Ivory Tower of Power

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UNIVERSITY CAMPUSES OFFER A PERFECT setting in which to establish a microgrid and maximize its operational benefits. The university setting also offers a unique collection of intellectual resources. In addition to improving operational efficiency, lowering operating costs, and reducing the campus's overall carbon footprint, a university microgrid is an ideal laboratory in which to conduct research to advance modern power system operation and integration of distributed renewable generation for the power delivery industry as a whole. It also provides opportunities for new graduate student research and learning.

The Microgrid at the University of California, San Diego

The University of California, San Diego (UCSD) has developed a state-of-the-art, self-sustaining microgrid by building on and enhancing the existing utility infrastructure. UCSD has a very close relationship and strong engagement with the local utility, San Diego Gas and Electric Co., based on the testing of advanced technologies. The relationship has been a very important factor supporting successful microgrid implementation. This university-utility cooperation has led to the San Diego region becoming home to one of the most advanced implementations of the smart grid in the United States and has attracted many demonstration projects to the area.

UCSD has a 42-MW microgrid with a master controller and optimization system that self-generates

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Microgrid Implementation at the University of California, San Diego

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92% of its own annual electricity load and 95% of its heating and cooling load. UCSD now saves more than US$800,000 per month by using the generation on its microgrid when compared with the alternative of being a direct-access customer importing energy from the grid. UCSD owns and maintains a 69-kV substation, 96 12-kV underground feeder circuits, and four 12-kV distribution substations throughout its 1,200-acre campus.

UCSD's Renewable Energy Portfolio

Since 2006, UCSD has had an aggressive plan to install renewable generation to reduce the university's overall carbon footprint and create a self-sustaining campus. There is 1.5 MW of photovoltaics (PVs) installed on campus and 0.8 MW off campus. An additional 0.8 MW of PVs will be installed on campus later this year bringing the total installed PVs to 3.0 MW. This will bring UCSD to 100% usage of all architecturally and structurally available rooftops for PV installations (see Figure 1). UCSD has also assisted with the development and demonstration of new types of PVs. A 5.5-kW concentrating PV (CPV) system, for example, was integrated into the UCSD microgrid in July 2009 and continues to operate exceptionally well. A redesigned and upgraded 22-kW prototype that was also installed by Soitec on campus later led to a major commercial CPV development including more than 300 MW of power purchase agreements. This is an excellent example of the "lab to market" model, as demonstrated in a university environment.

UCSD has also developed solar forecasting optimization algorithms to maximize microgrid assets (see the section on economic optimization below) and drive charge and discharge decisions for energy storage. Panasonic, the U.S. Department of Energy (DOE), and the California Solar Initiative have sponsored the Kleissl Solar Forecasting Laboratory at UCSD, which has developed a high-quality sky-imaging system and algorithms specifically targeted at high PV penetration on microgrids. Every minute, two sky-imaging systems work to detect clouds across the university campus (see Figure 2). Using advanced image-processing techniques, cloud positions are forecast at high granularity with respect to PV systems on the ground from one to 15 min into the future. For day-ahead forecasts, high-resolution models of the atmosphere over southern California and the adjacent Pacific Ocean are run to forecast the burn-off time of marine layer clouds and other weather events. The forecasts are blended and optimized using advanced deep machine learning techniques developed by Carlos Coimbra, a UCSD engineering professor.

UCSD has also installed a 3.8-million-gal thermal energy storage system to reduce peak load consumption by deferring the production of chilled water to cool campus buildings. This combined heat and power energy production system, which uses gas turbines with chilled-water thermal storage, has been very effective in increasing overall system efficiency to 66% (lower heating value, LHV) and reducing power production costs by using plentiful, low-cost, off-peak energy. UCSD has also installed a large, 2.8-MW fuel cell and has arranged to utilize biogas from the local City of San Diego sewage treatment plant as fuel for it (see Figure 3). This was the first permitted and operating directed-biogas fuel cell system in the United States. UCSD is also planning to add an absorption chiller to the fuel cell that will raise the LHV efficiency of the fuel cell from 46% to 68%. This will be the first such demonstration globally at the community level.

Energy Storage: A Key Element of UCSD's Renewable Integration

UCSD is also planning to increase utilization of its distributed PV generation by integrating distributed energy storage. By 2014, UCSD will have the largest, most diversified portfolio of energy storage integrated with PVs on a university campus in the world. With funding from the California Public Utilities Commission's Self-Generation Incentive Program (SGIP), seven energy storage systems with a total capacity of 2.7 MW and 5 MWh of storage will be installed and integrated primarily with UCSD's PV generation system. UCSD is also installing a vendor-funded demonstration of energy storage that will consist of 108-kW/180-kWh lithium-ion batteries to demonstrate the ability to utilize used EV batteries, a 125-kW/300-kWh flow battery energy storage system, and an existing 30-kW/30-kWh lithium-ion battery energy storage system, all of which will be integrated with existing rooftop PV generation.

The Microgrid Master Controller

Working with a local company, San Diego-based Power Analytics, UCSD has developed a microgrid master controller that can monitor and control the real-time operations of the microgrid and conduct power system analysis to verify reliability constraints for microgrid planning and operation. The UCSD microgrid power system and building facilities are highly instrumented, currently monitor approximately 84,000 data streams per second, and are designed for expeditious integration of distributed energy resources (DER). The microgrid controller is integrated with OSIsoft's PI data server on campus. Data collection and data analysis techniques are centrally managed by the on-campus PI servers, which are interfaced with the Power Analytics microgrid controller. The UCSD microgrid also has one of the largest U.S. academic installations of synchrophasors, also known as phasor measurement units (PMUs), for data collection and data processing capability; the system is able to leverage the high-density flash machines of the San Diego Supercomputer Center (SDSC). Six PMUs have been installed at strategic locations; in addition, six additional PMUs will be installed on a distribution circuit to provide a detailed understanding of the performance of high PV penetration, electric vehicle (EV) charging, and energy storage on a distribution circuit (see Figure 4). Ultimately, the microgrid controller is also expected to utilize these data to provide the capability to operate the UCSD microgrid in an islanded condition, if necessary. The California Independent System Operator (CAISO), the DOE, California Energy Commission (CEC), and San Diego Gas & Electric (SDG&E) are also collaboratively engaged to utilize the UCSD microgrid to improve the management and efficiencies of utility and statewide grid operations, including demand response, excess generation, renewable supply, load balancing, and power outages.

figure 1. UCSD is reaching 100% PV rooftop coverage; total installed PVs will be 3 MW (used with permission).

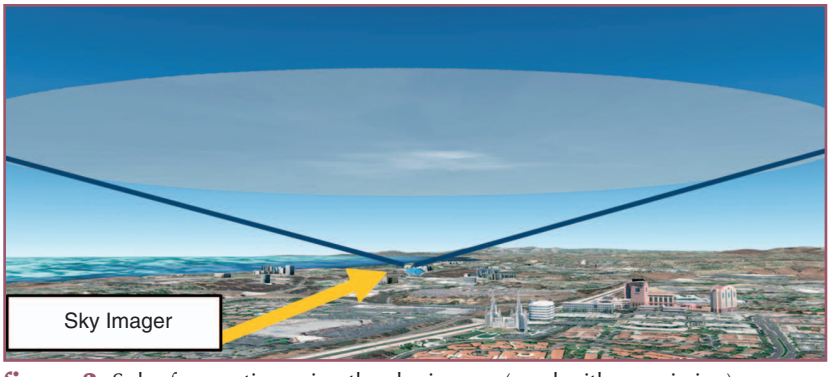

figure 2. Solar forecasting using the sky imager (used with permission).

Predictive Analytics

UCSD self-generates 92% of the annual energy supply for a community of 45,000 residents with increasingly sophisticated and growing demands. Managing and controlling the delivery of this locally generated power is a multivariate optimization and prediction problem that depends on many factors. Some of these factors are discoverable within the grid itself, while others, such as weather and economics, are only available outside the system.

Recent advances in predictive data analytics have the potential to greatly enhance the smart grid and amplify its impact by enabling the understanding of an increasing wealth of data about energy usage and the kinds of demands

figure 3. UCSD's 2.8-MW fuel cell, which utilizes biogas fuel (used with permission).

placed on the grid. UCSD researchers are working on a data-driven approach and facilitating a data-to-knowledge-to-action paradigm by leveraging resources and expertise at SDSC and across the entire campus. A number of research projects utilize smart grid data with advanced forecasting and "big data" analytics in order to realize real improvements in energy efficiency and reductions in energy cost. Recent advances in data analytics, especially machine learning in the areas of temporal and stochastic models, are being used and have shown the potential to greatly enhance the smart grid. Renewable energy prediction, distributed generation, patterns of energy usage, and the types of demands placed on the grid are some of the many important indicators being examined within the UCSD microgrid lab-to-market environment. Applying such approaches to the available data in the microgrid environment enables informed, real-time decisions and enhancements, resulting in a truly intelligent and more keenly optimized microgrid. This optimization increases the energy resources available to the community without additional capital investment in existing physical infrastructure.

Economic Optimization

Together with Philadelphia-based Viridity Energy, UCSD has deployed a software solution that uses sophisticated simulation and optimal control algorithms to optimize the utilization of distributed resources around the UCSD campus.

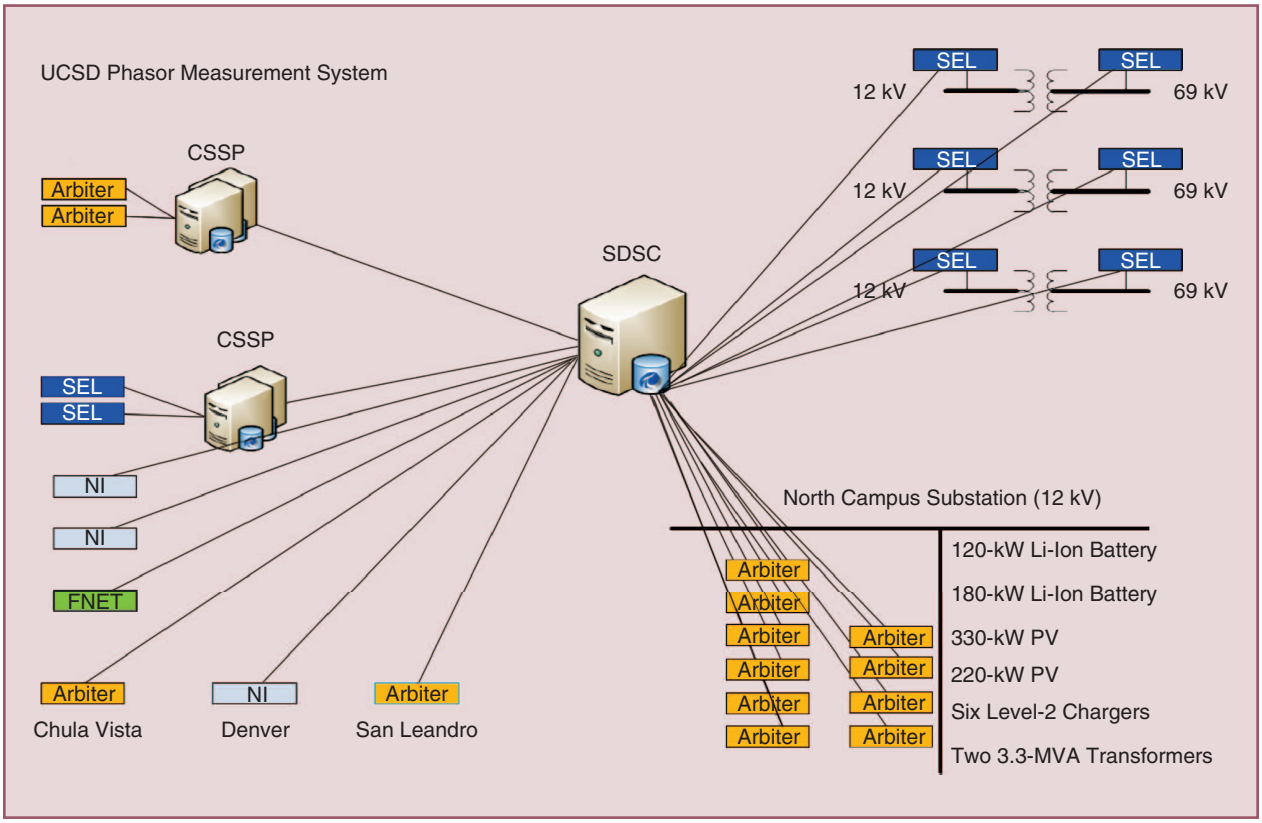

figure 4. UCSD's existing and planned PMUs.

This solution, based on Viridity's VPower platform, is designed to integrate the campus's diverse thermal and electrical energy storage and generation capabilities to minimize energy costs and the campus's carbon footprint. VPower works together with the Power Analytics master controller's capabilities to ensure that the economic optimization is consistent with the electrical constraints of the microgrid. This breakthrough approach to microgrid management will demonstrate that distributed resources can be coordinated to achieve both economic and environmental objectives while contributing to the reliability of the grid. While connected to the distribution system, the optimized microgrid can be viewed by the local utility as a "dispatchable feeder" and provide it with services in support of grid reliability while helping the utility defer investments in capacity expansion. In parallel, the optimized microgrid could participate in the future wholesale markets in the form of energy balancing and ancillary services and can benefit from the market revenues received to accelerate the return on UCSD's distributed assets investments. In an islanded mode, the microgrid becomes self-balanced. The storage resources, together with the various forms of renewable and nonrenewable generation, are optimized to meet reliability and power quality objectives. In grid-restoration mode, the microgrid can provide "black start" services to the main distribution grid following a blackout. Altogether, the solution deployed at UCSD demonstrates an approach that can contribute to the economic and reliable deployment of renewable generation and other distributed energy assets.

Integration of EVs

When installation is complete, UCSD will possess the largest, most diversified portfolio of EV chargers of any university in the world. There will be 25ECOtality Level 2 EV charging stations, some of which are already in place. In addition, UCSD will soon receive 26 "smart charging"–capable Level 2 and 3 dc fast chargers from RWE, Germany's second-largest utility, under funding from CEC through the AB 118 program. These new smart chargers will demonstrate intelligent, connected charging according to the ISO/IEC 15118 standard. When complete, the microgrid controller will be able to communicate with these smart chargers and initiate demand reduction or other actions as required.

Lessons Learned

The major benefits that have been realized through development of the UCSD microgrid include

- ✔ improved operational efficiency, flexibility, and monitoring capability
- ✔ reduced operating costs
- ✔ reduced greenhouse-gas production
- ✔ enhanced system reliability
- ✔ the advancement of smart grid and renewable energy technologies through lab-to-market commercialization
- ✔ the opportunity to integrate faculty research with microgrid operations.

UCSD and the CEC were selected for the State Leadership in Clean Energy (SLICE) Award in 2012. The award is given to organizations that demonstrate exemplary leadership and innovation in clean energy development. The following statement was provided by SLICE at the awards ceremony: "The microgrid, based at the University of California, San Diego (UCSD), integrates a wide range of renewable and distributed energy systems including a fuel cell, several photovoltaic systems, electric vehicles and electric vehicle batteries, a combined heat and power plant, and a thermal storage system. The relative power outputs of the various energy sources can be reoptimized hourly, preserving system stability despite natural fluctuations in renewable energy sources."

In conclusion, the university setting is ideal for microgrid implementation. This has been demonstrated at the UCSD campus, providing significant benefits for the community and for the advancement of energy technology.

For Further Reading

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