The Role of Fuel Cells within a Microgrid System

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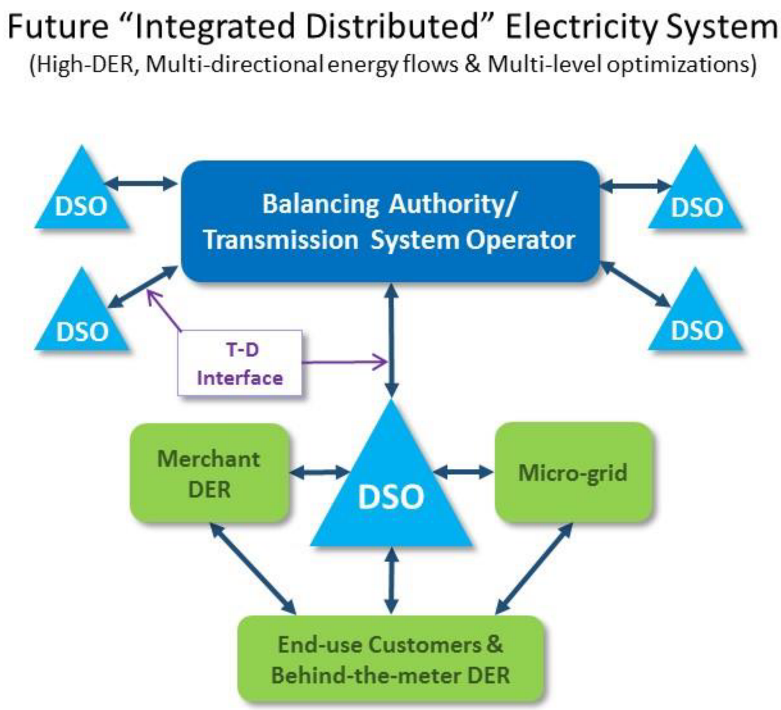
California is positioned to transition from the current inefficient, centralized transmission infrastructure to a 21st-century honeycomb of microgrids, each of which is connected to the transmission grid (i.e., a "macrogrid") via a buffered gateway utilizing fuel cell technology located at the substation nexus between the distribution and transmission grids.[1] In Figure 1 below[2], this gateway (represented by the two-way arrow labeled "T-D Interface") is managed and operated by a Distributed System Operator ("DSO") responsible for the microgrid's underlying local distribution area (items shown in green).



Within a microgrid, fuel cell assets provide a continuous energy "buffer" or management capability to cover shortages resulting from the inherent diurnal variations of renewable energy resources (i.e. photovoltaic).

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1 See DeMartini, Paul and Kristov, Lorenzo, "21st Century Electric Distribution System Operations," May 2014. In their paper, authors Kristov and De Martini identify this gateway nexus as "the basic building block of the new power system, namely, the set of distribution facilities that radiate from each transmission-distribution interface point, plus the DER and customers connected to those facilities." In a related footnote, the authors note that "[t]ypically this interface point is a substation linking a set of radial distribution circuits to the high-voltage transmission network."

2 See De Martini and Kristov, infra, at p. 2. It should also be noted that the "Micro-grid" in Figure 1 refers to the traditional application of microgrid systems to mission-critical facilities such as hospitals, data centers and commercial complexes. In our larger model, these systems are a subset and component of the microgrid local distribution area.

Capable of using natural gas, renewable biogas and hydrogen feed stocks, a fuel cell plant located at the substation gateway is superior to conventional gas turbine facilities in that a 50MW capability for example, could be created by "daisy chaining" a series of ten 5MW fuel cell modules. In our example, only one of these fuel cell modules might be required during normal daylight operations, with each additional module being brought on line as the Direct Renewable Resource produces less energy. (In our example, the Direct Renewable Resource could be a photovoltaic array that captures solar energy, which would drop in late afternoon to zero at night). On the transmission side of the gateway, a fuel cell plant could provide (i) back-up power to the transmission grid in a steady and reliable manner for other microgrids located within the state "macrogrid," (ii) excess power for sale to other states via regional transmission lines, or (iii) emergency power in the event of grid failure (for example, when the San Diego grid was "tapped" by the failure of a high-voltage transmission tower located outside the San Diego area).

Operated in tandem with electrolysis equipment utilizing gray water from local water treatment facilities, a fuel cell plant will be able to solve the "duck curve" dilemma[3] by being programmed to sequentially bring fuel cell modules online as Direct Renewable Energy sources decline in output, thereby meeting rising demand in the late afternoon hours and providing off-peak power using hydrogen previously electrolyzed from excess Direct Renewable Energy generated during previous peak periods. Under this system, grid instability from over-generation would no longer be a concern, curtailment measures would never be needed again and there would be no need to limit development of renewable resources as all excess Direct Renewable Energy would either be sold through the "macrogrid" or diverted to produce hydrogen through electrolysis.

In short, substituting fuel cells for conventional methane turbines ultimately creates a distinct pathway for the development of a renewable hydrogen economy, and creates additional demand for "green" hydrogen in a secondary market for fuel cell electric cars (FCEVs). As part of its long-term strategy, a DSO managing a microgrid could elect to store renewable hydrogen as an energy reserve to maximize resiliency and/or sell excess reserves to local refueling stations currently under development in the state of California. As the secondary FCEV market develops in California, the sale of renewable hydrogen to refueling stations (mandated by SB 1505 to equal one-third of all hydrogen produced for that purpose[4]) will become a secondary revenue stream for DSOs operating microgrids and their ratepayers who feed renewable energy back into the microgrid.

While the modularity, quiet operation and small footprint of fuel cell technology allows for strategic deployment of fuel cell power plants in densely populated areas within the local distribution area, we see other "competing" technologies as complementary to developing an optimized microgrid system. For example, in our 50MW model, it may be prudent to plan for the installation of a small battery component to provide frequency and or phase regulation services and on-demand power while fuel cell modules are sequentially coming online. By integrating both technologies, frequency response time can be maximized while also

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[3] California Independent System Operation (CAISO), "What the duck curve tells us about managing a green grid," (2013).

[4] California Environmental Protection Agency | Air Resources Board, "Facts About Environmental and Energy Standards for Hydrogen Production (SB 1505)," April 27, 2010.

maintaining a much smaller footprint than could otherwise be achieved by building an entire facility using battery technology. Supercapacitors may also provide a useful role in leveling extremely short load modulations. The ultimate goal is to bring the strengths of all renewable technologies to bear on developing the best microgrid possible.