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Solar-hydrogen energy storage for enabling Qatar solar-grid integration and eco-friendly transportation.

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2015

4th TAMUQ Annual Research and Industry Forum

Solar-Hydrogen Energy Storage for Enabling Qatar Solar-Grid Integration and Eco-Friendly Transportation

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Introduction

Qatar has drawn up an ambitious plan to install 1.8 GW of solar capacity by 2020. In the transport sector, green hydrogen produced from solar PV offers one of the best opportunities to reduce greenhouse gas emissions and significantly reduce dependence on fossil fuels. Use of zero carbon or 'green' hydrogen derived from renewable sources in Fuel Cell Electric Vehicles (FCEV) is expected to lead to a 90%-95% reduction in well-to-wheel emissions by 2020 when compared to existing internal combustion engines. In addition, from 2015, forecasts suggest 57,000 FCEVs will be sold annually with sales volume progressively increasing to 390,000 vehicles annually by 2020.

A recent pathways analysis study found that the use of hydrogen was essential for reducing the carbon emissions of the transport sector . It was further found that the application of hydrogen production by electrolysis served the requirement for controllable demand side managed (DSM) loads to act as sinks for constrained renewable energy such as solar PV.

Additionally, hydrogen can realise a more competitive financial value if hydrogen produced from constrained renewable generation is delivered to market as a high value gas rather than used for conversion back to electrical energy for use 'on-grid'.

Described within this poster is a Simulink model of hydrogen production, storage and cascade refuelling operations.

Hydrogen production by electrolysis served the requirement for controllable demand side managed (DSM) loads to act as sinks for constrained renewable energy such as solar PV.

Modelling

Figure 1 illustrates the modelling process that is undertaken to simulate the operation of hydrogen production and refuelling operations when powered from grid constrained energy such as PV.

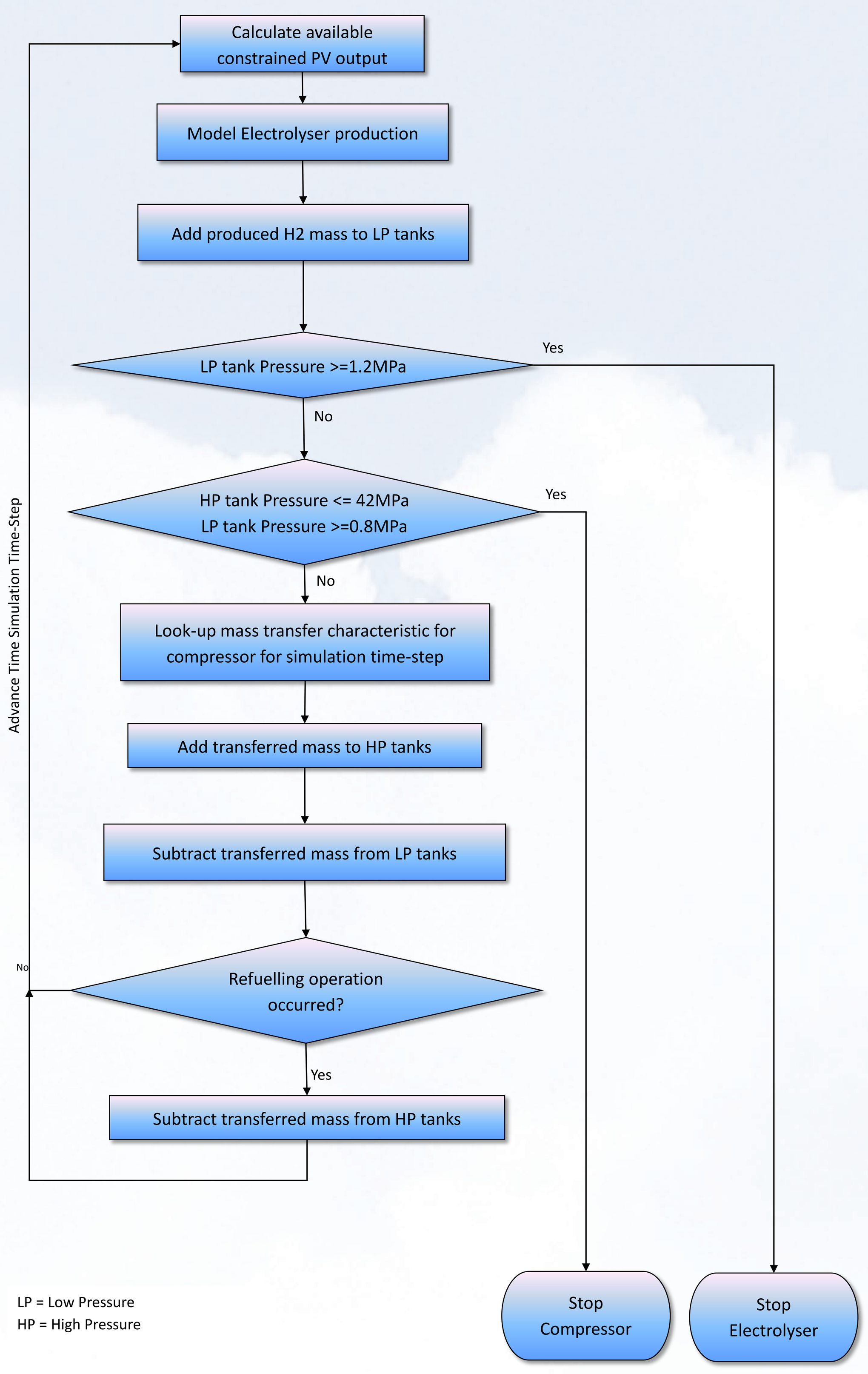

Figure 1: flowchart of modelling process.

Common FCEV refuelling infrastructure

A high pressure cascade refuelling station design offers a compromise to other configurations available on the market. It uses a small compressor, in some instances known as a booster, to replenish the refuelling station's hydrogen store.

In a cascade refuelling operation, hydrogen held in the stationary store is transferred into the vehicle fuel tank in three stages. This enables high on-board vehicle storage pressure to be achieved without the requirement for extremely large high pressure stationary storage tanks and/or compression. This is illustrated in figure 2.

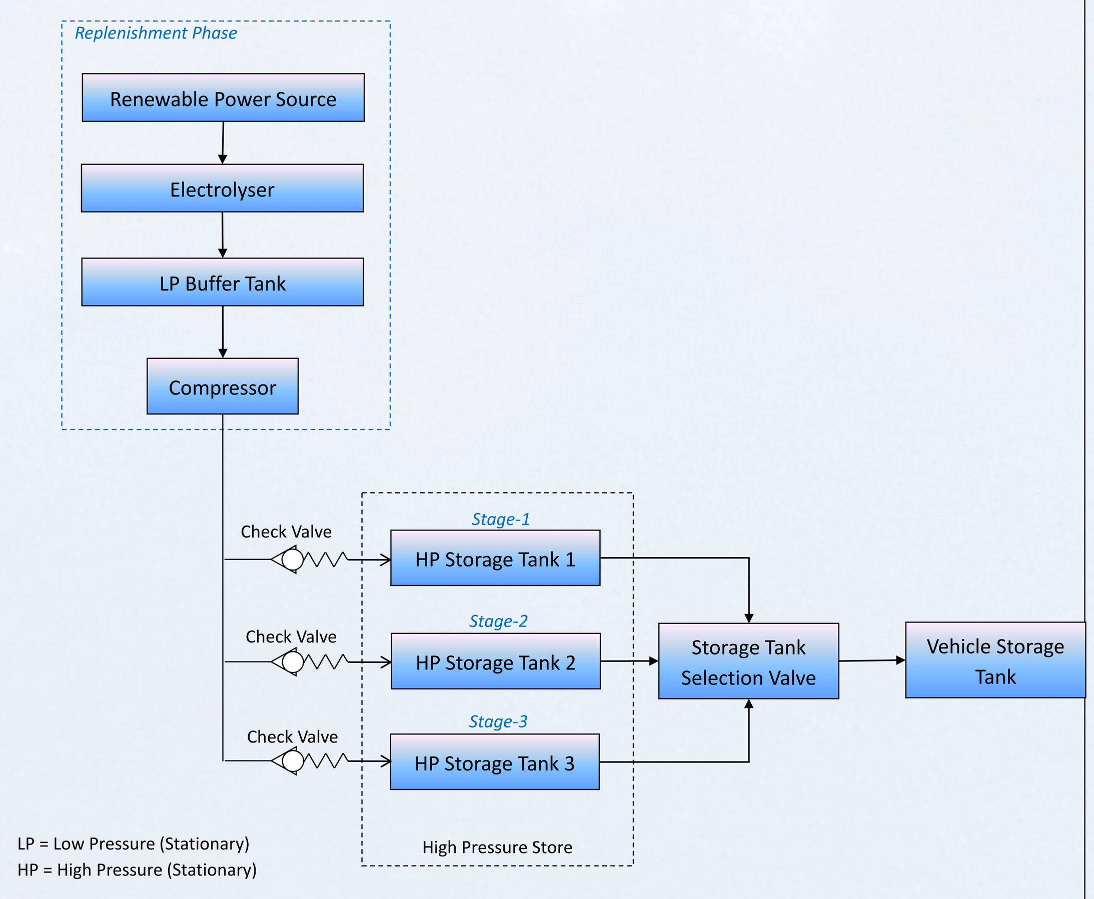

Figure 2: Overview of refuelling process

Mass transfer model

A mass transfer model has been developed to simulate the storage and refuelling performance of the hydrogen system. The model allows the pressure, volume and stored hydrogen mass to be simulated in order to identify if it is possible for a known hydrogen demand to be met from a renewable hydrogen source.

Typically the ideal gas relationship is used to describe the behaviour of hydrogen gas in transport applications. However, at pressures over approximately 1450 psig (100 bars) at normal ambient temperatures the results become increasingly inaccurate.

A mass transfer model has been developed in Simulink that incorporates National Institute for Standards and Technology (NIST) correction factors to deliver results that are accurate to within 0.01%.

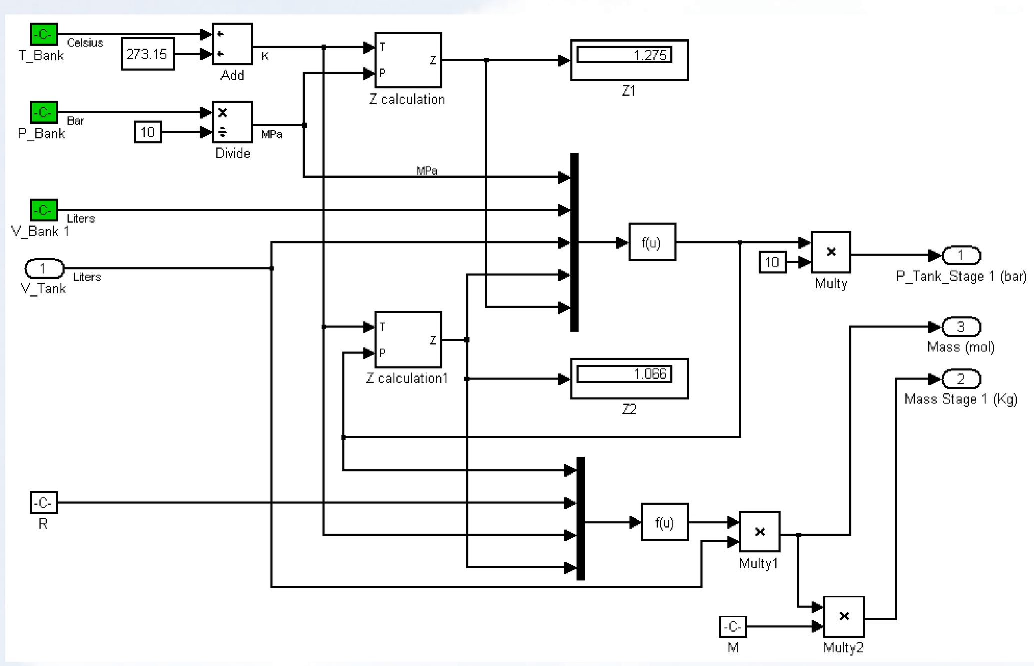

Figure 3: Excerpt of model code

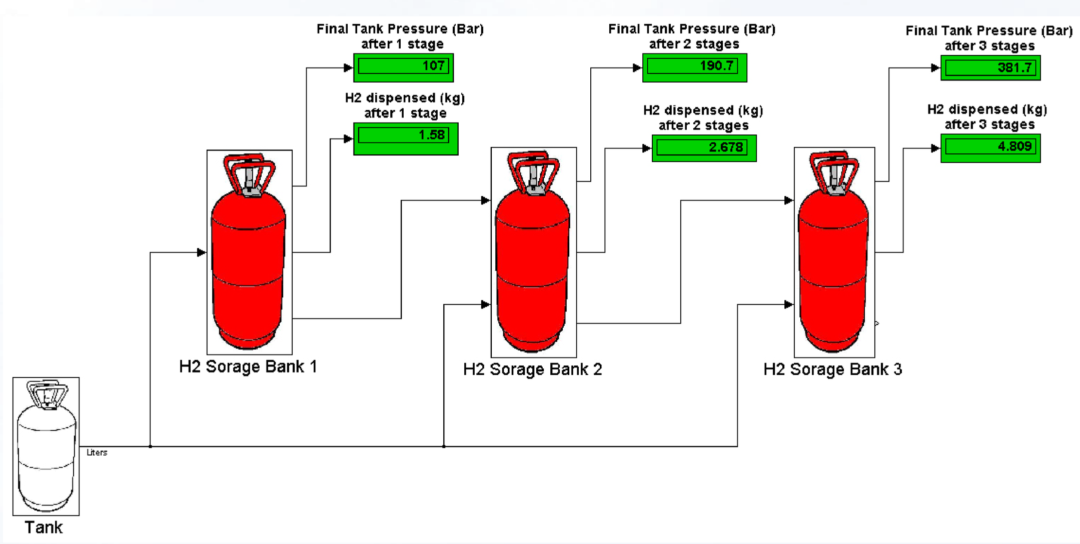

Figure 4: Screenshot excerpt of refuelling station performance

A mass transfer model has been developed in Simulink that incorporates NIST correction factors to deliver results that are accurate to within 0.01%.

Simulation Results

A simulation has been undertaken to identify if a vehicles daily hydrogen demand can be met by existing operational hydrogen infrastructure powered by constrained renewable energy. The results are shown in the last three rows of Table 1 along with Figures 5 to 7.

	Bank-1	Bank-2	Bank-3
Geometric Capacity (L)	82	82	1066
Starting pressure (Bar)	420	420	420
Pressure after refuel (Bar)	107	191	350
Mass Transferred (kg)	1.58	2.68	4.2
% of fill	38%	26%	36%

Table 1: Cascade Filling Simulation Results

Based upon how the hydrogen infrastructure is set up on site, the maximum daily transferable hydrogen quantity required to refuel the vehicle has been found possible to achieve from a relatively modest 12 bar 5.33Nm^3 electrolyser with the hydrogen production and compression operating as follows:

- Operate electrolyser for 10 hours per day from available renewable energy
- Compress 2.03kg during the 10 hours per day of electrolyser production
- Compress 2.17kg during the following 12.8 hours
- Total transfer of 4.2kg of hydrogen into cascade refuelling station is achieved in time 22.8 hours
- Low pressure buffer pressure level at end of a 4.2Kg daily transfer becomes 9.2 bar

A Typical 7 day simulated profile of production, compression and demand are shown in Figures 5, 6 and 7.

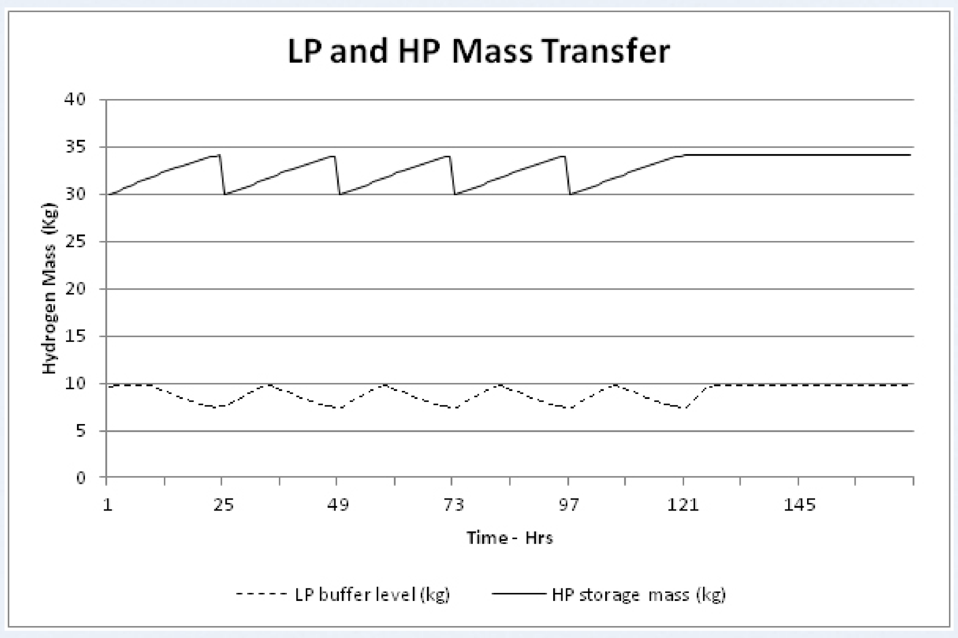

Figure 5: Hydrogen mass transfer between Low Pressure (LP)and High Pressure (HP) storage systems.

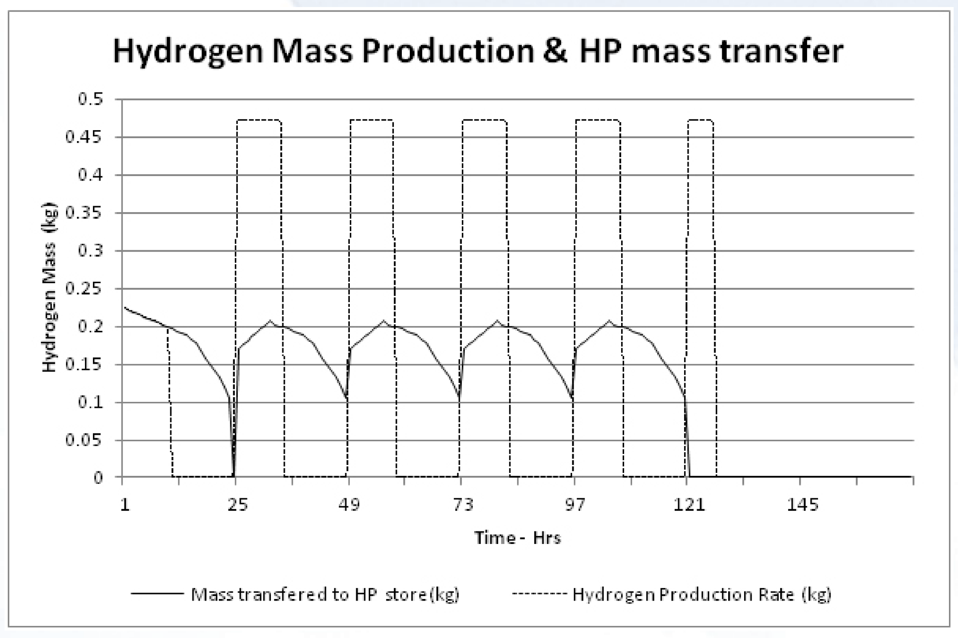

Figure 6: Hydrogen production and compression profile for 10hrs per day production

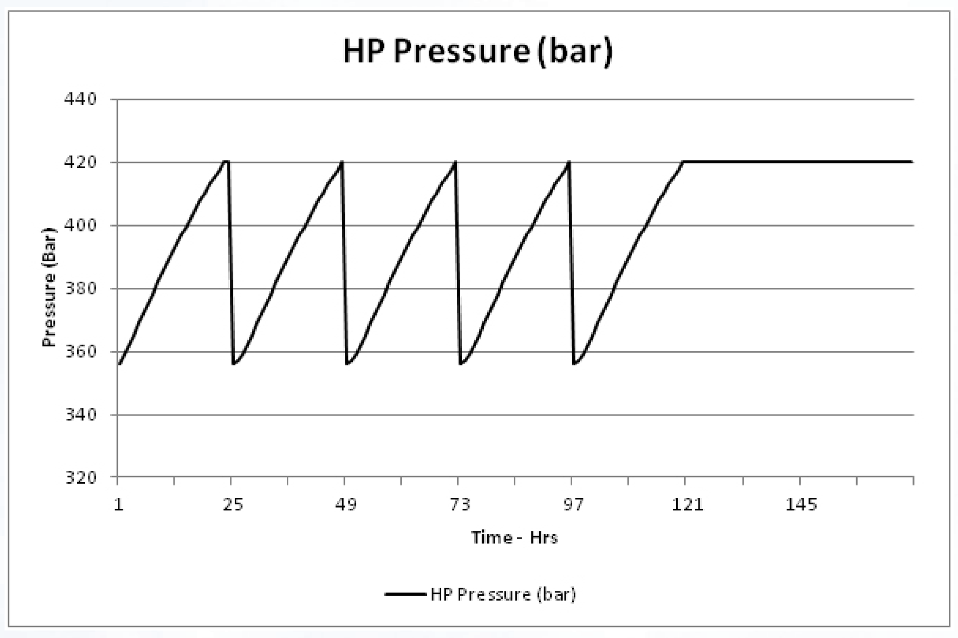

Figure 5: HP pressure cycle profile for 1 week of operation

Acknowledgement