VII.C.2 Development of the Hydrogen Station Equipment Performance (HyStEP) Device

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Project Start Date: September 2014
Project End Date: March 2016

Overall Objectives

- Accelerate commercial hydrogen station acceptance by developing and validating a prototype device to measure hydrogen dispenser performance.
- Develop a device capable of testing to the Canadian Standards Association (CSA) Hydrogen Gas Vehicle (HGV) 4.3 test method to test dispensers for compliance with the table-based fueling protocol defined by SAE J2601-2014.
- Make the device available for use by the state of California to commission existing and new hydrogen stations in the 2016–2017 timeframe.

Fiscal Year (FY) 2016 Objectives

- Publication of the device design to a publicly accessible website to enable third party development of such devices.
- Validation of the HyStEP device performance at National Renewable Energy Laboratory's (NREL's) Energy Systems Integration Facility (ESIF).
- Training of the HyStEP operators from the California Air Resources Board (CARB) and California Department of Food and Agriculture Division of Measurement Standards.
- Validation of the device performance at two hydrogen stations in California.
- Development of a contract to loan the device to CARB for deployment in California.
- Successful performance validation and handoff to CARB for deployment such that station providers and vehicle manufacturers accept the device for station commissioning.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

(E) Codes and Standards

Contribution to Achievement of DOE Technology Validation Milestones

This project contributes to achievement of the following DOE milestone from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Milestone 4.4: Complete evaluation of 700-bar fast fill fueling stations and compare to SAE J2601 specifications and DOE fueling targets. (3Q, 2016)

FY 2016 Accomplishments

- Posted all design documents to the Pacific Northwest National Laboratory-managed H2Tools website: https://h2tools.org/h2first/HyStEP.
- Successfully validated the performance of the device at NREL's ESIF by completing a comprehensive test matrix over a five-week period.
- Trained the California HyStEP operators during a week-long training session lead by Powertech, NREL, and Sandia at NREL's ESIF.
- Validated the HyStEP performance through three days of testing at the Hydrogen Research/Fueling Facility at California State University, Los Angeles (CSULA).
- Further validated the HyStEP performance through four days of testing at the Diamond Bar hydrogen station at South Coast Air Quality Management District (SCAQMD) headquarters, including side-by-side comparisons with Honda and Toyota fuel cell electric vehicles.

- Documented the successful validation testing in a series of three reports to the Fuel Cell Technologies Office.
- Completed a final training test with the HyStEP operators at the Santa Barbara hydrogen station which included side-by-side testing with Mercedes-Benz and Hyundai.
- Coordinated the deployment of the HyStEP device in California with CARB including execution of a contract between Sandia and CARB for the loan of the device.

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INTRODUCTION

It is generally agreed that policies and technology solutions need to be developed and implemented to help reduce the time to commission a hydrogen station. The current practice of hydrogen station acceptance, which burdens vehicle original equipment manufacturers (OEMs) with serial testing of stations because each OEM conducts its own testing and evaluation, can take months. This process is not practical or sufficient to support the timely development of a hydrogen fueling station network. This is especially true in the state of California where new stations are coming online currently and as many as 35 new stations are scheduled to be commissioned in 2016. Ultimately, a hydrogen station test device that can be used to verify station fueling protocol, average daily and peak fueling capacity, and fuel quality would be desirable to commission new stations. In the near-term, a test device designed specifically to test station fueling protocol that is technically effective, safe, robust, and user friendly will accelerate the commissioning of hydrogen stations. This device must be safe and effective to be useful, but also simple enough to design, fabricate, assemble, and implement quickly to meet the timetable of current station deployment in California. This project was carried out to develop such a device.

To meet this goal, the project team, along with contractor Powertech Labs, has developed the HyStEP device. The device includes three Type IV 70 MPa tanks capable of storing a total of 9 kilograms of hydrogen and instrumented with pressure and temperature sensors. The tanks are connected to a 70 MPa receptacle equipped with pressure and temperature sensors as well as Infrared Data Association (IrDA) communications integrated with a data acquisition, analysis, and control system. A valve near the receptacle attached to a vent manifold can be used to both simulate a leak for fault detection tests and for controlled defueling. A nitrogen purge system is also included. Additional temperature sensors will record ambient temperature near the receptacle and various external system temperatures. The HyStEP device is capable of performing the station validation tests defined in CSA HGV 4.3. These include IrDA communication tests, fault detection tests, and communication and non-communication fills.

APPROACH

The project team selected the device supplier through a competitive bid process and collaborated with the supplier on the design and acceptance testing of the HyStEP device. In order to prepare the device for real-world deployment, the device underwent extensive validation testing at NREL's ESIF. This testing included using the device to carry out many, if not all, of the tests defined in CSA HGV 4.3 to ensure safe and reliable operation. The method for data reporting was also refined during testing and proved out for a real-time report of the results that would be available at a commercial station. Following validation testing at NREL, the device was shipped to California for pre-deployment testing at two commercial hydrogen stations. The device was then put into service by the state through a contract between Sandia National Laboratories and CARB.

The device supplier provided the project team with a comprehensive set of documentation covering device design, operation, maintenance, and safety. The required documents were published by Sandia to a publicly accessible website.

RESULTS

Prior to shipping the device to NREL, validation testing of the HyStEP device at Powertech included leak and pressure tests, IrDA communication confirmation, alarm matrix validation, fueling tests, defueling, and purging. Several leak and pressure tests were completed at Powertech. A leak check to 87.5 MPa was carried out for the entire hydrogen fueling system except for the tanks. This test was completed just before the device was shipped to NREL with no leaks. The hydrogen fueling system, including the three tanks, thermocouple probes, and thermally-activated pressure relief devices, was then leak checked in increments of 10 MPa to 100% state-of-charge (~77 MPa and 42°C). The tanks remained at 100% state-of-charge for three days indicating zero leaks.

IrDA communications were verified using a benchtop system as well as using the Powertech hydrogen dispenser. In addition, halt and abort tests were successfully carried out using the dispenser. The alarm matrix was validated at Powertech through a series of tests. The system responses were checked and verified prior to shipping the device to NREL.

A number of fueling tests were carried out using the Powertech hydrogen dispenser at 35 MPa and 70 MPa as shown in Figure 1. Both communications and non-communication fuelings were carried out. Several of these tests were SAE J2601 compliant fills to target pressure or state-of-charge. Defueling procedures were carried out

FIGURE 1. HyStEP device sited at the Powertech hydrogen dispenser

and verified at Powertech as part of the fueling tests. This included defueling with the remote vent stack to verify operation. Finally, the hydrogen tanks were purged with nitrogen using the purge system prior to shipping the device to NREL.

Validation testing of the HyStEP device at NREL included six test sequences: (1) checkout and device training; (2) general instrument tests; (3) communication capability tests; (4) safety system tests; (5) dispenser communication tests; and (6) table-based fueling tests, defueling tests, and purge tests.

A Powertech engineer traveled to NREL for the checkout and training test sequence which took place over the first full week that the HyStEP device was on site. Initial checkout included an electrical inspection which the system passed with one minor modification. Training was provided by Powertech on the device setup, controls, fueling, defueling, and purging.

Instrument operation and sensor accuracy were checked then rechecked. Pressure transducer and gauge agreement was acceptable. Data collected from the pressure transducers on HyStEP was within +/-1% of the NREL pressure transducer in the dispenser. Hose temperature, as measured by the NREL dispenser, and receptacle temperature, as measured by HyStEP, were in good agreement. Thermocouples on HyStEP tubing were in good agreement with HyStEP tank inlet temperatures. HyStEP in-tank thermocouples were compared with externally placed NREL thermocouples. While general trends in the readings were similar, a large offset was observed as expected due to the thermocouple locations.

Safety system tests included tests of the hydrogen detectors as well as a select list of other alarms. Many of these tests involved confirming the safety system response to a valve failing to close. In addition, the electrostatic discharge button, nitrogen pressure monitor, and trailer door monitor were checked. All alarm conditions were confirmed as programmed.

To begin the communications test sequence, operators confirmed that protocol identifier (ID), software version number (VN), tank volume (TV), receptacle type (RT), fueling command (FC), commands sent from the HyStEP device were appropriately communicated to the dispenser. Then, during fills, three repeats each of the abort, halt, data loss then resume, data loss then abort and cyclic redundancy check fault tests were performed. In each test, the HyStEP performed as expected.

The team performed general fault detection tests by overriding volume, temperature, and pressure values during a fill.

The objective of the fueling, defueling, and purging tests was to exercise the device as it would be used in the field for these operations. To this end, NREL and Powertech performed both communications and non-communications fills. In conjunction with these fills, the team also tested the full tank refusal and exercised the defuel and purging systems.

A week-long operator training session was then carried out by Powertech, NREL, and Sandia at ESIF. Figure 2 shows the operators from CARB and Division of Measurement Standards next to the device sited at the NREL dispenser during the training. Operators were walked through the *Operations and Maintenance Manual* along with key design and safety documentation and then performed a series of hands-on tests using the device.

The HyStEP device was then shipped from Colorado directly to the Hydrogen Research/Fueling Facility at CSULA. The device was offloaded from the flatbed truck on

FIGURE 2. NREL's Hydrogen Infrastructure Testing and Research Facility

Friday, December 11, and setup at the dispenser as shown in Figure 3. Most of the CSA HGV 4.3 test matrix was carried out over a three day period the following week (December 14–16). Overall, the device worked according to expectations and the HyStEP operators were able to test most of its functionality, within the limitation of the station. While the station did not pass all of the tests, HyStEP was able to carry them out as expected and prescribed except as noted below. These tests included five complete tank fills with various combinations of the three HyStEP tanks.

Tests Completed

- Fault Detection Tests: All except for the ambient temperature and minimum fuel delivery temperature were tested. This was due to the limitation of the station. Operators were unable to modify the temperature signals on the dispenser.
- Communication Tests: All communication tests were carried out except for a couple of the invalid data value tests. We found that the HyStEP software was not compatible with these tests as defined in HGV 4.3. Powertech was notified of this discrepancy and modified the infrared hardware and software to resolve this issue.
- Fueling Protocol Tests: The CSULA station was originally designed to the SAE J2601 technical information report, not the new 2014 standard. However, it performs fills that meet the 2014 H70-T20 requirement. So, fills were performed with this protocol. Five fills were completed.
  - Single tank (76 L, 3 kg) non-communication X 2
  - Single tank (76 L, 3 kg) communication
  - Two tank (152 L, 6 kg) communication
  - Three tank (228 L, 9 kg) communication

FIGURE 3. Hydrogen Research/Fueling Facility at CSULA

HyStEP device testing at SCAQMD was successfully completed on Friday, January 22, after four days of testing (see Figure 4). As at CSULA, the device worked as expected, and the operators were able to carry out nearly all of the CSA HGV 4.3 test matrix over the four day period (Tuesday–Friday). While the station did not pass all of the tests, HyStEP was able to carry them out as expected and prescribed, with two exceptions. The tests included more than a dozen complete tank fills with various combinations of the three HyStEP tanks. These also include fills in comparison to two Toyota test vehicles and two Honda test vehicles.

Tests Completed

- Fault Detection Tests: All except for the ambient temperature and minimum fuel delivery temperature tests were completed. This was due to the limitation of the station. The ambient temperature sensor and the hose temperature sensor could not be modified as per the requirements of the test procedure.
- Communication Tests: As at CSULA, all communication tests were carried out except for a couple of the invalid data value tests.
- Fueling Protocol Tests: The SCAQMD station follows SAE J2601-2014 and includes an H70 and H35 nozzle. So, fills were performed with both nozzles, although most were H70 fills. Twenty-one fueling protocol tests were completed:
  - Six communication fills with various initial conditions and tank sizes.
  - Five non-communication fills (H35 and H70) with various initial conditions and tank sizes.
  - Ten additional tests per HGV 4.3.

FIGURE 4. Diamond Bar station at SCAQMD headquarters

FIGURE 5. First Element station in Santa Barbara

The final DOE-funded station test was carried out at the First Element hydrogen station in Santa Barbara as shown in Figure 5. This series of tests was primarily focused on operator training and OEM vehicle comparisons. Mercedes-Benz and Hyundai brought test vehicles to the site during the three day testing period for side-by-side comparisons. A similar test matrix was carried out as at SCAQMD.

CONCLUSIONS AND FUTURE DIRECTIONS

Validation testing of the HyStEP device was carried out at three hydrogen fueling stations (NREL Hydrogen Infrastructure Testing and Research Facility, CSULA, and SCAQMD), and a final training session at the Santa Barbara hydrogen fueling station. Overall, the HyStEP device provided consistent, reliable performance over all of the testing that included over 45 fills. The tests carried out at these stations included leak checks, sensor and instrument checks, IrDA communication checks, and tests that were carried out per the latest draft of CSA HGV 4.3. In addition, at the SCAQMD and Santa Barbara stations, OEM test vehicle fills were carried out along with HyStEP fills for comparison. The device was able to successfully carry out all tests per the HGV 4.3 procedures with the exception of two of the general fault detection tests and two table based communications tests. The two general fault detection tests both require modification of station temperature sensors that could not be performed at any of the stations. The communication tests were not performed correctly due to a limitation of the HyStEP IrDA hardware and software which was subsequently corrected by Powertech.

While no DOE-funded work has been carried out since March, CARB is now leading the deployment of the HyStEP device for commissioning hydrogen stations in California. Following pre-deployment testing, CARB, in conjunction with Division of Measurement Standards has operated the HyStEP device under a loan agreement with Sandia National Laboratories that may continue for a period of up to two years. To prepare for and carry out the deployment, CARB leads a California HyStEP Task Force that is responsible for determining a test schedule, station test matrices, and test data evaluation criteria. The task force consists of CARB and other state agency participants along with fuel cell vehicle manufacturers, hydrogen station providers, and H2FIRST members.

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

1. DOE Hydrogen and Fuel Cells Program Distinguished Achievement Award.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. Johnson, T.A. and Kashuba, M., Presentation at the CaFCP Station Providers group meeting, "Overview of the HyStEP Device," CSULA campus, December 2015.

2. Johnson, T.A. and Kashuba, M., Presentation at the CaFCP Vehicle OEM group meeting, "Overview of the HyStEP Device," Diamond Bar, CA, January 2016.

3. Johnson, T.A., Ainscough, C., Terlip, D., Meadows, G., et al., "Development of the HyStEP Device," SAE Technical Paper 2016-01-1190, 2016, doi:10.4271/2016-01-1190.

4. Johnson, T.A., "Development of the HyStEP Device," Presentation at the SAE 2016 World Congress, Detroit, MI, April 14, 2016.

5. Johnson, T. "Development of the Hydrogen Station Equipment Performance (HyStEP) Device," 2016 DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting, June 2016.

6. Terlip, D. and Ainscough, C., "HyStEP Validation Test Report," submitted to DOE on October 30, 2015, in fulfillment of NREL/Sandia National Laboratories Annual Operating Plan Milestone D13.

7. Terlip, D. and Ainscough, C., "HyStEP Validation Test Report," submitted to DOE on November 30, 2015, in fulfillment of NREL/Sandia National Laboratories Annual Operating Plan Milestone 17.1.

8. Johnson, T.A., "HyStEP Final Validation Report," submitted to DOE on February 2016 in fulfillment of NREL/Sandia National Laboratories Annual Operating Plan Milestone M20.1 Task 2.20.