CASE STUDY: OFF-GRID HYDROGEN REFUELLING STATION FOR FUEL CELL VEHICLES IN ARAGON

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ABSTRACT

This paper presents a technical and operational analysis of a 350 bar - on site production, 100% green - hydrogen refuelling station (HRS) placed in the facilities of the Hydrogen Foundation of Aragón (HFA). A simple but holistic dynamic model of the HRS is developed and validated using real in-field data gathered from a demonstrative off-grid PV powered PEM electrolyser system and refuelling tests performed with modified and commercial fuel cell electric vehicles (FCEV). Several refuelling strategies are addressed depending on hydrogen availability, overall efficiency, storage conditions and other external factors. Modifications to the existing HRS are proposed and a sensibility analysis is performed.

Keywords: HRS, off-grid, FCEV, hydrogen, electrolyser (max. 5 keywords)

INTRODUCTION

The ongoing global energy demand and the increasing need to reduce anthropogenic greenhouse gas (GHG) emissions to avoid the worst-case scenarios of global warming, requires the introduction of cleaner and more sustainable technologies into all sectors of the economy [1]. Furthermore, transport sector accounts for 25% of global GHG emissions from which 70% corresponds to road transport [2] [3], stressing out the importance of reducing emissions in this sector. In this line, hydrogen as an energy carrier is gaining momentum and is considered one of the key elements to migrate towards more sustainable practices especially in the energy and transport sector [4].

Nowadays, hydrogen is mainly used for industrial processes in the chemical industry and most of it is produced by fossil fuel-based methods such as steam-methane reforming (SMR) and coal gasification, both processes highly carbon intensive. However, generating hydrogen by means of water electrolysis coupled with renewable energy is one alternative to produce the so-called *green hydrogen* which minimizes carbon footprint and highly contributes to the 'zero emission' well-to-wheel potential of fuel cell electric vehicles (FCEV), especially if hydrogen is produced on-site with renewable sources.

Several publications are available in the literature tackling the analysis of hydrogen refuelling events [5] [6] [7] and off-grid hydrogen generation [8] [9], but scarce information is available addressing both matters and validated with real data. Therefore, this paper presents, in the framework of the H2PiyR project [10], an integral analysis to better understand the limitations and advantages of operating this HRS with an intermittent energy source.

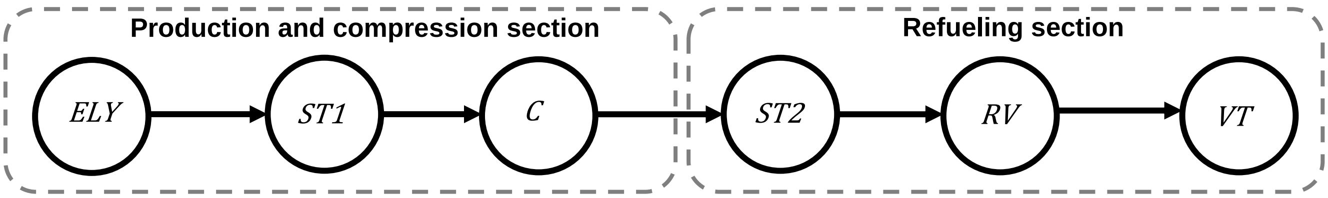
METHODOLOGY

In this section, the actual HRS components are described and the models used to perform the simulations are explained and validated.

HRS components

The analysed HRS is classified as D35 in the J2601 protocol [11]: nominal working pressure of 35 MPa and no hydrogen precooling. No communication between the car and dispenser is available. The main components of the HRS can be seen in *Figure 1*. High quality hydrogen (99.995%) is produced on-site by a 50 kW electrolyser (ELY) of polymer electrolyte membrane (PEM) technology of ITM company powered exclusively by a 64 kWp solar field (photovoltaic panels) and stored at low pressure (up to 20 bar) in an intermediate storage tank (ST1). Hydrogen is then compressed by a two-stage membrane compressor (C) and stored at high pressure in a three-bank rack at three different pressures allowing to perform cascade fillings. When a refuelling event is performed, the vehicle tank is filled with the hydrogen available in ST2 through the reduction valve located in the dispenser. The target pressure and filling strategy is commanded by the dispenser controller and the supervisory control and data acquisition (SCADA) of the HRS. Note that the reduction valve cannot be regulated during the refuelling event and must be calibrated periodically (depending mostly on ambient temperature) to avoid vehicle tank temperatures higher than 85 °C [11].

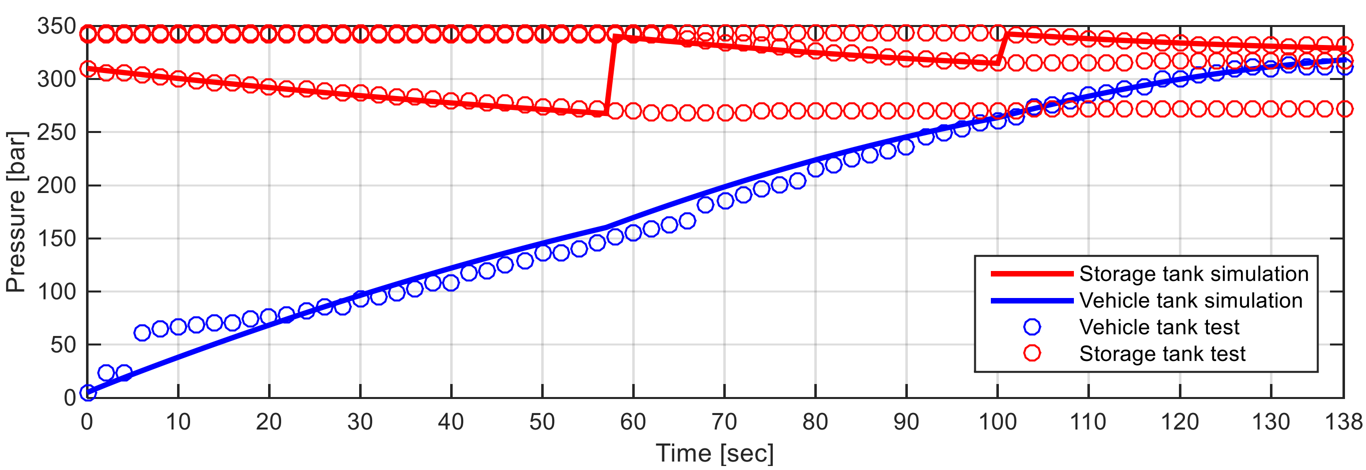
Figure 1. Hydrogen refueling station diagram - ELY: electrolyzer, ST1: intermediate storage tank, C: compressor, ST2: high pressure storage tanks, RV: reduction valve, VT: vehicle tank



Refuelling section model description and validation

This section is modelled using *Matlab* software applying the mass and energy conservation principles in each component and a heat transfer model in both storage tanks and vehicle tank. State equations based on Helmholtz-energy explicit formulation are used.

This model is tuned and validated performing refuelling events with an adapted FCEV with two tanks (type III) of 28 litres each. During the filling, the pressure of each of the high pressure storage banks and of the hose of the dispenser is measured by 4 pressure transmitters and recorded by the SCADA. Ambient temperature and the mass of hydrogen dispensed are also measured. In Figure 2 the pressure behaviour of the storage tanks and vehicle is presented during a cascade filling. The vehicle tank initial pressure is close to 5 bar and the high pressure banks are set to 310 and 340 for the low pressure and medium and high pressure respectively. It can be seen that there is a good correlation between the simulation and the test data except in the first 15 seconds where the simulation tends to underestimate the pressure measurements. This may be explained due to flow instabilities generated by the initial pulse the dispenser controller performs to estimate the tank initial conditions. Moreover, the calculated mass of hydrogen filled is found to

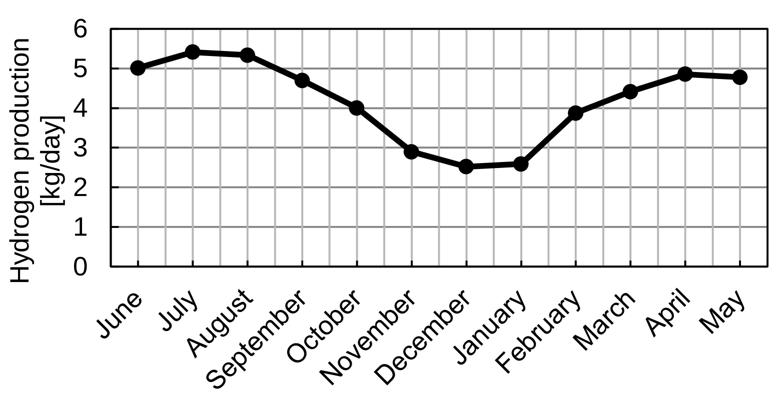


be 1.06 kg, differing by 7% with the value obtained with the mass flow meter installed in the dispenser.

Figure 2. Pressure behaviour during a refuelling test (circles) and simulation (solid line) of high-pressure storage tanks and vehicle tank

Production and compression model description and validation

A production model is developed based on the technical characteristics of the ELY, solar field and particular solar radiation available at the HFA facilities. It also



considers the real operating conditions of the ELY, metrological conditions and maintenance issues. The model is validated with experimental data gathered during the demonstration phase of the project ELY4OFF (FCH JU nº700359) [12] from March to September 2019. Since no data is available for a full calendar year, the model is used to extrapolate hydrogen production in the missing months.

In **¡Error! No se encuentra el origen de la referencia.** the average hydrogen production in a daily basis is presented for every month. Note that during summer and spring seasons hydrogen production is highermainly due to higher average solar radiation..

The compressor mass flow and power consumption are calculated using graphs provided by the manufacturer and validated during several compression events.

RESULTS AND DISCUSSION

In Figure *4* the temperatures and mass flow (through the RV) behavior during a refueling event is depicted. As it is expected, temperature in the vehicle tank increases rapidly due to the compression work inside the tank and the Joule-Thompson effect in the reduction valve boosted by the high initial mass flow rate. As the mass flow decreases, the temperature starts to decrease as the heat dissipates to the surroundings. An inverse behavior is observed in the storage tanks as hydrogen leaves the cylinders. A similar temperature evolution is also seen in [6].

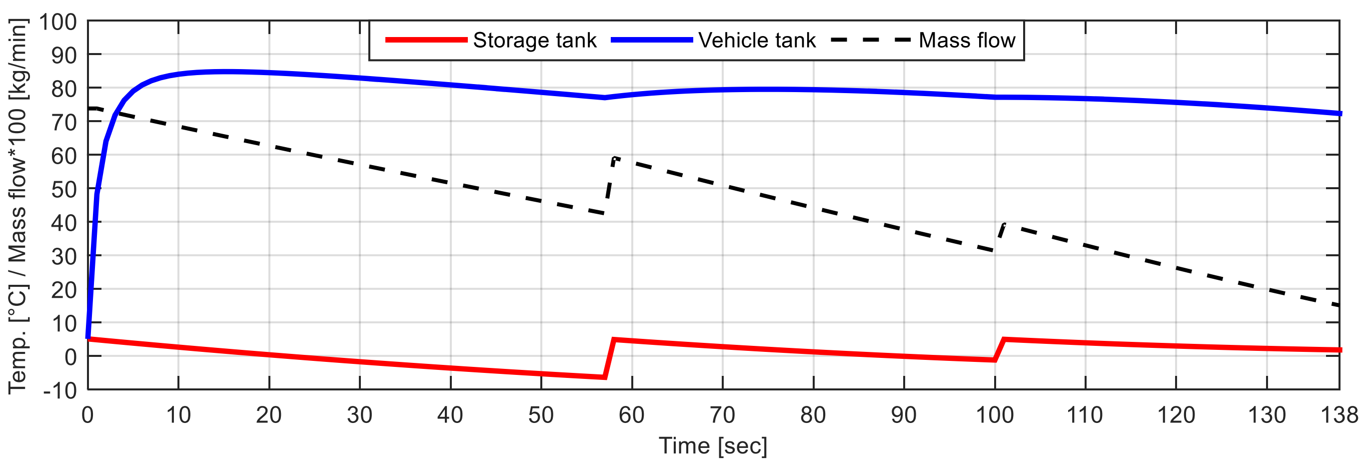


Figure 4. Temperature (red and blue solid lines) and mass flow (dashed line) evolution during a refuelling event

In addition, the HRS model will be used to address its capacity and performance to refuel FCEVs considering real operation conditions, different refuelling strategies, hydrogen availability and overall efficiency. A sensitive analysis will also be performed by changing key characteristics of the components of the HRS. These outcomes are still being analysed and final results are going to be available in the final version of the paper.

CONCLUSIONS

In this extended abstract the methodology and validation with real data of the HRS model is briefly explained and results concerning the temperature behaviour are presented. Outcomes regarding performance to refuel FCEVs in real operation conditions and sensitive analysis are going to be available in the complete version.

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