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Microgrid and renewable generation integration: University of California, San Diego

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HIGHLIGHTS

- UCSD has dispatchable distributed energy resources that can support RE integration.
- Each RE integration strategy is feasible and cost-effective in certain conditions.
- Current tariffs and market prices are insufficient; alternative strategies are needed to leverage DER.
- Co-optimization of thermal and electrical systems, and of monthly and daily energy costs is essential.
- Results are relevant to using campus, C&I loads and CHP resources to support renewables integration.

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ABSTRACT

This paper is a microgrid study of the University of California, San Diego (UCSD), a large campus with diverse distributed energy resources (DER). It highlights a microgrid's "missing money", which sharply differs from a natural-gas-fired generation plant's "missing money" due to large-scale wind generation development. In response to UCSD's expressed financial interest, we assess three strategies for integrating renewable generation: peak load shifting, onsite photovoltaic firming and grid support. While all three strategies are technically feasible and can be cost-effective under certain conditions, California's current tariff structures and market prices do not offer sufficient incentives to motivate UCSD to offer these services. Alternative incentive mechanisms, which may resemble to those used to encourage renewable generation development, are necessary to induce UCSD's DER offer for renewables integration. Such mechanisms are also relevant to commercial and industrial loads across California, including the vast combined heat and power resources.

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1. Introduction

This paper is motivated by three transformative events already taken place in the electricity industry in various parts of the world. The first event is electricity market reform and deregulation that have led to competitive wholesale markets in Europe, North America, South America, Australia, and New Zealand [1]. Wholesale electricity spot-market prices are highly volatile, thanks to: (a) daily fuel-cost variations, especially for natural gas that is used by combustion turbines (CT) and combined-cycle gas turbines (CCGT); (b) hourly weather-sensitive demands with intra-day and inter-day fluctuations that must be met in real time by generation and transmission already in place; (c) planned and forced outages of electrical facilities; (d) hydro conditions for a system with significant hydro resources; (e) carbon price fluctuations affecting thermal generation that uses fossil fuels; (f) transmission constraints that cause transmission congestion and generation re-dispatch; and (g) lumpy capacity additions that can only occur with a long lead time.

The price volatility with occasional spikes has led to extensive research on electricity price behavior and dynamics, as well as electricity derivatives and their use in risk management [2 and references thereof]. Despite the price spikes, these wholesale energy markets unlikely provide sufficient generation investment

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Nomenclature

AS	ancillary services
CHP	combined heat and power
CCGT	combined-cycle gas turbine
CHW	chilled water
CT	combustion turbine
CUP	central utility plant
DER	distributed energy resource
DR	demand response
HW	hot water
LDC	local distribution company
ODM	optimal dispatch model
Peak	hours when electricity demand is highest
PLS	permanent or peak load shifting
TES	thermal energy storage
WC	water cooler or chiller

incentives, a market design challenge aptly summarized by [3,4] as a "missing money" problem that has led to the development of capacity markets in the U.S. [5].

The second event is the rapid development of renewable resources. Leading this development are solar and wind generation, chiefly due to their abundance [6–8]; government policies: easy and low-cost transmission access, financial incentives (e.g., feed-in-tariffs, government loans and grants, and tax credits); quota programs (e.g., renewable portfolio standards (RPS), cap-and-trade programs for carbon emissions, and renewable energy credits) [9–14]; and declining costs [15,16].

With its zero fuel cost, wind generation reduces wholesale market prices by displacing dispatchable thermal generation [17]. This price-reduction effect, also known as the merit-order effect, has been demonstrated through model simulations [18,19], as well as through regression analysis of market data for various regions in Australia, Europe and the U.S. [20–32]. While potentially benefiting electricity consumers by reducing electricity prices and monthly bills [22,32],[1] the merit-order effect also weakens the investment incentive for the CT and CCGT [2,19,33,34].

The third event is smart grid development. A smart grid generally refers to a collection of advanced technologies, devices and techniques that upgrade current transmission and distribution networks and improve the efficient use of alternative energy sources [35]. It differs from the traditional grid in several aspects, including: (a) a smart grid is an integrator of centralized and distributed generation; (b) a smart grid can accommodate large amounts of variable generation sources; (c) consumers can become producers with localized generation such as photovoltaic (PV) and demand response provision; (d) a smart grid allows multi-directional power flow; and (e) a smart grid can increase the situational awareness of grid operations through smart meter and advanced measurement devices such as phasor measurement units (PMUs).

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to an electric transmission grid. It can connect and disconnect from the grid to operate in grid-connected or island-mode.[2] It enhances a smart grid's performance by reducing outage time, improving grid resilience against natural disasters, and integrating distributed energy resources (DER) [36–40].

Microgrids are well suited to provide demand response. On January 25, 2016, the U.S. Supreme Court ruled that federal regulators may encourage electricity users such as schools, hospitals and shopping centers to reduce consumption at peak times in exchange for price breaks.[3]

This paper is a microgrid study of the University of California, San Diego (UCSD),[4] thereby presenting an alternative perspective of the "missing money" problem, beyond the documented challenge of an insufficient generation investment incentive. The study has the following salient features:

- It is nested within California's restructured electricity industry comprising deregulated wholesale energy markets and regulated local distribution companies (LDC) that serve end-use customers. It shows: (a) how the LDC's ratemaking can alter the economics of the UCSD microgrid's operation; and (b) how UCSD may participate in the ancillary services (AS) market for regulation operated by the California Independent System Operator (CAISO).
- It analyzes three operational strategies for UCSD that can aid the state's renewable energy integration. While these strategies complement the use of flexible CTs and CCGTs, their implementation is unlikely under the LDC's current rate structure and the state's existing market structure.
- It demonstrates the role that a microgrid like UCSD and DER may play in the state's smart grid development by offering renewables integration services through participation in wholesale markets, balancing onsite distributed renewable resources, and offering AS to a grid operator.

The paper is timely and relevant because of the state's clean energy initiatives:

- California continues to progress toward its greenhouse gas (GHG) emissions reduction target of 1990 emission levels by 2020 as established by the Global Warming Solutions Act (AB 32). In October 2015, Governor Brown signed the Clean Energy and Pollution Reduction Act of 2015 (SB 350),[5] which increased the state's energy efficiency goals and requires a 50% Renewable Portfolio Standard by 2030.[6]

[1] In California, renewable energy's per-MWH procurement cost includes the renewable generation cost and incremental transmission and grid integration costs. These procurement costs are typically higher than wholesale market prices and borne by the customers of a load serving entity such as a local distribution company (LDC). As renewable generation can also reduce wholesale market prices, the net bill effect to customers is the difference between (a) the incremental above-market procurement cost of renewable generation; and (b) the cost savings due to lower market prices for the MWH supplied by non-renewable generation. The LDC's customers enjoy net bill savings when (a) is less than (b).

[2] Definition as per the U.S. Department of Energy Microgrid Exchange Group. See https://building-microgrid.lbl.gov/microgrid-definitions.

[3] The Supreme Court decision is discussed in the following article: http://www.nytimes.com/2016/01/26/business/energy-environment/supreme-court-upholds-a-federal-approach-to-power-pricing.html?ref=energy-environment.

[4] For details of the study, see http://calsolarresearch.ca.gov/images/stories/documents/sol2_funded_projects/Viridity/CSIRDD_Viridity_Task 6-8_Report.pdf.

[5] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB350.

[6] https://www.caiso.com/Documents/Updateon2015_50_SpecialStudy.pdf.