DOCKETED

Docket Number:	17-IEPR-12
Project Title:	Distributed Energy Resources
TN #:	220141
Document Title:	Advanced Power and Energy Program White Paper - Managing the Dynamics of a 100 Percent Renewable Electric Grid
Description:	N/A
Filer:	System
Organization:	University of California, Irvine, Advanced Power & Energy Program/Scott Samuelsen
Submitter Role:	Public Agency
Submission Date:	7/13/2017 2:11:32 PM
Docketed Date:	7/13/2017

Comment Received From: Scott Samuelsen
Submitted On: 7/13/2017
Docket Number: 17-IEPR-12

Advanced Power and Energy Program White Paper: Managing the Dynamics of a 100 Percent Renewable Electric Grid

Additional submitted attachment is included below.

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July 13, 2017

California Energy Commission
MS Dockets Office, MS-4
Re: Docket No. 17-IEPR-12
1516 Ninth Street
Sacramento, CA 95814-5512

Re: 2017 IEPR Joint Agency Workshop on Integration of Distributed Energy Resources on the California Grid

The Advanced Power and Energy Program at the University of California, Irvine submits the attached white paper "Managing the Dynamics of a 100 Percent Renewable Electric Grid" for consideration of the Joint Agencies in the Distributed Energy Resources Docket (17-IEPR-12). This paper addresses the need for a combination of renewable resources, storage, and firm continuous power generation to enable a flexible, 100% renewable electric system.

Sincerely,

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Managing the Dynamics of a 100 Percent Renewable Electric Grid

Assessment and results produced by the Advanced Power and Energy Program (APEP) at UC Irvine

EXECUTIVE SUMMARY

100% Renewable Grid. Deployment of renewable resources is needed to meet California's energy demands in parallel with achieving California's environmental quality goals. For a 100% renewable electric grid, the power generation must (1) source all of the energy from the sun using solar PV, solar thermal, wind, hydropower, and bio power, and (2) convert the solar-derived energy into power with a net zero emission of greenhouse gases (GHG) and criteria pollutants, a zero demand of water, and zero waste.

Challenge. A major challenge to reach a 100% renewable grid is the management of the dynamics associated with the diurnal and seasonal variation, intermittency, and limited capacity factor that accompany a high penetration of solar and wind power generation. In addition to accurate forecasting of intermittent solar and wind resources,[1,2] the following are required to meet this challenge:

[1] A systems analysis methodology to identify the technologies required to enable and manage the solar and wind resources associated with a 100% renewable grid,[3] and

[2] Widespread introduction of complementary energy storage and 24/7 clean, load-following power generating technologies.[3]

Systems Analysis. The first requirement is particularly demanding due to the complexities associated with the components and operation of a modern electric grid. Under the auspices of the California Energy Commission, a major systems analysis resource, the "Holistic Grid Resource Integration and Deployment (HiGRID)" tool, has been developed to guide planning a modern electric grid.[4] Over the past two years, a myriad of scenarios has been evaluated with HiGRID to determine the resources needed to manage and enable the intermittency, diurnal variation, and constrained capacity factor associated with a 100% renewable electric grid. Without exception, two key resources are needed to provide the required ENERGY and POWER capabilities: (1) energy storage comprised of batteries, hydro, and hydrogen; and (2) clean, high-efficiency 24/7 load-following power generating resources.

24/7 Clean Load-Following Power Generation. Stationary fuel cells are emerging as uniquely suited to provide the required clean, high-efficiency 24/7 load-following power generation resource with virtually zero emission of criteria pollutants, and no net water demand. Already meeting initial market demand for base load power generation, more than 30% of power generating fuel cells are operating today on biogas in California.[5] To meet the demands of the next-generation grid, stationary fuel cells systems are being (1) developed and deployed with the requisite load-following attributes, (2) developed to operate on hydrogen as well as natural gas and biogas, and (3) developed to integrate with a gas turbine engine to create a "hybrid" power generator with remarkably high efficiency. Simply stated, stationary fuel cells are (1) a key resource, along with storage, required to manage and enable a 100% renewable grid, and (2) a perfect match to hydrogen energy storage in providing the ideal means for converting massive amounts of renewable fuel into electricity.

Hybrid Fuel Cell Gas Turbine (FC-GT) System under Development by LG Fuel Cell Systems for the California Market

SUPPORTING INFORMATION

Systems Analysis Example 1: The UCI Microgrid. The Advanced Power and Energy Program, Business and Administrative Services of UC Irvine, Southern California Edison, and other partners are exploring the future grid through (1) the physical deployment of high levels of renewable power and various smart grid, energy conversion, and storage technologies on campus, and (2) system analyses using physical models of power generators and energy storage. The goal is to develop dynamic dispatch and control algorithms for managing the UCI Microgrid, equipped with co-generation and a high-use of solar PV, to become completely carbon neutral. Through the systems analyses, the team has developed and analyzed various technology implementation scenarios. Figure 1 presents a representative result of the analyses for the future dispatch and control of the UCI Microgrid for a winter month with a high use of solar PV systems (34 MW), a 27 MW hydrogen electrolyzer, and 170 MWh of hydrogen energy storage in the natural gas system to capture the otherwise curtailed PV.

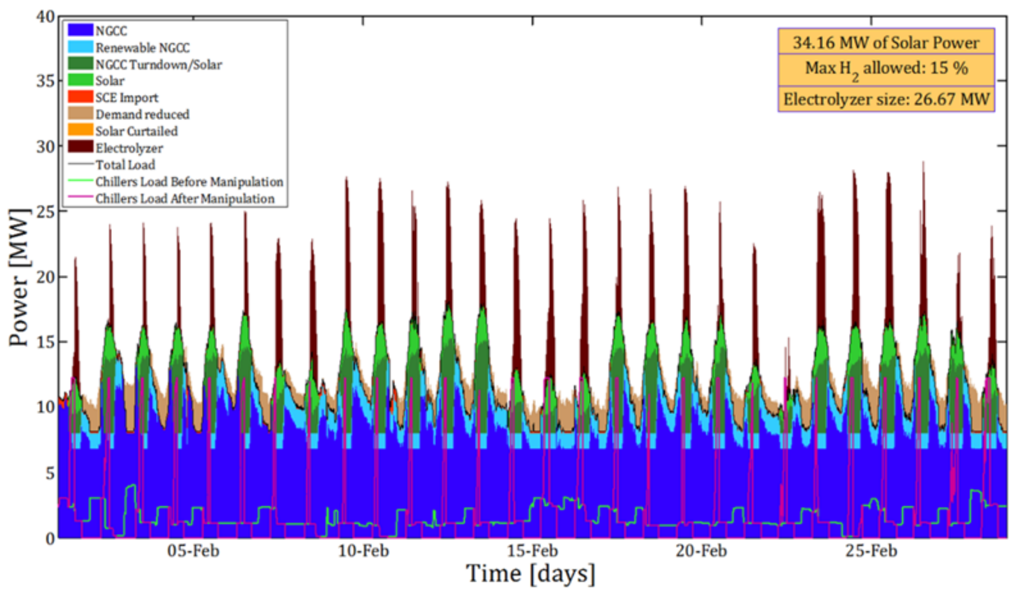

Figure 1. Simulated dynamic dispatch of UCI power and energy resources for a future Winter scenario

A key takeaway is that, for the State of California, both energy storage and clean, high-efficiency 24/7 load-following power generation resources are required to manage the dynamics of a 100% renewable grid. Today, fueled power generation, produced primarily through natural gas combined cycle (NGCC) power plants, meets the majority of the electricity demand but with associated emission of criteria pollutants and efficiencies limited by heat engine constraints. Alternative and emerging clean high-efficiency fueled power generators can achieve low emissions of GHG and virtually zero emission of criteria pollutants. The principal example is stationary fuel cell technology. Even using natural gas, fuel cells reduce GHG and criteria pollutant emissions compared to the current grid.[6] These fueled power generators operate on directed and locally sourced biogas as well, producing renewable power today throughout the nation. Fuel cells are capable of operating directly from hydrogen and have highly dynamic dispatch capabilities to both (1) manage the diurnal variation, constrained capacity factor, and intermittencies associated with renewable solar and wind power generators, and (2) increase the maximum penetration of renewable resources that can be accommodated in the utility grid network.

Systems Analysis Example 2: Carbon Reduction Potential of Fuel Cells and Energy Storage. A detailed understanding of utility grid network dynamics and their evolution over time is required to understand the power generation and energy storage needs of a grid as it evolves toward 100% renewable operation. The California electricity system dispatch tool (HiGRID)[4] was utilized over a portfolio of scenarios to evaluate various forms of storage (e.g., electric battery, hydrogen battery, pumped hydro, compressed air, and flow battery energy storage) and power generation (e.g., gas turbines, fuel cells) to manage a high-penetration of renewable solar and wind resources and achieve, overall, a stable and resilient 100% renewable grid. Examples of the results include the following:

- The fundamental characteristics of hydrogen energy storage and fuel cell use, which allow independent sizing of power (MW) and energy (MWh) capacities, make them an essential grid support technology for the 100% renewable case,
- The use of natural gas fuel cells today (with current performance) can reduce greenhouse gas emissions more than energy storage for cases of 33% and 50% renewable energy use (Figure 2),
- The ratepayer costs for use of natural gas fuel cells to achieve these higher GHG reductions are lower than the costs of corresponding energy storage technologies to achieve lesser GHG reductions (Figure 3),
- If biogas resources can be sufficiently increased, they can best be used in fuel cells to produce additional GHG reductions with ultra-low criteria pollutant emissions,
- Fuel cells today can operate with dynamic load-following characteristics and are evolving to have very significant ramping capabilities which will enable even higher renewable solar and wind deployment,
- The natural gas system can evolve to store massive amounts of renewable fuel, preferably hydrogen made from otherwise curtailed renewable power, which future fuel cell systems can use to produce zero GHG and zero criteria pollutant emission power,
- While hydrogen battery technology will carry the bulk of the storage required, electric battery technology will also contribute in the 100% renewable case with characteristics of relatively fixed power and energy capacities for shorter term and smaller energy storage, and
- Both battery and fuel cell systems use inverters to provide power to the grid, which can be used to enhance grid reliability by providing various ancillary services in the future.

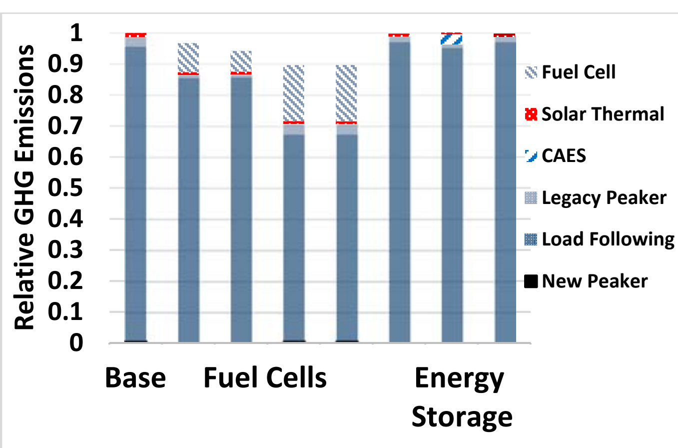

Figure 2. 33% Renewables: CO_2eq Emissions

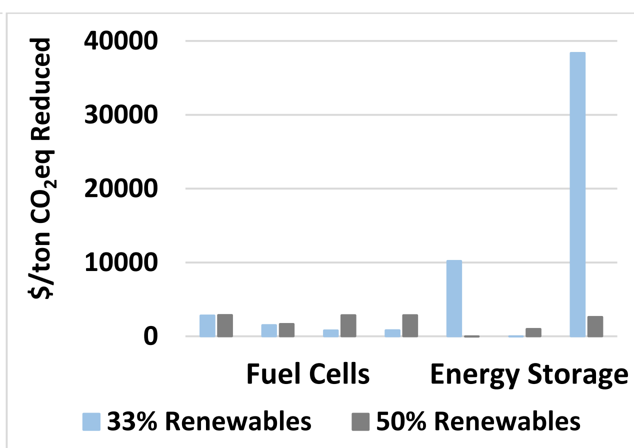

Figure 3. CO_2 Reduction Cost per Ton Reduced

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