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# Master of Science Thesis Proposal

## Multi Energy Systems:
### Assessing energy flexibility in industrial parks using multi energy modelling

**Thesis Project Name:** Investigating Unknown (In)flexibilities Provided by the Detailed Modelling of Power-to-X Converters Considering Grid Support Strategies

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

## I. Problem Statement

Traditionally, energy systems are de-coupled from each other, which means, even though tight interactions between them exist they do not consider what is happening inside the other systems. However, in a multi energy system, different energy sources such as electricity, gas, heat, cooling, transportation, etc. optimally interact with each other at lower system levels with the help of coupling technologies. What's new in those systems is the integration of RES. Because, multi-energy systems with renewable energy sources (RES) are considered to have better technical, economical, environmental and operational advantages than those conventional energy systems. But of course the new transition has some technical problems to overcome.

The planning and operation of such multi-energy systems needs to be coordinated to make optimal use of the available resources. Conventionally, central (community) energy management system (CEMS) is provided with the information of surplus and shortage amounts only at each time interval. This limited information may lead to an increase in the operational cost of the multimicrogrid (MMG) systems. Due to the interdependencies and connectivity between previously distinct energy vectors, a more holistic energy management strategy and modelling approach must be provided.

Another problem is that heat pumps and electrolysers have the potential to be a central part of an efficient, renewable and interconnected energy system, but there is still some work to be done. Many studies consider a heat pump or electrolyser as a black box which can be easily used for smart grid purposes. However, this can strongly influence the performance of the system. In other words, approximations made in traditional model formulations can result in suboptimal or even infeasible operation points. Therefore, the design of the whole heat pump (and electrolyser) system should be investigated with respect to be optimally adapted to the requirements from the electric system.

**As a result, this project proposes, investigating the impact of flexibility service providers' models on demand side management (load levelling) by using co-simulation in OpenModelica environment**.

## II. Organizations Involved (Customers)

From a social perspective the stakeholders directly and indirectly involved in the design, building and operation of such a system, are the local power, heat, gas and water distribution companies, gas suppliers, H2 producers, TSO, DSO, ISO, the equipment, system and software manufacturers but also municipalities, regulators, policy makers.

## III. Objectives & Requirements

### A. *Objectives*

- Investigating the impact of flexibility service providers on demand side management
- Development of models to evaluate their effect on the grid support strategy.
- Development of multi-agent based control strategy for the operation of the system.
- Multi-objective evolutionary optimization algorithm

### *B. Requirements*

- Analyze the network in terms of strength, sensitivity of parameters or disturbances in order to understand the benefit of service provided to the grid. (Defining performance indexes for the evaluation of effect of models on the grid support.)
- Identify technologies related to the system.
- Identify optimization technique,
- Evaluate control strategies
- Identifying the model requirements of flexibility providers
- The identification and quantification of demand flexibility

## IV. PROPOSED APPROACH

Proposed approach consists of;

1. Simple and detailed modelling for flexible processes that support the grid
2. Developing multi-agent control strategy for such system
3. Defining grid support objective requirements (Load Levelling)
4. Co-simulation of different models and control strategies
5. Defining key performance indicators, metrics (KPIs) to measure difference in results

MES typically cover a wider range of timescales going out to hours in, for example, the case of transfer of gas through a gas transmission network or energy user behaviour, or months in the case of seasonal influences on the need for energy for heating or cooling and seasonal storage. Such issues often lead to separation of variations that arise in different timescales into different models (co-simulation).

Co-simulation allows experts from all involved technical domains to actively participate in the process. It allows domain experts to rely on the tools that they are most familiar with and which are considered industry standards. Therefore, network models can be compiled using the most suitable state-of-the-art tools, which typically come with extensive component libraries, enabling a high-detail representation down to the component level.

Several regulation (ancillary) services can be considered;

- Voltage\Frequency support (Power quality and regulation)
- Spinning\Non-spinning reserve
- Demand side management (Load shifting, levelling, shedding, following)
- Transmission curtailment prevention, transmission loss reduction
- Black start
- Unit commitment

**Demand-side management for load levelling on hourly basis is selected to be the grid support service of this system.** Using an aggregated load profile, demand curve will be smoothed to an average level by flexibility of the systems and grid. By smoothing the demand curve significant reduction on peaks and deeps must be achieved.

Potential benefits of peak reduction on an aggregate level involve lower electricity generation costs, less need for peak generation and reserve power plants and less need for transmission capacity.

When demand side management is done to counteract feed-in peaks from renewables, this leads to an increased capacity of the electric grid to integrate renewable electricity generation, especially on the local distribution grid level (in the case of negative peaks caused by a feed-in surplus from renewable energy sources).

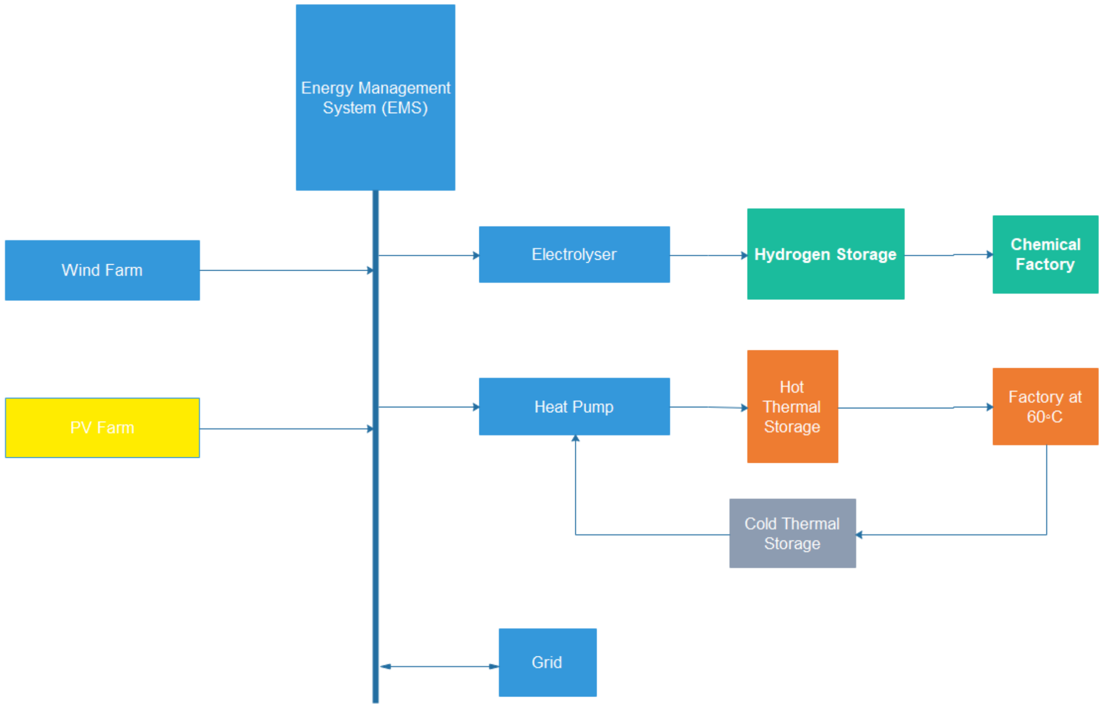
**Following optimization objectives will be considered;**

- Operational cost minimization
- Achieving the lowest possible variation on the demand curve (maximizing the load levelling grid support)

## V. Conceptual Model

Conceptual model is illustrated in figure 1. Overall system has the following major elements;

1- **Renewable energy sources:** Offshore wind farm and PV farm in an industrial are will be considered.
2- **Central energy management system & Distributed EMSs**
3- **Heat pump:** consists of condensator, compressor, expansion valve, evaporator
4- **Grid:** includes electrical load
5- **Hydrogen and heat storages:** Storage tanks will be modelled such as total heating and hydrogen storage capacity to be enough to meet the heating and hydrogen demands during the working period assuming the whole power cannot be produced instantly with the available load.
6- **Basic demand models (Loads):** Considering industrial area, three different demand (load) models, based on assumptions, will be implemented:
    - **Electrical demand:** It will be modelled inside the grid as an electrical demand of a factory.
    - **Heat demand**: Hot sanitary water supply of an industrial area or a factory requiring hot water supply at 60 °C can be considered.
    - **Hydrogen demand:** Chemical factory or steel factory can be considered for hydrogen demand.




**Internal controllers and power electronic converters are not shown in this figure*

Fig. 1. Conceptual model

**In this project, a hierarchical Energy Management System (EMS) for optimal Multi-Energy System's operation has been proposed and is based on Multi-Agent System (MAS). In this way, each subsystem (heat pump, electrolyser) has been considered as an autonomous agent that can communicate with other agents of the system with the information about the adjustable power also, in addition to the surplus and shortage information. This additional information will result in a variety of options for the Central EMS to fulfill the load demands of its network.**

Two task required for controller:

1. Planing and scheduling (mostly day-ahead) of the flexible systems' operation (heat pump & electrolyser) ahead of time as a reaction to a forecast or broadcasted signal (e.g. day-ahead prices)
2. Change of operation as a reaction to a real-time signal

Additionally, model proposed in this study is based on the concept of cooperative MMG operation in contrast to the competitive models proposed recently. The objectives of competitive and cooperative models are different, i.e., the objective of cooperative MMG system is to reduce the operation cost of the entire network while in competitive environment objective of each MG is to maximize its own profit. In addition, both the models find their applications in different environments and have their own pros and cons.

The type of model (black box, grey box or white box i.e. physical) and the mathematical formulation determine the effort for modelling and the type of the resulting optimization problem (optimal control problem).

Previous models often assume constant conversion efficiencies and no warm up or cool down periods for both technologies (heat pump, electrolyser), which could lead to overall infeasible or sub-optimal solutions. However, dynamics that can be effective to reach the most optimal operation point must be considered for the detailed modelling of such technologies.

Further possibilities for detailed models will be investigated in the concept development phase. However, it is proven below that new models are needed for a better understanding of multi-energy systems.

**Following considerations are made, and to be discussed, in order to adequately represent the dynamics of main elements' performance and the factors which influence them.**

**Considerations for dynamics of detailed models:**

- **Heat pump:**
    - Minimum run and pause times and ramping rate constraints are examples for limitations to consider when integrating heat pumps to a smart grid. Finding and improving such smart grid bottlenecks in heat pump component and circuit design can improve flexibility characteristics and lifetime of a heat pump unit.

    - Studies that consider heat pumps using the typical energy hub modelling procedure, would model COP of a heat pump as constant when in fact it is dependent on a number of factors including the part load percentage, outdoor air temperature, and ground temperature. Therefore, more realistic models must be developed to allow true optimal control of heat pumps within a multi-vector district energy system.

    - Heat pumps are generally modelled by a COP or seasonal performance ratio; however, this is far from constant in reality. Many factors including part load, outdoor air temperature, and ground temperature can influence the conversion efficiency of a heat pump.

- **Electrolyser:**
    - Most of the previous studies model the electrolysers or power to gas systems as a constant efficiency and were interested in long-term economic effects over a large geographic scale. Thermodynamic analysis of electrolysers and power to gas plants is important for those systems and only considered for small amount of research made. Previous studies assess the energy demand for producing hydrogen at different pressures using different electrolysis pathways. However, these models are highly complex and would be problematic to integrate into real-time, operational, district optimization. This means that short-term, simplified, modelling of part load efficiencies is not covered in the state of the art literature and represents a significant research gap.

- **Power generation:** Different methods can be compared to predict Wind farm and PV farm generation.

## VI. Test Scenarios

Simulation test scenarios will be developed in the concept development phase according to the developed simulation models, their objectives and the grid service.

## *VII.* Prospective Research Question

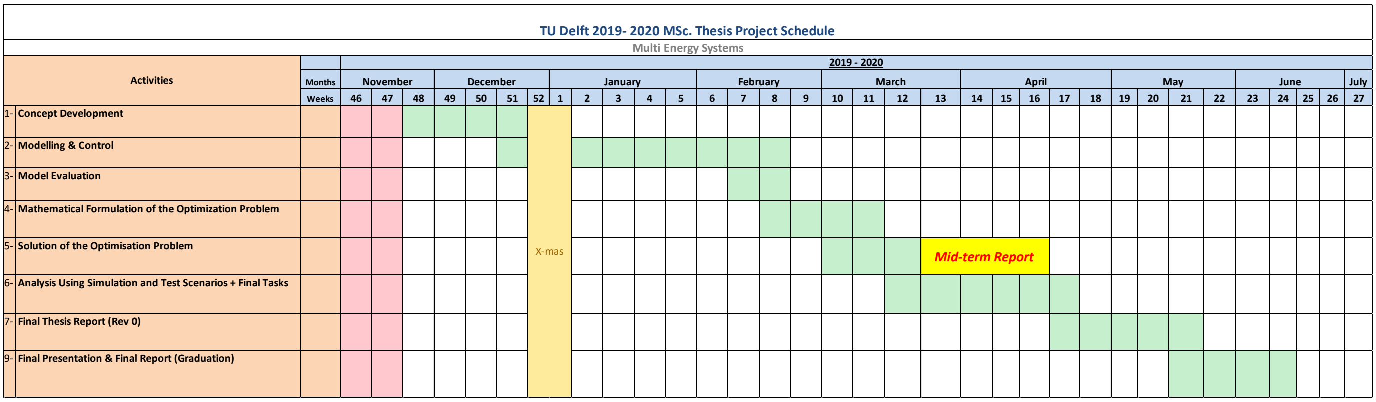
1. **What are the hidden (in)flexibilities provided by the detailed modelling of multi-energy system converters considering load levelling grid support in an industrial perspective?**
2. **Assesing the flexibility of multi-energy systems with multi-agent based energy management strategy.**

## VIII. Expected Outcomes

Expected outcomes are listed below;

- Impact of flexibility service providers' models on demand side management.
- A multi-objective evolutionary optimization algorithm for such system.
- Recommendations for sizing heat pumps, electrolyzers, storage and the choice of control approach.
- Recommendations for modelling flexibility providers.
- Flexibility provided by multi-agent based energy management strategy.

## IX. Project Schedule




## References

[1] G. Morales-España, L. Ramírez-Elizondo, and B. F. Hobbs, "Hidden power system inflexibilities imposed by traditional unit commitment formulations," Appl. Energy, vol. 191, pp. 223–238, 2017.

[2] R. Murr, H. Thieriot, A. Zoughaib, and D. Clodic, "Multi-objective optimization of a multi water-to-water heat pump system using evolutionary algorithm," Appl. Energy, vol. 88, no. 11, pp. 3580–3591, 2011.

[3] P. Mancarella, "MES ( multi-energy systems ): An overview of concepts and evaluation models," Energy, vol. 65, pp. 1–17, 2014.

[4] J. Reynolds, M. W. Ahmad, and Y. Rezgui, “Holistic modelling techniques for the operational optimisation of multi-vector energy systems,” Energy Build., vol. 169, pp. 397–416, 2018.

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

[6] D. Fischer and H. Madani, “On heat pumps in smart grids: A review,” Renew. Sustain. Energy Rev., vol. 70, no. May 2016, pp. 342–357, 2017.

[7] H. Arce, S. H. López, S. L. Perez, M. Rämä, K. Klobut, and J. A. Febres, “Models for fast modelling of district heating and cooling networks,” Renew. Sustain. Energy Rev., vol. 82, no. January 2017, pp. 1863–1873, 2018.

[8] International Energy Agency, “Application of industrial heat pumps: Part A,” 10thIEA Heat Pump Conf., pp. 1–12, 2011.

[9] H. C. Becker, F. Maréchal, and D. Favrat, “Methodology and Thermo-Economic Optimization for Integration of Industrial Heat Pumps,” vol. 5341, 2012.

[10] P. Mancarella, G. Andersson, J. A. Peças-Lopes, and K. R. W. Bell, “Modelling of integrated multi-energy systems: Drivers, requirements, and opportunities,” 19th Power Syst. Comput. Conf. PSCC 2016, no. October 2017, 2016.

[11] V. H. Bui, A. Hussain, and H. M. Kim, “A multiagent-based hierarchical energy management strategy for multi-microgrids considering adjustable power and demand response,” IEEE Trans. Smart Grid, vol. 9, no. 2, pp. 1323–1333, 2018.