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To cite this version:

Xavier Roboam, Claude Andrieux, Christophe Turpin, Bruno Sareni. Energy Modelling of a Hydrogen hub (electricity, heat, transport vehicle) for future Airports. Symposium de Génie Electrique, Université de Lorraine [UL], Jul 2018, Nancy, France. hal-02981850

HAL Id: hal-02981850

https://hal.science/hal-02981850v1

Submitted on 28 Oct 2020

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Energy Modelling of a Hydrogen hub (electricity, heat, transport vehicle) for future Airports

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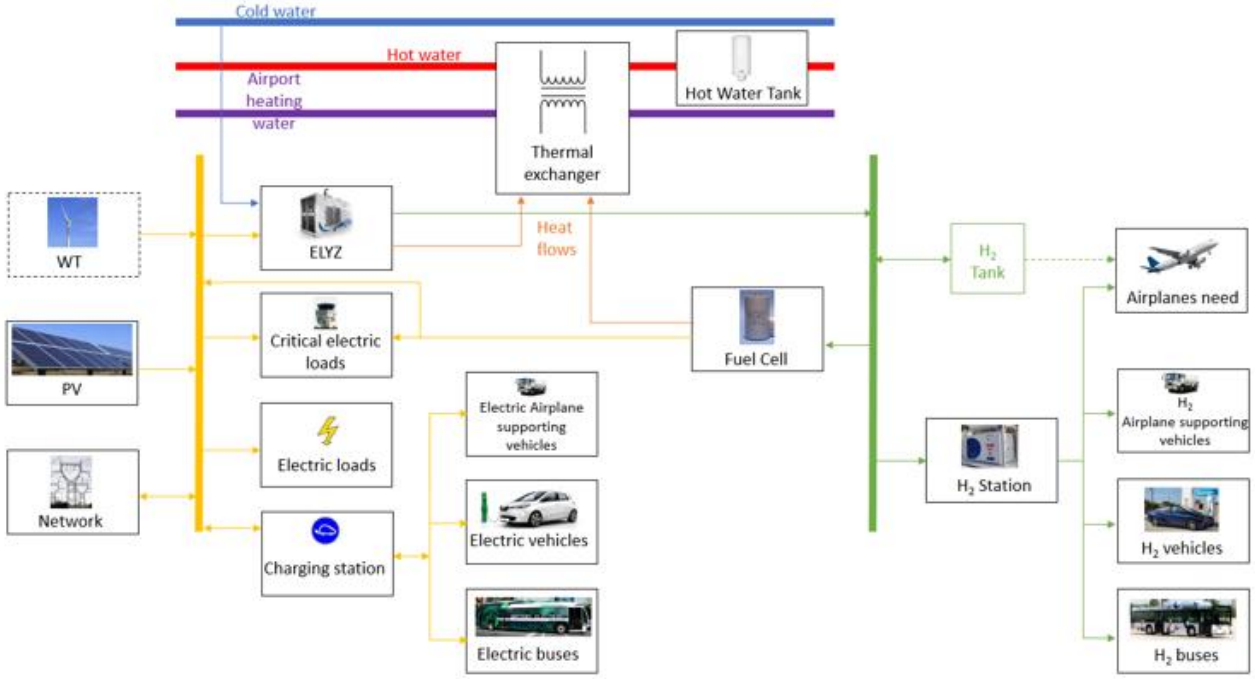

Fig. 1. Overview of the "hydrogen hub": a "multiflow" network.

RESUME – The Occitanie region has just launched a project – called HYPORT – around a "hydrogen hub" used for electric demand and for airport vehicles. Heat recovery from fuel cells and electrolyzers is also a major issue for this hub. This paper deals with the first part of this project which consists in creating a sizing tool for a hydrogen hub devoted to future airports. An energy vision of all device models (renewable sources, electrolyzers, fuel cells, electric demand and transport load profile) integrating a simplified energy management is proposed.

Keywords - hydrogen, hybridization, renewable energy, airport.

1. INTRODUCTION

Hydrogen is on its way to become one of the main energy vectors in the context of sustainable energies. The ability to produce hydrogen by combining renewable electricity sources (solar PV, wind turbines) and a water electrolyzer opens a wide range of possibilities [5,6]. But efficiency of hydrogen devices (fuel cells, electrolyzers) makes the heat recovery (co-generation) especially relevant [8], so that a "hydrogen hub" with a "multi flow" network (electricity, hydrogen and heat) can be addressed to face demands in terms of electric needs, but also hot water demand and mobility (hydrogen and/or electric vehicles) requirements [9,10]. In parallel, there is a wish from airports to reduce their environmental footprint, their consumption and the noise of their activities. Hydrogen appears to be one solution to their problem, assuming that its price does not exceed the business-as-usual one.

Using renewable electricity in an airport and using the airport as a real scale test for renewables has already been done on different sites. It can be mentioned that in the airport of Aichi in Japan, a new way of setting PV panels had been tested: the bifacial panel installed vertically [1]. The Hyport Project [7] will allow both airports of Toulouse-Blagnac and

Tarbes-Lourdes-Pyrénées to be part of the research in hydrogen technologies.

In this paper, after having presented the characteristics of the HYPORT project, the energy based models of the devices are described. Note that at this first stage of the HYPORT project, we do not benefit of actual and accurate data and the design process will only be based on simplified data feeding the models. Then, the EMS strategy based on heuristic choices is presented before displaying the main analysis results.

2. The Hyport Project

The HYPORT Project has been launched by the Occitanie region and involves a wide set of partners, the LAPLACE lab being among them. The objective of this project is to develop and set up hydrogen ecosystems (hub) in future airport areas. Both airports targeted by the project are Toulouse-Blagnac (an international platform) and Tarbes-Lourdes-Pyrénées (a regional platform). The consortium aims at developing economically viable hydrogen ecosystems in airports, lowering ecological footprint while developing a research activity around hydrogen.

3. The Sizing Tool

3.1. Description of the tool

The sizing tool is designed around three energy flows: electricity, hydrogen and heat. Heat recovery from losses in fuel cells and electrolyzers will be exploited for water heating in electrical hot water tanks. An overview of the whole multiflow system is displayed on the Fig. 1.

For the electrical part, electricity will be produced by photovoltaic panels and possibly wind turbines. This electricity will contribute to feed electrical needs of the airport, for example: lights, electric heaters, air conditioners, computers, etc. Recharge stations for electric vehicles will be set up to supply the electric cars, buses and ground vehicles supporting aircrafts. Using electric vehicles will allow the airport to reduce its carbon dioxide (CO_2) emissions. When there will be more electricity produced than consumed, the surplus will be stored under three different ways: hydrogen through water electrolysers, heat through a hot water tank or electricity through charging stations for electric vehicles. In case of a lack of electricity, fuel cells will be able to produce back up electricity, especially in cases of grid faults. Finally, the grid will be used to balance electricity consumption and production of the airport.

For the hydrogen flows, a hydrogen tank fed by the electrolyzer and several hydrogen consumers are implemented like fuel cells described in the electric part. Then, hydrogen cars, buses and airplane supporting vehicles are implemented to compare the use of electric and hydrogen vehicles. Another part of the produced hydrogen will be possibly sent to future embedded systems in aircrafts.

The heat network will be composed of several pipes from the electrolyzer and the fuel cells to heat exchangers that will be connected to a hot water tank in the airport. This co-generated heat will allow both to reduce the electric consumption of the hot water tank and to increase the efficiency of the electrolyzer and the fuel cells.

3.2. Description of the models

The models of the tool have been established with the Matlab® framework. Most of them have been collected form the Insul'Grid project [1], completed and adapted to fit in the Hyport project. The models are divided in four categories: the renewable sources, the hydrogen devices, the loads and the energy management.

3.2.1. The renewable sources

For the sources, renewable electricity can be produced either by photovoltaic panels or wind turbines. The latter seems more unlikely and will not be described in this paper.

The photovoltaic model input is the Global Horizontal Irradiance (GHI) found on the place the panels will be settled. With that information, the Global Tilted Irradiance can be found, using a tilted angle for the panels chosen by the user. At last, the value of the power received by the panels is transformed into an electric power value. This is obtained using efficiency curves of different types of panels which are implemented in the tool. These sources are connected to the utility electric grid as any other electric device in the airport network.

The wind turbine model is based on a similar principle. The wind speed corresponding to the installation site is needed. Then the curve giving the production of a wind turbine in function of the wind speed is used to get the power produced by the wind turbine.

3.2.2. The hydrogen devices

The hydrogen devices are composed of a PEM electrolyzer system, a PEM fuel cell system and a pressurized hydrogen tank. They can be used in different configurations. For example, the H2/O2 battery is the case where the components are gathered next to each other and work the same way as a battery: electricity is stored, from electrolyzer, into a hydrogen tank and transformed back into electricity through the fuel cell. Another way to use them is to separate them from each other. The hydrogen produced can be used in other components and electricity can still be produced out of it. In both configurations, it is possible to use the co-generated heat.

The electrolyzer is a device that transforms water electricity and heat into hydrogen and oxygen. It is modelled using a linear approximation of its polarization curve (1). It is the curve that gives the voltage of the electrolyzer as a function of its current. The linearized electrical model is a voltage source alongside with a resistance in series. An ageing simplified model can be associated [1] if the life cycle of the network is concerned as for a techno-economic analysis or optimization; this topic has to be addressed in the next future in the project.

$$U_{ELYZ} = E_{ELYZ} + R_{ELYZ} \cdot I_{ELYZ} \quad (1)$$

For the thermal management, an electrolyzer is supposed only to consume heat from a theoretical point of view. However, for PEM electrolyzers, the heat needed is given by the

irreversible losses (due to activation, diffusion, ohmic phenomena) inside the component. As a result, the overproduced irreversible heat not needed by the reaction must be extracted and can be used.

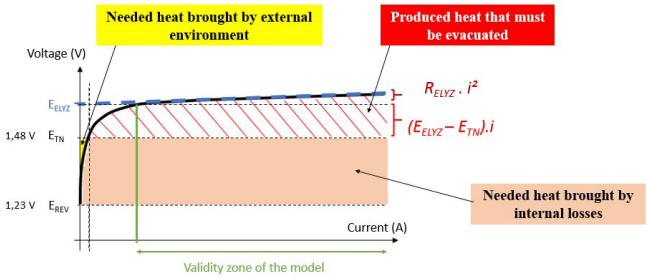

Fig. 2. Polarization curve of a PEM electrolyzer with thermal details.

The following equation (2) gives the thermal power extracted from the electrolyzer.

$$P_{TH\ ELYZ} = (E_{ELYZ} - E_{TN}).I_{ELYZ} + R_{ELYZ}.(I_{ELYZ})^2 \qquad (2)$$

The fuel cell is modelled the same way as the electrolyzer. A linear approximation of its polarization curve is done and the final model is a voltage source in series with a resistance (3).

$$U_{PAC} = E_{PAC} - R_{PAC} \cdot I_{PAC} \qquad (3)$$

For the thermal management, it is easier than for an electrolyzer. The whole heat produced must be evacuated; it corresponds to the heat chemically produced by the reaction to which it must be added the heat electrically produced (due to ohmic losses). All that heat can theoretically be extracted.

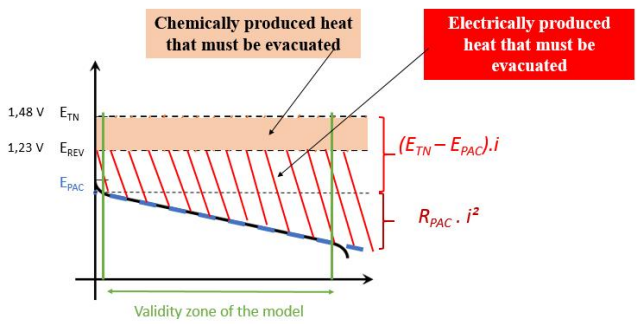

Fig. 3. Polarizaion curve of a PEM fuel cell with thermal details

The thermal power extracted from the fuel cell is given on the equation (4).

$$P_{TH\ PAC} = (E_{TN} - E_{PAC}).I_{PAC} + R_{PAC}.(I_{PAC})^2 \qquad (4)$$

Nevertheless, for both components a coefficient corresponding to the part of the extracted heat that can be really used is introduced. It is usual to consider that approximatively 2/3 of this heat is recoverable (fuel cell assumed non-insulated thermally here): indeed, a part of the produced heat is directly evacuated by the air flow (nitrogen is just passing through the cathodic side), the external natural convection and the radiation.

In a first approach, the hydrogen tank is modelled using the perfect gas law.

$$P_{tank} = \frac{n_{H2} \cdot R \cdot T_{tank}}{V_{tank}} \qquad (5)$$

The number of moles in and out will allow to get the pressure inside the tank, the variation of the quantity of hydrogen inside the tank is qualified using the number of moles of hydrogen in and out of the tank. The pressure is then calculated to evaluate the state of charge of the tank: this SOC is defined using the ratio between the pressure of hydrogen in the tank and the maximum authorized pressure of the tank.

3.2.3. The consumers

A first set of consumers of the energy hub is constituted of the “non-sheddable” electric loads which correspond to a use that cannot be delayed. Waiting so far for actual data in the Hyport project, this first set of loads will be simplified with a constant higher level during the day than during the night: it has been chosen to set up a fictive simple base of consumption.

A second set of loads is constituted by “sheddable” loads, which degrees of freedom in terms of control can be exploited by the EMS (Energy Management System).

Among them, the hot water tank is modelled considering that stored water inside has a homogeneous temperature with no heat losses. The only variables are the volume of the tank and the input/output water flow. The operation temperature is chosen to stay between 55 °C and 65 °C to respect sanitary norms. The temperature of the water inside the water tank is modelled doing an enthalpic balance on the water:

$$T_{ecs}(t + dt) = T_{ecs}(t) + \frac{P_{elec} + \left[\left(T_{ef}(t) - T_{ecs}(t)\right).C_p(H_2O).D\right]}{V_{tank} \cdot \rho_{H2O} \cdot C_p(H_2O)}.dt \qquad (6)$$

With:
- $P_{élec}$ the electrical power
- $T_{ecs}(t)$ the temperature of the water inside the tank at instant t [°C]
- $T_{ef}(t)$ the temperature of incoming water at instant t [°C]
- $C_p(H_2O)$ the specific heat of water, 4180 [J/kg/K]
- ρ_{H2O} the water density, 1000 [g/L]
- V_{tank} the volume of the tank [L]
- D the water flow [kg/s].

The temperature of incoming water is currently a constant equal to the monthly mean temperature of the location. The water flow is a parameter that can be chose by the operator, it can vary in function of the hour of the day, but for our first

approach it has been chosen to set the water flow to a constant assuming than there is always someone using water somewhere in the airport.

Other shedding electric loads are related to the charge of electric vehicles. The simplified model of the electric vehicles is based on the Renault ZOE. The vehicle has a reserve of energy of 41 kWh that can be consumed during a mission profile. It will then come to the charging station to refill its battery. The “vehicle to grid” case where it is possible to use the energy stored in the vehicle for the network management, while it is connected to the charging station has not been treated yet. During charging, the vehicle will receive a constant charging power during one simulation time step. The value of the charging power depends on the power available in the charging station but cannot exceeds the maximum charging power of the vehicle.

For the case of hydrogen vehicles, it is the same principle except that hydrogen is stored instead of electricity, the local storage being ensured by connecting the vehicle to the hydrogen global storage (hydrogen station) associated with the electrolyzer. The model is based on the Toyota MIRAI embedding around 5 kg of hydrogen. The vehicle will consume hydrogen during its mission and will go to the hydrogen station to refill its tank. The full charging of a hydrogen vehicle lasting approximatively five minutes, it is set that it takes only one step time of simulation to fill a hydrogen vehicle (in the current version of the tool, one step time corresponds to ten minutes).

To analyse the use of all vehicle classes, two different fictive missions have been created. The first one represents a vehicle class used by employees of the airport for one hour. The second one represents the transfer of people between the airport and the inner city being planned to last two hours. It has been chosen to represent the evolution of the missions through the mean power consumed during each mission. On the Fig. 4, the state of charge of two electric vehicles accomplishing the two missions are displayed. It is also possible to see that the charging of the vehicles (after the mission is accomplished) is done only if there is power available in the charging station. On the Fig. 4, it is shown that there was not enough power to fill the second vehicle to 100% of state of charge.

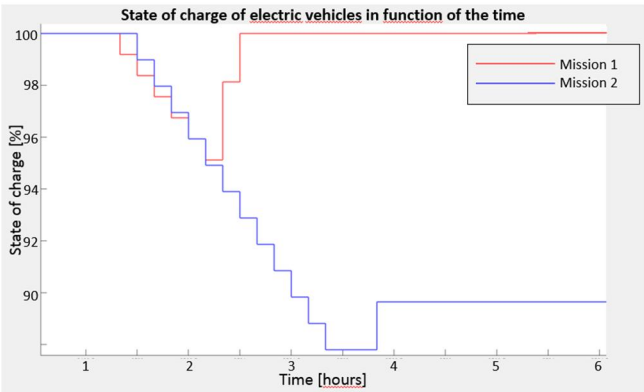

Fig. 4. State of charge of two electric vehicles during mission 1 and 2.

3.2.3. *The energy management system (EMS)*

The last part deals with the energy management issue. The global issue aims at maximizing the energy autonomy of the airport. It is divided into two subparts: the actual energy management system and the performance indicators chosen to demonstrate whether the energy management is effective or not. To set up the EMS, four ways of storing or consuming energy have been considered:

- Electrical energy provided by renewable sources can be directly consumed by electric loads,

- The rest can be stored under hydrogen form into the gas tank:

  - under heat form into the hot water tank,

  - and directly into the electric vehicles batteries.

On the one hand, it has been chosen to store the surplus of energy by priority where it is the more needed. For that purpose, a generic SOC (State of Charge) has been defined for each energy flow: the ratio between the hydrogen pressure in the tank and the maximum authorized pressure of the tank, for the hydrogen storage; the ratio between the energy in a vehicle and the maximum energy acceptable by the vehicle, for several vehicles the generalized SOC is the mean of each SOC of each vehicle divided by the number of vehicles; and the SOC of the hot water tank is given by the ratio between the temperature of the water in the tank and the maximum authorized temperature in the tank. Thus, the generic states of charge of the three storages will be checked and the lower SOC will be charged. On the other hand, when there is a lack of electricity to balance the consumption, the fuel cell will be activated. It will consume hydrogen from the hydrogen tank to increase the production of electricity. The algorithm of the EMS is displayed on Fig. 5.

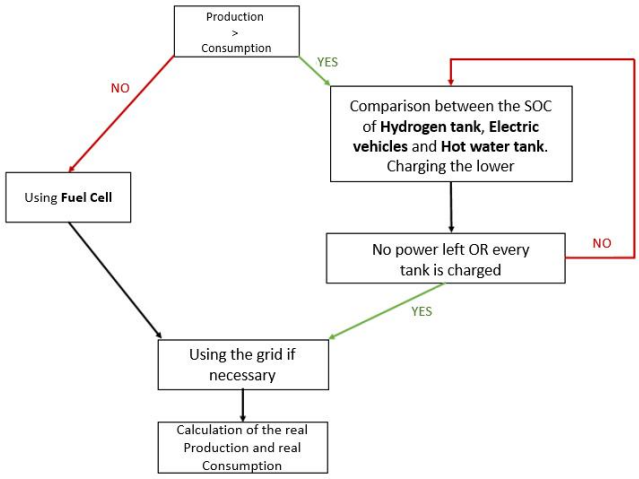

Fig. 5. Scheme of the EMS algorithm

However, this algorithm alone is not enough to fulfil some essentials services like keeping the temperature of the hot water tank between 55°C and 65°C, getting every vehicle mission completed and never having an empty tank of hydrogen. To get those services it is necessary to add at least four rules:

- The hot water tank is electrically reheated whenever its temperature falls under 55°C

- Electric vehicles can charge with electricity from the grid if their SOC is under 30%

- The fuel cell will not be used and the electrolyzer will function with electricity from the grid if the hydrogen tank's SOC fall under 50%

- If the SOC of the hydrogen tank rise above 60%, hydrogen vehicles are charged to the maximum.

Those rules degrade the performance of the EMS by using electricity from the grid, but they allow to realise every essential service which is the priority of the airport.

Once the EMS is working, it is necessary to check whether it is effective or not in the framework of the HYPORT project. The rate between production and consumption, the rate of self-consumption (which is the ratio between the power consumed during time of production and the total power produced) and the rate of self-production (which is the ratio between the power consumed during time of production and the total power consumed) are studied. Finally, it has been concluded that those rates are complementary but not sufficient. The most relevant indicator regarding the energy autonomy can be characterized by the energy exchanged in both directions with the electric utility grid. Hence the energy based objective is to minimize the value of this indicator to have an airport as energetically autonomous as possible. It is displayed in the Fig. 6.

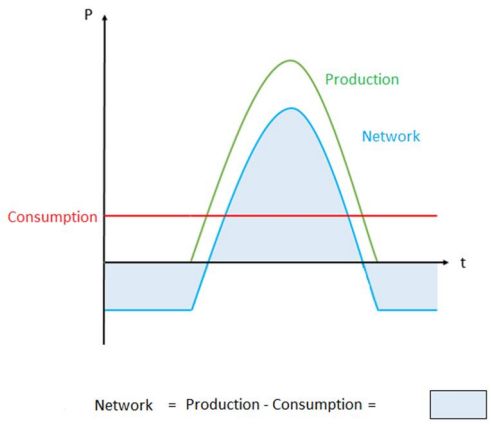

Fig. 6. Scheme of the fourth indicator: Network exchanges

4. Results

The obtained results have to be taken cautiously, with a qualitative vision, because a lot of simplifying assumptions have been made in this first approach considering the lack of actual consolidated data. The inputs may not be as close to the reality as expected. Nevertheless, those results are a good way to check the proper functioning of the tool. Moreover, the results allow having a first estimation of the energy management performance. Using the sizing displayed on Fig. 7 and simulating one year of the airport operating, it appears that the use of the heat produced by the hydrogen devices may strongly reduce the electric consumption of the hot water tank by almost 80% (see Fig. 11.).

Component	Size
PV panels	1000
Electrolyzer	150 kW
Fuel cell	50 kW
Hydrogen tank	35 m^3
Electric Vehicles	7
Hydrogen Vehicles	5
Hot water tank	1 m^3

Fig. 7. Example of the components sizing used for the multi flow simulation.

A closer look to the time chronograms can give an indication of the pertinence of different laws used in the EMS. For example, the charging of hydrogen vehicles whenever the state of charge of the hydrogen tank rise above 60%. In the Fig. 8 is displayed the state of charge of the hydrogen tank and a generalized state of charge of the hydrogen vehicles (the generalized state of charge of the hydrogen vehicles is the mean every step time of every states of charge of all the hydrogen vehicles). It clearly appears that the imposed law is respected by the EMS and that it allows all hydrogen vehicles to be fully charged at those periods and leads to the accomplishment of every mission required by the airport. The state of charge of electric vehicles and the temperature of the water inside the hot water tank are also displayed in Fig. 9 and Fig. 10.

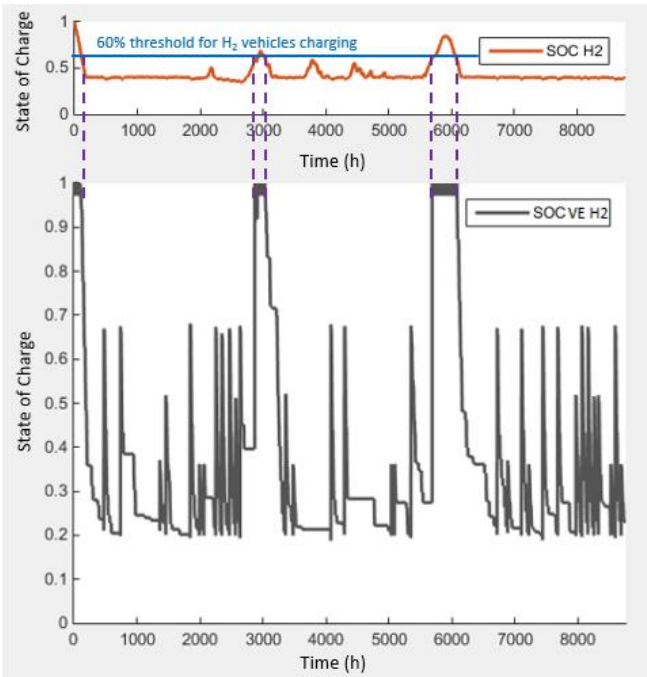

Fig. 8. States of charge of hydrogen tank and hydrogen vehicles for one year

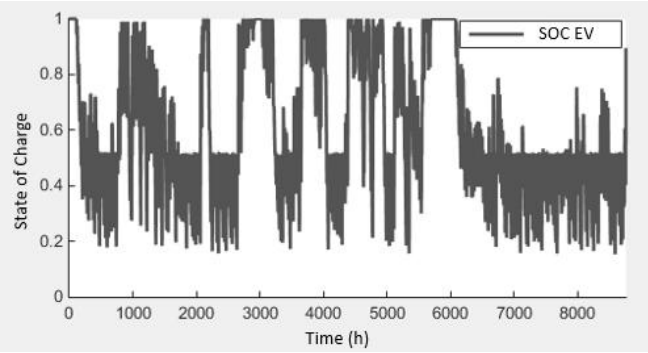

Fig. 9. State of charge of electric vehicles for one year

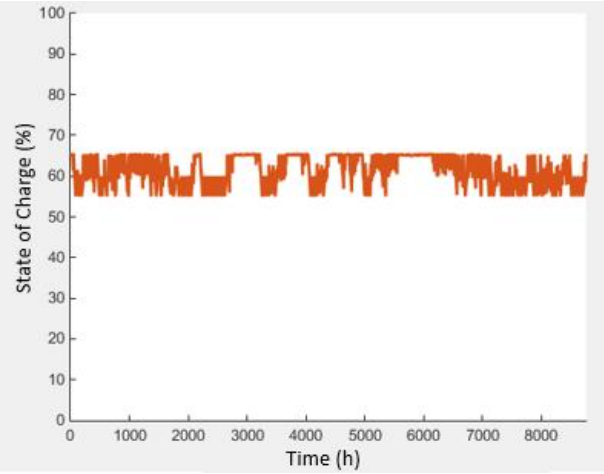

Fig. 10. Temperature of the water inside the hot water tank for one year

5. Conclusion

In the future, the complete tool will have to include three axes: the technical axis, which is the one that has been presented in this paper, the economical axis and the ecological axis, which will be treated in next steps. Those two complementary axes are essential for the dimensioning of the whole system. They will allow to choose the more adapted size of the components that will have the smallest impact on the environment and be the cheapest for the investors.

Even though it was not possible to use actual data from airports, it has been possible to model all components needed in the system and to make them work together. The results of simulation may not be close to the reality; however, they show that the tool is operating and that it would be possible to get reliable results with actual future inputs.

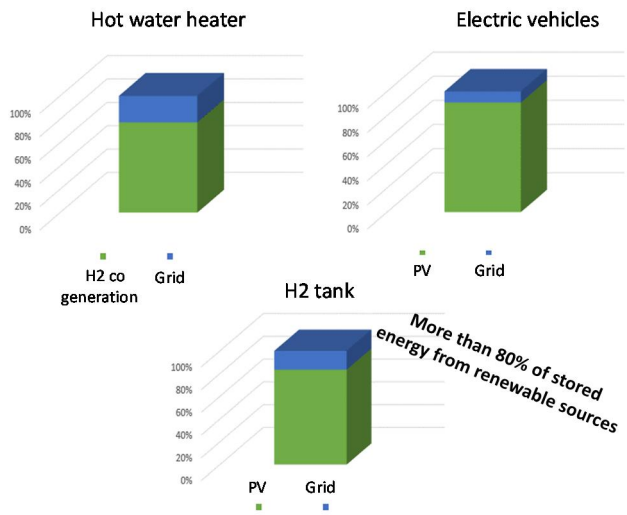

Fig. 11. PV sources vs utility grid balance

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