



Design of a Zero-Emission Metal Hydride-based Refueling Station for H₂-powered L6e Light-Duty Hybrid Vehicles

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Abstract: This paper investigates the potential of hydrogen as a sustainable alternative fuel to mitigate the environmental impact of the automotive industry. It presents the design of a hydrogen refueling station for L6e light vehicles, powered by a photovoltaic system. The study optimizes the capacity of the energy storage elements (buffer battery and hydrogen tank) and of the electrolyzer to minimize the levelized cost of hydrogen storage for a fleet of 8 vehicles in urban driving cycles. Key components such as the photovoltaic system, PEM electrolyzer, and hydrogen storage method are discussed.

Introduction: An ecologically sustainable mobility is necessary to reduce the environmental impact of this sector, in line with the 17 points of sustainable development set out by the UN [1]. Transport still accounts for 26.6% of total greenhouse gas emissions in the EU, falling far short of the objectives of the European Green Deal targets to reduce greenhouse gas emissions by 60% compared to the 1990 levels [2]. The characteristics that make hydrogen particularly interesting for its applications in the energy and automotive fields, namely in Fuel Cell-powered cars, are: absence of local emissions, high energy density, high driving range compared to battery electric vehicles, short refueling times [3]. In terms of on-board and stationary hydrogen storage solutions, Metal Hydrides (MH) are a promising alternative to traditional compression or liquefaction storage systems, inasmuch the theoretical energy density is higher and the safety issues overcome [4,5], thanks to a lower storage pressure.

Methodology: A hydrogen refueling station is powered by a PV system to produce green hydrogen, which is then stored in a MH storage system (see Fig. 1). A buffer battery decouples



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energy generation and utilization in the PEM electrolyzer (PEM-EL). A 8-element fleet of L6e small quadricycles, with an individual daily mileage of 20 km and a driving range of 160 km is considered, for a total yearly hydrogen demand of $m_{H_2} = 144.2$ kg. The hydrogen demand was determined through the development of a detailed digital model of the quadricycle and an extensive experimental campaign conducted in previous studies within the framework of the HySum project [7, 8]. The digital model was then used to estimate the vehicle's range under various operating conditions, fuel sizings, and driving cycles, leading to an average specific consumption of about 0.35 kg/100 km for the vehicles [9]. The yearly energy demand is $E_e = LHV_{H_2} \cdot m_{H_2} / \eta_{PEMEL} = 6,860.6$ kWh, where LHV_{H_2} and η_{PEMEL} are the hydrogen lower heating value (33.3 kWh/kg) and the PEM-EL efficiency (70%). A seed Real Driving Emissions cycle in terms of speed, acceleration, and road slope is selected to generate a vehicle fleet driving mission [6]. From the original drive cycle, the cinematic inputs are discretized in a finite states number to define a comprehensive state variable. We treat the driving cycle as a Markovian chain process and we use a Montecarlo approach to generate several driving cycles with the same probabilistic features. An iterative optimization procedure is carried out on MatLab to minimize the Levelized Cost of Hydrogen (LCOH) taking battery and MH tank capacities, and the PEM-EL rated power as variables and assuming the formula defined in [10] for the LCOH. The hydrogen storage medium is LaNi₅, with a gravimetric density of 1.40%, whose dimensions are determined in previous works [4,5]. One module can store approximately 1 kWh of hydrogen and deliver a maximum rated power of 1 kW [4]. An external jacket of LiNO₃ – 3H₂O facilitates the ab/desorption thermal cycle [11].

Results: By selecting central Italy on the tool PVGIS [12], a photovoltaic plant of 4.85 kW_p is sized, which produces the needed amount of energy E_e each year, assuming a null yearly variability for simplicity. A PEM electrolyzer with a rated power of 3.75 kW and delivery pressure of 14 barg is employed. The Li-Ion buffer battery has a capacity of 1.5 kWh, whilst the MH tank comprises 570 modules in parallel for a total of approximately 17.1 kg of hydrogen. An estimated LCOH of 11.46€/kg is achieved. A total of 41,760 km driving range is covered in one year by the fleet. The on-board hydrogen is stored inside a MH tank of 600g H₂. The MH tank presents a decrease in fill level during wintertime, where less energy is produced by the PV plant, and an increase during summertime, where more energy is available (see Fig. 2). The small buffer battery aids during wintertime whilst it is almost unused

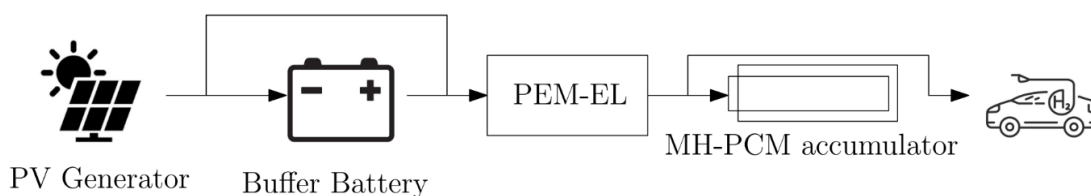


Figure 1: FCEV refueling station layout. PV panels and buffer battery work in parallel

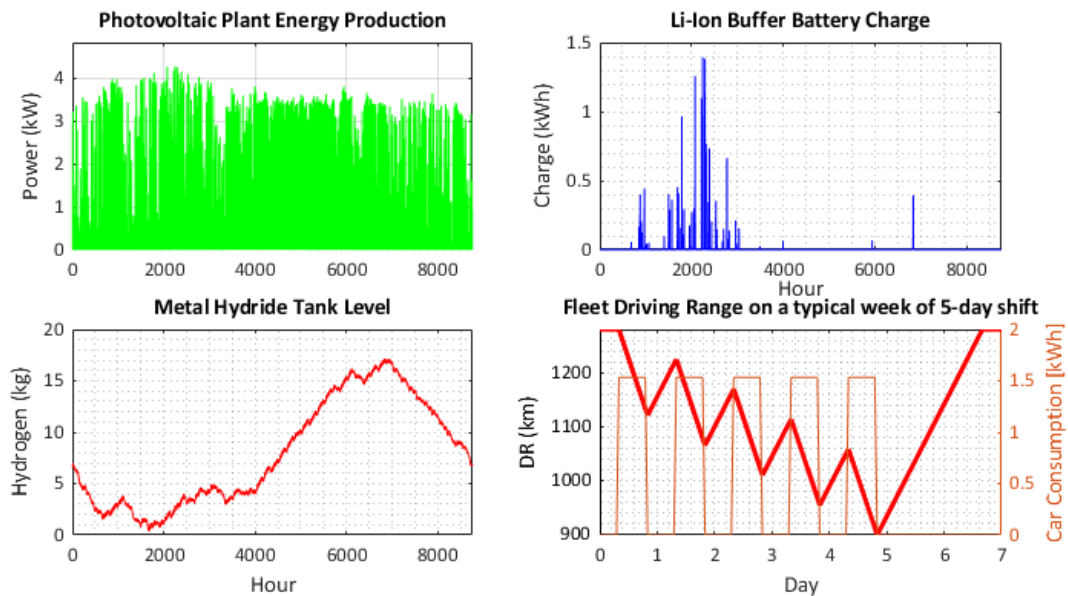


Figure 2. Results of the optimization procedure: (top-left) Yearly PV production (4.85 kW_p); (top-right) buffer battery hourly charge; (bottom-left) hourly MH hydrogen tank level; (bottom-right) cumulative driving range of 8-car fleet on a typical week, along with the hourly car consumption in kWh.

during summertime. Cars are recharged during night-time and weekends, thus the sawtooth profile.

Conclusions: The project demonstrates the feasibility of designing a hydrogen refueling station for 8 L6e light-duty vehicles powered by a photovoltaic system and a Metal Hydride-based H₂ accumulator, offering a sustainable alternative for urban transportation (daily mileage = 20 km). Future work should focus on optimizing the integration of the electrical system to enhance reliability and efficiency, as well as a sensitivity study on green hydrogen production costs and to battery/MH tank capacities.

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