UNIVERSIDADE FEDERAL
DE SANTA CATARINA
Centro Tecnológico - CTC

Model Predictive Control in Microgrids Considering Demand Management, Hybrid Energy Storage and User Satisfaction

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II WORKSHOP INCT CAPE 2024 - Florianópolis - Brazil

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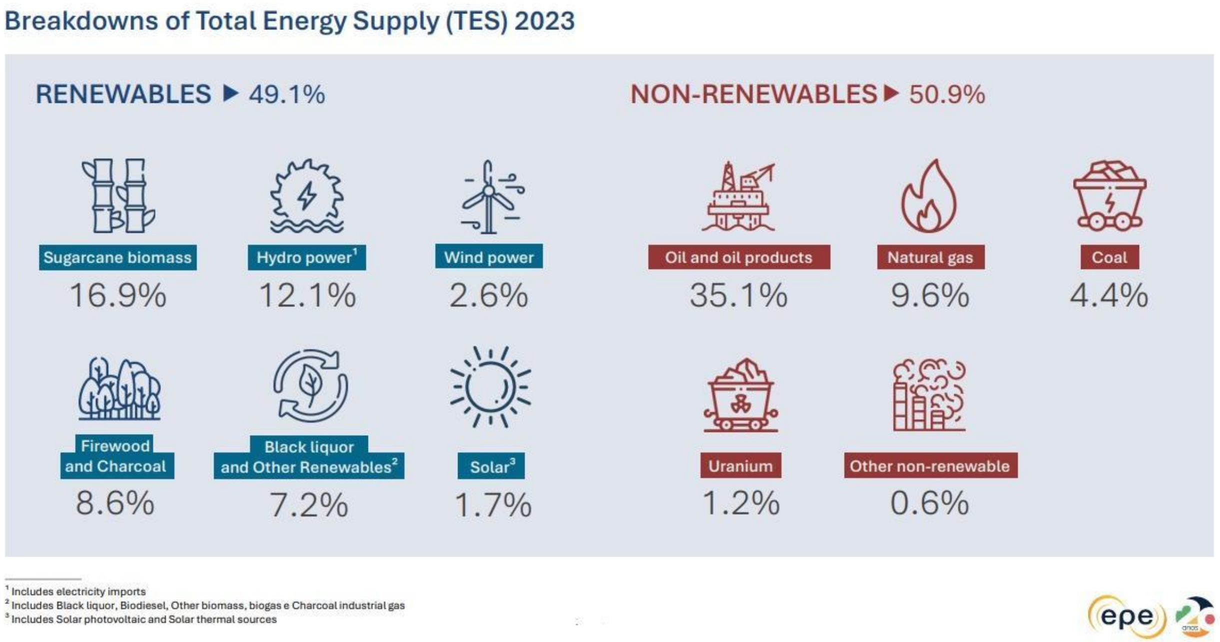
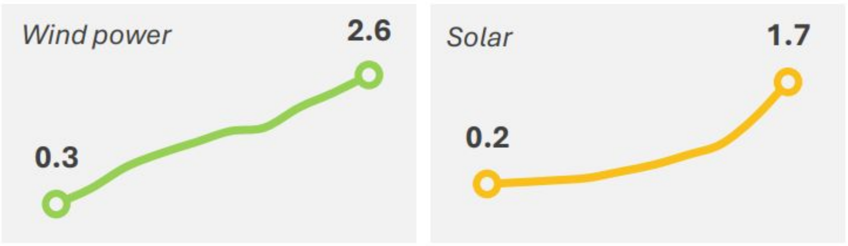
INCT CAPE

Context: Brazilian situation

- 49,1% Renewables (world <15%)
- Eolic and solar are increasing
- Distributed generation is increasing

- Microgrids important actors
- Storage systems
  - Thermal
  - Batteries
  - H2





2014 to 2023

Context: microgrids

- local generation
- load control
- buy and sell energy
- hybrid storage systems

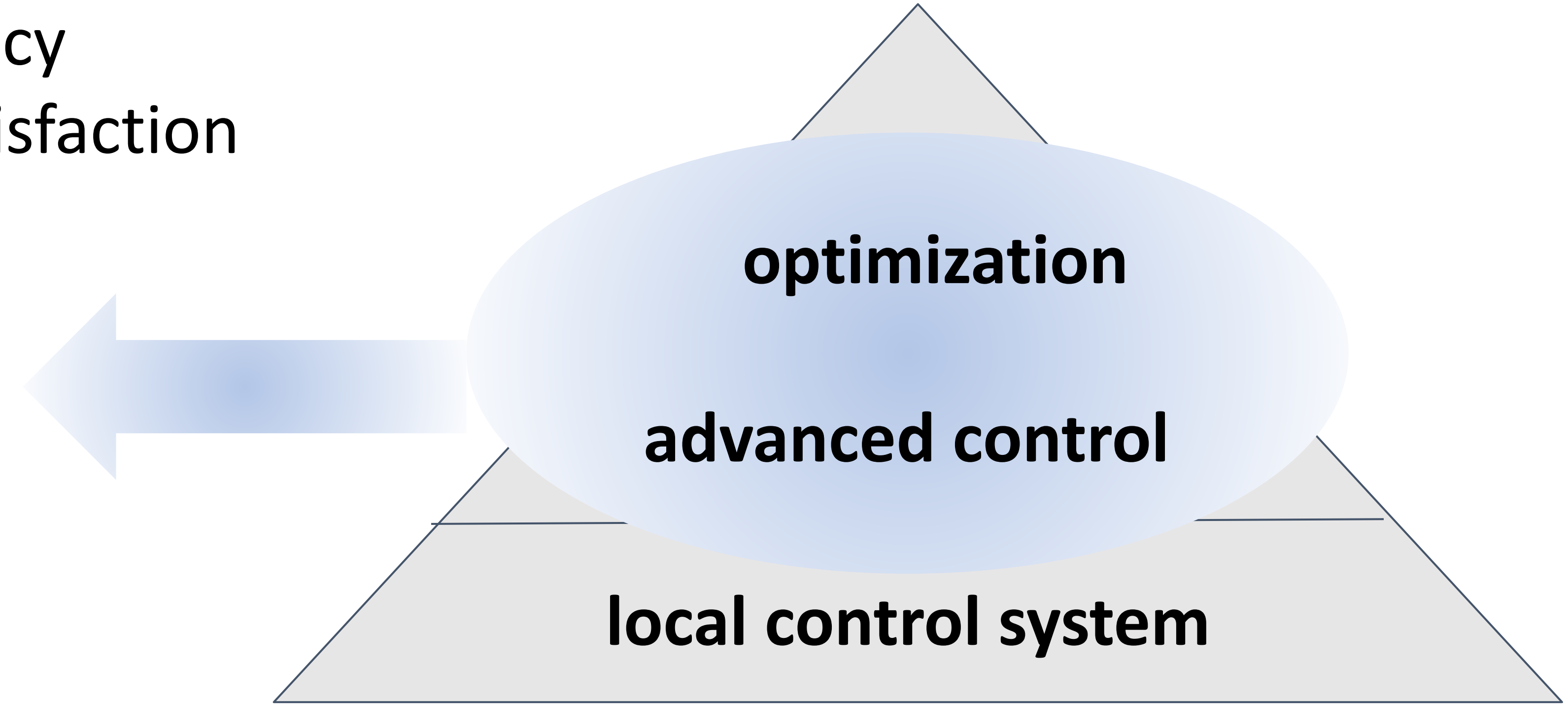
- Challenges
  - Increase energy production;
  - User satisfaction;
  - Efficiency and quality;
  - Nacional technology.
- Sustainability
  - Environmental;
  - Economic

Model-Based Predictive Control & **Quality of Experience**

Objectives

- To propose an EMS for the microgrid
    - minimize the cost of used energy
    - maximize efficiency
    - consider user satisfaction

EMS MPC with Demand Management Actions



automation pyramid

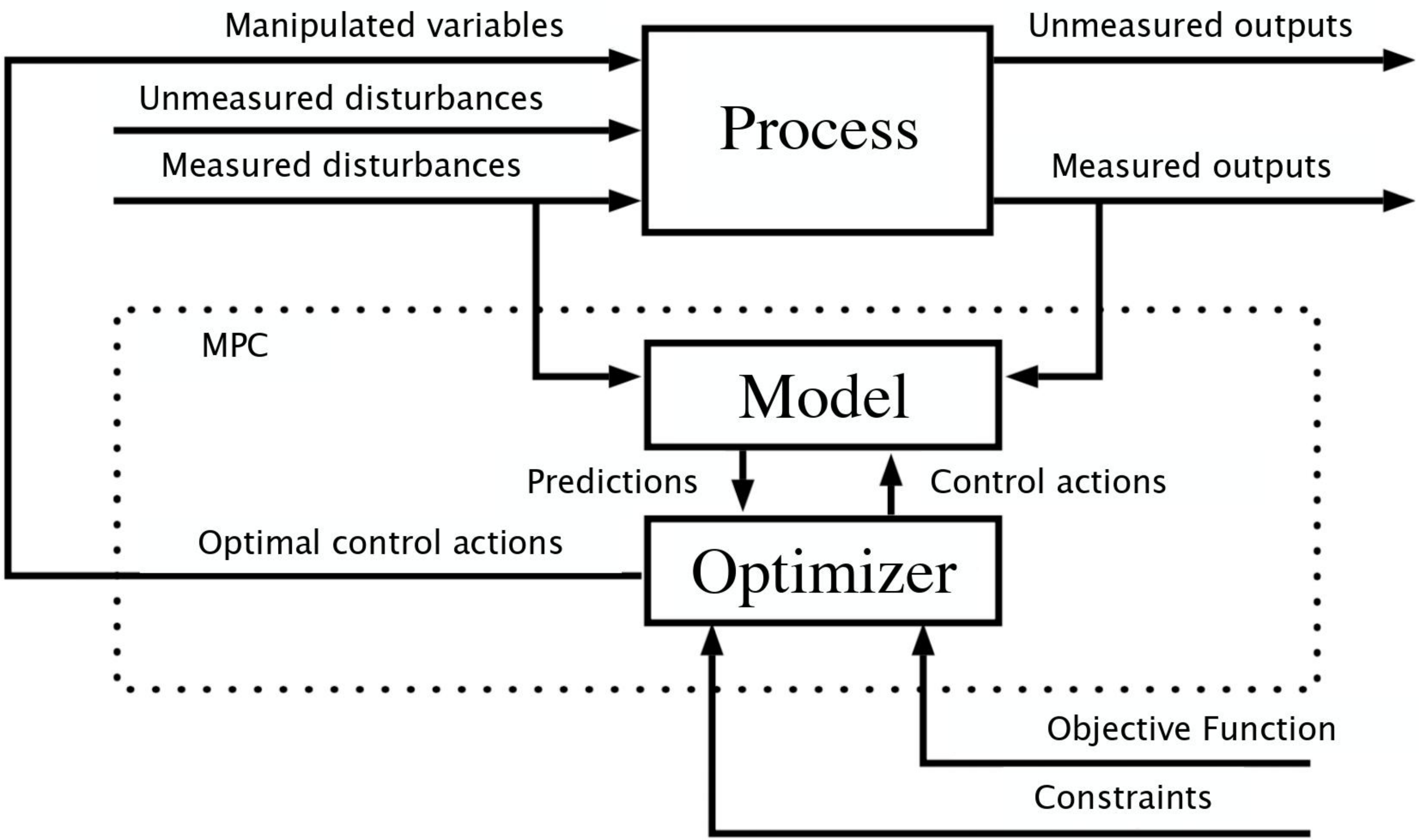
Agenda

- **MPC-EMS for the microgrid**
- QoE metrics and demand management
- Modeling and control formulation
- Results and discussion
- Final Remarks

MPC - the adequate choice

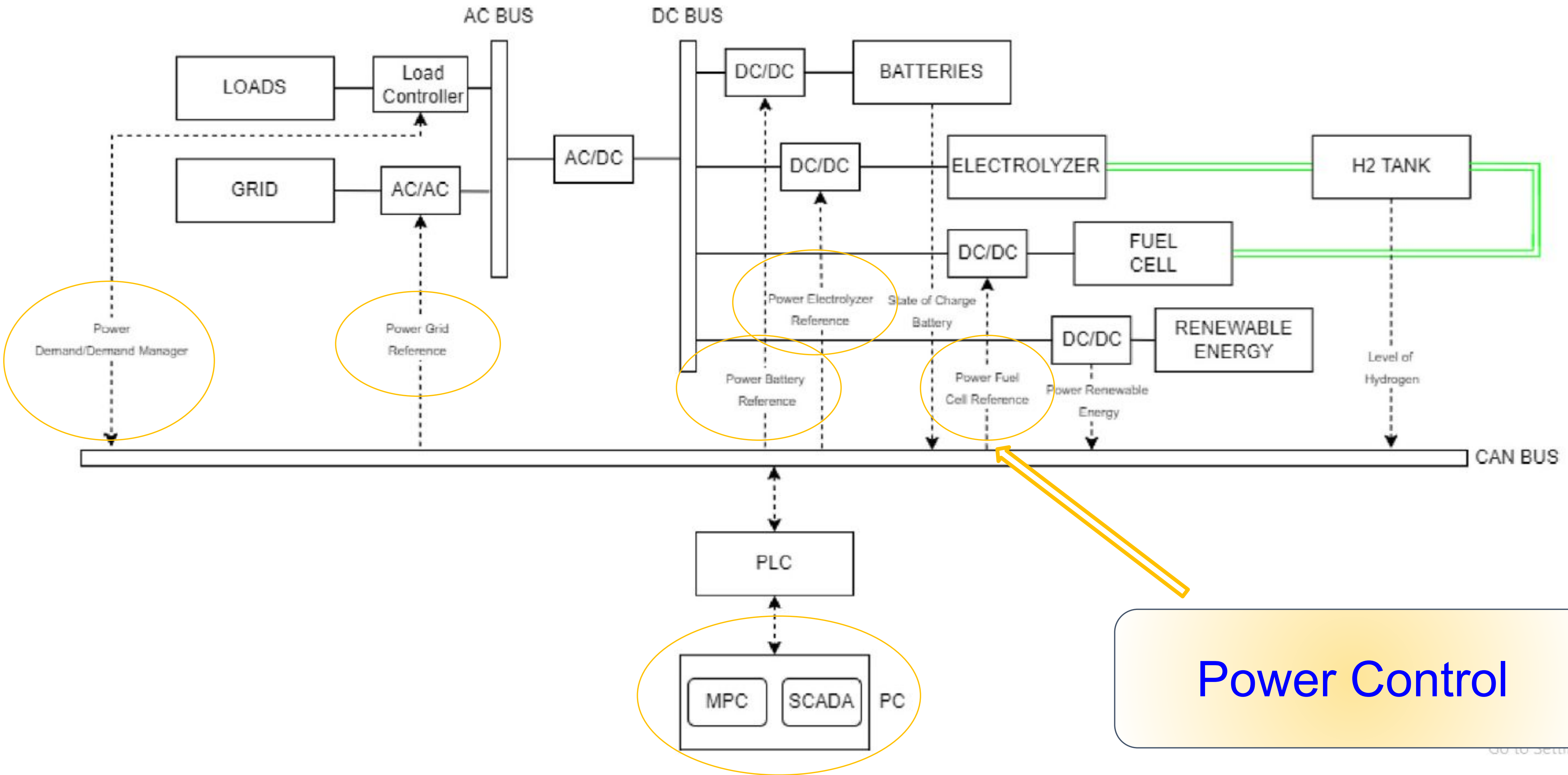
- Model-Based Predictive Control (MPC)
  - One of the most important advanced control techniques
  - Growing number of researches
  - Many successful applications
  - Solution of an optimization problem
- MPC allows natively handling
  - Different control objectives - including economic ones
  - Constraints
  - Multivariable and hybrid systems

MPC idea



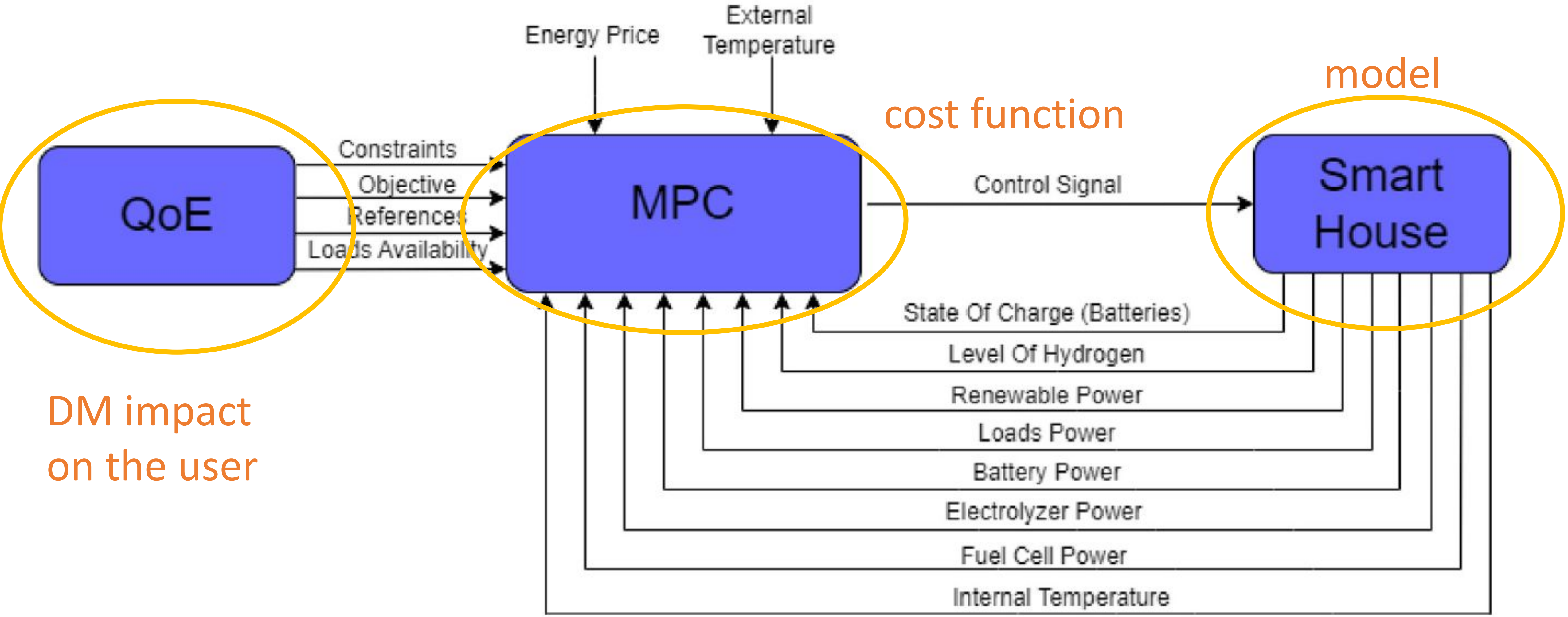
- MPC Algorithm
  - Prediction
  - Optimization
  - Receding horizon

MPC in the microgrid case study



Power Control

MPC in the microgrid case study



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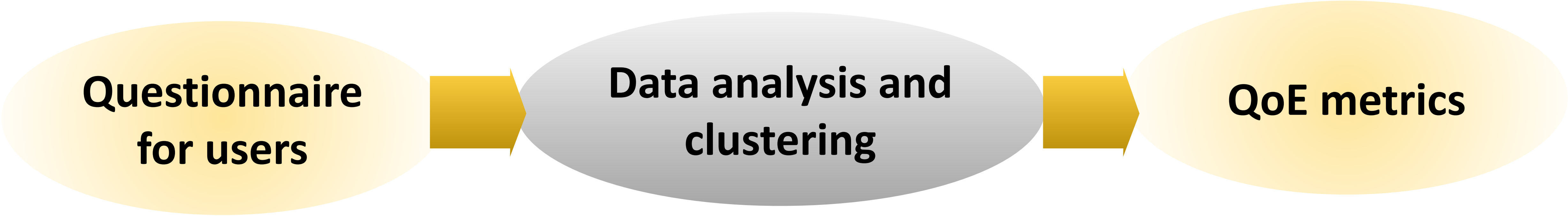
QoE approach

- Interaction between users and an EMS
- Classes of loads: sheddable, curtailable and shiftable
- Several user profiles
- The impact caused on users is weighted by QoE curves (or CQoE)
- The decision-making process is based on the QoE curves



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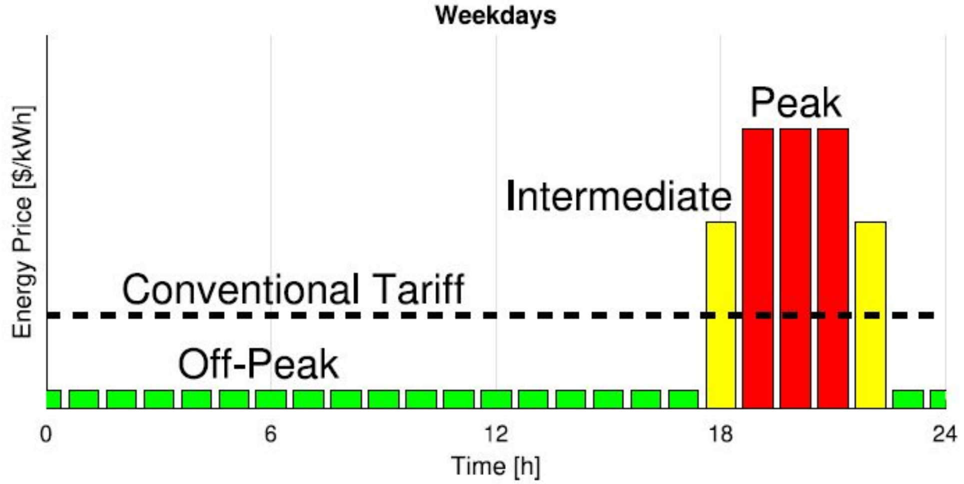
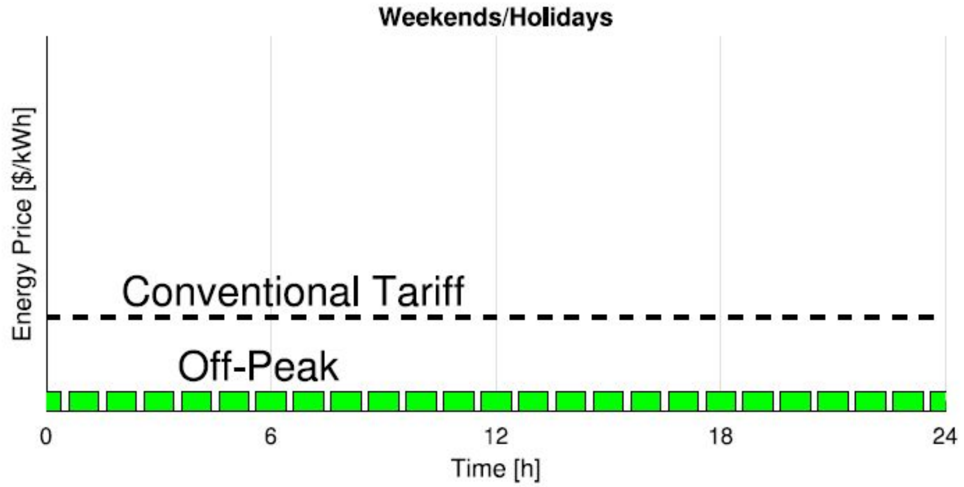
Microgrid models

- Tariff rules
  - Flexible model
- Storage system models
  - Accumulator model
  - Efficiency
  - Constraints
- Load (demand) models
  - Type of loads
- Power generation and power consumption
  - Energy transformation - efficiency
  - Constraints





Storage models

Sampling

Charge efficiency

State of charge

$$x(k+1) = x(k) + \frac{t_s}{\eta_i^d C_i} P_i(k) + \left(\frac{\eta_i^c t_s}{C_i} - \frac{t_s}{\eta_i^d C_i} \right) P_i(k) \delta_i(k),$$

binary
0- discharging
1- charging

Discharge efficiency

Power

Capacity

Min value of power

$$P_i(k) \geq m_i(1 - \delta_i(k))$$

$$P_i(k) \leq M_i \delta_i(k),$$

Max value of power

binary and real variables
MLD constraints
bilinear problems
auxiliary variable z_i $P_i \delta_i$

$$z_i(k) \leq M_i \delta_i(k)$$

$$z_i(k) \geq m_i \delta_i(k)$$

$$z_i(k) \leq P_i(k) - m_i(1 - \delta_i(k))$$

$$z_i(k) \geq P_i(k) - M_i(1 - \delta_i(k))$$

Storage system constraints

HARD

$$SoC_B(k) \leq SoC_B^{max}$$

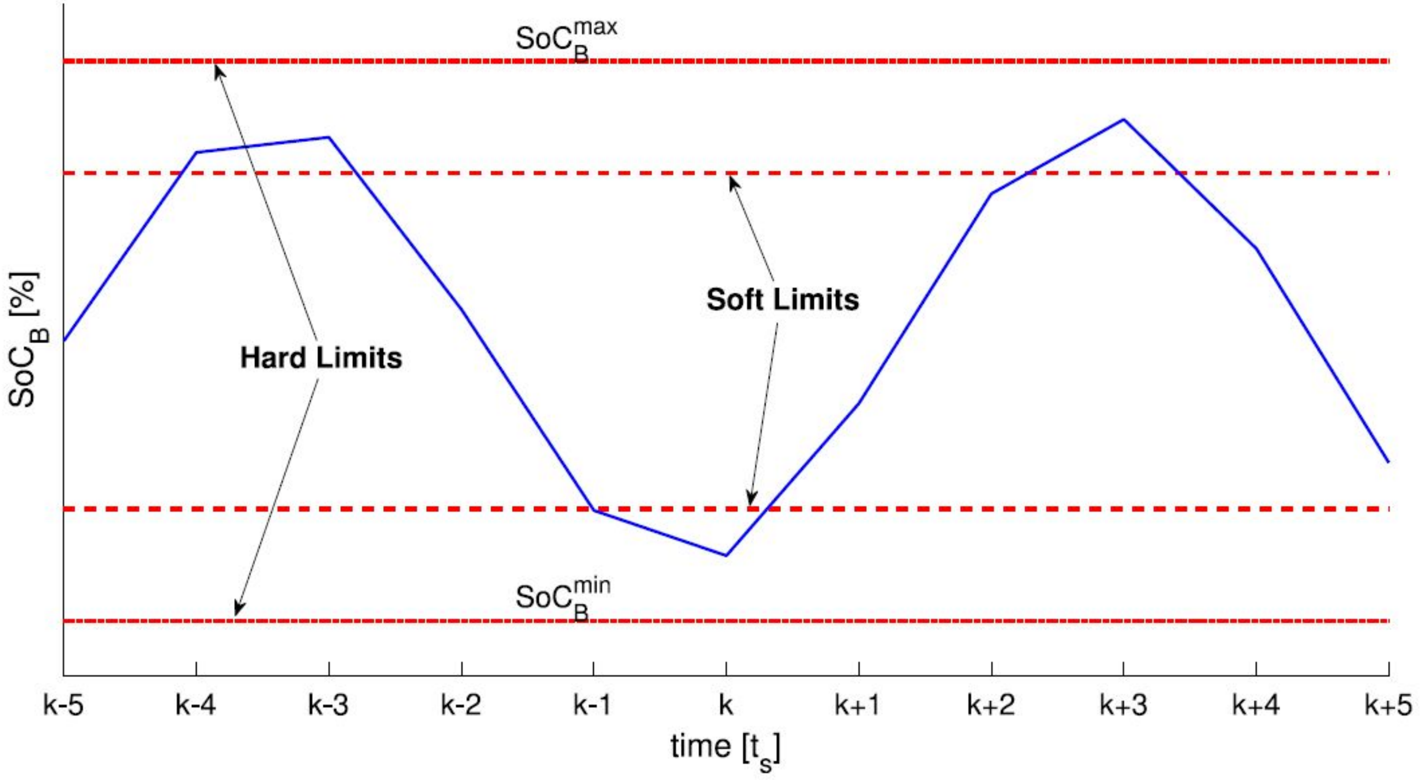
$$SoC_B(k) \geq SoC_B^{min}$$

SOFT

$$SoC_B(k) \leq SoC_{\xi}^{max} + \xi_B(k)$$

$$SoC_B(k) \geq SoC_{\xi}^{min} + \xi_B(k)$$

Slack variables



$$\xi_B(k) \geq SoC_B^{min} - SoC_{\xi}^{min}$$

$$\xi_B(k) \leq SoC_B^{max} - SoC_{\xi}^{max}$$

Load Power and Demand Actions

$$S_L(k) = S_{PR}(k) + S_{SH}(k) + S_{DM}(k) + S_{TF}(k) + S_{AC}(k) + S_{EV}(k)$$

Total Power

Priority — sheddable — dimerizable — time-flexible — air conditioning — electrical vehicle

no DM actions

accept DM actions

$$S_{SH}(k) = \delta_{SH}(k) S_{SH}^{max}(k)$$

Binary (0-1)

$$S_{DM}(k) = \gamma_{DM}(k) S_{DM}^{max}(k)$$

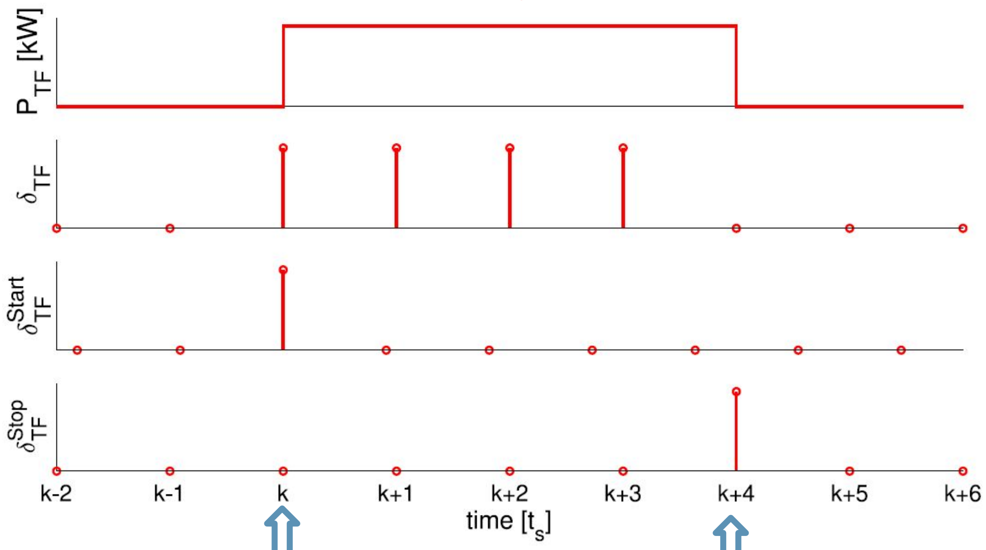
$$\gamma_{DM}(k) \leq \gamma_{DM}^{max}$$

$$\gamma_{DM}(k) \geq \gamma_{DM}^{min}$$

continuous (%)

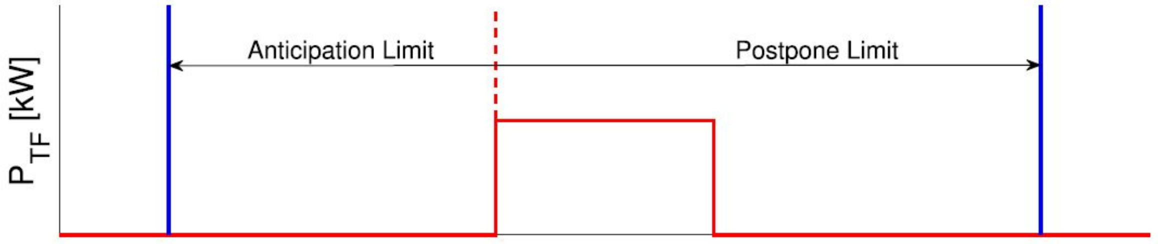
Time flexible loads

availability window

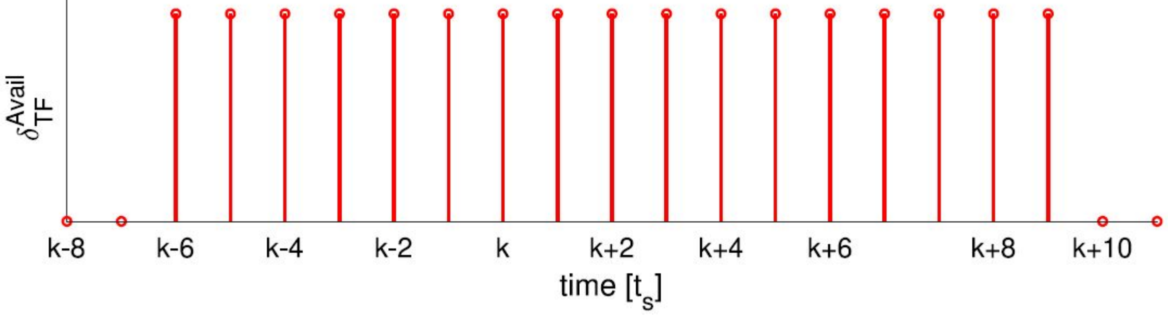


Start

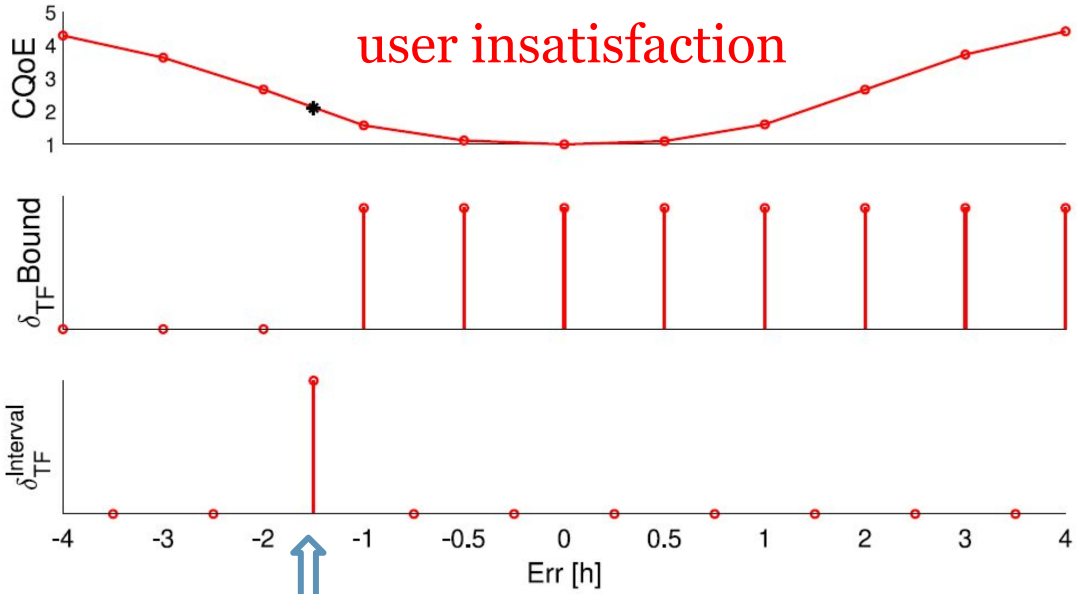
Stop



binary variable indicating when load is able to start



user insatisfaction



complementary QoE

Start

Power models and constraints

AC BUS

$$S_G(k) = S_L(k) - S_C(k)$$

Grid Load Converters

$$S_i(k) = P_i(k) + jQ_i(k)$$

$$P_G(k) \geq PF_{lim}|S_G(k)|$$

Power Factor Limit

$$|S_C(k)| \leq S_C^{max}$$ Max Power

DC BUS

Converters

$$P_C(k) = P_R(k) - P_E(k)$$

Renewable Energy Storage

$$P_C(k) \leq P_C^{max}$$

Max Power

Cost function

Batteries

$$J_B = \alpha_B \sum_{i=0}^{N} P_B^2(k+i)$$

H2 system

$$J_{H_2} = \alpha_{H_2} \sum_{i=0}^{N} P_{H_2}^2(k+i)$$

$$J = J_{WT} + J_{PF} + J_B + J_{H_2} + J_{QoE} + J_{\xi_B}$$

Tariff rules

$$J_{WT} = \sum_{i=0}^{N} EP(k+i)P_G(k+i)t_s$$

Slack variables

$$J_{\xi_B} = \alpha_{\xi_B} \sum_{i=0}^{N} \xi_B^2(k+i)$$

Power factor

$$J_{PF} = \alpha_{PF} \sum_{i=0}^{N} Q_G^2(k+i)$$

Quality of Experience

$$J_{QoE} = \alpha_{SH} \sum_{i=0}^{N}(1-\delta_{SH}(k+i)) + \alpha_{DM} \sum_{i=0}^{N}(1-\gamma_{DM}(k+i)) + \alpha_{TF} \sum_{j=1}^{N_{QoE}^{TF}} CQoE_{TF}^{j}(k) + \alpha_{AC} \sum_{i=0}^{N} \sum_{j=1}^{N_{QoE}^{AC}} CQoE_{AC}^{j}(k+i).$$

Optimization problem

$$\min_{u} \; J_{WT} + J_{PF} + J_B + J_{H_2} + J_{QoE} + J_{\xi_B}$$

s.t. models and constraints

u = decision vector ⇒ S_G, S_{SH}, S_{DM}, δ_{TF}^{Start}, P_{AC}, P_{EV} and S_C

grid power (S_G)

DM actions (S_{SH}, S_{DM}, δ_{TF}^{Start}, P_{AC}, P_{EV})

actuating converters (S_C)

mixed-integer quadratically constrained quadratic programming (MIQCQP) problem

Avoids NLP problems

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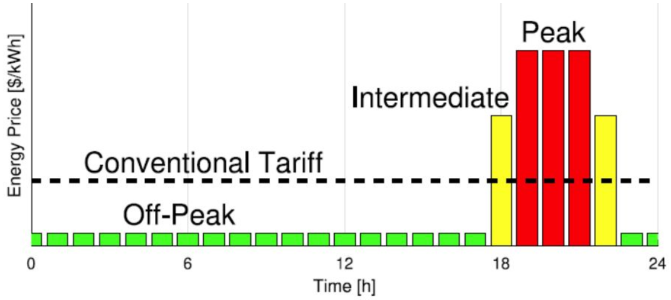
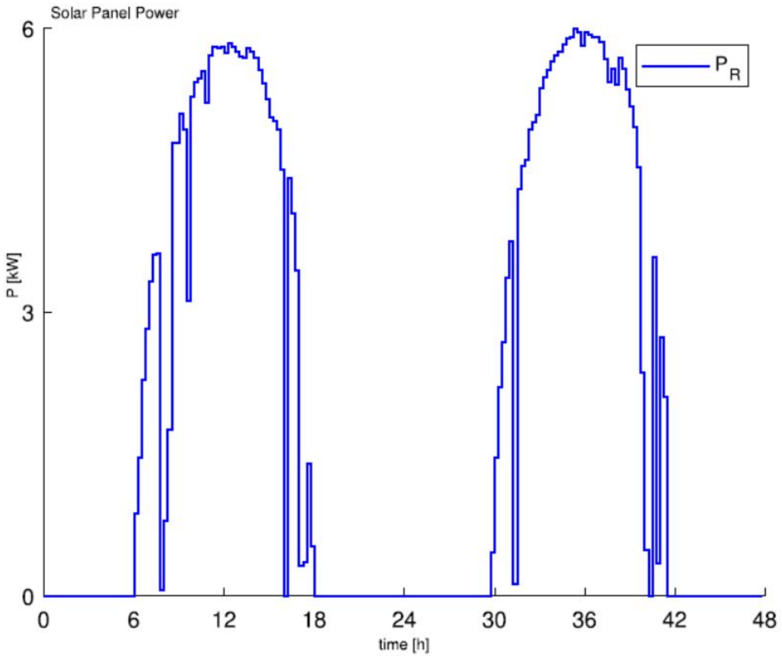
Results and discussion

Brazilian white tariff



Solar profile for 48 h

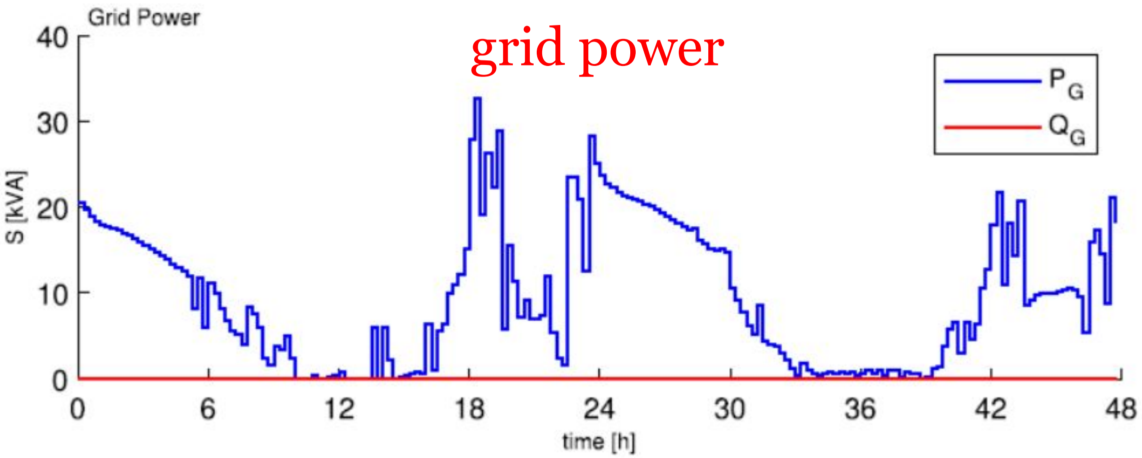


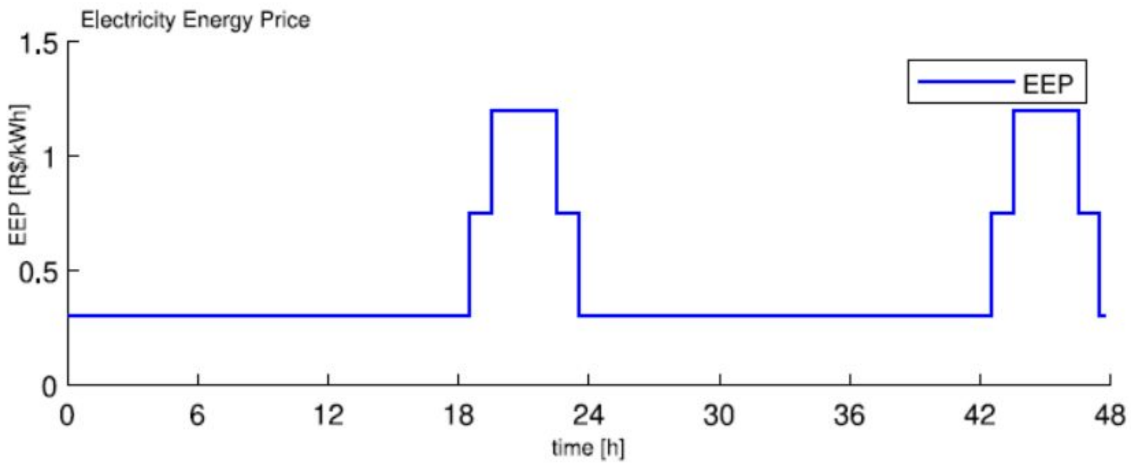
Special loads availability window.

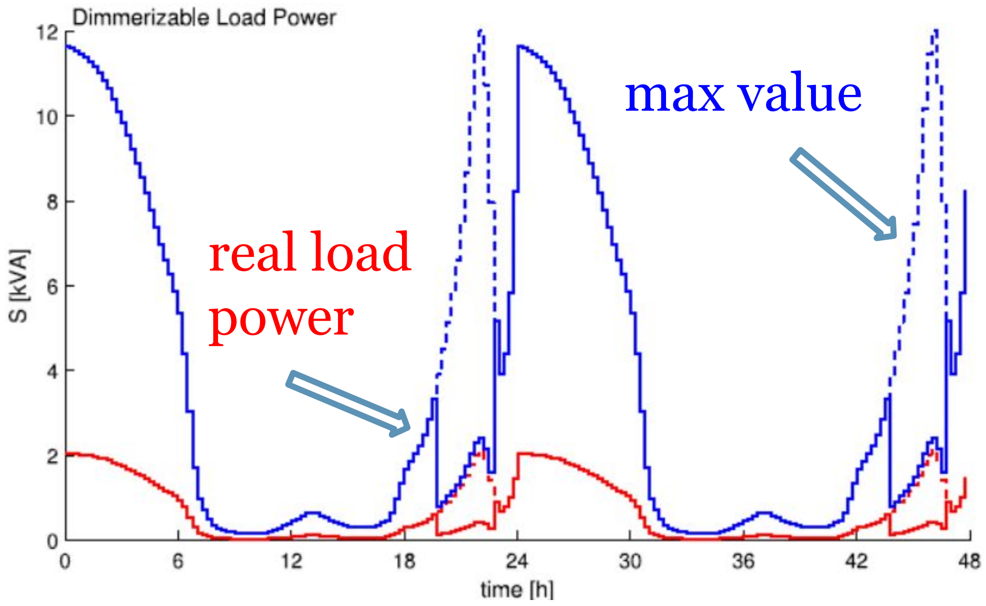
	Early Limit [h]	Late Limit [h]
Time-Flexible 1	5	13
Time-Flexible 2	14	22
Air Conditioning	18	24
Electric Vehicle	18	30

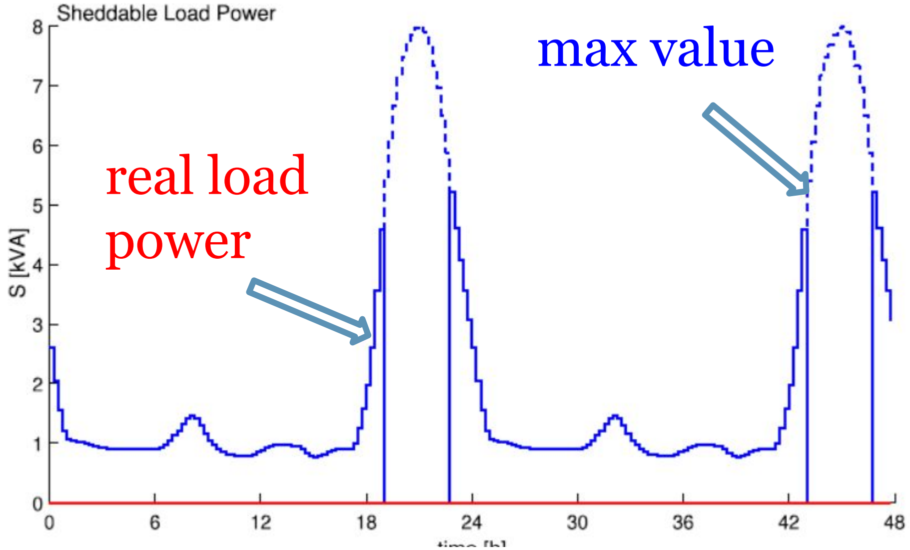
Two scenarios (48 h and one year) - sampling 15 min and N=12 h

Grid and Load Power

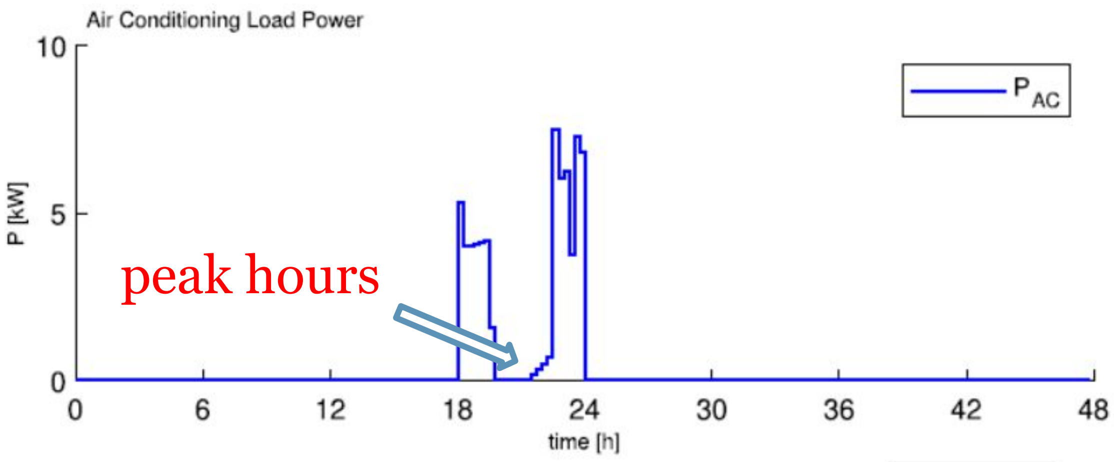


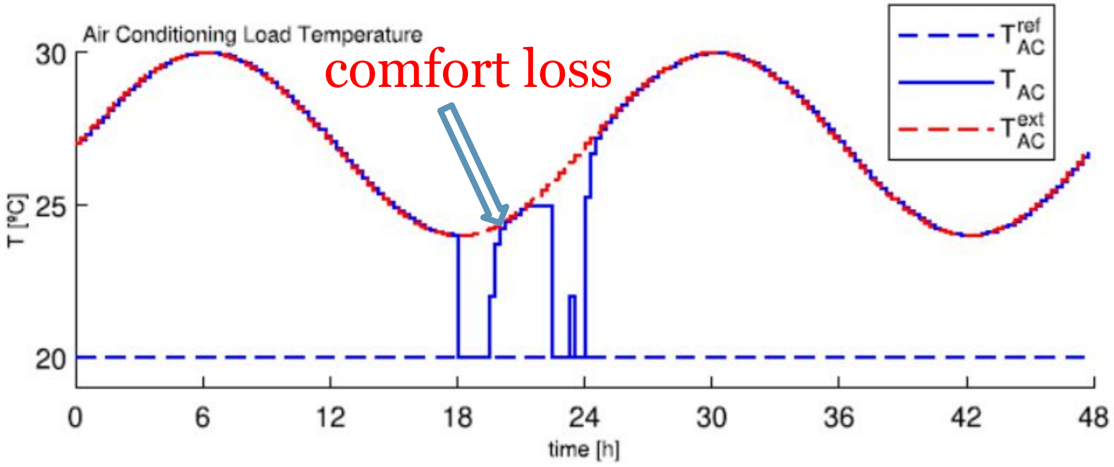


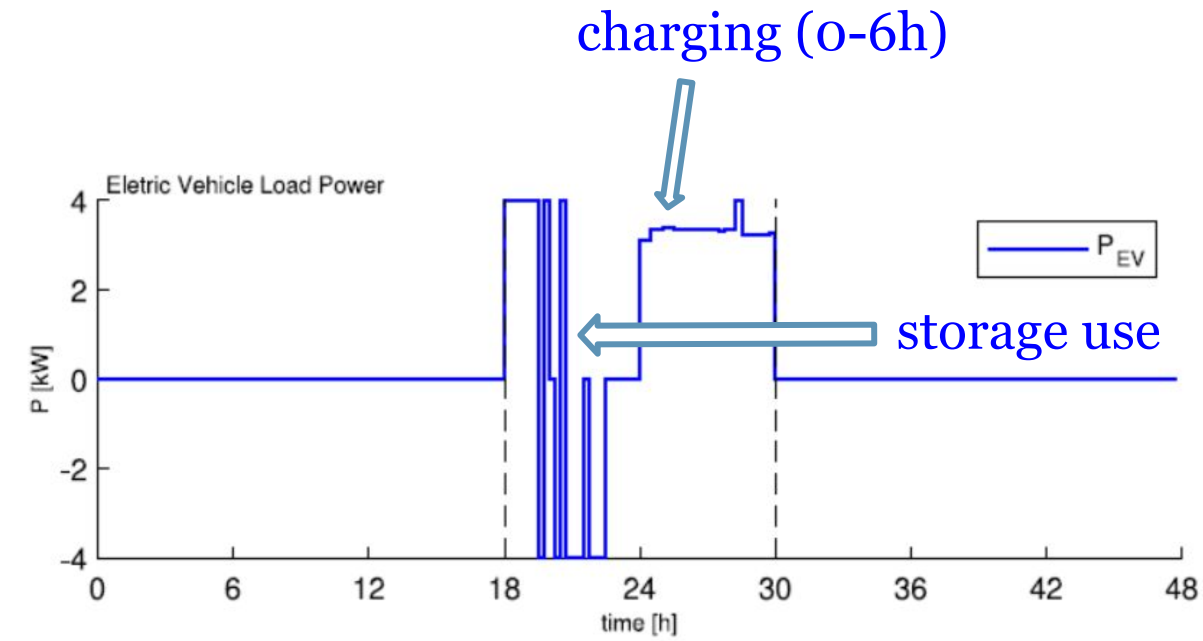


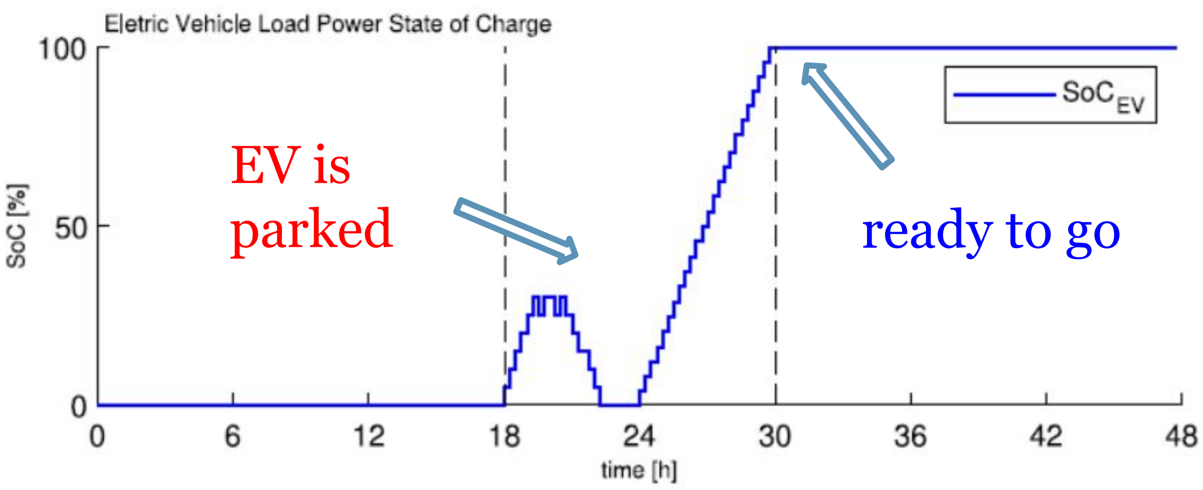


Electrical Vehicle and AC



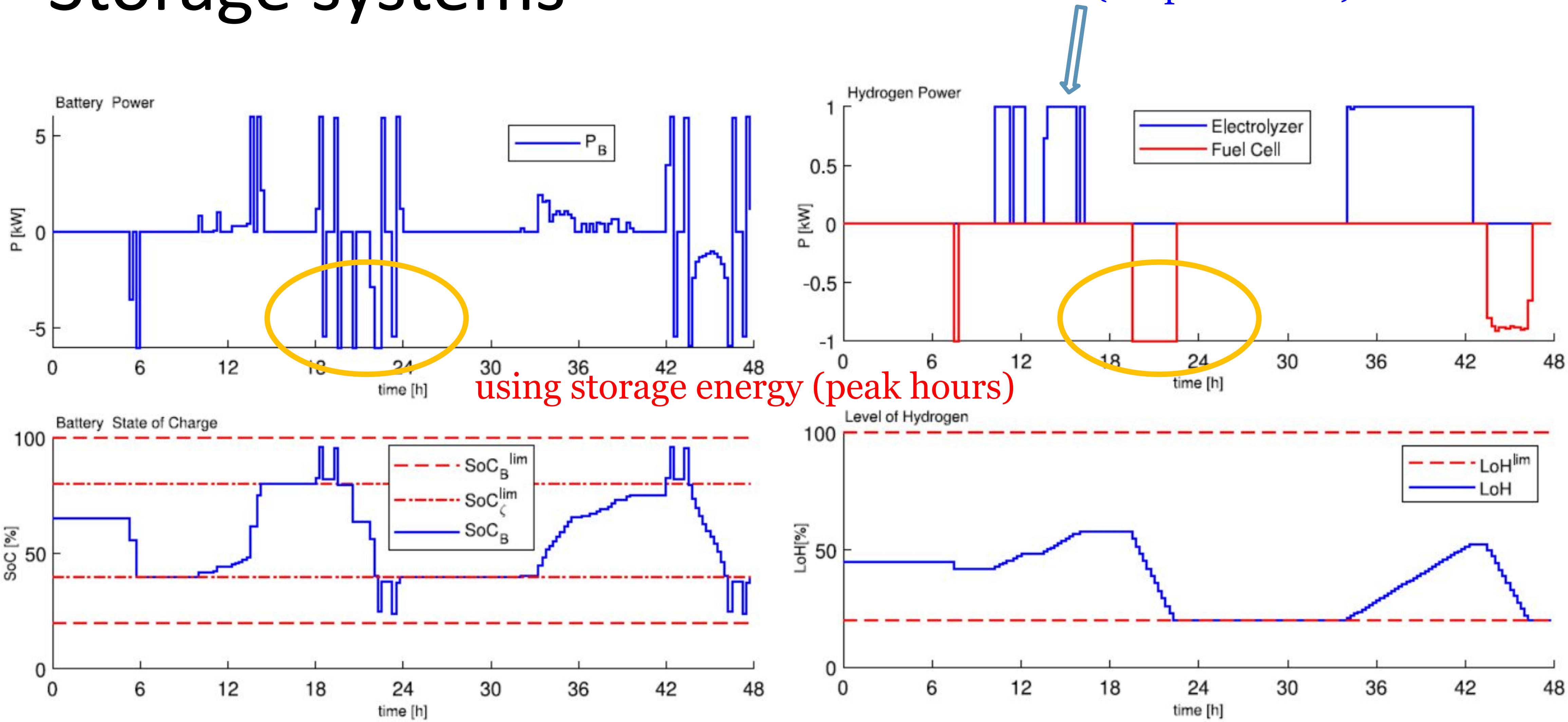




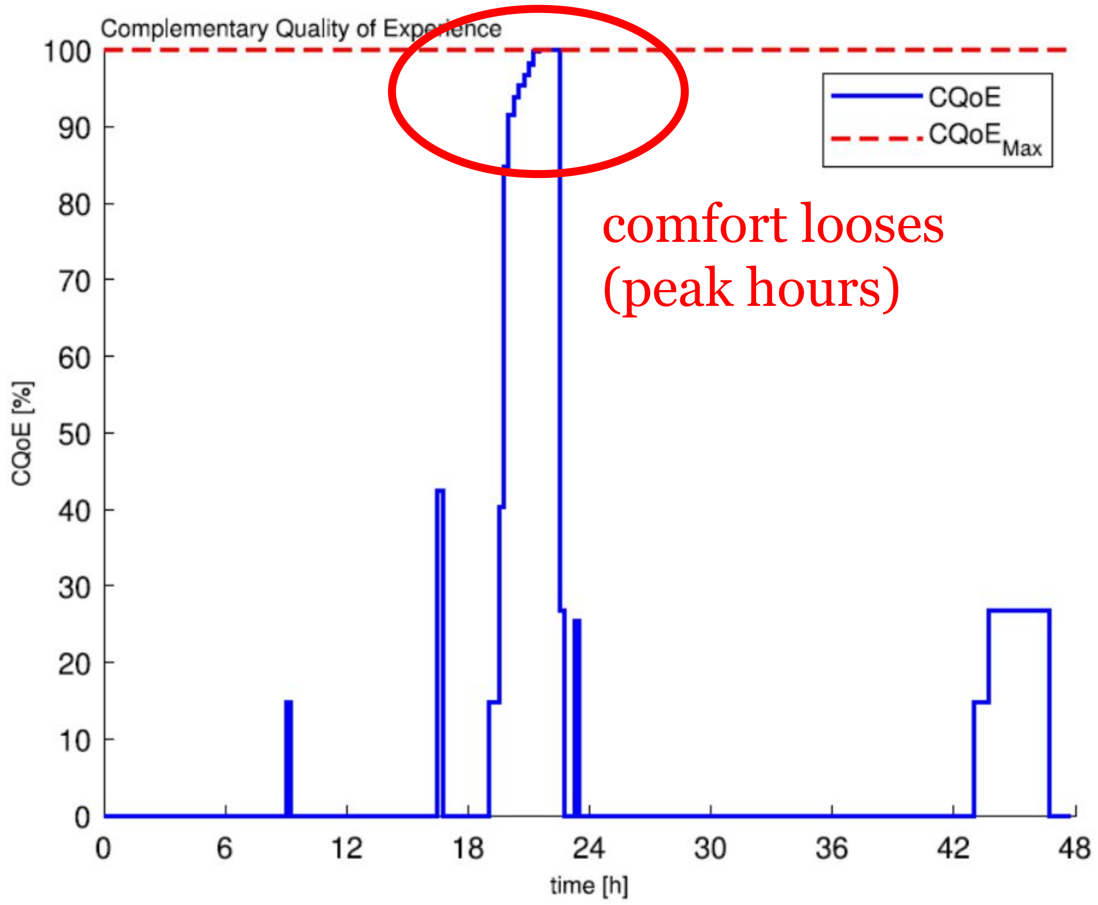


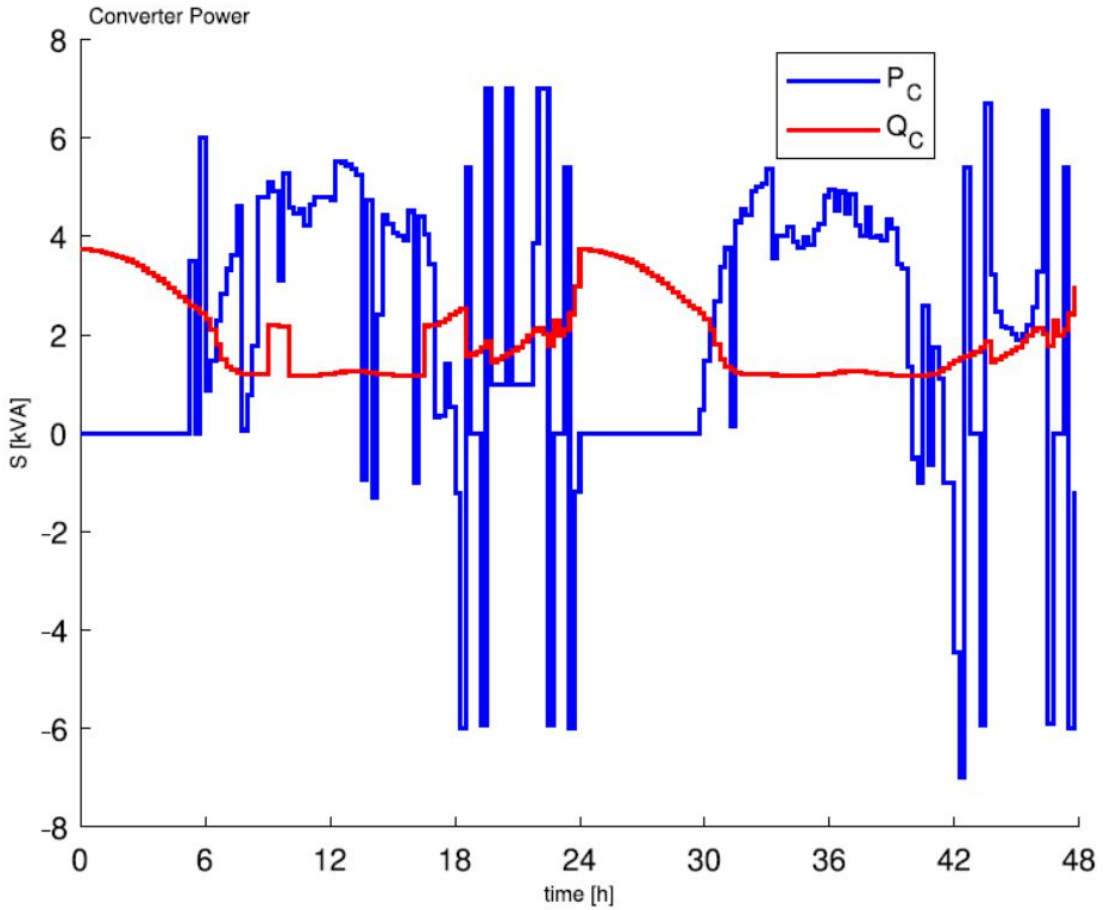
Storage systems

producing H2
(off-peak hours)

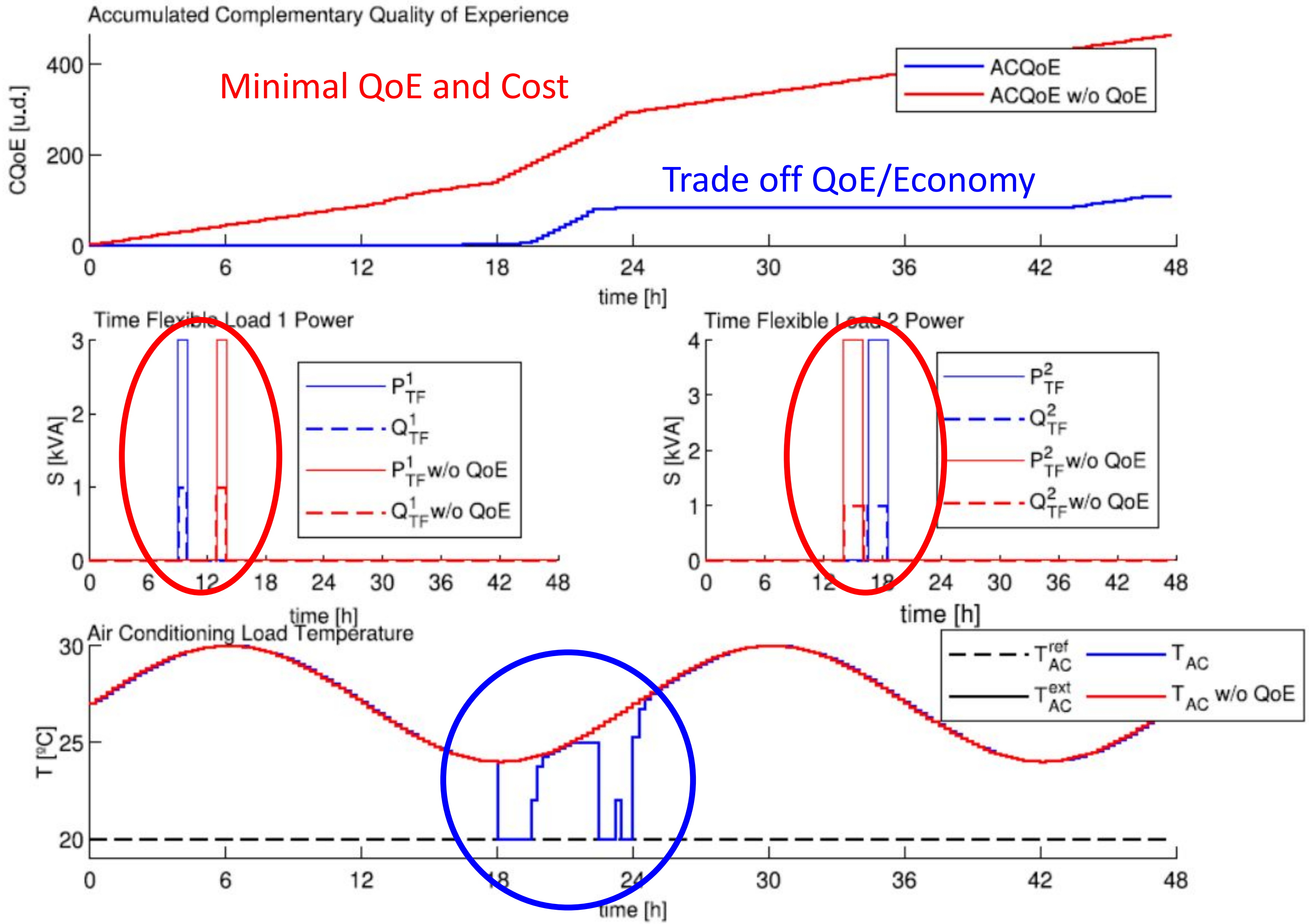


QoE and Converted Power





Comparative Results



Load shift

Load control

One year results

Comparison over one year of operation.

	SH-EMS with QoE	SH-EMS without QoE	Without SH-EMS
Electrical energy bill [BRL]	38 452.75	25 555.47	48 599.75
Accumulated CQoE [u.d.]	19 399.75	84 707.37	0

an equilibrium between $ cost and comfort

minimal $ cost high loss of comfort

100% comfort and high $ cost

Main objective of MPC
Trade-off Objective Function

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Final remarks

The controller shows high flexibility

The hybrid storage system take advantage of the particular properties of each system

Controllable loads are easy managed

Discomfort (QoE) and cost are easily considered

Working on a real plant for validation

Thanks to all the team!

Thank you for your attention!