

**Master of Science Thesis**

**Mid-term Review**

**Multi Energy Systems:**

**Assessing energy flexibility in industrial parks using multi energy modelling**

**Thesis Project Name:** Investigating Unknown Flexibilities Provided by Power-to-X Converters Considering Grid Support Strategies

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**Version Control:** [**https://github.com/caneryagci/Multi-Energy-Systems-Thesis-Project.git**](https://github.com/caneryagci/Multi-Energy-Systems-Thesis-Project.git)

# Problem Statement

Increasing shares of renewables will lead to a rising demand for ancillary services at the same time that less conventional plants will be available to provide these services.

# Research Questions

## **Model related research question: What are the hidden flexibilities provided by the electrolyser modelling?(Load(Demand) side Flexibility, DSM)**

Electrolyzer was decidedly modeled using ODEs (ordinary differential equations) for efficiency characterization. ODEs are most commonly used for practical applications of electrolyzers, such as in an industrial environment, as opposed to some papers using PDEs (partial differential equations), which are more commonly used for characterization of mass transport behavior and discretized thermodynamics within each cell. PEM technology is chosen over alkaline for its faster response to load changes.

*[-] J. Webster and C. Bode, “Implementation of a Non-Discretized Multiphysics PEM Electrolyzer Model in Modelica,” Proc. 13th Int. Model. Conf. Regensburg, Ger. March 4–6, 2019, vol. 157, pp. 833–840, 2019.*

Comparing with fuel cell systems, very few electrolysis models develop input-output models suited for control and diagnosis analysis. Thus, knowing energetic optimisation needs, this topic remains an opened research domain; (iv) a lot of developments have to be accomplished in the modelling fields of phenomena understanding, control design.

*[-] P. Olivier, C. Bourasseau, and P. B. Bouamama, “Low-temperature electrolysis system modelling: A review,” Renew. Sustain. Energy Rev., vol. 78, no. February, pp. 280–300, 2017.*

## **Area specific industrial research question: How much residual heat demand can be supplied from curtailed renewable energy in Port of Rotterdam and what is its effect on grid and storage size? (Supply Side Flexibility, Curtailment) Also the effect of adding new flexible load to the already existing flexible load on overall flexibility will be studied.**

# Methodology

## **Hypothetical Maasvlakte 2 Energy Park (Microgrid with AC feeder)**

Fig. Panda power figure

## **Flexibility**

* Flexibility metrics and parameters

### **Electrical System Flexibility (for Grid Operator)**

#### **Supply-side Flexibility(RE Curtailment)(Adding Heat system and storage)**

[1] RE schemes in which surplus RE production is utilized for different purposes,i.e.combining new loads to the power systems such as heating demand with storage. Also the effect of adding new flexible load to the already existing flexible load on overall flexibility will be studied.

* **Curtailed RE (How will you measure?) (**Transmission curtailment prevention, transmission loss reduction**)[1]**
  + Transmissioncurtailmentprevention and transmissionlossreduc- tion are ancillaryservicesthattemporarilyreducetheamountof current flowingincertainpartsofthepowergrid,increasingthe efficiency ftransmissionandpreventingproductioncurtailment due topowerlinelimitations.
  + **With abundantrenewableenergyproductionandnomeansof storingexcesspower,powerproductionmayneedtobecurtailed (cut off)toensuresystemstabilityorduetolimitationsintransmission infrastructure.However,withenergystorage,the powerplantsmaycontinueharvestingenergyevenwhilebeing disconnected fromtherestofthegrid.** **Renewablepoweris injected ntotheenergystoragesysteminsteadofthegrid,and when hegridisreadyforthedispatch,thestorageisdischarged. The durationrequirementforsuchmeasuresrangesfrom5to 12 h.**
  + **Storagealsoallowsincreasingtheefficiency oftransmission. Because transmissionlossesareproportionaltothesquareofthe current flow,thenetresistivelossescanbedecreasedbytime- shiftingsomeofthecurrentfromapeakperiodtoanoff-peak period, evenwhenaccountingforthelossesduetostorage.**
  + **Ontheother hand, asthecapacityfactororVREismuchlessthan1,thelossof**
  + **electricity producedisnotproportionaltothepowercurtailed.**

#### **Demand-side Flexibility** (Two DSM variables for flexibility) (DSM, load following, load shifting) (DSM, Load Shifting via nH2,ouput; Load following via storage, Supply demand active power balance continuos control of pressure with pmax, pmin constraints)

### **Cost Flexibility (For Industry)**

In this report, until now, flexibility is defined as electrical system metric through active power measurement,. However, flexibility can also be defined/measured differently as the reduction of the system total cost for a specific amount of time. This aspect of flexibility is especially important for industrial cases since economical concerns are higher.

## **Hierarchical Agent based control (Cost consideration definiton)**

Basically, at the lower control level(OpenModelica), I will have AC/DC converter or controlled (AVR,EXC,PSS) generator model (for windfarm), with real input connectors. Through these models, I will implement grid support by controlling P/f, Q/V with proportional control and/or direct input from higher control level (energysim)/Grid.

At the higher control level, I will have csv file for heat, gas, electricity prices, with these and data from FMU's, the objective of the global optimization will be to minimize the operational cost.

**OpenModelica (Electrical System Flexiblity):**Optimize local components via grid data and set values coming from Energysim, calculate/send to Energysim adjustable power amount.

**Energysim/Pandapower (Cost Flexibility):**Runs global optimization for minimizing operational cost of MMG system. Sends parameter set values to OpenModelica converter models (viaEnergySim).

## **OpenModelica and Libraries**

## **Pandapower and Optimal power flow(Cost consideration implementation)**

## **Co-simulation and Energysim**

# Modelling(Control)

## **Renewable Energy Sources**

### Wind Farm

### PV Farm

## **Grid**

### Pandapower

## **Industrial Loads**

### **Power-to-Gas (Electrolyser)**

#### Electrolyser

#### Compressed Gas Energy Storage(CGES) (700 bar)

#### Flexibilty Switch

### **Power-to-Heat (E-boiler+Heat Pump)**

### **Electrical Base Load**

* + - To represent the constant base load in the industrial area.

# Co - Simulation Scenarios

## First case

First simulate gas system connected to renewables and see the required size of the storage and plot grid parameters(f). Measure the flexibility of electrolyser and curtailed renewable energy.

## Second case

Connect heat pump to the previous system as load and do the same measurements again. Expecting reduced curtailed renewable power, better grid performance(less power injection from grid, more stable frequency/active power) and smaller storage size. Measure the flexibility of electrolyser.

[1] RE schemes in which surplus RE production is utilized for different purposes,i.e.combining new loads to the power systems such as heating demand with storage.

## Third case:

Add PDF of Weibull and Beta for windspeed and beta distribution see the effect on results vs. historical data (simulation must be long(yearly))

# Inıtial Results

# Further Improvements

## Heating system (E-boiler and HP and Storage)

## Model Improvements

* + - PV Model (less detail, better control)
    - Storage Losses
    - Storage “heatport” for Tambient
    - Electrolyser “heatport” for Tambient (see the effects on flexibility)
    - Flexibility Control models

## Optimal Power flow considering cost signals (Cost optimization) (Cost Flexiblity)

## Curtailment measurement with capacity factor

**References**

[1] P. D. Lund, J. Lindgren, J. Mikkola, and J. Salpakari, “Review of energy system flexibility measures to enable high levels of variable renewable electricity,” Renew. Sustain. Energy Rev., vol. 45, pp. 785–807, 2015.

**APPENDICES**

**A.**