Multi Energy Systems:

Investigating Hidden Flexibilities Provided by Power-to-X Considering Grid Support Strategies

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Research Problem

- With increasing share of renewable energy, power balance became more challenging for grid operators
- Replacing production based on fossil fuels in industries, such as chemicals, petrochemicals, food, steel cement; large-scale electrification(P2X) leads to more sustainable industrial complex and provides the necessary flexibility in the new energy system
- Due to approximations made in model formulations, flexibilities provided by MES components to network can be concealed in the simulation results (hidden flexibility)
- Inaccurate flexibility analysis of P2X may lead to increased transmission losses, higher operational cost or misinterpretation of MES capacity
- (Palensky & Dietrich, 2011) suggests that, a good combination of Market DR (price signals) and Physical DR is necessary. Existing hierarchical management of MES models not considers energy cost of production(€/MWh). This results with unnecessary trading of electricity and increse in operational cost

MES: Multi Energy System
P2X: Power-to-X
DR: Demand Response

Flexibility

”Flexibility is ability of a component or a collection of components to response challenges caused by power fluctuations in energy systems. ”

” Hidden flexibility is the difference between the amount of energy consumed/stored by the simplified and the detailed model of P2X during flexibility service. ”

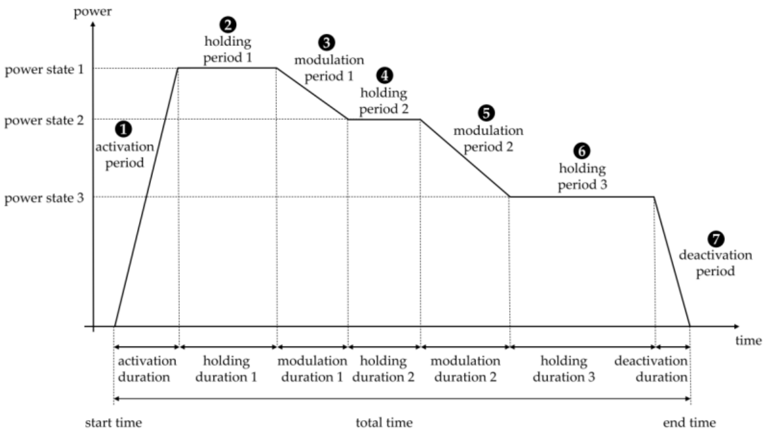

Fig. an exemplary flexible load measure with the corresponding parameters [1]

RE: Renewable Energy
P2X: Power-to-X

Research Questions

- What options exist for minimizing curtailment of renewables in MES?
  - Which options are available in industrial area?
  - Which option has the best performance for the grid and the most profit for the P2X owner?

- How much model detail impacts the flexibility analysis?
  - What should be the detail of a model (heat pump, electrolyser) for desired MES analysis?

- What is the optimal deployment of flexibility in order to reduce operational cost for P2X owner?
  - What should be the control architecture of MES?
  - How can different energy domains can be combined and optimized for flexibility?
  - What are the dependencies between flexible load pairs?

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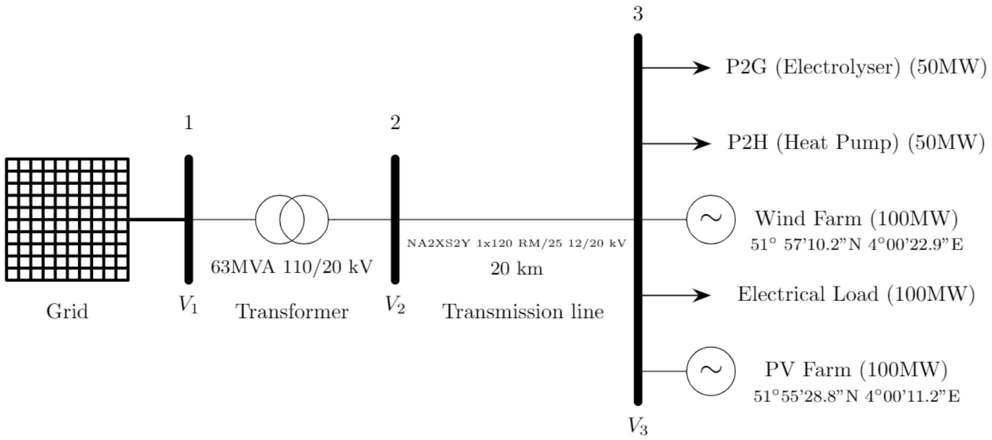
MES: Multi Energy System
P2X: Power-to-X

Research Question 1 - MES Design

RQ1 (P2X Selection): What options exist for minimizing curtailment of renewables in MES?

- Which options are available in industrial area?
- Which option has the best performance for the grid and the most profit for the P2X owner?



(Bode & Schmitz, 2018) compares different combinations of MES and concluded that, a combination of P2G with electric heat pumps or combined cycle gas turbines has the best cost performance in a MES with renewables.

MES: Multi Energy System
P2G: Power-to-Gas
P2H: Power-to-Heat

Research Question 2 - Hidden Flexibility

- **RQ2 (Hidden Flexibility):** How much model detail impacts the flexibility analysis?
  - What should be the detail of a model (heat pump, electrolyser) for desired MES analysis?

	Physical Domains	**Modelling Approach**	**Dynamic Behaviour**	**Modelling Scale**
Simple Model (Electrolyser)	Electrochemical Electrical	Analytic + Empirical	Static	Cell/Stack
Detailed Model (Electrolyser)	Electrochemical Electrical Thermal	Analytic + Empirical	Static + Dynamic (ODE)	Cell/Stack + BOP

MES: Multi Energy System
ODE: Ordinary Differential Equation
BOP: Balance of Plant

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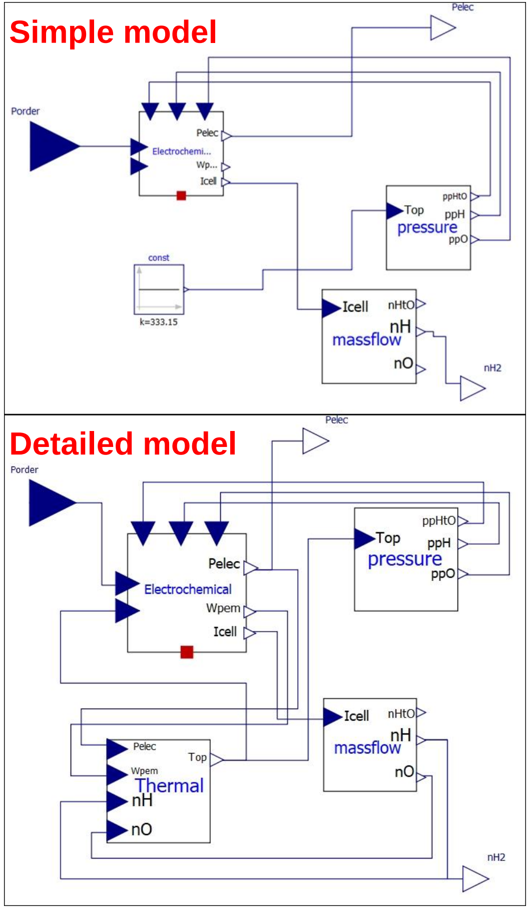
Electrolyser model



- Thermal submodel
  - BOP: circulation pump, cooling
  - Static vs. First order dynamics
  - Temperature, Pressure, current effects

Electrochemical: $V_{cell} = V_{ocv}(T,p) + V_{act}(T) + V_{ohm}(T)\ \ [V]$

Thermal:

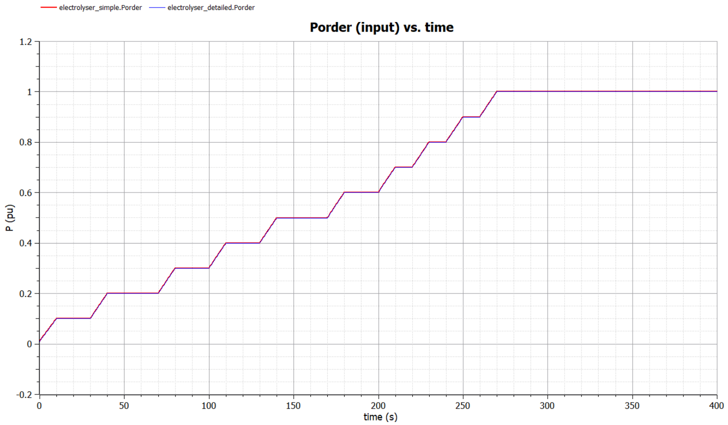
$$C_{th}\frac{dT}{dt} = \dot{Q}_{electrolysis,heat}(V,I) + \dot{W}_{pump,loss}(P) - \dot{Q}_{cooling}(P) - \dot{Q}_{loss}(T) - \sum_j \dot{n}_j.\Delta h_j$$

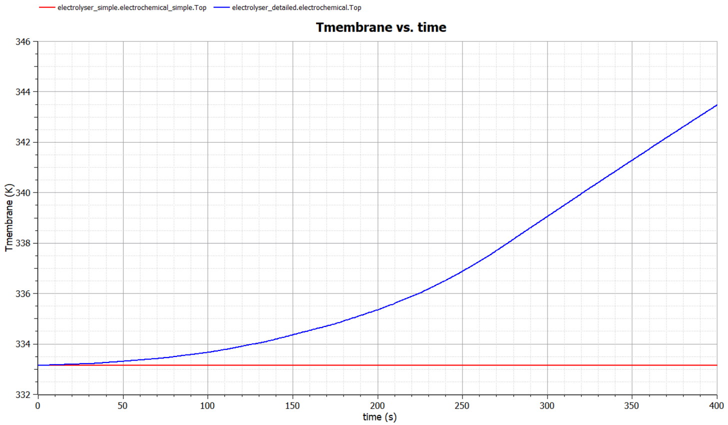
Pressure: $pp_{H2O} = 6.1078.10^{-3}.exp\left(17.2694.\frac{T-273.15}{T-34.85}\right)\ \ [bar]$

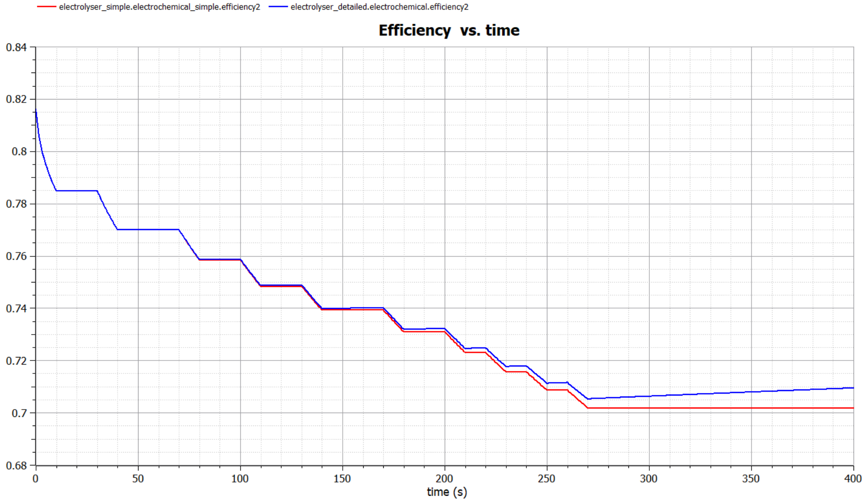
Massflow: $\dot{n}_{H_2} = \frac{n_{cells}.I}{2.F}\eta_f\ \ [mol/s]$

BOP: Balance of Plant

Electrolyser Model Comparison







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Hidden Flexibility Analysis

Base case:
Without any flexibility service, measuring the amount of excess RE with scheduled gas & heat demand profiles. None of the P2X available for flexibility service (static P2X).

First case (hidden flexibility):
For a given flexibility request, comparing the detailed model with simple model, and quantify hidden flexibility. Single P2X available for flexibility service.

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Optimum Deployment of Flexibility with Hierarchical Energy Management

Objective function: $$\min \sum_{i \,\epsilon\, gen, sgen, load, ext\_grid} f_i(P_i)$$

Cost function: $$f_{pol}(p) = c_n p^n + \cdots + c_1 p + c_0$$

Constraints:

Element	Constraint	Remark
Load **Generator** **External Grid**	$P_{min,i} \leq P_i(t) \leq P_{max,i}$ $Q_{min,i} \leq Q_i(t) \leq Q_{max,i}$	Operational power constraints (Device flexibility)
Transformer	$L_i \leq L_{max,i}$	Branch constraint (Maximum loading percentage)
Line	$L_i \leq L_{max,i}$	Branch constraint (Maximum loading percentage)
Bus	$V_{min,i} \leq V_i(t) \leq V_{max,i}$	Network constraint

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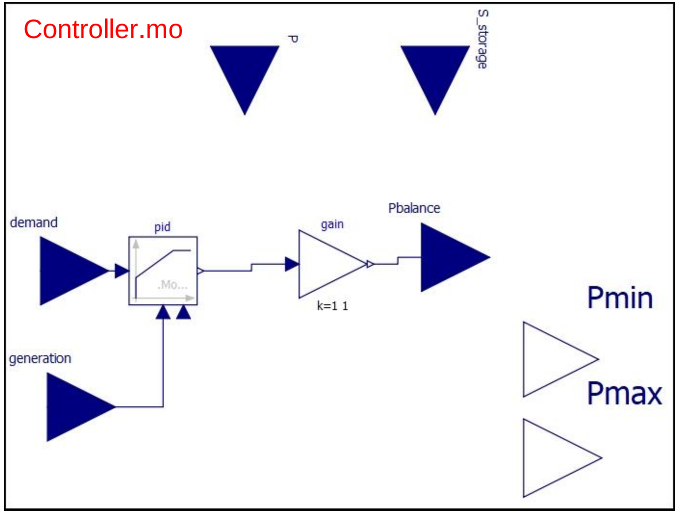
Adjustable Power Decision Making for Electrolyser



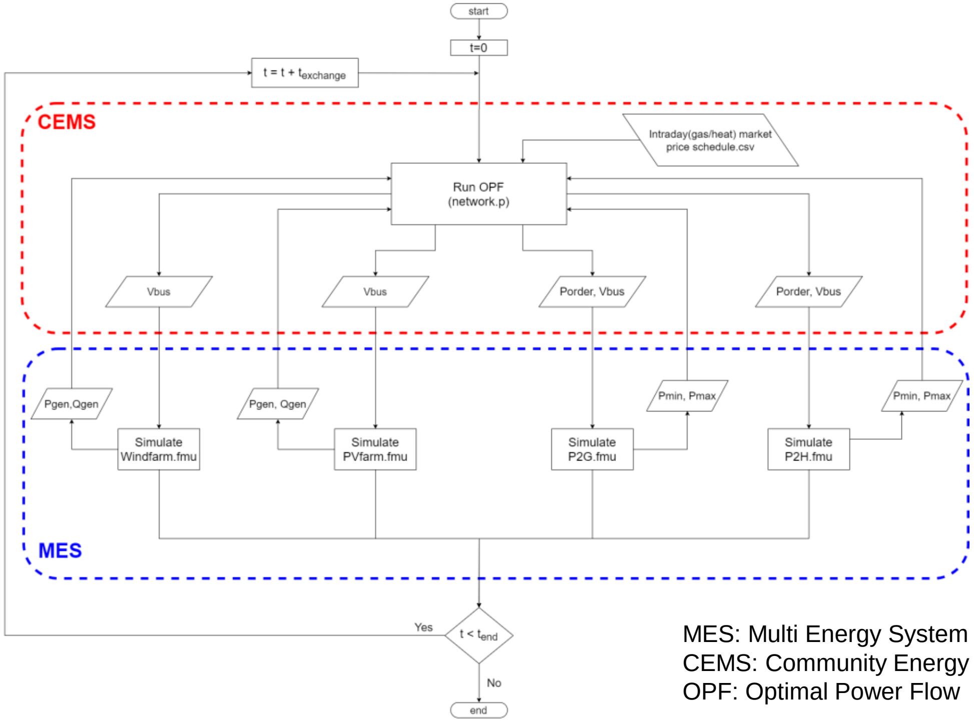
Constraint decision:

$$Pmin = \begin{cases} 0.1\,pu, & S_{storage} > S_{max} \\ P_{balance}, & S_{storage} \leq S_{max} \\ 1\,pu, & S_{storage} < S_{emergency} \end{cases}$$

$$Pmax = \begin{cases} Pmin, & S_{storage} > S_{max} \\ 1\,pu, & S_{storage} \leq S_{max} \\ Pmin, & S_{storage} < S_{emergency} \end{cases}$$

Research Question 3 - Optimal Deployment of Flexibility

- **RQ3 (Optimal Deployment of Flexibility):** What is the optimal deployment of flexibility in order to reduce operational cost?
  - What should be the control architecture of MES?
  - How can different energy domains can be combined and optimized for flexibility?
  - What are the dependencies between flexible load pairs?



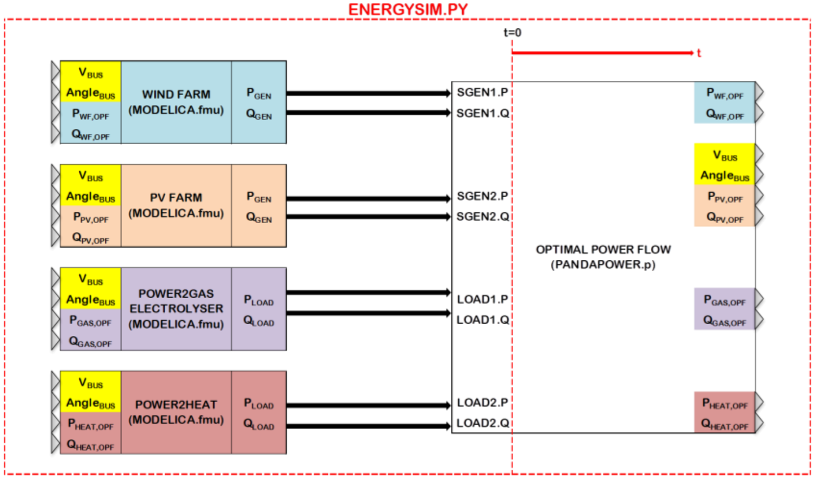
MES: Multi Energy System
CEMS: Community Energy Management System
OPF: Optimal Power Flow

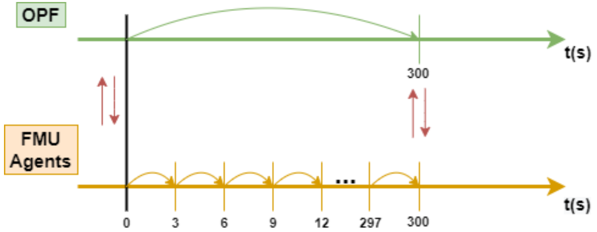
Simulation Tools

1. Pandapower
   - To solve optimal power flow problem and manage MES

2. OpenModelica
   - For fast simulation of complex dynamics from different energy domains, using object-oriented programming language

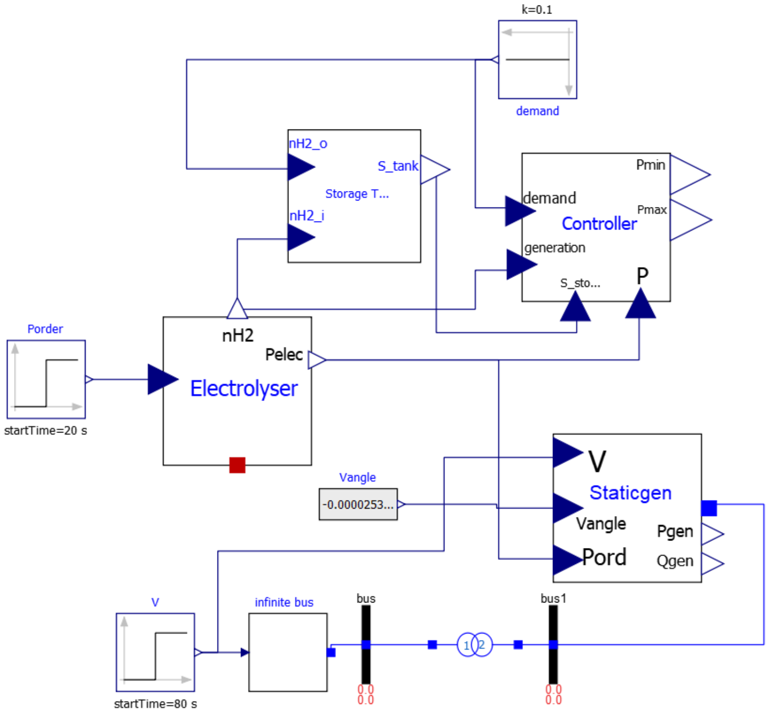
3. Energysim (Co-simulation)
   - Allows to implement complex simulations with reduced computational burden by using only necessary I/O's





I/O: Input/Output
FMU: Functional Mock-up Unit
OPF: Optimal Power Flow

Power-to-Gas Model



- ***Storage*****,** calculates energy stored
- **Electrolyser,** calculates electrical power consumed and H_2 flow rate
- ***StaticGenerator,*** provides electrical interface and controls Qload
- ***Controller,*** calculates Pmin, Pmax constraints for PandaPower

Optimal Deployment of Flexiblity

Second case (optimal deployment of flexibility):

With Market DR (price signals) and adjustable power level control, measuring the amount of shared flexibility between P2G & P2H and quantify the reduction in total operational cost. Both P2X available for flexibility service

Base case:

Without any flexibility service, measuring the amount of excess RE with scheduled gas & heat demand profiles, None of the P2X available for flexibility service.

First case (hidden flexibility):

For a given flexibility request, comparing the developed model with simple models, and quantify hidden flexibility. Single P2X available for flexibility service.

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P2G: Power-to-Gas
P2H: Power-to-Heat

Future Plans

Must:

1) Finalize P2H.fmu model

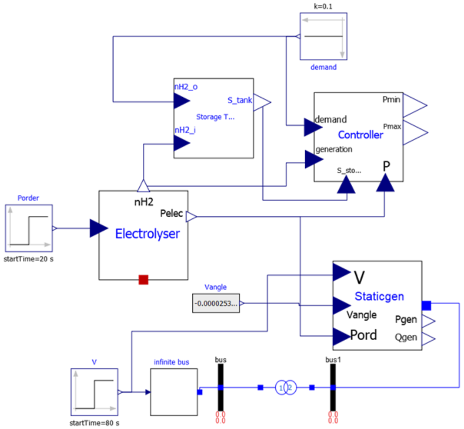
2) Create input files from historical data (windspeed.txt, solar irradiation.txt, demand profiles.csv)

3) Combine models in Energysim for co-simulation, flexibility analysis

Further improvements:

1) *Add more detail to models*

2) *Improve resolution of weather data*



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Version Control: https://github.com/caneryagci/Multi-Energy-Systems-Thesis-Project.git

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