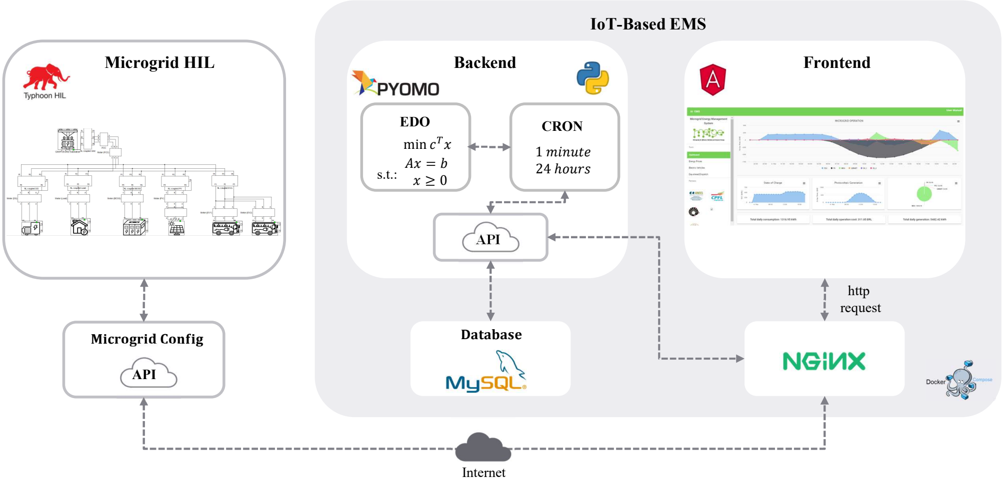

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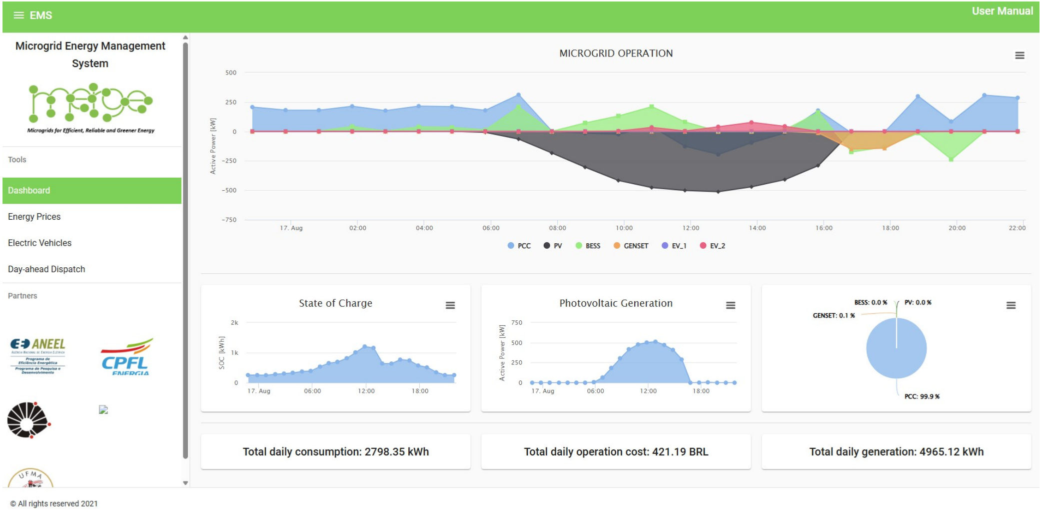


Figure 4: Frontend of GUI EMS.

EMS software architecture

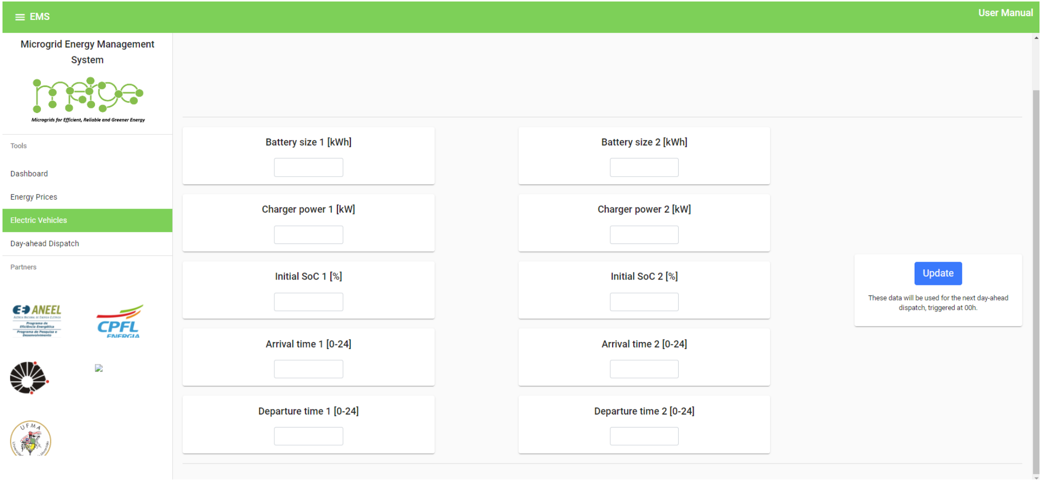


Figure 5: Frontend of GUI EMS - EVs tab.

Case study: CAMPUSGRID microgrid

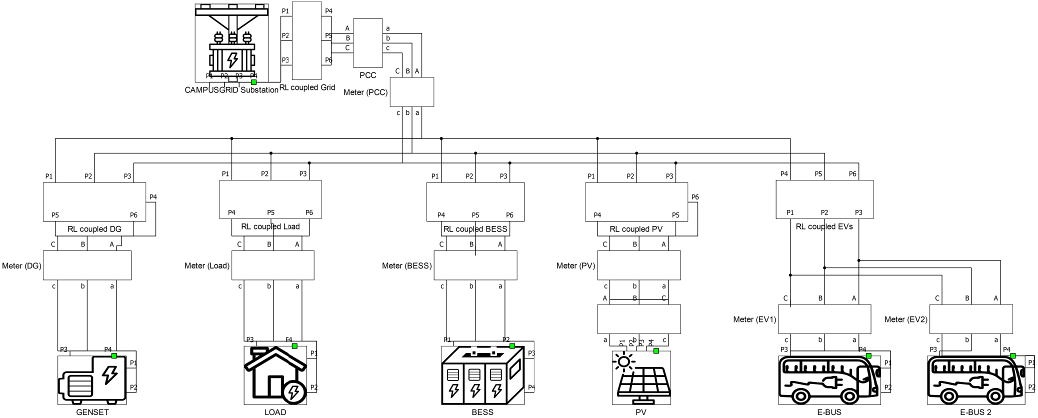


Figure 6: Microgrid CAMPUSGRID schematic in Typhoon HIL 604.

Case study

- Case I: Without contingencies.
- Case II: Contingency at 16:00 hours.
- Case III: Contingency at 08:00 hours.
- Case IV: Without contingencies, including EV.
- Case V: Contingency at 16:00 hours with EV.
- Case VI: Contingency at 08:00 hours with EV.
- Case VII: Contingencies at 08:00 and 16:00 hours with EVs.

Remembering the MOOP:

$$
\left.
\begin{array}{rl}
\textbf{minimize} & f_{costs} \\
\textbf{subject to} & f_{ens} \leq \varepsilon_p, \\
& \text{Operation of three-phase distribution systems} \\
& \text{Islanded operation} \\
& \text{Genset operation} \\
& \text{BESS} \\
& \text{EVs}
\end{array}
\right\} \quad (3)
$$

Test and Results

Multi-objective Optimization Analysis

Algorithm 1: ε-Constraint Method for MOOP

Data: Parameters of the MOOP, including scenarios and contingencies
Result: Pareto front

Initialize: Set of ε_p values;
for *each* ε_p *value in the set* **do**
    Solve: (3);
    Store: Non-dominated solutions;
end
Generate Pareto front;
Compute: The centroid of the Pareto front;

Tests and Results

Multi-objective Optimization Analysis

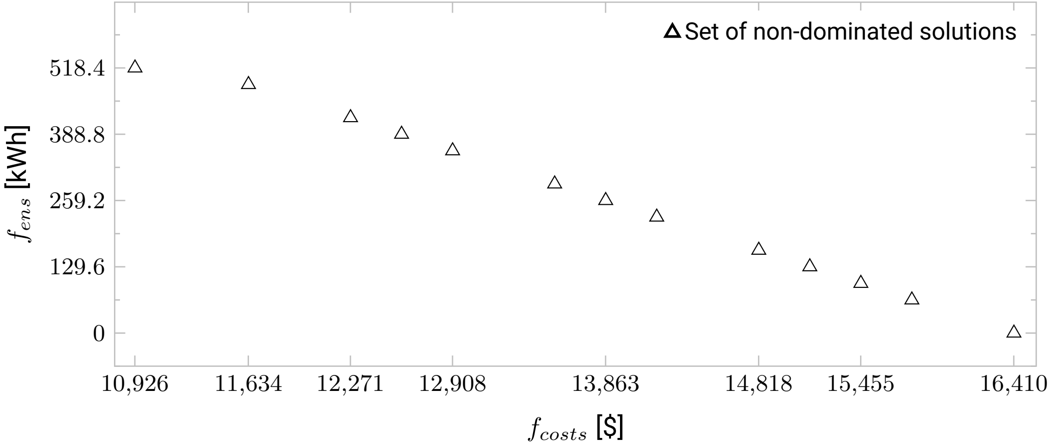
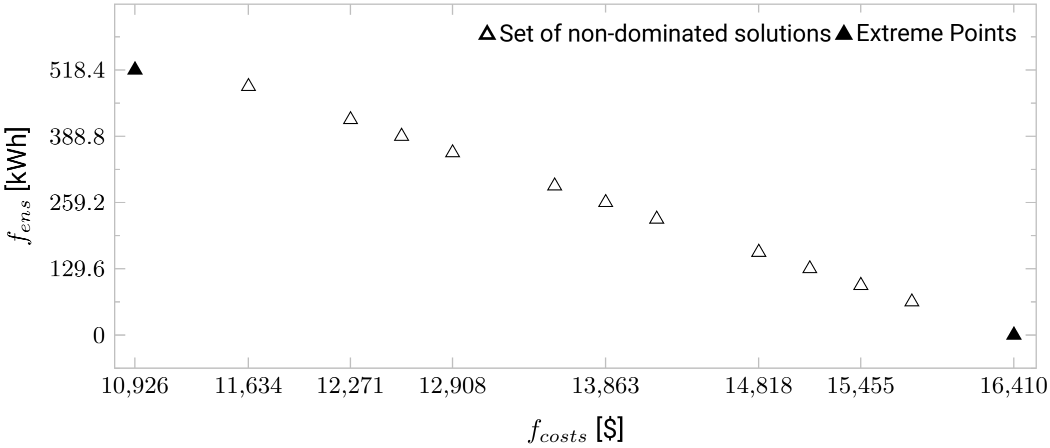


Figure 7: Pareto front

Tests and Results

Multi-objective Optimization Analysis



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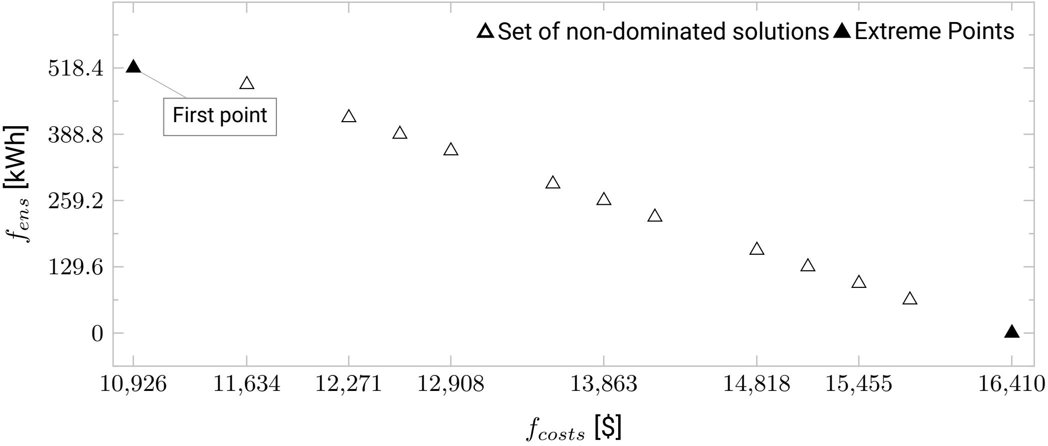

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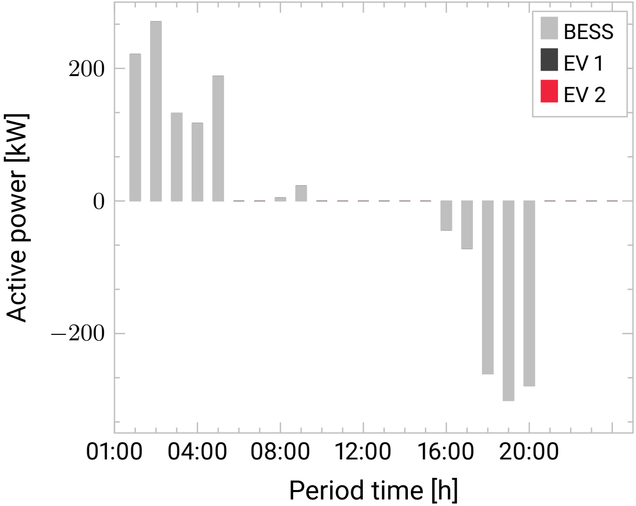

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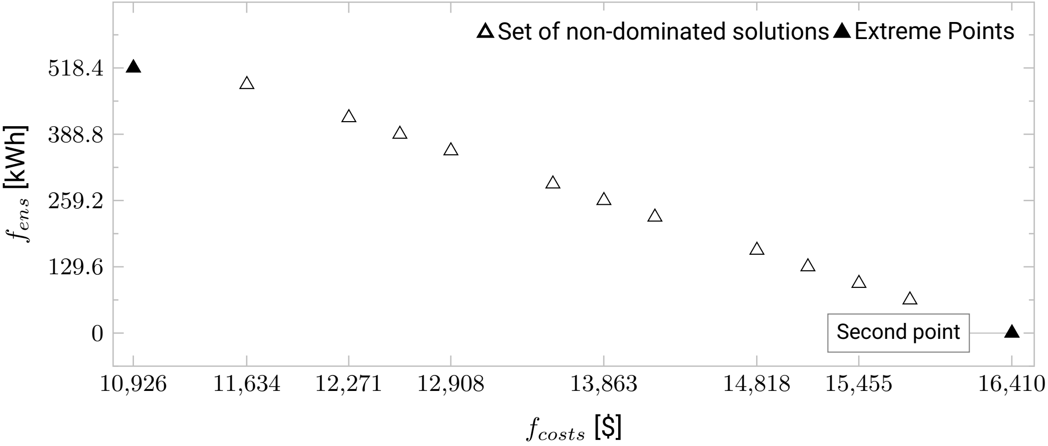

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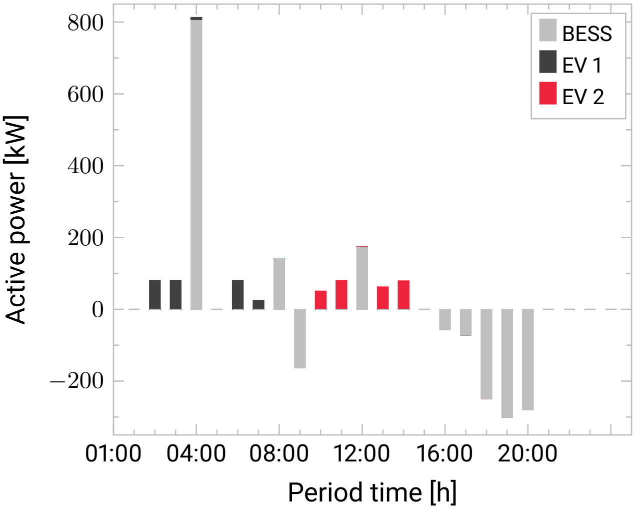

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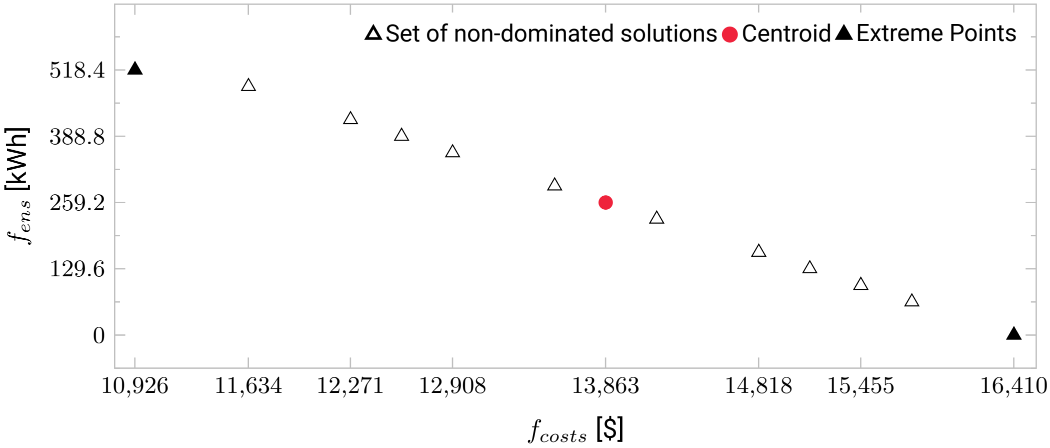

Figure 7: Pareto front

Remembering the case studies

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- **Case VII: Contingencies at 08:00 and 16:00 hours with EVs.**

Results: Case VII: Contingencies at 08:00 and 16:00 hours with EVs

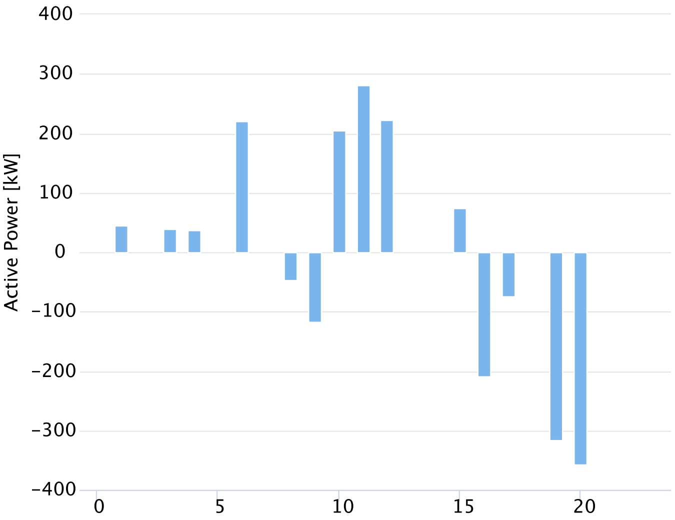

Figure 8: BESS dispatch for case VI.

Results: Case VII: Contingencies at 08:00 and 16:00 hours with EVs

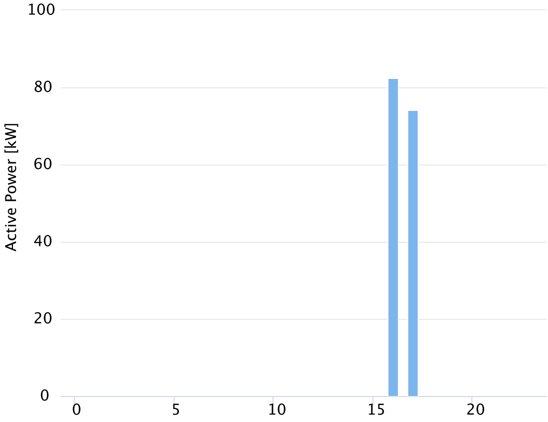

Figure 9: Genset dispatch.

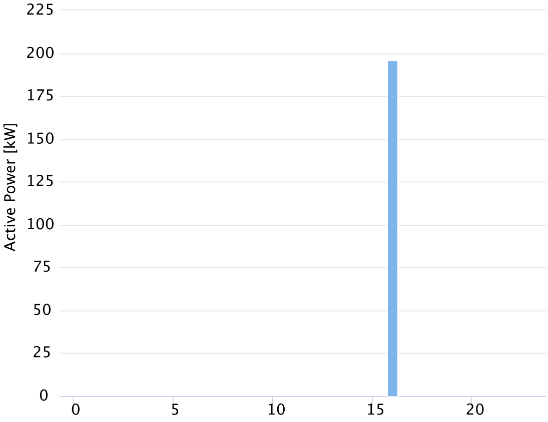

Figure 10: PV curtailment.

Results: Case VII: Contingencies at 08:00 and 16:00 hours with EVs

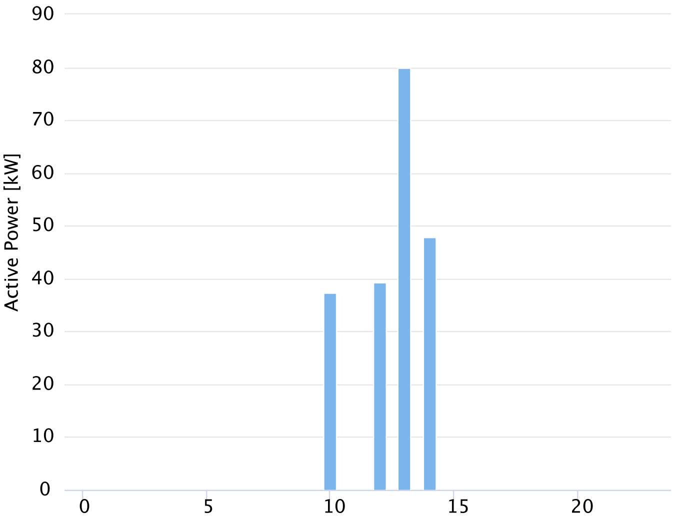

Figure 11: EV 2 dispatch.

Results: Case VII: Contingencies at 08:00 and 16:00 hours with EVs

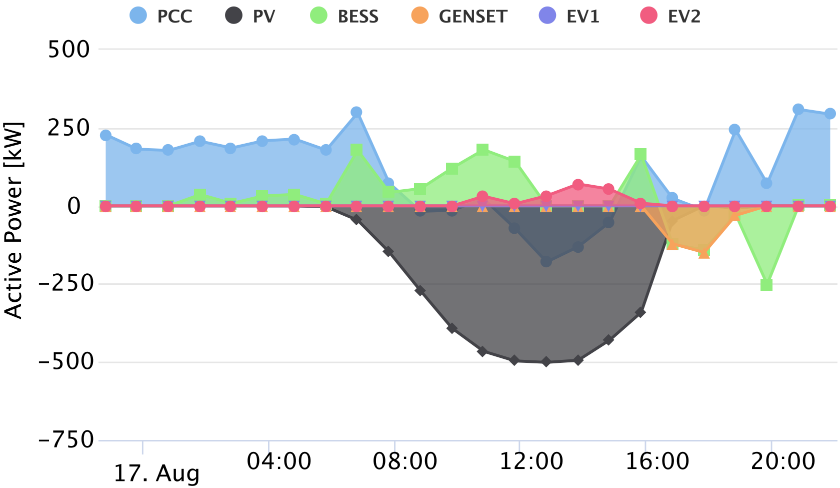

Figure 12: Microgrid operation 24 hours.

Conclusions

- Developed a multi-objective optimization model for the EMS.

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Work plan and schedule

- **01:** Taking courses.
- **02:** Continuing courses and introduction to the MERGE project.
- **03:** Learning the CAMPUSGRID microgrid mathematical model using Python and Pyomo.
- **04:** Implementing the mathematical model with linearizations, contingencies, and scenarios in Pyomo.
- **05:** Gaining knowledge of backend (Flask API and database) and frontend (Angular) technologies.
- **06:** Preparing case studies for 24-hour simulations with Typhoon HIL604 software.
- **07:** Preparing for the qualification exam.
- **08:** Continuing simulations, including a rolling horizon approach and PV forecasting.
- **09:** Writing and preparing the master's thesis.
- **10:** Defending the master's thesis.

Table 1: Scheduled and project status

Stage	1st 2023	2nd 2023	1st 2024	2nd 2024
01				
02				
03				
04				
05				
06				
07				
08				
09				
10				

Done To do

Thank you!

Acknowledgments: