UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

Modelling and dimensioning of hybrid hydrogen production projects

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Madrid, January 2023

Introduction and Motivation

The hydrogen economy is based on the idea of using hydrogen to decarbonize hard-to-abate sectors, it´s gaining momentum, and with it, the need to set definitions, regulations, and policies on what are the different types of hydrogen, which types should be incentivized and for what uses.

The European Union, as part of the RePower EU plan, has set a target for twenty million tonnes of green hydrogen by 2030, of which, ten million must be domestically produced.

The estimated electrolyzer capacity required to achieve this, assuming average load factors, is of around a hundred gigawatts and this is linked with the necessity of generating over five hundred additional terawatt-hours of electricity from renewable resources.

In the lastest publication of the Delegated Act by the European Commission on the definition and requirements for Green Hydrogen it is clearly stated that requirements of additionality, temporal correlation and geographical correlation will play a key part on the definition of what is considered green hydrogen and whether the targets set out I this and previous plans will be achievable.

The proper dimensioning to satisfy all these temporal correlation, geographical correlation and additionality requirements will be of importance in the near future, particularly as these restrictions get tighter towards the end of the decade. Therefore, a tool to help in the performance of quick estimates on the investment requirements of the components comprising a hybrid green hydrogen production project will be of great utility.

Objectives of this Master Thesis

The main objective of this Master Thesis is the development of an optimization tool to optimally dimension the different components of a hybrid generation project to produce green hydrogen and satisfy industrial hydrogen demands.

The project should be able to consume electricity from the network as well as from a solar photovoltaic plant. It should have the potential to incorporate both, electricity, and hydrogen storage and ~~an~~, of course, an electrolyzer.

This system will be subjected to a set of restrictions that will arise from the technical limitations of the components such as technical minimum stable levels of storages or other restrictions linked to sensible economic constraints such as the maximum size of the electrolyzer or the solar plant.

It is also intended to fully supply the hydrogen demand or buy green hydrogen from the market and perform a correlation of green hydrogen certificates at different timescales such as yearly, quarterly, monthly, daily, or hourly. These green certificate correlation and balancing schemes will be the starting point of the scenarios for the analysis to be performed.

The objective of this scenario analysis is to explore the costs associated with the potential regulatory positions on the temporal correlation for green hydrogen, a topic of relevance under the current investment climate in the energy sector.

In summary, a computational model will be developed capable estimating the most economical outcome for green hydrogen generation in terms of the sizing of the different components in the facility and the optimal utilization of these components based on a number of restrictions of technical and regulatory nature.

Preliminary Table of Contents

Description of the methodology

The first step in this project will be to assess the state of the art, what the current status of the technology is, the costs and uses. A number of hybrid projects are already in operation and many more in development phase, these will be reviewed in order to get as many ideas as possible on potential configuration and scenario analysis based on the successes and difficulties these projects have faced.

Also, the are a big number of potential hydrogen offtakers with drastically different requirements for their hydrogen demands and this will also have to be explored in order to increase the amount of potential hydrogen uses to be supplied from the different hybrid project configurations.

Therefore, the first step is to perform a review to select material and information to have readily available for each of the modelling phases.

The main work of this Master Thesis will be divided into two clear blocks, with eventual overlaps, but quite distinct in the variety of tasks involved in each of them.

The initial phase will involve the development of an optimization model for the operation of a hybrid renewable energy project for green hydrogen generation.

The renewable energy project will include solar photovoltaic technology as well behind the meter battery storage, which will be connected to each other, to the network and to the electrolyzer that would be employed to produce the green hydrogen.

The plan is to allow the solar plant to feed the electrolyzer, charge the battery and the option of dumping the excess electricity in the network will be explored although it will not be part of the first iteration of the model as it will involve additional research and constraint definition in order to result in a realistic optimization of operations.

The battery should also be able to charge from the grid to take advantage of low prices caused by excess renewables elsewhere in the system and even be capable of arbitration, the benefit of which will be accounted as a reduction in the total cost of production of hydrogen through the year.

Additionally, the hydrogen production project will include hydrogen storage capacity to take advantage of those hours of lower electricity prices or excess renewable generation from the solar plant to produce low-cost hydrogen to be stored for later usage.

Therefore, the electricity demand required to power the electrolyzer and other auxiliary processes, such as compression, will be supplied by a combination of solar photovoltaic, battery storage and supply from the grid.

The initial system configuration described can be visualized in figure 1 below, where electricity flows are blue and hydrogen flows are green.

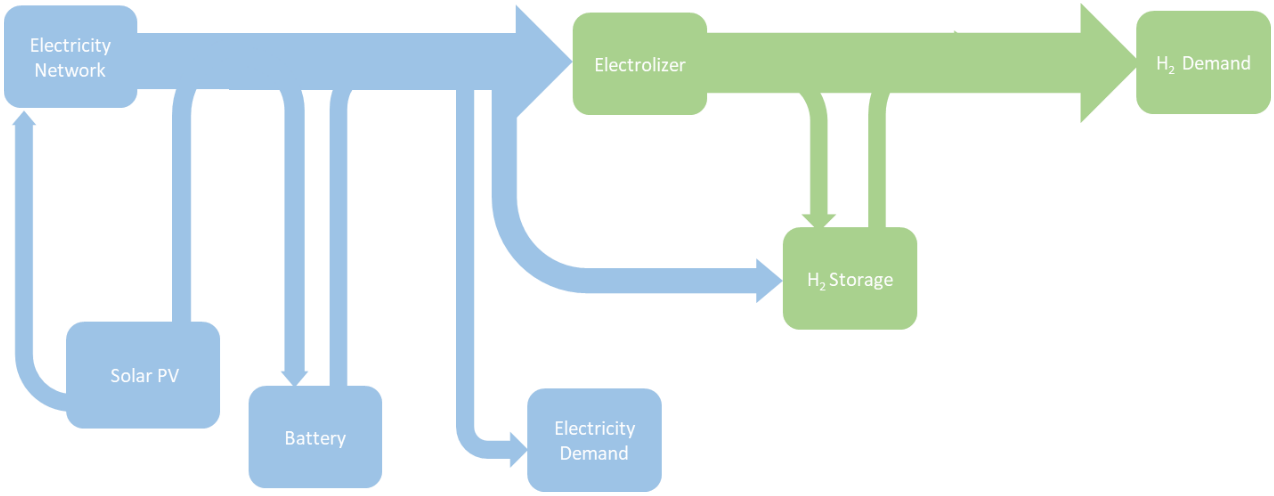


Figure 1. Schematic of system layout.

To properly design the electricity supply side of the system, careful consideration will be needed on the choice of hourly electricity prices to represent the grid and correlated hourly solar profiles representative of the same system.

The hydrogen demand hourly profiles will be of particular relevance as the choice of profile will have a significant and direct impact on the capacity requirements of each of the system components. For instance, if we consider a baseload hydrogen supply hourly profile in which the hourly hydrogen demand is constant, the minimum capacity of the electrolyzer is conditioned by this hourly demand level, the size of the solar plant, battery storage and hydrogen storage will likely have to be larger than in a scenario where hydrogen demand is very flexible and therefore the total cost of hydrogen production will be larger.
Potential renewable hydrogen consumer profiles will be explored in order to assess what the cost of hydrogen could be and what system configurations, in terms of system component capacity, better satisfies the hydrogen needs of different types of consumers.

The cost of hydrogen generation will be based on the cost of electricity consumption and therefore all the cost components of each of the technologies will have to be explored, as well as the technical restrictions particular to each technology. The following data will have to be gathered in order to properly account for the total cost of generation at every interval.

- Grid
    - Hourly price curves for a particular region
    - Tolls and charges that should reflect in a premium to be paid during peak or potential congestion hours.
- Solar Photovoltaic Plant
    - Capex/Investment and other costs to be recovered through its technical life.
    - O&M or other costs related to operation.
    - Solar Profiles for the same region as the demand curves.
- Battery Storage
    - Capex/Investment and other costs to be recovered through its technical life.
    - O&M and other costs related to operation.
    - Efficiencies
    - All this data should be explored for at least a couple of options of different duration.

- Electrolyzer
  - Capex/Investment and other costs to be recovered through its technical life.
  - O&M or other costs related to operation such as water.
  - Ramp limits and technical minimum/maximum load.
  - Potentially consider including an efficiency profile based on load.
- Hydrogen Storage
  - Capex/Investment and other costs to be recovered through its technical life.
  - O&M or other costs related to operation.
  - Other storage system cost such as compression. (Both in terms of $/kg of hydrogen and in terms of kWh/Kg of hydrogen.)
- Hydrogen Demand
  - Different hourly profiles based on the industry/consumer considered will be developed.
  - Define a cost of non-served hydrogen. (or alternative hydrogen supply).
  - Green hydrogen cost projections that will serve as a competitive counterpart to choose whether to produce or to buy from elsewhere.

This last point will involve a significant effort as the proper definition of the cost of buying green hydrogen produced somewhere else will be a determinant limit in the cost competitiveness of the green hydrogen production facility configurations proposed.

Another aspect to focus on is the temporal correlation of electricity consumption and green/renewable energy certificates. As stated in the recently published delegated act for renewable liquid and gaseous transport fuels of non-biological origin by the European Commission, the correlation requirements will be hourly by 2030 if not before and this leaves the electrolyzer with four potential alternatives for electricity supply:

- Directly from the solar photovoltaic plant during hours of sun.
- From battery stored electricity generated by the solar photovoltaic plant.
- From battery stored electricity consumed from the grid with a renewable energy certificate.
- From the grid with a renewable energy certificate.

This hourly temporal correlation requirement in combination with different hydrogen consumption profiles will lead to very different optimal dimensioning of the different technologies in the system and to different hydrogen production costs.

The network consumption, as mentioned, will be subjected to curves of hourly prices based on sufficient years to make the results robust, and the same applies for the solar photovoltaic profiles, at least three different solar years will be considered.

This model will be developed and executed using GAMS, with the mathematical definition performed from scratch and this is the reason why I have allowed some flexibility in some of the restrictions imposed to certain technologies and to the system as a whole, as several complications could arise from this and the time for the development of the model is limited.

The intention is to expand this model from a production only model in which the installed capacities are set by the user to a version in which the installed capacities are decision variables, an expansion model. In this manner I would be able to calculate the optimal dimensioning of each component. This will involve more elaborate mathematical development of the model and more debugging time or time to ensure investment decision are made correctly, but I think it will be worth the extra effort as the finalsed model is intended to be used as an instrument to make quick estimates of dimension requirements of the technologies in hydrogen generation hybrid projects. The option to set minimum and maximum thresholds for the installed capacity of the technologies is necessary as it will be a way to activate or deactivate the possibility to include a technology partially or totally.

The second phase of the work will consist primarily of scenario design and analysis. In order to generate the most value from this study a number of scenarios will be explored, some in line with the restrictions proposed in the Delegated Act and some derived from variations in those proposals, in order to explore what the resulting range of hydrogen production costs would be and what tendencies in optimal dimensioning of hybrid project elements results from these restrictions.

This first iteration will consist of a baseload hourly demand profile, the likely supply requirement for a significant portion of the industrial consumers, and this will be calculated for the purely most economical case, without temporal correlation restrictions and without limits on the amount of each technology that can be built. This case, according to the Delegated Act, would be considering the production of hydrogen as green hydrogen if the energy mix has a renewable share of at least 90% or carbon dioxide intensity below 18 gCO_2e/MJ.

The cases that will follow in the analysis will derive from the results on the first one mentioned above and could be subjected to changes from the initial proposals during the planning period but will potentially include one or more scenarios in which the solar capacity is limited to sensible values based on land availability. Limits on battery and hydrogen storages, both on capacity and prices based on the storage pressure and compressors required, will also be set.

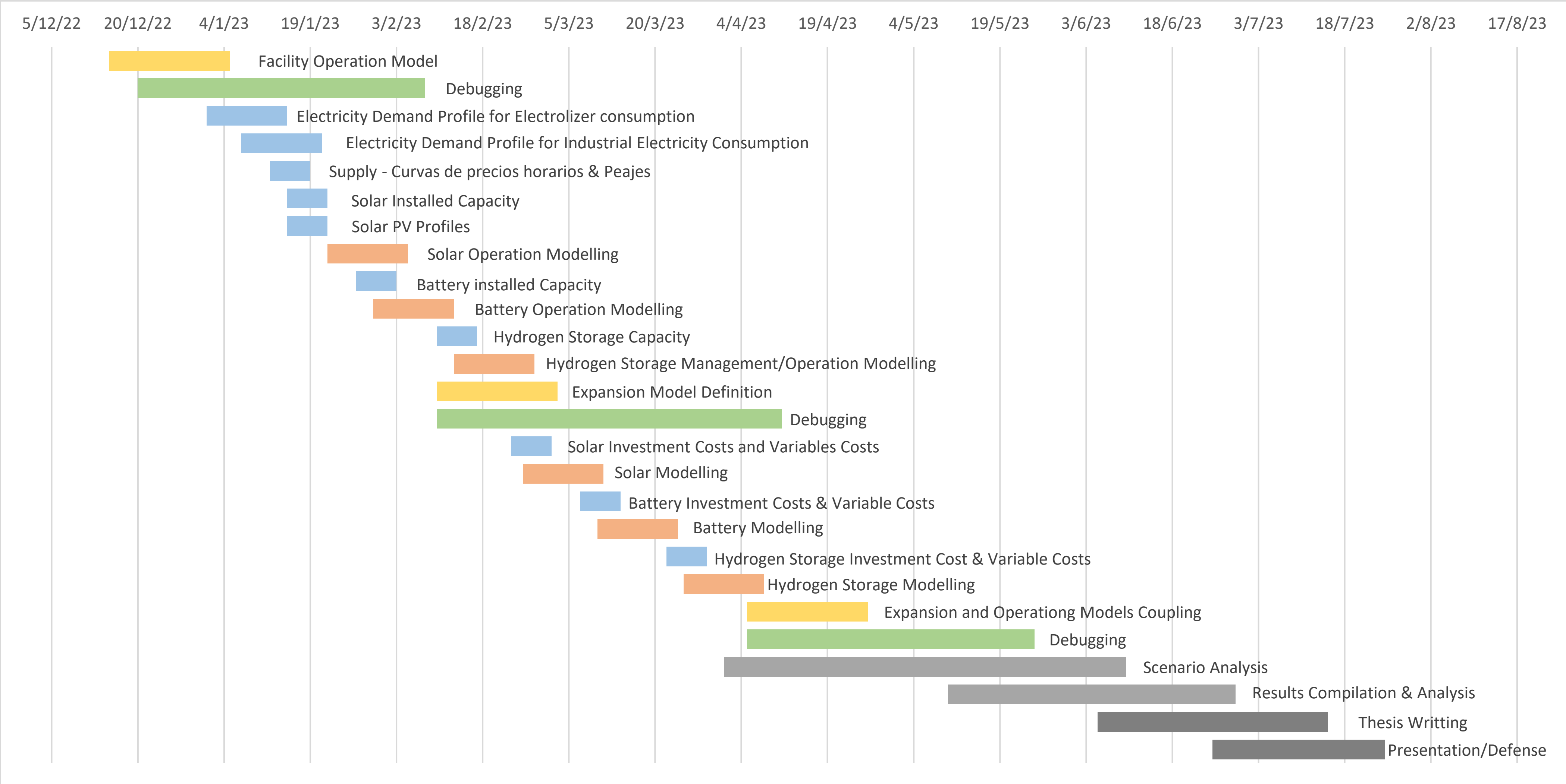
Other scenarios will set the price of green hydrogen bought from the hydrogen market as high as the price of non-served hydrogen in order to force the facility to dimension the generation and storage components in such a way that makes the project fully autonomous in its capability to satisfy the hydrogen demand. This should also give a good indication of price for the supply of all hydrogen demand from onsite renewable energy generation and storage.

All these scenarios will be used to validate the model and for analysis in combination with various requirements of temporal correlation of green certificates.

In summary, the main parameters that will be used in combination with each other to define the final scenarios for the analysis to be performed with this tool are the demand profile, the limitations set to the technologies in terms of capacity, the cost of green hydrogen from the hydrogen market and the temporal correlation requirements.

The conclusion of this scenario analysis will be an assessment of the implications of the requirements for green labelling hydrogen, its cost-competitiveness against other hydrogen production schemes and the potential technologies that will benefit from these hydrogen industry development ambitions.

Work Plan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4/5/23
19/5/23
3/6/23
18/6/23
3/7/23
18/7/23
2/8/23
17/8/23
Facility Operation Model
Debugging
Electricity Demand Profile for Electrolizer consumption
Electricity Demand Profile for Industrial Electricity Consumption
Supply - Curvas de precios horarios & Peajes
Solar Installed Capacity
Solar PV Profiles
Solar Operation Modelling
Battery installed Capacity
Battery Operation Modelling
Hydrogen Storage Capacity
Hydrogen Storage Management/Operation Modelling
Expansion Model Definition
Debugging
Solar Investment Costs and Variables Costs
Solar Modelling
Battery Investment Costs & Variable Costs
Battery Modelling
Hydrogen Storage Investment Cost & Variable Costs
Hydrogen Storage Modelling
Expansion and Operationg Models Coupling
Debugging
Scenario Analysis
Results Compilation & Analysis
Thesis Writting
Presentation/Defense