HYDROGEN STORAGE APPLICATIONS IN INDUSTRIAL MICROGRIDS

Marie-Louise Arlt, University of Freiburg / Lawrence Berkeley National Lab, +1 (650) 460-4885, marlt@lbl.gov
Gonçalo Ferreira Cardoso, Lawrence Berkeley National Lab, gfcardoso@lbl.gov
Dean Weng, Electric Power Research Institute, dweng@epri.com

Overview

In this study, we investigate the economic effectiveness of hydrogen storage systems in industrial microgrids. This analysis is enabled by an extension made to the Distributed Energy Resources – Customer Adoption Model (DER-CAM), a decision support tool used to optimally size and schedule distributed energy resources (DER) under multiple microgrid settings, where we introduce the ability to model electrolyzers and hydrogen storage. The system under analysis consists of a Polymer Electrolyte Membrane (PEM) electrolyzer, a pressurized vessel, and a Proton Exchange Membrane Fuel Cell (PEMFC). We analyze the potential to mitigate costs associated with volumetric time-of-use (TOU) rates through arbitrage, reduce peak loads, and optimize the use of on-site generation, amongst others. The analysis is supported by a case study using real load data from two manufacturing plants (medium and large-sized) with significant process heat loads.

We find that hydrogen storage systems can be economically viable as an electricity storage system to mitigate daily on-site load variability, if confronted with TOU and demand peak rates. Furthermore, taking into account the existing tariff schemes and the lifetime of assets, hydrogen storage can be competitive with other storage systems such as standard electrochemical storage. Further analysis considering the simultaneous use of electricity and heat recovery by CHP fuel cells shows positive results but minor increases in costs and CO_2 emissions. Additional research and extensions to DER-CAM are needed to explore further uses of hydrogen in a microgrid context, such as long-term storage, fuel production for hydrogen vehicles, or in combination with the production of synthetic gases.

Methods

DER-CAM is a state-of-the-art decision support tool developed by the Lawrence Berkeley National Laboratory (LBNL) used extensively to address the problem of optimally investing and scheduling DER under multiple microgrid settings (Mashayekh et al. 2017). The model is formulated as a Mixed Integer Linear Program (MILP), and key inputs to DER-CAM are customer loads, market tariffs including electric and natural gas prices, techno-economic data of generation and storage technologies including capital, operation and maintenance costs.

Key outputs include site-wide energy costs, the optimal installed onsite capacity and dispatch of selected technologies, as well as load management decisions. The primary objective of the model is to find the optimal combination of technology adoption and operational strategies to supply all energy end-uses required by the site under consideration, while minimizing costs and / or CO_2 emissions.

Through this work, DER-CAM has been extended to include the ability to model electrolyzers, hydrogen storage, along with modifications to the existing fuel cell modeling capabilities. Table 1 describes the key techno-economic data used to characterize the technologies used in the study. For our case study, we use industrial load data as described in Table 2. We evaluate both load scenarios using TMY3 weather data from the San Francisco International Airport (NREL 2015) and respective industrial PG&E load tariff schemes.

For the analysis, we performed optimization runs for dispatch and investment using different scenarios. Parameters of interest include enabling/disabling of different investment options, efficiencies, and component costs. We compare results with regard to installed storage capacities, total annual costs, and total annual CO_2 emissions.

*Table 1. Overview on main techno-economic parameters**

Component	Parameter	Value
Electrolyzer	Investment	2,000 USD/kW
	Efficiency	70%
Pressurized vessel	Investment	17 USD/kWh
	Efficiency	95%
PEMFC	Investment	3,000 USD/kW
	Efficiency	60%
Li ion battery	Investment	500 USD/kWh
	Efficiency	80%

Table 2. Case study: Key data of industrial loads

	Load 1	Load 2
Process	Wood-processing	Molding process
Annual el. demand	218 MWh_{el}	24.0 GWh_{el}
Peak demand	118 kW_{el}	5.9 MW_{el}
Annual gas demand	1.3 GWh_{th}	3.2 GWh_{th}
Electricity tariff[1]	A-10	E-20
Gas tariff	G-NR1-E	G-NR1-E

** Sources (amongst others): PEM electrolyzer - (Götz et al. 2016), (Felgenhauer und Hamacher 2015), and (Fichtner 2014); pressurized vessel: (Parks et al. 2014);PEMFC: (IEA 2015); battery -(Tesla 2017)*

Results

Hydrogen storage can be an option to flatten demand and reduce exposure both to high TOU rates in peak hours and peak demand rates. However, given the low efficiency of the recovery cycle, price spreads between on- and off-periods must be at least 150% to justify conversion and storage instead of electricity purchase. For the PG&E tariff schemes of interest, those price spreads are only 80.7% between TOU peak and TOU off-peak at the maximum (for PG&E E-20 in summer).

This picture can change if peak demand rates are in place due to the additional incentive to flatten loads. In this setting, for Load 2, a 53.23 kW electrolyzer, a 1,010.66 kWh hydrogen storage, and one 250 kW fuel cell as well as 3.1 MW_p of PV are installed. This reduces total annual costs compared to no PV and storage system by 9.7% (including annualized investment). For Load 1, under PG&E schedule A-10, only reduced demand peak rates apply and optimal investment is restricted to PV only (62 kW_p).

If electric storage is included as an investment option, no specific preference for either option under the assumptions of the model can be determined. For Load 2, the total costs for the two scenarios hydrogen storage versus electrochemical storage differ by less than 0.2 %. Optimal investment for Load 1, however, includes an electric storage of 38.54 kWh along with 66.06 kW_p of PV installations, decreasing costs by 6.2 % compared to the reference scenario. The relative equivalence of both storage technologies might be surprising considering the low overall roundtrip efficiency of the hydrogen storage system as well as the high capital cost of electrolysis components. However, this is seemingly counterbalanced by the longer lifetime as well as the lower minimum load of electrolysis components.

Another promising application of electrolysis is the ability of fuel cells to provide heat. This can be particularly attractive for loads with high shares of heating as it is the case for the loads of interest. DER-CAM allows for the analysis of sector-coupling options. According to (EPA and CHP Partnership 2015), net electrical efficiency for a PEM fuel cell with combined heat and power (CHP) is 35.3 % with a power-to-heat ratio of 0.7. Using a fuel cell with CHP contributes to a small increase in costs and CO_2 emissions for Load 2. The additional provision of heat does not compensate the efficiency disparity between hydrogen and electric storage.

Regarding CO_2 emissions, hydrogen storage is comparable to electric storage despite lower conversion efficiency, if PV and electric storage life-cycle emissions are considered. Using the manufacturing CO_2 emission values suggested by (Pellow et al. 2015) and (Dale 2013) for an integrated analysis, overall CO_2 emission levels associated with the installation and operation of hydrogen storage system were found to be approximately equal to those of the scenario considering electric storage.

Conclusions

Hydrogen storage systems can contribute to flattening electricity demand in industrial microgrid settings. Using real industrial load data, we show in a case study that hydrogen storage systems can be a comparably attractive option for storage. While its efficiency of conversion is low compared to other available storage technologies such as electrochemical storage, it exhibits advantages in terms of lifetime and the minimum load as well as state of charge. The use of CHP fuel cells in industrial applications is an interesting option but, in our case study, leads to minor increases in total costs and CO_2 emissions. Including CO_2 emissions for manufacturing for an integrated analysis, hydrogen storage is comparable with conventional batteries, making it a potentially better solution if efficiencies and CO_2 prices increase. In future work, other applications of hydrogen storage will be explored including long term storage options, hydrogen vehicles, or the production of other synthetic gases.

[1] PG&E A-10 and PG&E E-20 are industrial tariffs offered by Pacific Gas & Electric in the San Francisco Bay Area, and contain both a volumetric time-of-use component and power demand charges.

Acknowledgments

The authors would like to acknowledge the U.S. Department of Energy for partially supporting this work under the Grid Modernization Laboratory Consortium.

References

Dale, Michael (2013): A Comparative Analysis of Energy Costs of Photovoltaic, Solar Thermal, and Wind Electricity Generation Technologies. In: *Applied Sciences* 3 (2), p. 325–337. DOI: 10.3390/app3020325.

EPA; CHP Partnership (2015): Catalog of CHP Technologies. Section 6. Technology Characterization – Fuel Cells. Available online: https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies_section_6._technology_characterization_-_fuel_cells.pdf (as of June 02, 2017).

Felgenhauer, Markus; Hamacher, Thomas (2015): State-of-the-art of commercial electrolyzers and on-site hydrogen generation for logistic vehicles in South Carolina. In: *International Journal of Hydrogen Energy* 40 (5), p. 2084–2090. DOI: 10.1016/j.ijhydene.2014.12.043.

Fichtner (2014): Erstellung eines Entwicklungskonzeptes Energiespeicher in Niedersachsen.

Götz, M.; Lefebvre, J.; Mörs, F.; McDaniel Koch, A.; Graf, F.; Bajohr, S. et al. (2016): Renewable Power-to-Gas: A technological and economic review. In: *Renewable Energy* (85), p. 1371–1390.

IEA (2015): Technology Roadmap. Hydrogen and Fuel Cells. Paris. Available online: http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHydrogenandFuelCells.pdf.

Mashayekh, Salman; Stadler, Michael; Cardoso, Gonçalo; Heleno, Miguel (2017): A mixed integer linear programming approach for optimal DER portfolio, sizing, and placement in multi-energy microgrids. In: *Applied Energy* 187, p. 154–168. DOI: 10.1016/j.apenergy.2016.11.020.

NREL (2015): National Solar Radiation Data Base. 1991- 2005 Update: Typical Meteorological Year 3. Available online: http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/, last update on January 19, 2015.

Parks, G.; Boyd, R.; Cornish, J.; Remick, R. (2014): Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs. Systems Integration. National Renewable Energy Laboratory (NREL). Denver.

Pellow, Matthew A.; Emmott, Christopher J. M.; Barnhart, Charles J.; Benson, Sally M. (2015): Hydrogen or batteries for grid storage? A net energy analysis. In: *Energy & Environmental Science* 8 (7), p. 1938–1952. DOI: 10.1039/C4EE04041D.

Tesla (2017): Powerwall. Available online: https://www.tesla.com/powerwall (as of June 02, 2017).