# UCI Microgrid

## Introduction

The University of California, Irvine (UCI) is relatively young with the first graduating class in 1966. Today, UCI is acclaimed internationallyfor its academic strength in energy and environmental studies as well as its operational record in energy efficiency.

As a cornerstone of one of the youngest, largest, and most prestigious planned communities in the country (the City of Irvine), UCI wasestablished on sprawling undeveloped acreage on the bluffs bounding the Pacific Ocean. This allowed the University of California to methodically and systematically design a new campus from scratch with a large, circular central park encircled by a one-mile underground utility tunnel loop to convey central energy and information infrastructure.

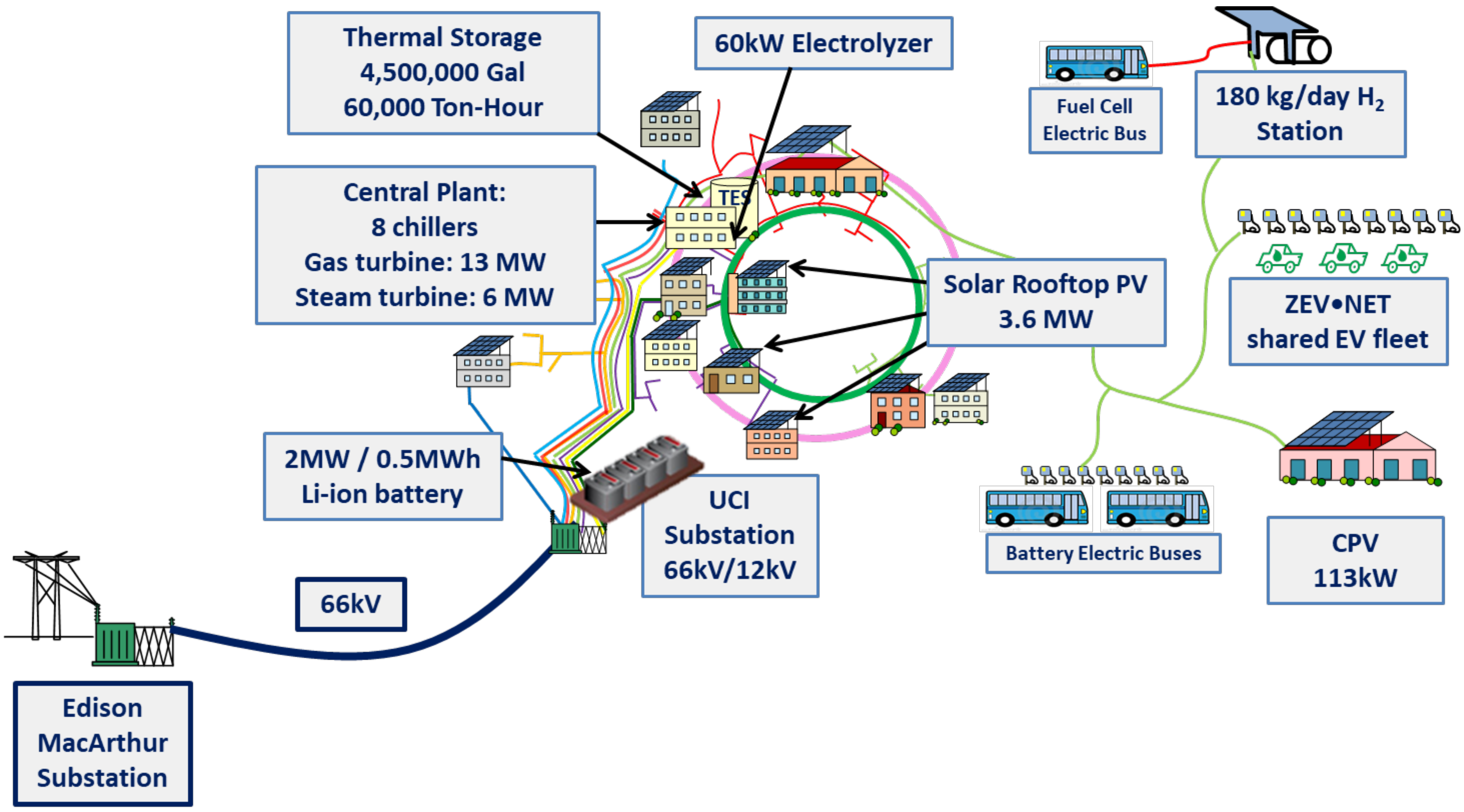


Figure 1: University of California, Irvine Microgrid | Green Ring: Central Park | Purple Ring: Utility Tunnel

The UCI Microgrid (UCIMG) is anchored in this tunnel with radial feeds from the tunnel to serve the sprawling campus community (Figure 1). Today, the UCIMG is a community-scale microgrid with an average weekday population exceeding 50,000 and sensitive loads typical of a major research university conducting activities totaling more than $300M with a wide array of building types (residential,office, research, classroom), transportation options (automobiles, buses, shared-cars, bicycles), and a wide array of distributed energy resources (DERs).  Through an array of prior and current research programs, the UCI Advanced Power and Energy Program (APEP) has teamed and collaborated with the UCI Administration and UCI Facilities Management (FM) to integrate key microgrid hardware, software, and simulation assets into the UCI Microgrid.

UC Irvine has several major goals: 1) Net zero carbon by 2025 (not only UCI but entire UC system), 2) increased reliability, and 3) reduced operating costs through optimized resource dispatch, demand response, and ancillary services provision.

As shown in Figure 1, UCIMG is a test bed that (1) is served by Southern California Edison (SCE) through the UCI Substation which steps down voltage from 66kV to 12kV using two transformers (25 and 38 MVA), (2) encompasses ten 12kV circuits, (3) includes more than 4 MW of solar power, (4) is served by a 19MW natural gas fired combined cycle plant, (5) incorporates centralized chilling including one of the largest thermal energy storage tanks in the country (4.5 million gallons/60,000 ton-hours), and (6) serves all major buildings with district heating and cooling. Additionally, UCIMG is in the process of deploying a microgrid controller as well as commissioning a blackstart generator capable of blackstarting the central plant in the absence of the utility grid.

UCIMG also contains a unique set of distributed energy resources that is unparalleled in the world including: (1) electric vehicle charging at multiple parking locations, (2) hydrogen fueling for fuel cell vehicles, (3) electric bus charging stations, (4) two-axis tracking concentrated solar photovoltaic systems, (5) advanced building energy efficiency measures, (6) advanced building monitoring and control, (7) advanced power, power quality, and thermal metering, (8) unique PV/battery electric charging installation ("CarShade") for 20 plug-in electric vehicles, (9) 60 kW electrolyzer for producing hydrogen for pipeline injection (Power to Gas), and (10) a 2MW/ 500 kW-hr Li-Ion battery deployed at the UCI substation . Additionally, UCIMG includes a zero-emission bus fleet with 20 battery electric buses and one fuel cell electric bus operated by Anteater Express.

The following section presents more details of the major hardware assets of the UCIMG. Each of these assets has been inventoried, characterized and modeled. The subsequent section introduces the UCIMG model development and verification via comparison to data acquired by conventional metering deployed throughout the microgrid, and advanced high-resolution and high-response metering at over 100 key locations

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## UCI Microgrid Hardware Assets

### Substation and Campus Circuits

The electric service for the UCI campus has already experienced a history of change and steady growth that defines its present characteristics. The early campus was served directly from two SCE 12 kV circuits that entered the UCI central plant. Each of these twocircuits separated into sub-circuits that fed the portion of campus around the central plant. A third SCE 12 kV circuit fed the East Substation, which was located on the opposite side of campus. This third line also connected to a bus bar that energized more sub- circuits to serve the east side of campus.

In 1990, the UCI Substation was built to accept a SCE 66 kV service directly and step the voltage down to 12 kV locally and thereby displace three legacy circuits. Most buildings in the main UCI campus are still served by infrastructure derivative of these three main circuits. The primary feed for the UCI Substation is an SCE 66 kV line with a single billing meter. The two UCI Substation transformers, which cannot be paralleled, each serve 5 circuits and a capacitor bank. The 12 kV side of the two transformers are connected with a tie- line switch. Generally, one of the two transformers is disconnected with one transformer serving the entire campus load. When the turbine goes offline (e.g., for preventive maintenance), the tie-line is automatically opened and the second transformer is connected. This occurs because a single transformer is insufficient to support the entire campus load without the local generation and fault duty from two transformers in parallel would exceed the interrupting rating of the 12 kV breakers. At present, the two capacitor banks at the UCI Substation are disconnected due to a resonance issue that occurred when the19MW combined cycle plant was installed. The turbines associated with the plant generate reactive power to augment this need.

The history and vision of the UCI electric service have already led to a power system that is flexible for modifications. The emphasis on reliability for campus buildings has led most building transformers to have two circuit sources that can easily shift load. The circuits themselves are reconfigurable through existing switches that were installed to meet various stages of the campus growth. In addition, the utility tunnel provides convenient access to re-conductor critical circuits for increased capacity. At present, most 12 kV circuit feeders have available capacity. Currently, UCIMG is on an *inadvertent export* interconnection agreement allowing for little export got a very short among of time before the gas turbine is tripped. This interconnection agreement limits (1) the PV capacity on UCIMG (note that the gas turbine cannot operate in low capacity factors due to emissions limits), (2) participation in wholesale electricity markets, and (3) the capability of the microgrid to serve surrounding community in case of a grid outage.

### Central Plant

The UC Irvine Central Plant consists of 8 electric chillers, a steam turbine chiller, a thermal energy storage tank, boilers (used only for backup), a 13 MW gas turbine, a heat recovery steam generator (HRSG), a duct burner, and a 6 MW steam turbine (Figure 2). The centralplant serves all the campus heating and cooling loads as well as the majority of the campus electric loads. The 8 electric chillers are capable of supplying 14,500 tons, and the steam driven chiller is capable of an additional 2,000 tons. The campus cooling load averages 3,100 tons (74,400 ton-hours per day) with a peak annual demand of 13,900 tons. The thermal energy storage tank uses a thermocline to minimize mixing. The chillers operate to facilitate this thermocline while also increasing efficiency by recirculating water exiting the chiller back to the chiller inlet until 39°F is maintained at the chilled water exit. The thermal energy storage tank is able to shift, on average, 65% of the chilling load during the day to the night when electricity prices are lower and temperatures are cooler, which resultsin more efficient chiller operation via better heat rejection through the cooling towers. The campus heating load averages 44 MMBtu/hr with a peak annual demand of 100 MMBtu/hr. The heating load is served entirely through recovered heat from the gas turbine and use of the duct burner. The HRSG can supply 52,000 lbs/hr steam without duct fire and 120,000 lb/hr with duct fire. The campus electric loadaverages 13.4 MW with a peak annual demand of 18.6 MW (note: this is the electric load separated from the electricity used to serve thecampus cooling loads). The gas turbine and steam turbine supply about 96% of the electrical needs on the campus with the balance being served by solar resources (3.5%) and utility import (0.5%).

The priority of the gas turbine exhaust is to serve the campus heating load and the second priority is to serve the steam turbine. Thermal energy storage facilitates managing the cooling demand of the campus and is used as a resource for load shifting. These systems do not need to be operated as tightly as the electricity system. For example, dropping a chiller does not immediately lead to a rise in temperature. More time for recovery is possible with the thermal systems. Therefore, the electricity system is first priority. Additionally, the condenser is oversized to allow excess steam generated to be dumped. The UCI chilling plant electric demand can reach 10 MW at full output, representing a substantial portion of the total campus load. The chillers are cycled according to age and coefficient of performance (COP) with the newest chillers with the highest COPs being run the most. The UCI TES tank, considering a chiller COP of 5, is equivalent to 0.7 kW per ton or 42 MWh of electric storage capacity (or 210 MWh-t of cooling). Running at full capacity, the tank can store 7 hours of chiller operation, or essentially one day worth of campus cooling. The TES tank is a proven cost competitive technology that dispatches the campus cooling load demand to reduce demand charges and shifts cooling load from on-peak to off-peak. With proper coordination, the TES tank can increase the achievable renewable penetration on the UCI campus and thus facilitates integration of more PV on campus.

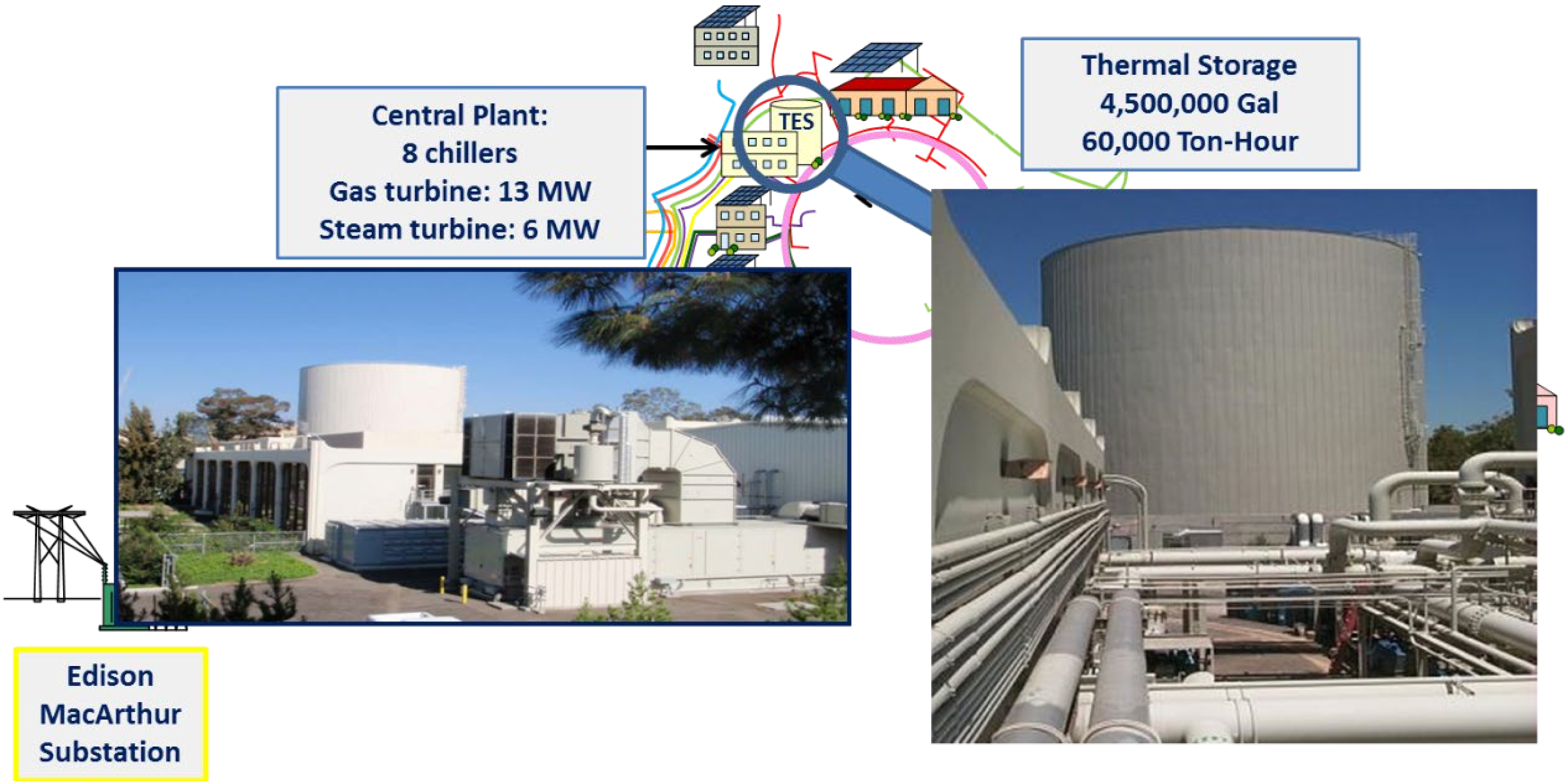



Figure 2: UC Irvine Central Plant[GR1]

### Renewable Power

UCI has 893 kW of fixed panel solar photovoltaic installed on the rooftops of 12 buildings (Figure 3). This system is owned and operatedby a third party provider with the electricity purchased by UCI through a power purchase agreement (PPA). The capacity factor for these panels, in operation since 2008, was 0.187 in 2012, which is reasonable given the coastal climate. An additional 113 kW of concentrated solar photovoltaic with two-axis tracking was installed in 2012 as part of a research project funded by the California Public Utilities Commission through the California Solar Initiative. This research involves collecting CPV andinterconnect data to (1) support design improvements, (2) inform advanced inverter control studies, and (3) develop and evaluate simulation modeling of intermittency on primary circuits. The campus solar resources are causing the gas turbine to be turned down at times of low electric demand and high solar irradiation. Figure 4 shows UCIMG data at 15 minute resolution for a weekend in May 2012. The gas turbine can be seen having to respondto changes in solar output. At the time show in the figure, UCIMG was on a *minimum export* interconnection agreement with the utility.

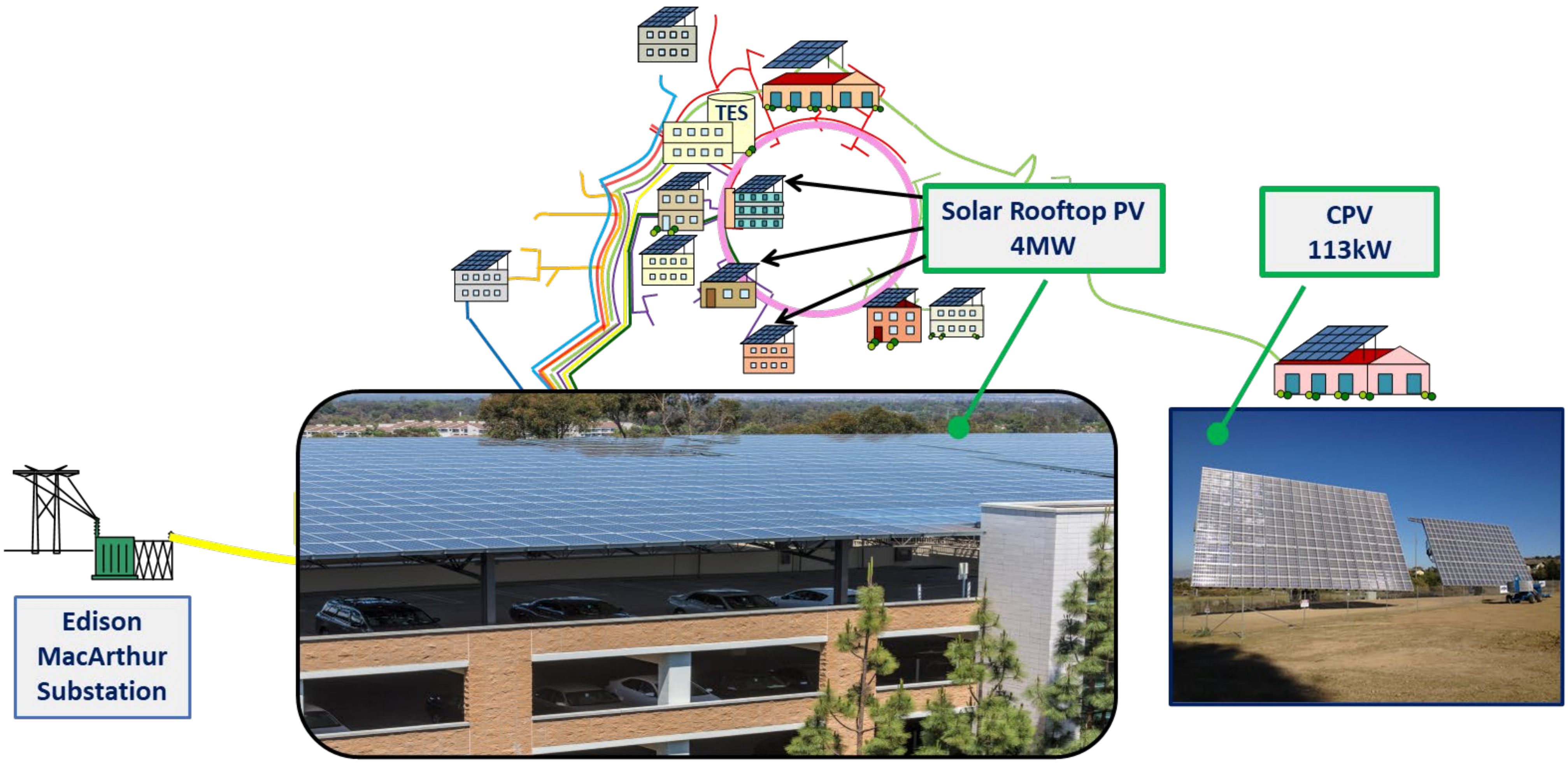



Figure 3: UCI Microgrid Renewable Power

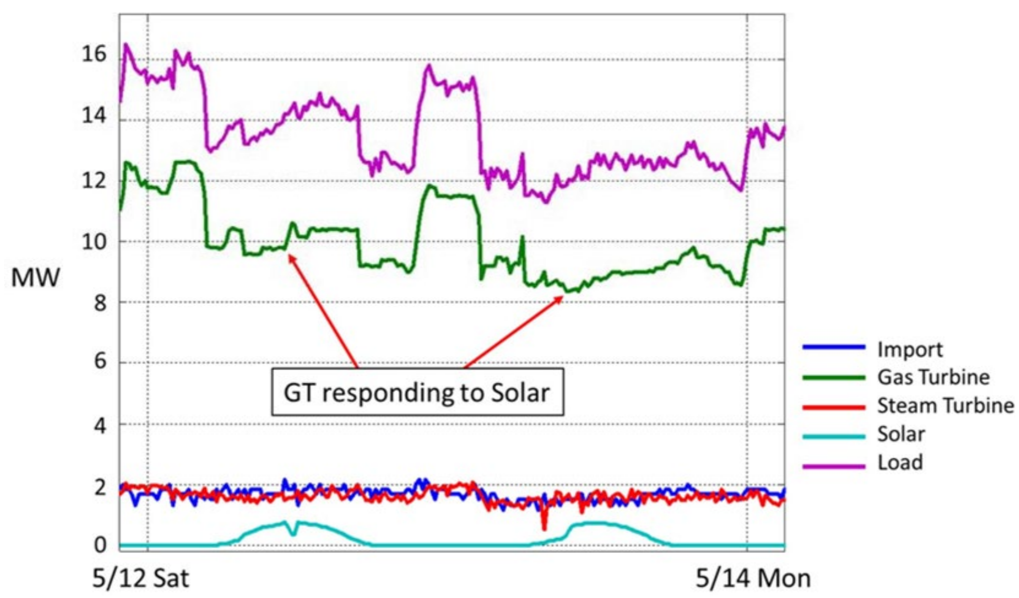



Figure 4: Gas Turbine Responding to Solar Output in 2012

Since then, UCIMG had added an additional ~3MW of solar PV on three parking structures and has moved to an *inadvertent export* interconnection agreement with the utility. Figure 5 shows UCIMG data for several days in May 2021.

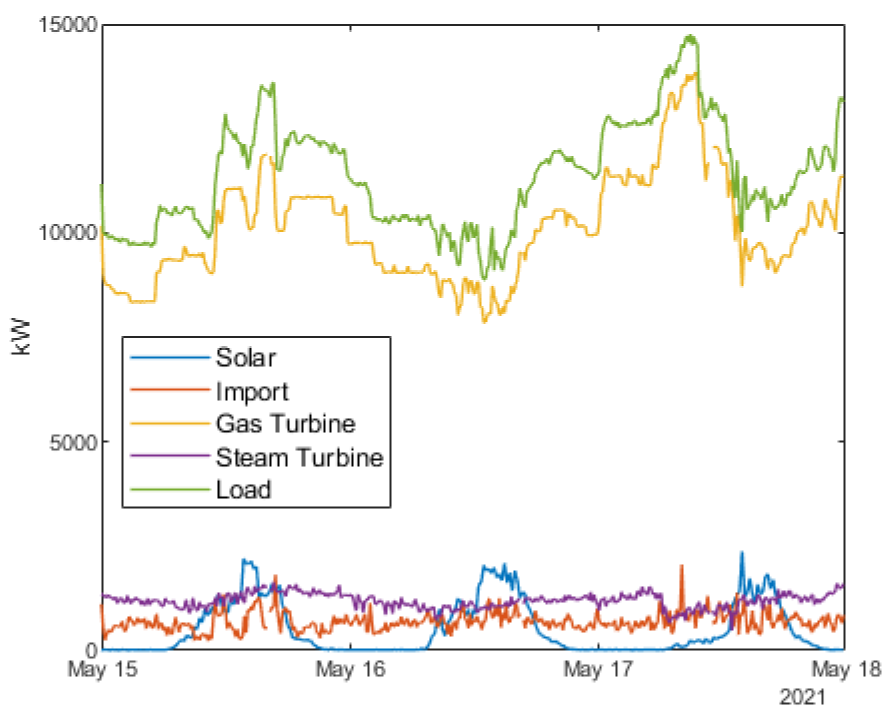



Figure 5: UCIMG Data in May 2021

### Metering and Monitoring

More than 120 smart meters are deployed across the UCIMG. These smart meters have the capability to provide meter data at 1Hz to the UCIMG controller.. The locations of these meters (Figure 6). were selected based on a visibility study based on load flow analysis. These meters have 12 to 24 independent channels and can submeter different building loads including solar PV, lighting, and compressors, and are also capable of demand response including auto-demand response. The data from these meters as well as SEL relays across the UCIGM in conjunction with Demand Response capabilities including Auto-Demand Response, provides the UCI Facilities Management team with information necessary to make decisions as more intermittent renewables are installed on the UCIMG in addition to allowing the UCI Microgrid to operate as a smart power and demand response asset for the California Independent System Operator.

### Electric Vehicle Charging

The UCIMG includes 180 Level 1 and Level 2 electric vehicle chargers by ChagePoint. Additionally, the UCIMG includes 20 chargers at 80 kW each for 20 battery electric buses deployed in the UCI Anteater Express fleet. The APEP also administers the Zero Emission Vehicle Network Enabled Transport (ZEVNET) program (Figure 7) that currently involves a fleet of 12 Scion iQ EVs.

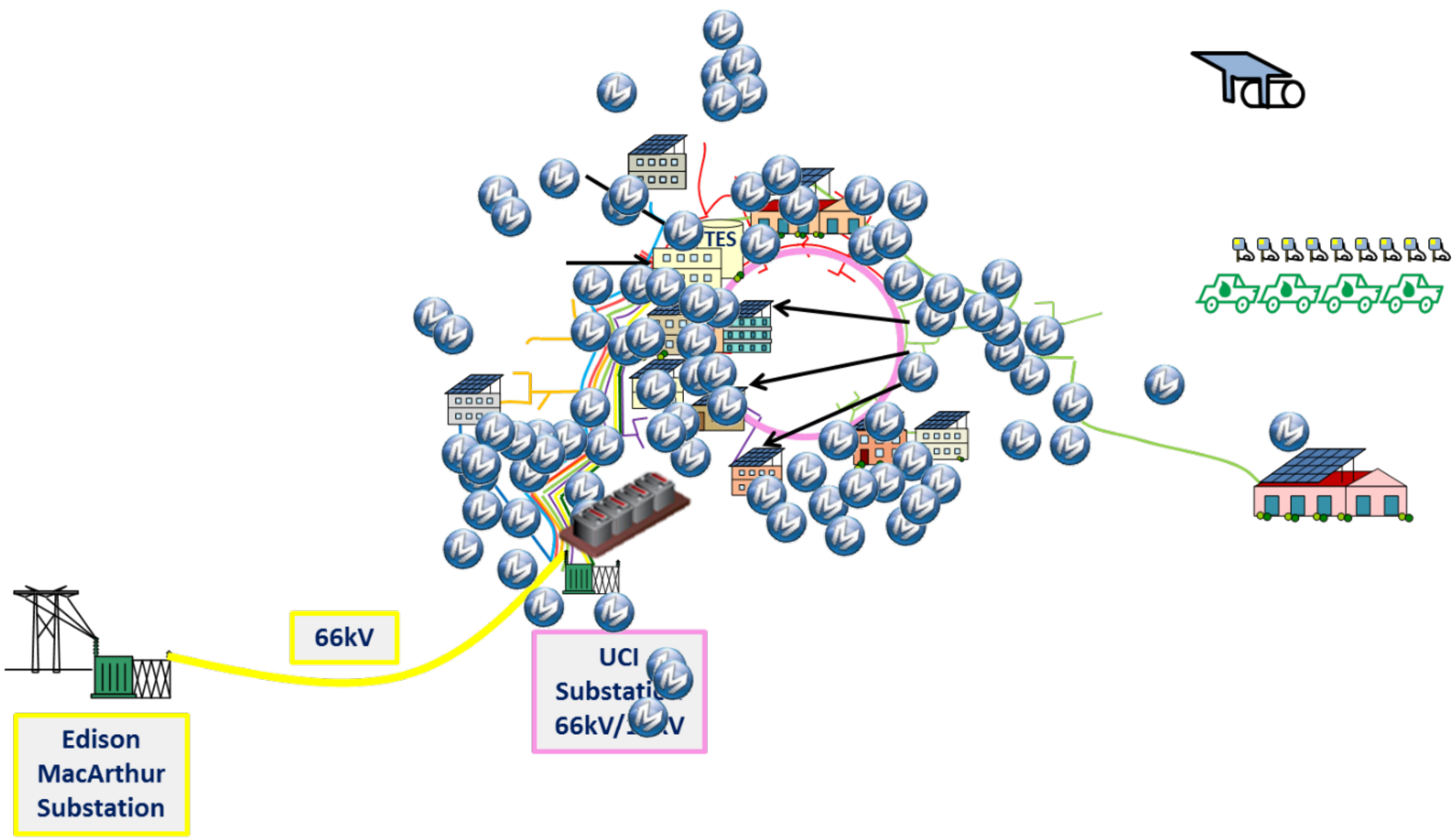



Figure 6: Deployment of MelRok Meters

### Hydrogen Fueling Station

The UCI Hydrogen Fueling Station serves the fueling needs of fuel cell vehicles for several major car manufacturers (Toyota, Honda, Hyundai) and a fuel cell electric bus deployed in the Anteater Express fleet and, as needed, fuel cell electric buses deployed by the Orange County Transit Authority. The station is administered by APEP and is capable of delivering fills at 35MPa and 70 MPa (Figure 8). The station began operation in 2003 with a capacity of several kg per day. In 2007, the station was upgraded to a capacity of 25kg/day. In 2015, the station was upgraded to a capacity of 180 kg/day and was opened to public in November 2015. The station dispenses an average of 310,kg/day (~110 fills per day) with the highest 420 kg dispensed in a single day. This station is set to be replaced in December 2022 with a higher capacity station, two dispensers, and four fueling positions.

### Energy Efficiency and Demand Response

UCI undertook a deep energy efficiency initiative beginning in 1993 that has led to a reduction in load exceeding 50% of "business asusual" today (Figure 9). What started as a goal to reduce load by 20% has far exceeded that initial goal, a result that has brought international attention and numerous awards to the campus. Sierra Magazine, for example, has voted UCI as the coolest campus in thecountry for two years running.

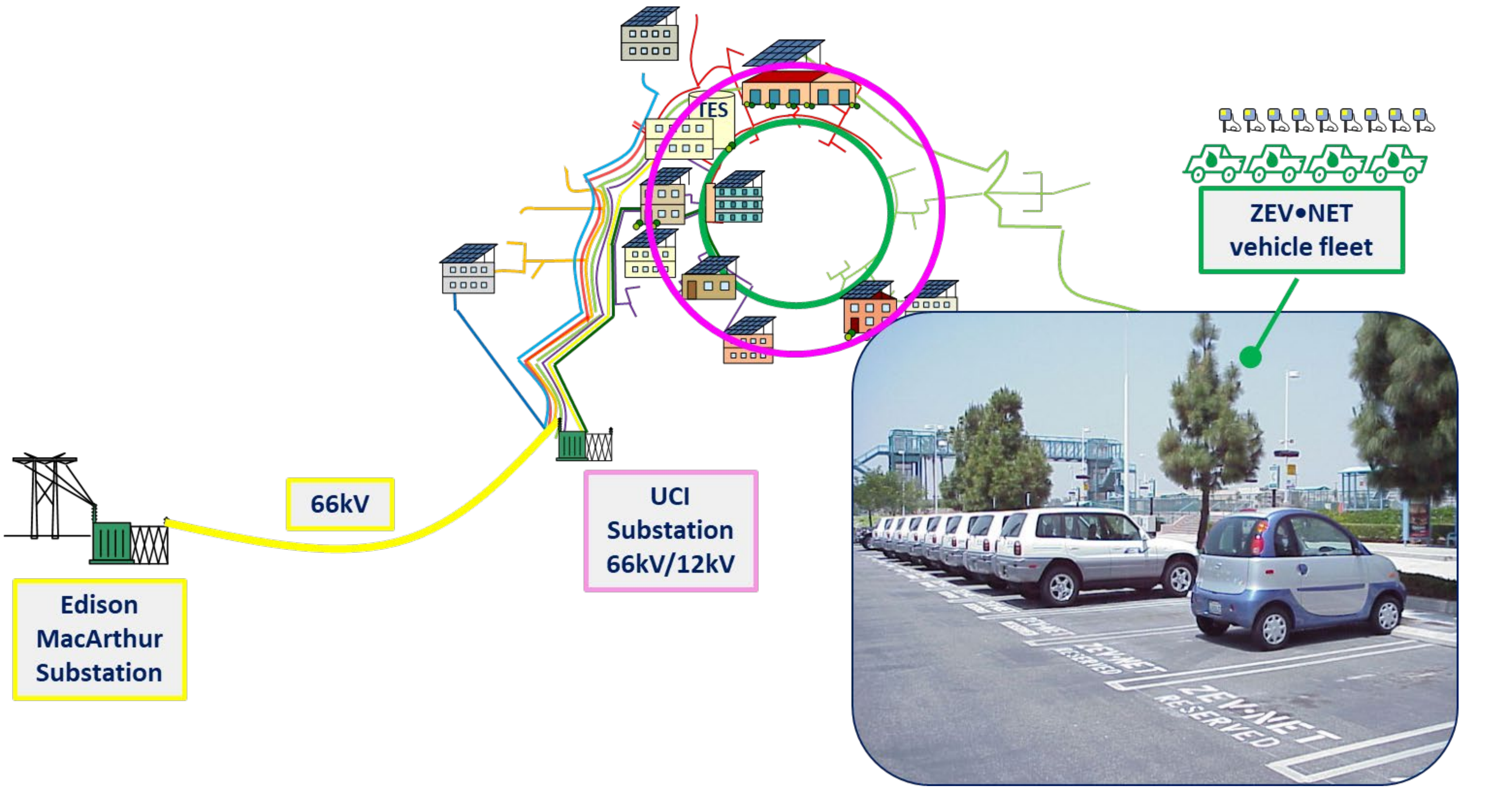



Figure 7: UCI Microgrid Electric Vehicle Charging


Figure 8: UCI Hydrogen Fueling Station

UCI has been the model for reaching the sustainability goals of UC, implementing a wide and creative variety of energy efficiency measures through various award-winning programs including the Better Building Challenge through the Office of Energy Efficiency and Renewable Energy in the Department of Energy. The program, launched in December 2011 by President Obama, targets a reduction in energy consumed across the campus by 20% by 2020. The program works to match participants with solution providers to enable this challenge to be met. Thus far, UCI has not only met but exceed the targets despite adding one million square feet (a 24.8% reduction in GHG emissions in 2016 alone). In addition, the Natural Sciences II building serves as a showcase for the Better Buildings Challenge in order to highlight the UCI Smart Labs Initiative. UCI also participates in demand response programs through, EnerNOC, a registered demand response provider for Southern California Edison. The campus has nominated 700kW of demand response so far. This is achieved in various ways involving the steam turbine, HRSG, chiller plant, and thermal energy storage tank. UCI also has plans to implement demand response at the building level.

Furthermore, UCI continues to achieve the highest waste diversion rate at 82 percent in the UC system, is among the top ten in RecycleMania, and ranked platinum in STARS (Sustainability Tracking, Assessment & Rating System) in 2018. UCI is No. 1 in among U.S. universities, No. 2 overall in Sierra magazine's 2019 'Cool Schools' ranking and has been among top 10, ten years in a row.  More information on sustainability practices, targets, and progress towards targets can be found in: https://www.ucop.edu/sustainability/ and https://sustainability.uci.edu/

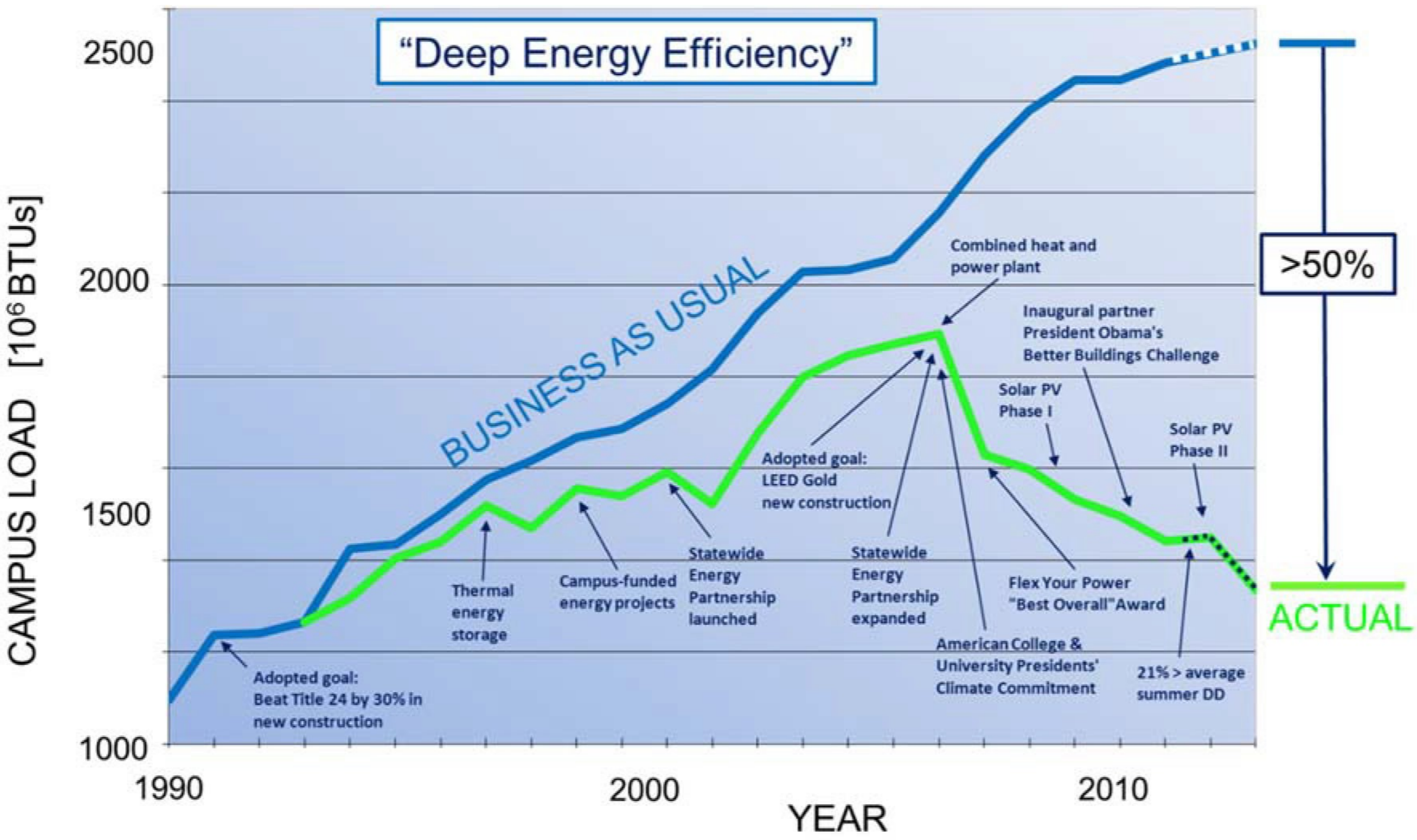



Figure9:  UCI Deep Energy Efficiency Experience

### UCI Microgrid Model and Simulation Assets

APEP has developed a model of the UCIMG and thereby establish a simulation platform for understanding and managing the effects of high penetrations of localized renewables in the community. The UCIMG model was developed using connectivity information (e.g., line impedance, transformer nameplate) provided by UCI FM and calibrated using the campus energy management and monitoring system.  Later on, a more detailed modeled was developed on MATLAB Simulink and using OPAL-RT Artemis to enable hardware-in the loop (HIL) testing of the microgrid controller. Figure 10 shows the comparison of simulation results from the APEP UCIMG models to measured data. The model is capable of simulating steady-state and dynamic phenomena as well as temporal events such as PV generation and capacitor switching. Transients during transition to islanded operation and back to grid-tied operation can also be captured by this model. Steady-state qualities of interest are real/reactive power flow and the voltage profile across the radial circuits. Dynamic phenomena include power quality (third harmonic distortion and flicker), frequency stability and transients (faults and voltage sags/swells).

Calibrating the campus model to measured data ensures the model accurately simulates the system impedance and losses; once calibrated, the model is capable of exploring the effects of future technology such as increased renewable generation, and advancedinverter controls, and energy storage.

The UCIMG model will also import real time information from the meters and relays across system to inform the model for more accurate predictions. It is envisioned that the UCIMG model will be used to manage high penetration of intermittent renewables by allowing the UCI FM to evaluate management options in real time to enable them to have better control of the UCI Microgrid.

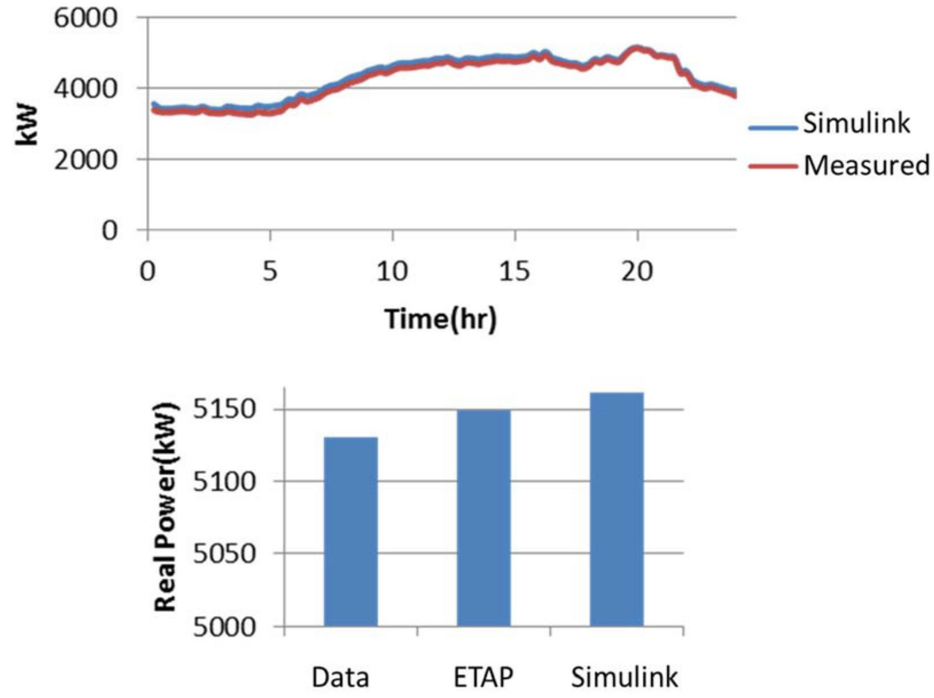



Figure 10: Examples of APEP Microgrid Model Performance

## Generic Microgrid Controller Research

Under funding from the U.S. Department of Energy (DOE), APEP collaborated with Southern California Edison to establish proceduresand protocols for the utilization of microgrid resources, identify the policy and standards required to enable and foster the microgrid market, and systematically assess the associated economics. In conjunction with two Irvine companies, ETAP and MelRok, and five "Microgrid Partners,[1]" APEP is developed the specifications for a "Generic Microgrid Controller (GMC)" which resulted in IEEE 2030.7 through active participation of APEP in the committee. The main objective of this project was to develop and test a Generic Microgrid Controller (GMC) that provides (1) seamless islanding and reconnection of the microgrid, (2) efficient, reliable, and resilient operation of the microgrid with the required power quality, whether islanded or grid-connected, (3) existing and future ancillary services to the larger grid, (4) the capability for the microgrid to serve the resiliency needs of participating communities, (5) communication with the electric grid utility as a single controllable entity, and (6) increased reliability, efficiency and reduced emissions.

The objectives of the project were achieved in two phases: (Phase I) Research, Development and Design ("Design"), and (Phase II) Testing, Evaluation, and Verification ("TEV"). In Phase I, specifications were developed for the GMC and a detailed test plan was established to test the functional requirements of the GMC. The GMC addresses two core functions, transition and dispatch, as well as several optional higher level functions such as economic dispatch, and renewable and load forecasting.

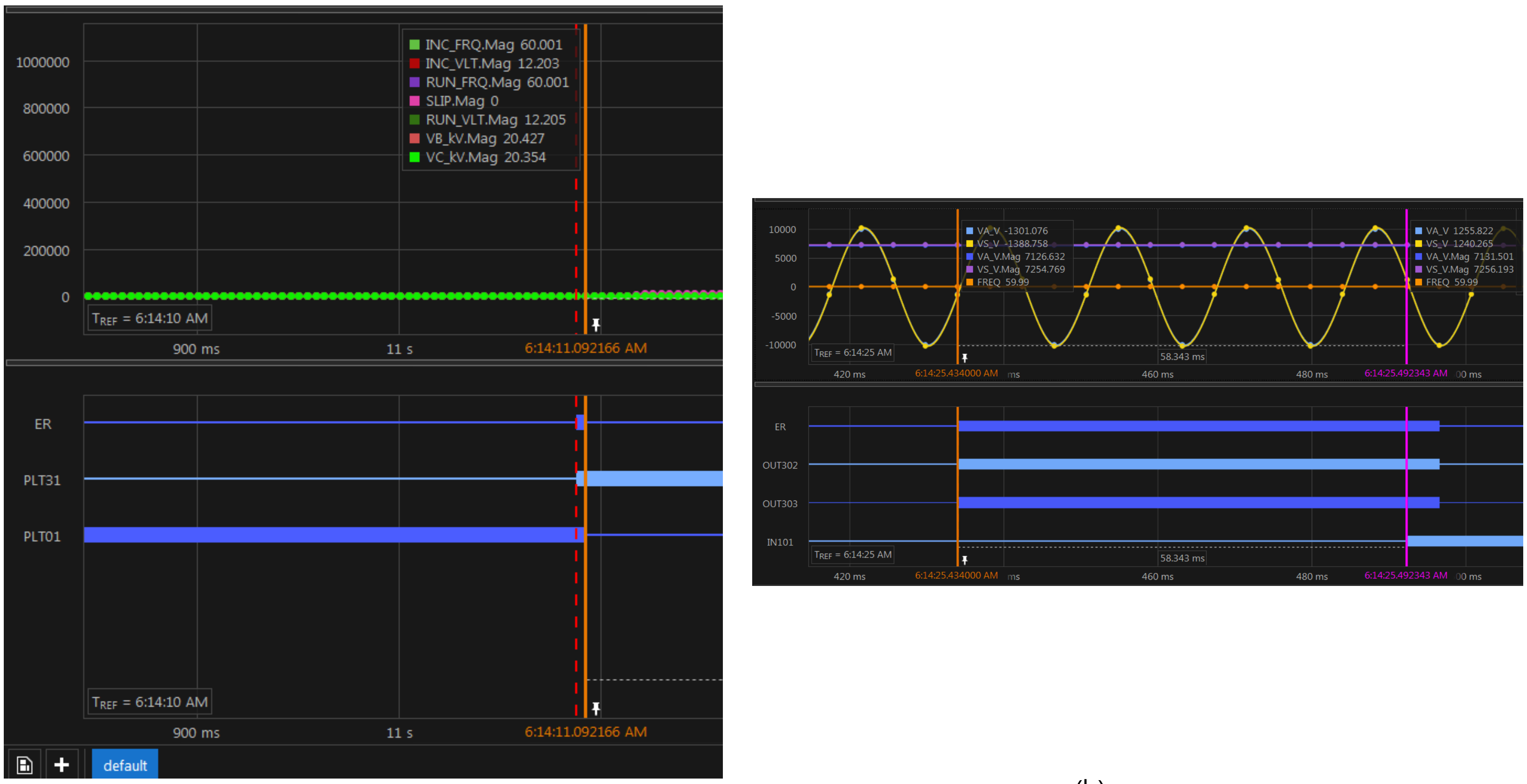
For the purposes of Phase II (TEV), the GMC was applied to two microgrids: (1) the 20 MW-class UCI Microgrid (UCIMG), and (2) the 10MW-class UCI Medical Center Microgrid (UCIMC) using a commercially viable platform (ETAP). Both microgrids and their components were modeled using the Simulink platform and run on an advanced real-time OPAL-RT hardware-in-the-loop (HIL) simulator. Model simulation results were used to further inform the development of a controller designed for uninterrupted operation of the microgrid through events including islanding, reconnection, and internal/external faults. The simulations demonstrated proof-of-concept, identified the system's operational limits, and anchored a test plan for an islanding demonstration of the UCIMG.

Once the performance of the GMC was established and tested in HIL, the TEV expanded to include field testing at the UCIMG. The UCIMG was then islanded for 75 minutes for a field demonstration which required coordination with UCI Facilities Management, the UCI Administration, the UCI Office of Design and Construction, the local utility partner (Southern California Edison), the manufacturer of the UCIMG Co-Gen (Solar Turbines), and Schweitzer Engineering Laboratories (SEL). During the 75-minute islanded operation, step loads were added including three 200hp pumps and campus building loads. In addition, a 500 kW chiller was dropped from the load at approximately 60-minutes into the excursion. The islanding test demonstrated the ability of the UCIMG to disconnect from the grid and island, operate in islanded mode under conditions of load changes, and resynchronize and reconnect to the larger grid. Figure 11a and Figure 11b show the HMI of SEL 451 and 751 during auto-sync and reconnection phase of the demonstration.

## Microgrid Controller and Blackstart Generator

Recently UCIMG went through an upgrade increasing the power capacity of UCI substation and replacing the transformers, addition of south and east substation in the microgrid providing additional redundancy, addition of an alternate 12 kV supply to cogen and chiller plant, and addition of SCADA fiber optic cable for high-speed loop and communication.

[1]Port of Los Angeles, Port of Long Beach, Irvine Ranch Water District, UCI Medical Center.




(a) (b)

Figure 11: (a) SEL 451,and (b) SEL 751 During Auto-Sync Phase of the Demonstration

With this upgrade and successful islanding demonstration, UCI Administration and UCI FM elected to deploy a permanent microgrid controller which is under way and set to be commissioned in 2022. For additional redundancy, UCI decided to deploy a diesel blackstart generator which will be able to help start up the central plant in the absence of the grid. This blackstart generator further increases the reliability and resiliency of UCIMG, and ensures that if seamless islanding is unsuccessful, the central plant will remain operational after a short outage. This blackstart generator is shown in Figure 12.

Figure 12: UCI Blackstart Generator

## Summary

The UCI Microgrid represents a special opportunity for testing how microgrids operate internally as well as how they interface with the rest of the future smart grid. The relationship between APEP and UCI FM has enabled the UCIMG to become a test bed for different technologies through the development of the UCIMG model, deployment of advanced metering, and various pilot projects. In addition, the same substation that serves the UCIMG also served the Irvine Smart Grid Demonstration project allowing the UCI Microgrid to be tested in the context of smart grid features. The history of the UCI Microgrid is also fundamental to its capability as a test bed. The original design and evolution of the campus provides an attractive platform to support a flexible and robust platform for the deployment and evaluation of the various technologies and circuit configurations emerging in the microgrid future.