

So welcome to my Master thesis midterm presentation again. In this project I am investigating the hidden flexibilities provided by industrial P2X considering grid support strategies.

I will quickly review my research problem and the flexibility definition then we will move on to details.

Power balance became a bigger problem for grid operators due to volatile nature of RES and one of the solutions to this problem is increasing the flexibility. ---- Electrification of industrial processes are one of the most promising ways to increase flexibility because they currently account for 30-35% of the global energy demand.----- However, in the previous projects during the modelling of such P2X devices significant amount of simplifications are made and this led to losing some of the essential dynamics that might be crucial to understand the flexibility of P2X.---- Inaccurate flexibility analysis of P2X may lead to increased transmission losses, higher operational cost or miscalculation of MES capacity. ---Finally, planning and operation of such MES needs to be coordinated. Prof. Palensky and Dietrich mention that a good combination of Market DR and Physical DR is necessary to run a network optimal. So that means, besides physical parameters I also have to consider price signals in order to operate my network optimally. However, existing models do not take these market DR into account because it increases the simulation complexity. This results with unnecessary trading of electricity and increase in operational cost.

3.

In this project, Flexibility defined as ability of a component or a collection of components to response challenges caused by power fluctuations in energy systems. From an operational perspective, P2X flexibility becomes relevant in situations where there is excess RE supply relative to demand and therefore, electricity prices are low. During excess RE, storing this energy in P2X, provides power balance for the grid and reduces operational cost for P2X owners by shifting their load. This figure explains the characteristic parameters of flexibility so basically one ramp up, one ramp down and one holding duration that defines the total flexibility time. Finally, hidden flexibility defined as the difference between the amount of energy consumed by the simplified and the detailed model of P2X during flexibility service. But this sentence will make a lot more sense after I explained my simple and detailed model in the following slides.

4.

Here is my three research questions. I will answer each question one by one in the following slides. Therefore I will just quickly review here. The first question is about P2X selection and MES design. When it comes to electrification of industry there are so many options exist with various combinations of electricity, gas, heat and storage but this part explains why I have decided to model electrolyser and heat pump. The second question is about hidden flexibility and it focuses modelling part. Due to approximations made in the model formulations, flexibilities provided by those devices can be concealed in the simulation results. In other words, question is, how the modelling of these devices affect the flexibility analysis? So the hidden flexibility part ends here and the last research question is about optimal deployment of flexibility and it focuses on simulation method but not modelling. For the optimal deployment of flexibility price signals should also be considered in a more holistic energy management system but it is not in the previous projects due to its effect of increasing simulation complexity. So in other words, how these price signals can be combined with the physical situation of a P2X for operational decision making?

5.

Lets start with the first RQ1 which is about MES design, .... This part was also clear in the previous presentation. I have decided to model electrolyser because hydrogen can be stored at high energy densities and it can be transported in the existing gas networks. Additionally, electrolyser technology is able to provide the necessary performance for grid ancillary services. I have decided to model heat pump because boiler combined with heat pump is commonly recommended for its high conversion efficiency. I also have decided the location and the capacity of my RES according to articles about Port of Rotterdam. Finally, the research of Bode & Schmitz supports MES design because they compare different combinations of MES and concludes that P2G with electric heat pumps has the best cost performance in a MES with renewables.

6.

So in the previous presentation the answer to my second RQ was not on the slides and this confused you. Now I want to clearly explain it.

The second RQ is about hidden flexibility and modelling .... In order to answer this question, first of all, I had to create two different models. The table you see here summarizes the features of each model. Simple model, operates at constant temperature but detailed model calculates the temperature of the electrolyser system with dynamic thermal submodel. Both models are semiempirical and have static equations but the thermal submodel is dynamic which makes the general behaviour of the electrolyser system dynamic. Finally, thermal submodel equation also includes BOP elements that affect the temperature evolution.

7.

Here is my models in Modelica. Thermal domain is modelled with lumped thermal capacitance model. Temperature of the entire electrolyser system is simplified in one equation here and Thermal capacitance value is calculated experimentally in the reference paper. The first term on the right side is for heat generated by electrolysis reaction and it depends on cell voltage and current, second one for the work contribution of circulation pump, third one for the heat removed by cooling system, these two has linear relation with the consumed active power. Fourth one is for the heat lost to ambient it depends on operation and ambient temperature and the last one comes from enthalpy lost with the products leaving the system, it has empirical equation that depends on temperature. As you can see from the equations adding this dynamic submodel to the system makes the general behavior of the electrolyser dynamic, since each submodel depends on temperature parameter directly or indirectly.

8.

So this slide directly explains the hidden flexibility I have been talking about by comparing the simple and detailed model efficiencies for the same active power inputs. Active power input can be observed in the upper left side. Increasing electrical power consumed by electrolyser causes an operating temperature rise in the detailed model however the temperature of the simple model is constant since it is assumed like that during modelling. This temperature difference causes different efficiency results and therefore consumed electrical power in both models. Correct Evaluation of the operating temperature reveals the hidden flexibility by the correct efficiency characterization. So, I am investigating this effect in order to understand the true flexibility of P2X.

9.

These are my hidden flexibility analysis to answer RQ2.

In the base case none of the P2Xs are available for flexibility service so..... This result gives information to define holding duration of the flexibility service. In the first case I am investigating the hidden flexibility by comparing simple and detailed model for a given flexibility request. Therefore only one P2X is available for flexibility service here and flexibility request is nominal active power order for the defined holding duration in base case.

So RQ 2 ends here.

10.

And this slide is the beginning of the RQ 3, which has no relation with hidden flexibility but the optimal deployment of flexibility, how excess RE is shared between to available and flexible P2X. First of all, I have to make this clear I am using directly the optimal power flow solver of Pandapower which is enough to answer my research question. Therefore the information in this slide page is directly from pandapower. What pandapower optimal power flow solver does is it has objective function to minimize operational costs using polynomial cost functions. While doing this pandapower considers the following constraints.

Bus constraint contains maximum and minimum voltage magnitude, branch constraints contain maximum loading percentage and the most important part of this slide operational power constraints where the active and reactive power generation of generators or loads can be defined as flexibility for the OPF.

So that means This higher control level in pandapower has to communicate with the modelica agents and learn the adjustable power level which is  $P_{min}$  and  $P_{max}$  in order to calculate the optimum operating point within this range. So the optimal power flow solver calculates the exact operation point considering price signals but within the available range defined by the physical situation of the agents. In other words, I enhanced the current OPF of Pandapower by adding my OM agents and controlling these boundaries depending on the physical situation of agents. And this is the part where I focused and created my model for the decision making of active power boundaries.

11.

In a normal operation where there is available space in the storage, minimum active power is controlled such that scheduled hydrogen demand is always balanced by the hydrogen generation of electrolyser. However, when there is no available space in the storage, electrolyser is forced to work under 10% load until storage energy level is lower than maximum. And when the storage energy level is below emergency level, electrolyser is forced to work at nominal power until it reaches at least the emergency level. This Figure below shows the response of the PID block here. How hydrogen generation follows the hydrogen demand set value can be observed.

12.

After explaining my methodology, here is my RQ3 and detailed flowchart for this part. My research question is .... I am repeating one more time, This part has no relation with hidden flexibility, but it investigates the optimum way to share excess RE between flexible loads considering Market DR and Physical DR at the same time. In order to do that I have advanced the simulation method by adding price signals and making the active power boundaries dependent on the physical situation of agents. I will repeat the flow of the simulation as well, at  $t=0$  optimal power flow solver in pandapower calculates the optimum operation point with the objective of minimizing operational cost. After that the results of the OPF are sent to MES agents. Agents simulate until the next exchange time and send out the adjustable power level binding information to higher control level.

13.

Having explained my models and flowchart, I had to combine all models in one environment in order to implement flexibility analysis. Energysim allows me to combine all models and implement this complex simulation in a relatively simple way by only using necessary i/o. Figure on the left is just to show the general methodology and the figure on the right shows the macro step time that optimal power flow solver and Modelica agents exchange information, and micro step time that the agents simulate until the next macro step.

14.

This figure is here to summarize my overall power to gas model. I have explained my electrolyser model in RQ2 and controller in RQ3. Besides these, Static generator model is from iPSL library and it provides interface with the electrical network. The storage tank model simply calculates the available energy storage level by comparing the charging and discharging rate of storage. So it is simplified with one differential equation.

15.

Having first case for hidden flexibility analysis, in the second case I am investigating optimal deployment of flexibility by adding price signals and adjustable power level decisions. In this case both P2X are available for flexibility service. Price signals will cause available excess RE to be shared in order to reduce total operational cost but this information will depend on the binding information coming from agents. Investigating this effect of having Physical DR and Market DR at the same time is the answer to my RQ3, I will measure the amount of flexibility shared between P2G & P2H and quantify the reduction in total operational cost of the system by comparing with the first case.

16.

So in the following weeks, I need to finish my P2H model. This will be similar to P2G model. Simply I need to switch this electrolyser with heat pump and adjust the other models according to that. Then I need to create my input files to represent the area. These are my gas/heat demand profiles and windspeed, solar irradiation for RES. I will create these files by using historical data or giving references. Finally, I will connect my models in energysim and carry out the co-simulation for plotting and analysis. Approximately each step will take one week and I am adding one more week just in case if I face with a problem. So in 4 weeks I am expecting to have my final results.