Modeling and Investigation of Control of a Power Infrastructure Resource Management System for a Radio Base Station

A study on sustainable power management for ICT-infrastructure

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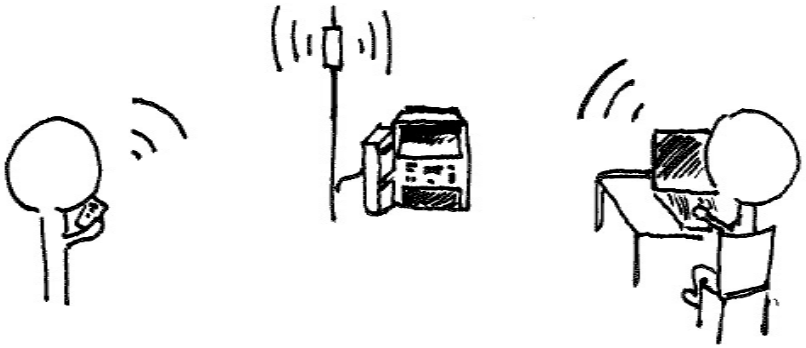
Agenda

1. Use Case
2. System Model
3. Controller Model
4. Experiment and Results
5. Conclusion
6. Questions

Use Case



- Radio Base Station

- Information Communication Technology (ICT)
  - 2021: Global Greenhouse Gas Emissions (GHG) ~ 2.1 – 3.9%
  - Majority of emissions from infrastructure

- Given the status quo of information flow, what are the possibilities?

A first glance – Power management

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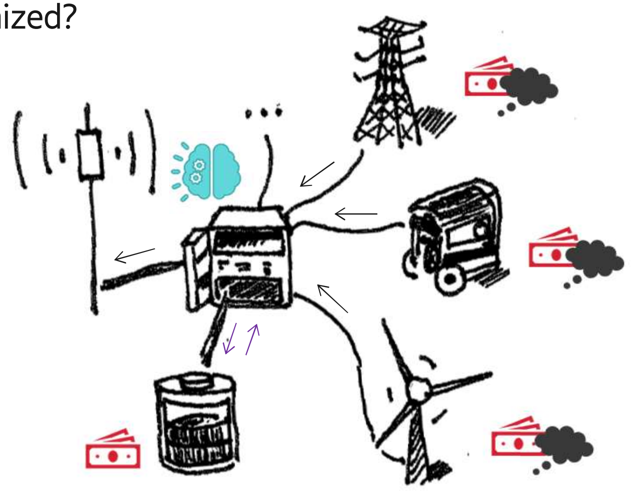
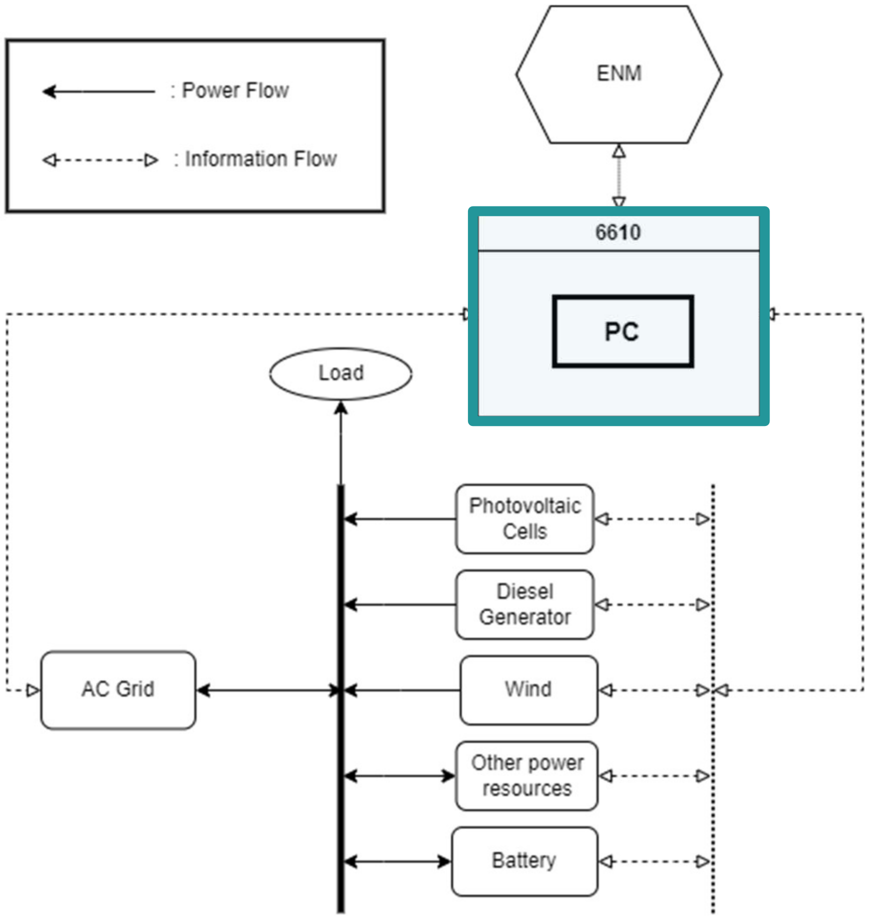
- The Power Infrastructure (**PI**):
  - The 6610 Controller Unit (Brain)
    - The Power Controller (**PC**)
    - Manages the available power resources

- Given a load, how can the "brain" manage the power resources such that
  - operational cost
  - and carbon dioxide emissions

  are minimized?

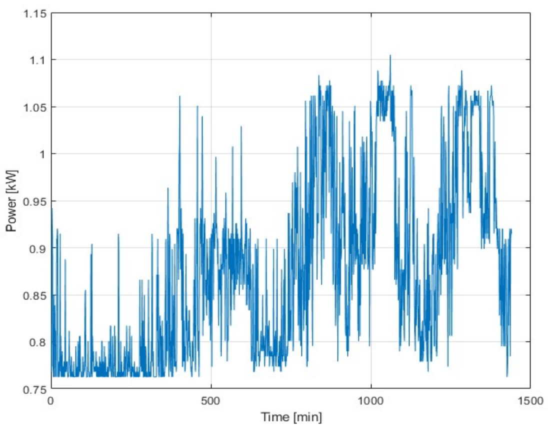


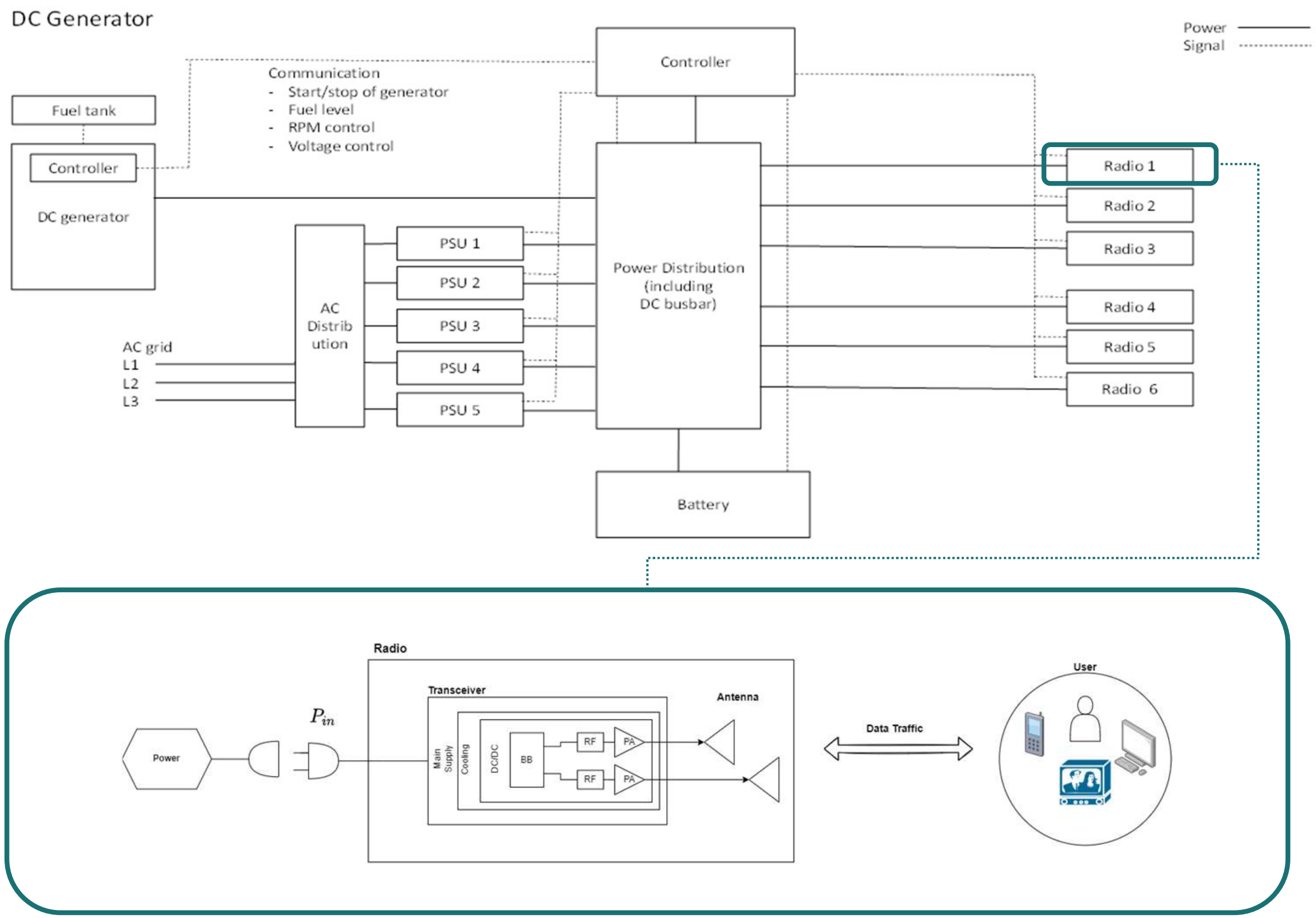


System Model

Considered Sources

- AC-grid
- Generator
- Battery

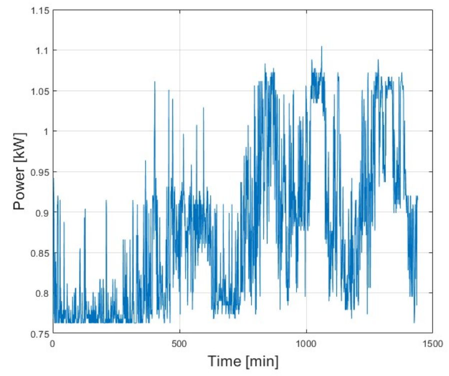




System Model – External Input

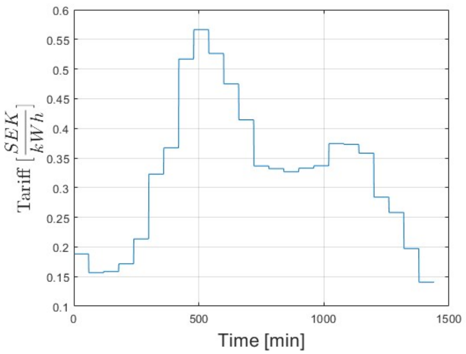
- Load Profile (LP):

$$\mathrm{LP} = \{P_{in_0}, P_{in_1}, \dots, P_{in_N}\}$$



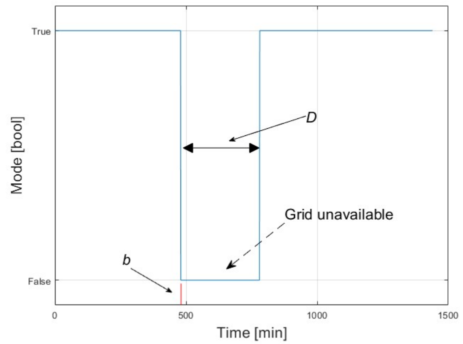
- Grid Tariff (GT):

$$\mathrm{GT} = \{T_0, T_1, \dots, T_N\}$$



- Grid Mode (GM):

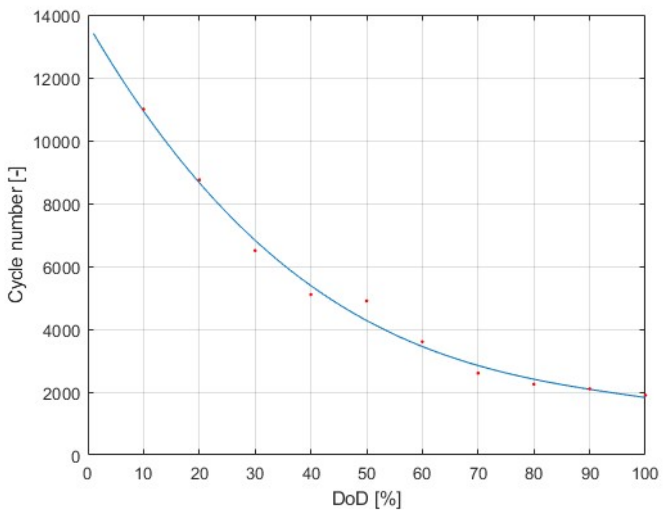
$$\mathrm{GM} = \{M_0, M_1, \dots, M_N\}$$

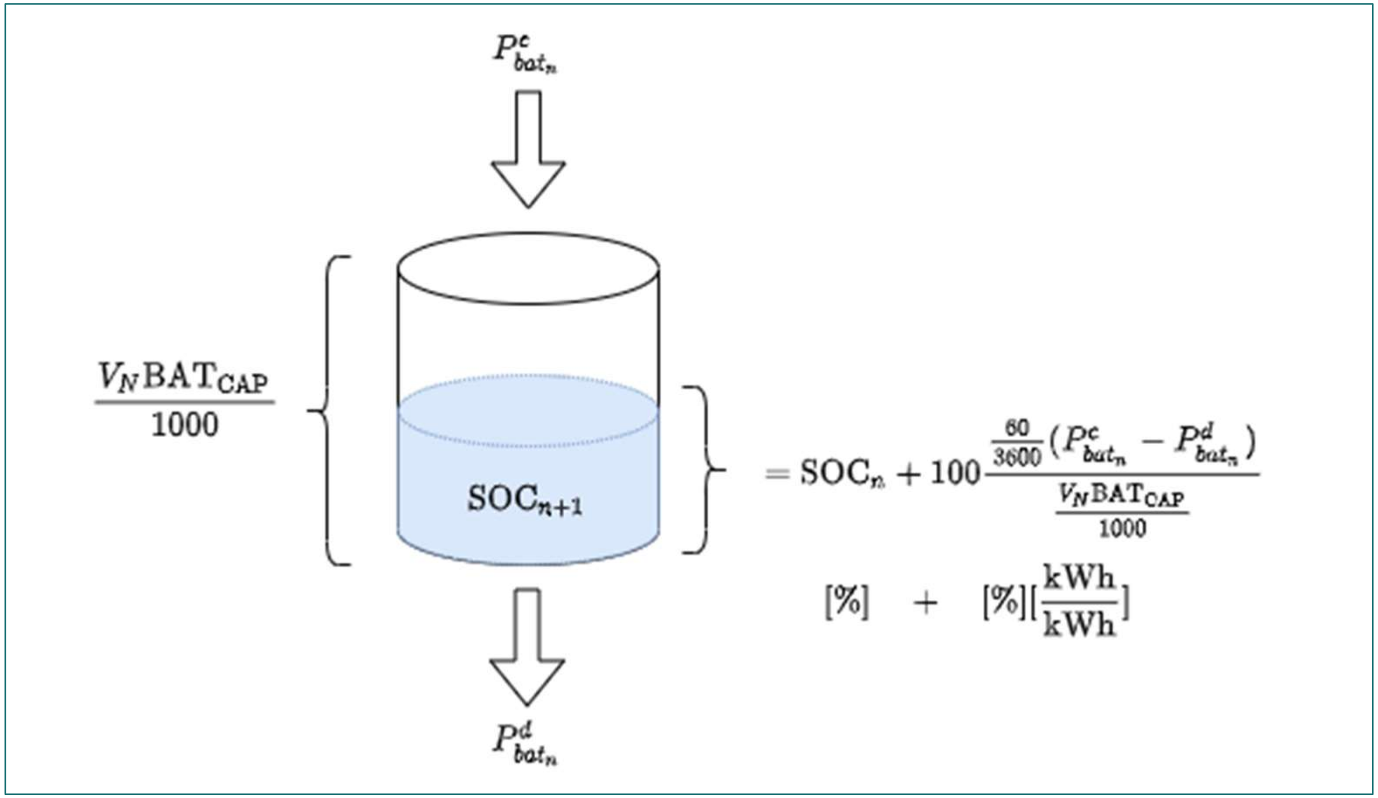


- So we form a Input set $\mathcal{I} = \{\mathrm{LP}, \mathrm{GT}, \mathrm{GM}\}$

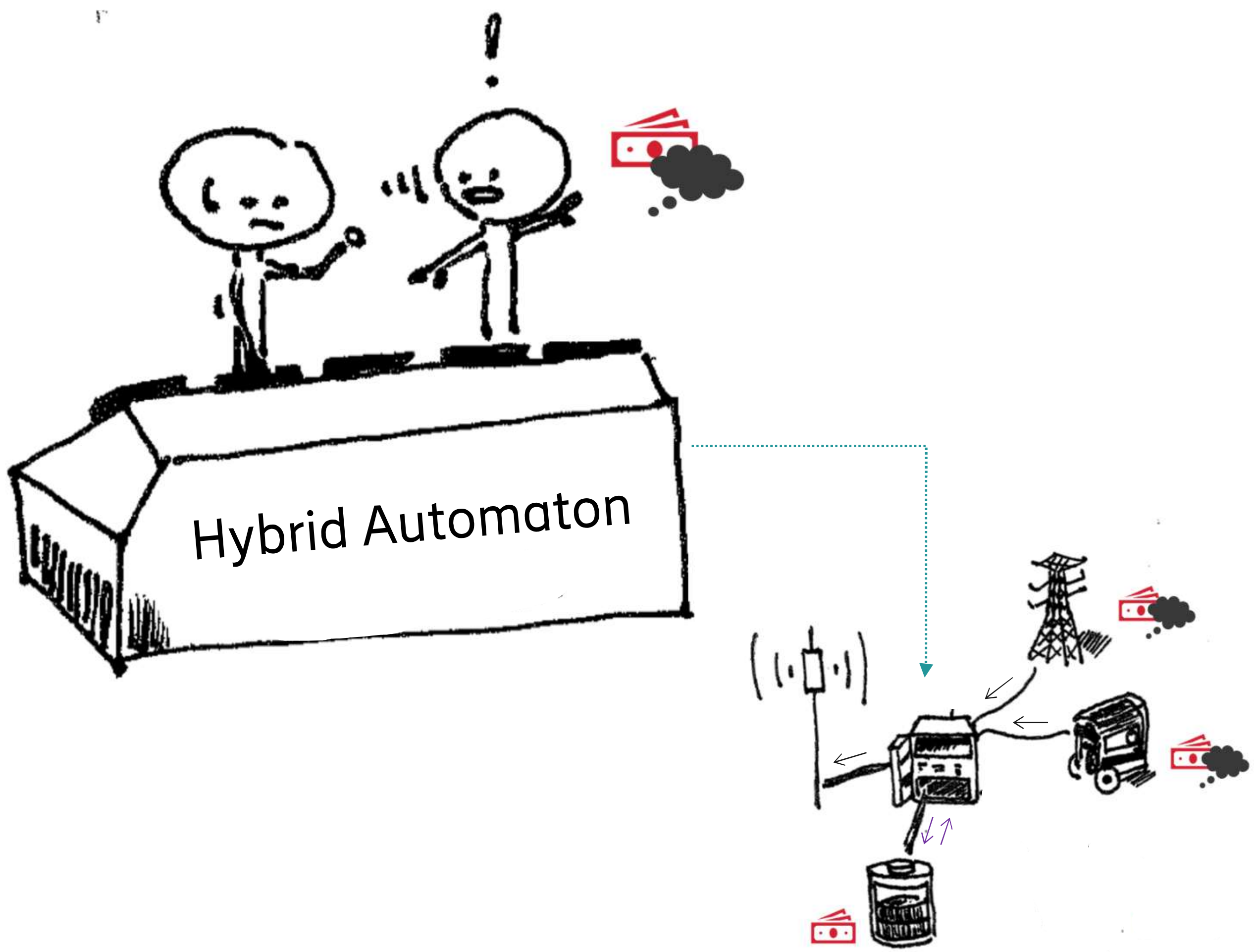
System Model – Dynamics

- State of Charge (SOC)
- Fuel Level (FL)
- Battery Cost (BC)



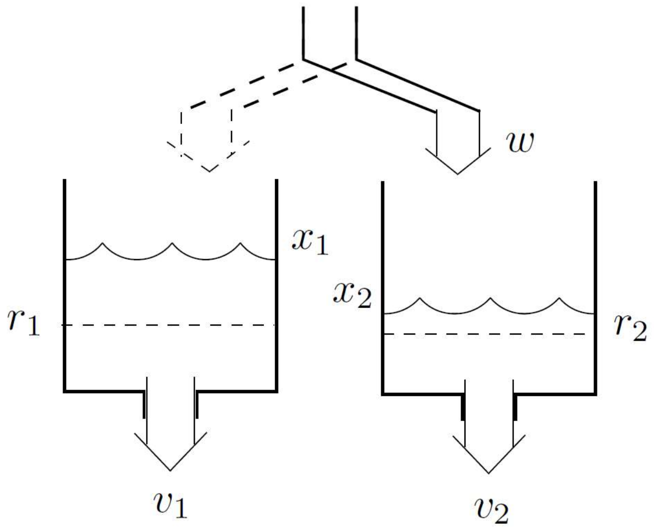


Controller Model



Hybrid Automaton - Introduction

- Hybrid automaton is a modelling language defined by a collection $H = (Q, X, Init, f, D, E, G, R)$
- Lets go for an example in order to explain these variables.
- Consider a two-water tank system.



Notation	Description
x_1	Water level for tank 1
x_2	Water level for tank 2
v_1	Flow velocity out of tank 1
v_2	Flow velocity out of tank 2
r_1	Critical water level for tank 1
r_2	Critical water level for tank 2
w	Water flow input

Hybrid Automaton - Introduction

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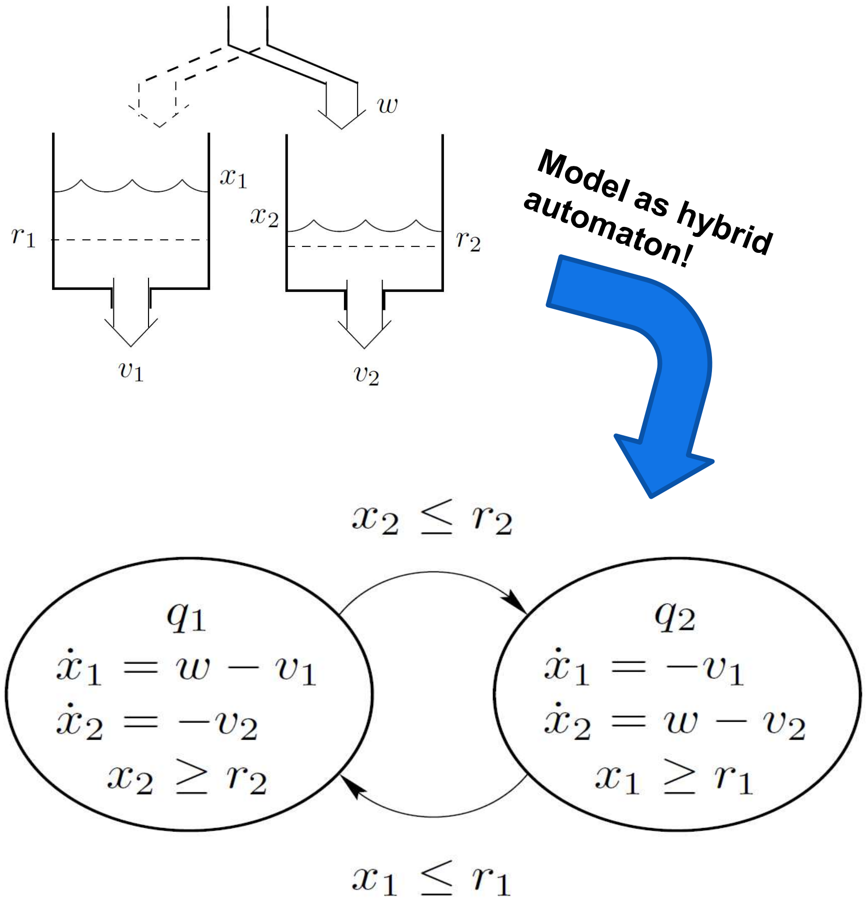
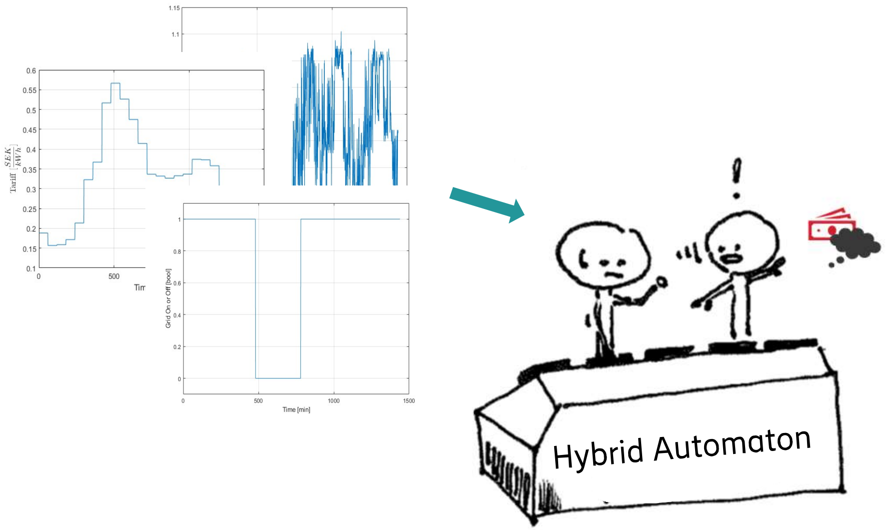
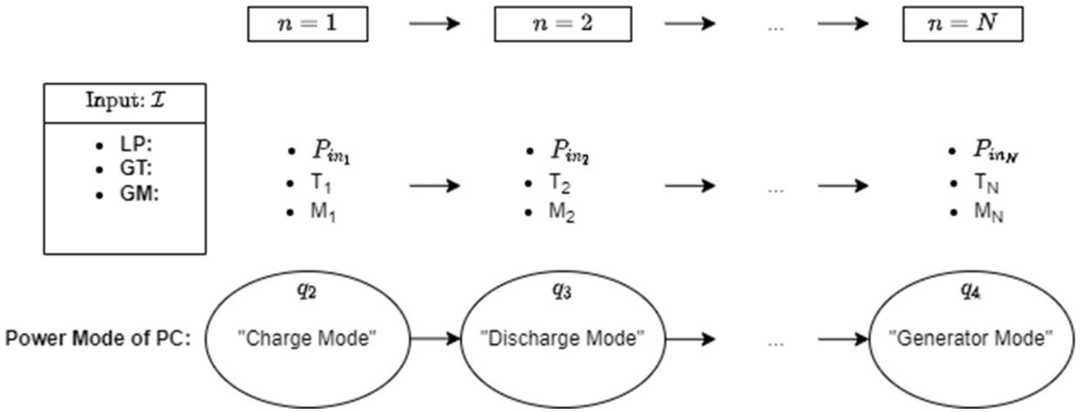
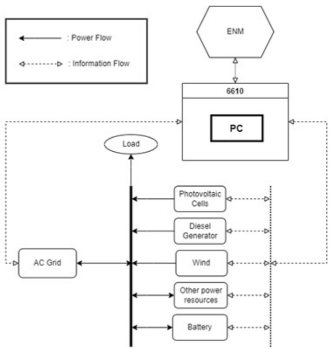


Notation	Description	Water tank
Q	discrete state space	$Q = \{q_1, q_2\}$
X	continous state space	$(x_1, x_2) \in X \subseteq \mathbb{R}^2$
$Init \subseteq Q \times X$	initial conditions	$Init = \{q_1, \bar{x}\}$
$f: Q \times X \rightarrow X$	vector fields	$f(q_1, \bar{x}) = \begin{cases} \dot{x}_1 = w - v_1 \\ \dot{x}_2 = -v_2 \end{cases}$ $f(q_2, \bar{x}) = \begin{cases} \dot{x}_1 = -v_1 \\ \dot{x}_2 = w - v_2 \end{cases}$
$D: Q \rightarrow 2^X$	domains	$D(q_1) = \{x \in X \mid x_2 \ge r_2\}$ $D(q_2) = \{x \in X \mid x_1 \ge r_1\}$
$E \subset Q \times Q$	edges	$E = \{(q_1, q_2), (q_2, q_1)\}$
$G: E \rightarrow 2^X$	guards	$G(q_1, q_2) = \{x \in X \mid x_2 \le r_2\}$ $G(q_2, q_1) = \{x \in X \mid x_1 \le r_1\}$
$R: E \times X \rightarrow 2^X$	reset conditions	



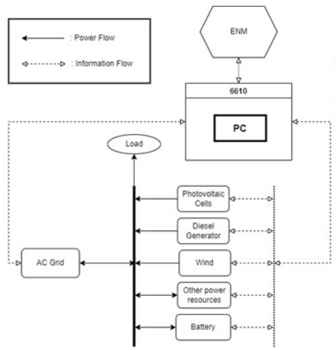


Power Mode	Notation	Dynamics
Grid Mode	q_1	$P_{grid_n} = P_{in_n}$ $P_{gen_n} = 0$ $P^c_{bat_n} = 0$ $P^d_{bat_n} = 0$
Charge Mode	q_2	$P_{grid_n} = P_{rect}$ $P_{gen_n} = 0$ $P^c_{bat_n} = P_{grid_n} - P_{in_n}$ $P^d_{bat_n} = 0$
Discharge Mode	q_3	$P_{grid_n} = 0$ $P_{gen_n} = 0$ $P^c_{bat_n} = 0$ $P^d_{bat_n} = P_{in_n}$
Generator Mode	q_4	$P_{grid_n} = 0$ $P_{gen_n} = P_{in_n}$ $P^c_{bat_n} = 0$ $P^d_{bat_n} = 0$
Insufficient Mode	q_5	$P_{grid_n} = 0$ $P_{gen_n} = 0$ $P^c_{bat_n} = 0$ $P^d_{bat_n} = 0$



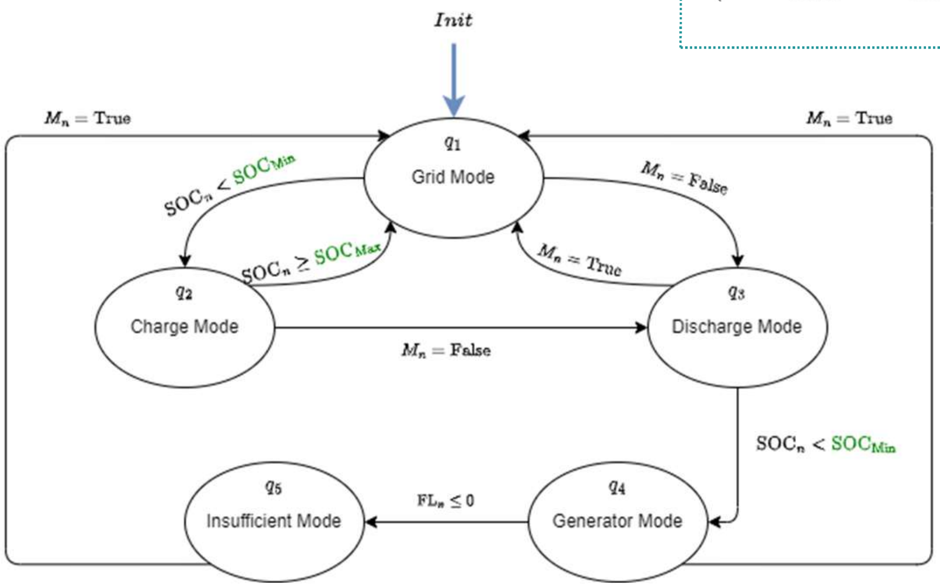
Policy 1: Baseline

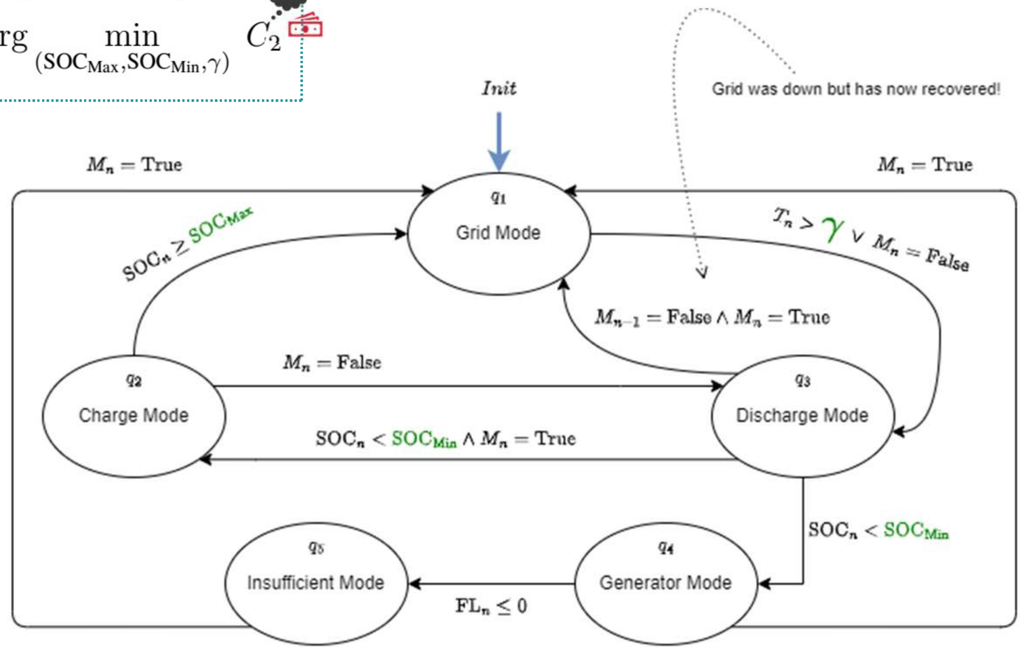
Policy 2



$$(\mathrm{SOC_{Max}}, \mathrm{SOC_{Min}})^{1*} \in \arg \min_{(\mathrm{SOC_{Max}}, \mathrm{SOC_{Min}})} C_1$$

$$(\mathrm{SOC_{Max}}, \mathrm{SOC_{Min}}, \gamma)^{2*} \in \arg \min_{(\mathrm{SOC_{Max}}, \mathrm{SOC_{Min}}, \gamma)} C_2$$

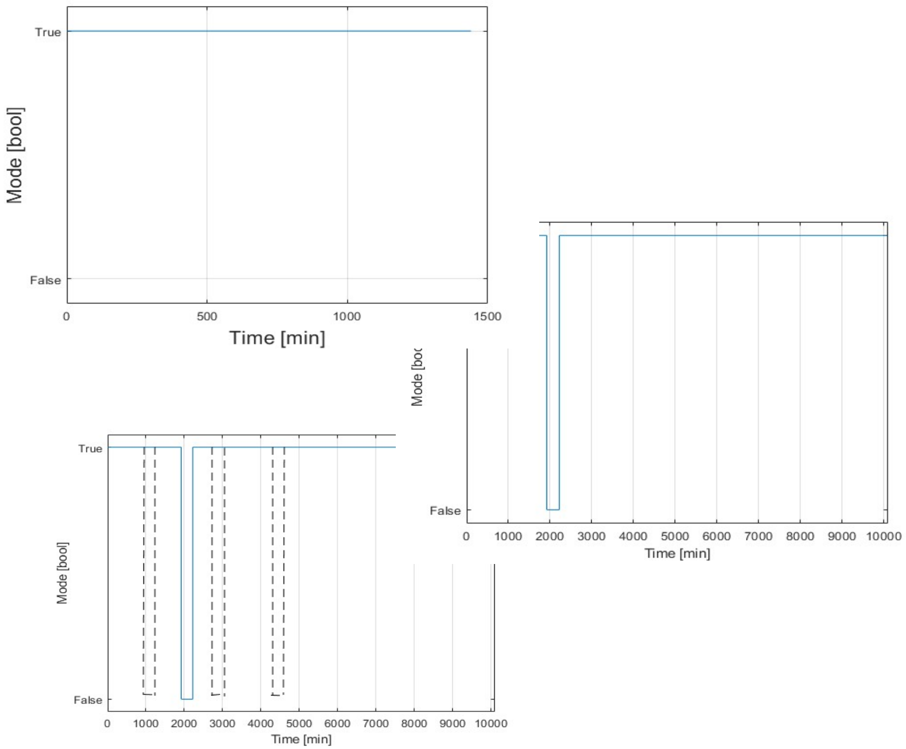




Results

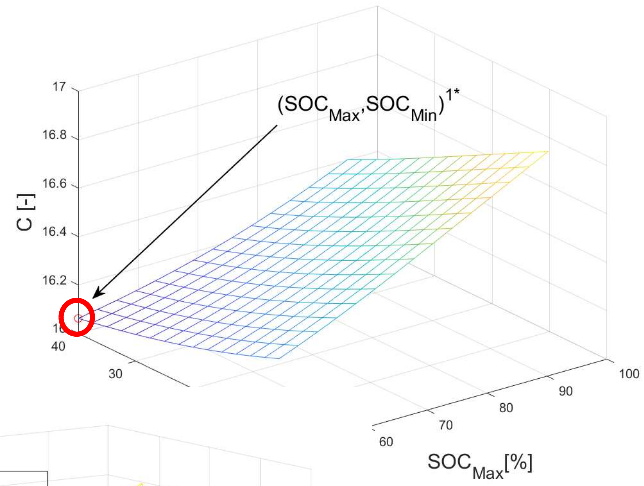
Study 3 different Scenarios of RBS operation.

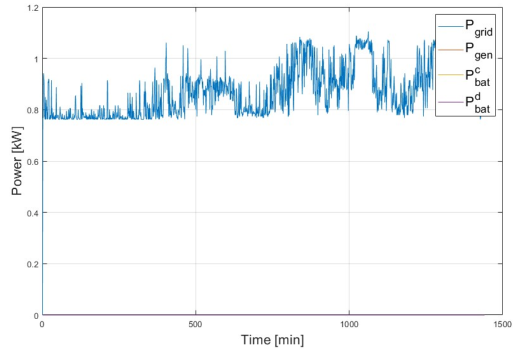
- Scenario 1: No grid failure
- Scenario 2: Determined grid failure
- Scenario 3: Random grid failure

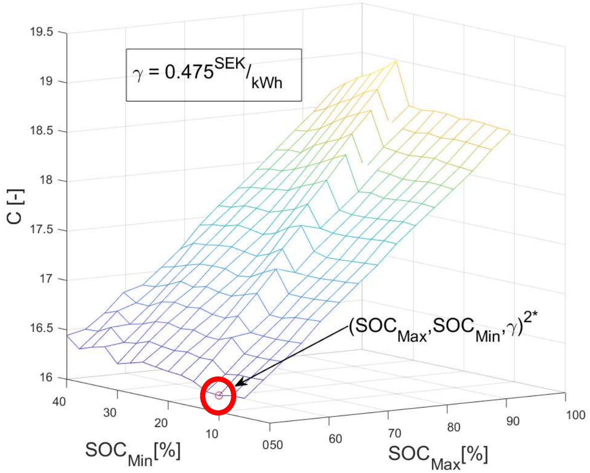


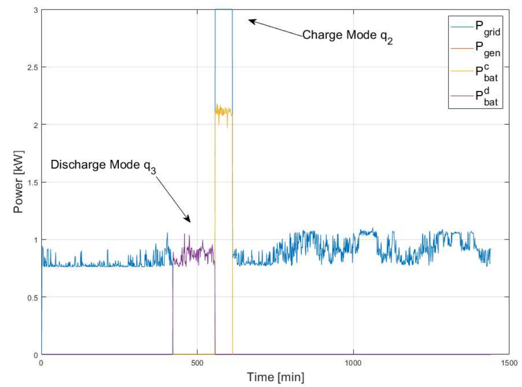
Result 1

- No grid failure
- Policy 1 lowest emission and cost.







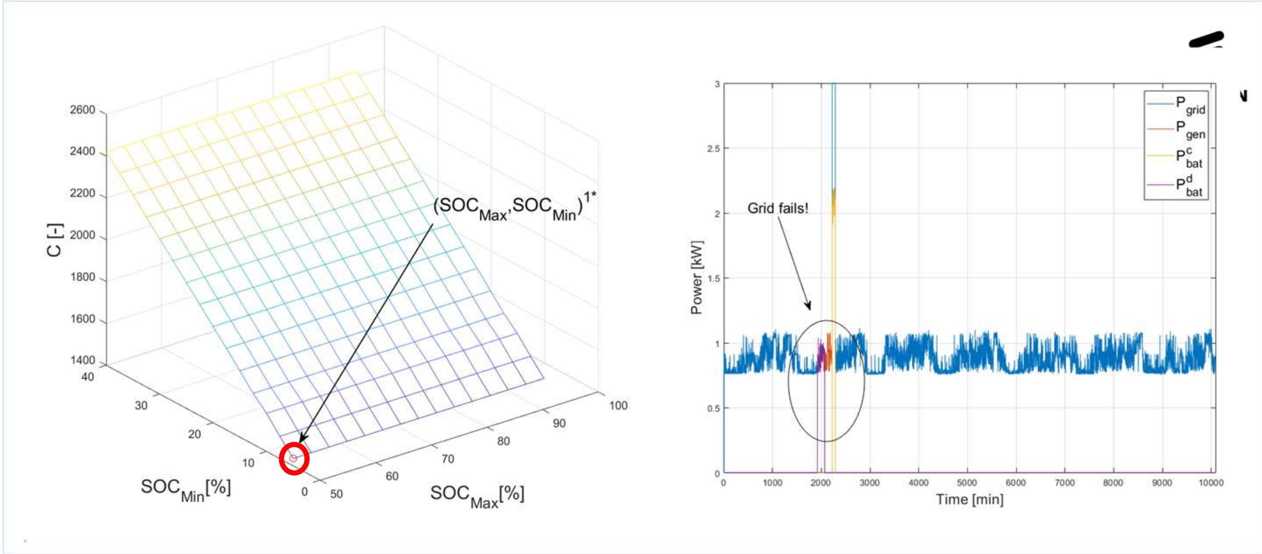


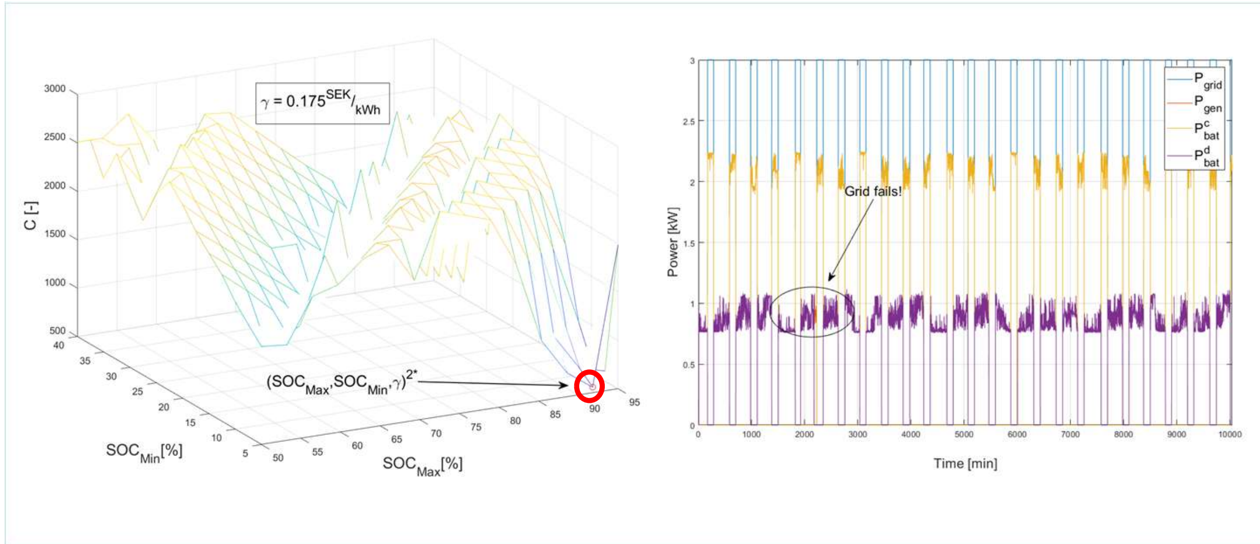
	Policy 1	Policy 2
SOC_{MAX} [%]	50	50
SOC_{MIN} [%]	40	10
γ [SEK/kWh]	-	0.475

	Policy 1 (Baseline)	Policy 2
OC [SEK]	6.97 (100%)	7.095 (101.7%)
CO2 [kg]	9.09 (100%)	9.07 (99.8%)
C [-]	$C_1 = 16.06$ (100%)	$C_2 = 16.17$ (100.7%)

Result 2

- Grid failure
- Policy 2 performs significantly better





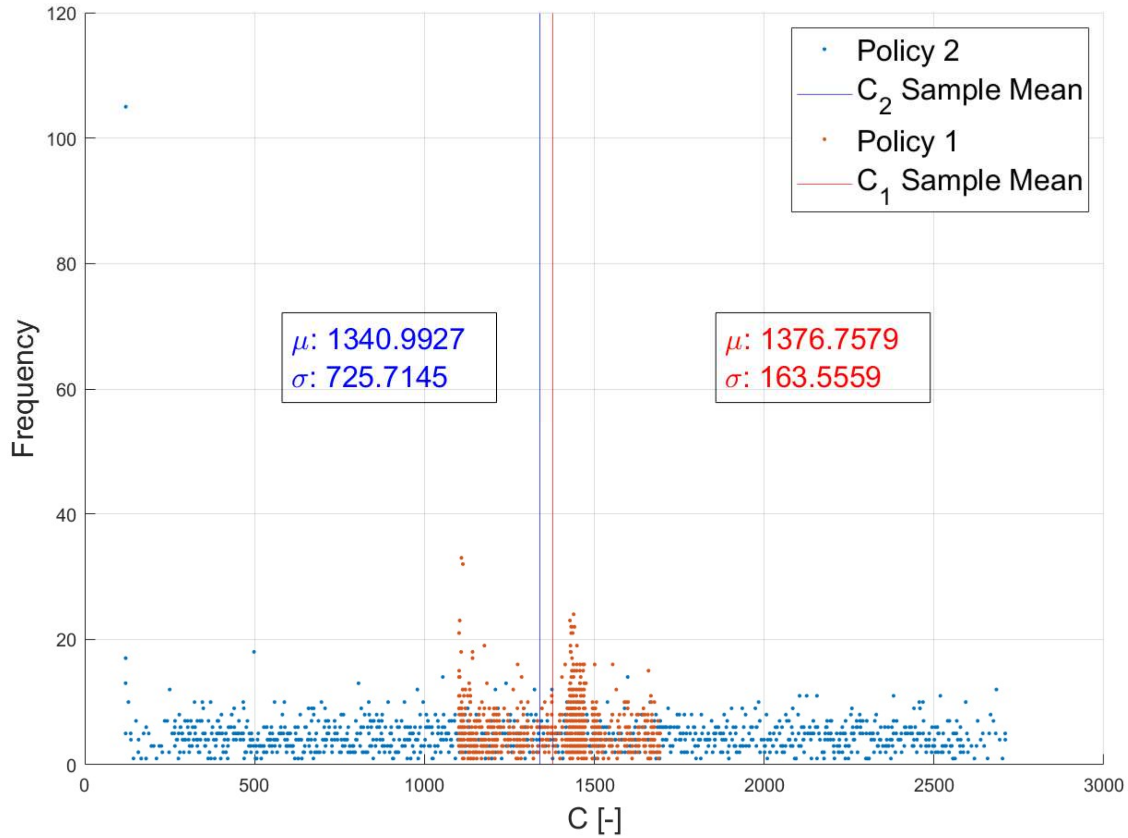
	Policy 1	Policy 2
SOC_{MAX} [%]	50	91.79
SOC_{MIN} [%]	5	5
γ [SEK/kWh]	-	0.175

	Policy 1	Policy 2
OC [SEK]	1252.2 (100%)	456.2 (36.4%)
CO2 [kg]	182.6 (100%)	101.51 (55.6%)
C [-]	$C_1 = 1434.8$ (100%)	$C_2 = 557.7$ (38.8%)

Result 3

- Random grid failure
- Policy 1 or Policy 2?

	Policy 1	Policy 2
μ_{OC} [SEK]	1199.4 (100%)	1168.1 (97.4%)
μ_{CO2} [kg]	177.4 (100%)	172.9 (97.5%)
μ_C [-]	1376.8 (100%)	1341.0 (97.4%)
σ_{OC} [SEK]	148.8 (100%)	660.3 (443.8%)
σ_{CO2} [kg]	14.75 (100%)	65.5 (444.1%)
σ_C [-]	163.6 (100%)	725.7 (444.0%)



Conclusion

- The RBS PI can be modelled as a hybrid dynamical system.

- Policy 2 has potential of cost and emission savings, and performs best at times when the grid may be unavailable. The cost variance is higher than that of Policy 1.

Publication

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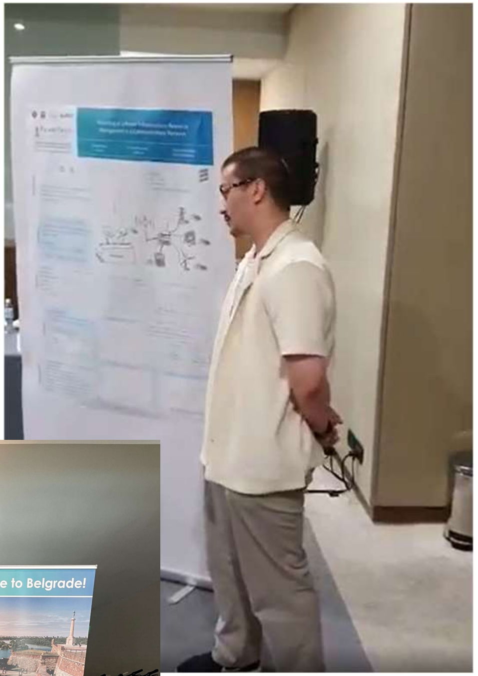
- Paper accepted and presented at 2023 IEEE Belgrade PowerTech
- Published in 2023 IEEE Belgrade PowerTech Proceedings
  [G. Lenart, F. Shamurad and L. Eleftheriadis, "Modelling of a Power Infrastructure Resource Management in a Communication Network" 2023 IEEE Belgrade PowerTech, Belgrade, Serbia, 2023, pp. 1-6]
- Resulted in a Defensive Publication



Thank you for your attention!

Questions?

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