University of California Riverside
Testing Facilities for Sustainable Technologies

UC RIVERSIDE

Electric Drive Vehicle Testing Laboratories

UC Riverside

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UC Riverside's Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT) has unique capabilities to test a variety of electric drive vehicles, including pure battery electric, fuel-cell, hybrid electric, and plug-in hybrid electric vehicles. With two state-of-the art chassis dynamometers, both light-duty and heavy-duty EVs can be tested. CE-CERT has developed a wide range of electric drive testing protocols, providing research results to industry, government agencies, and academia.

Electric Drive Vehicle Testing Laboratories

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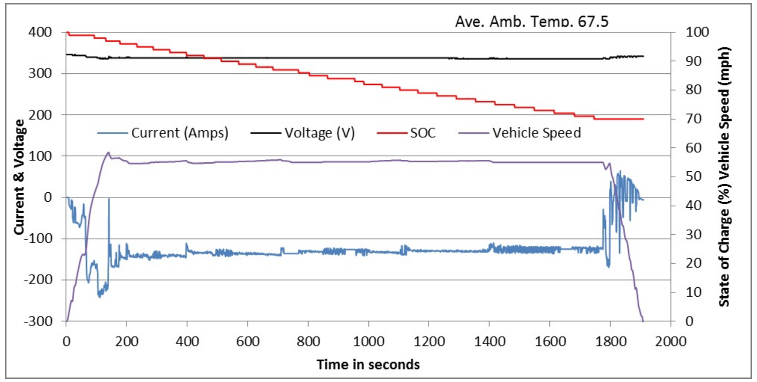
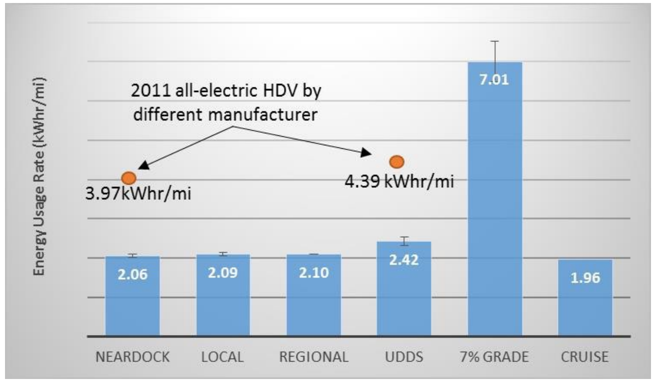
Dynamometer Systems capable of testing a wide range of electric-drive vehicles

CE-CERT's dynamometers have been designed to handle a range of vehicles and vehicle loads at on-road driving conditions. The Heavy-Duty 48" Electric AC Chassis Dynamometer has dual, direct connected, 300 horsepower motors attached to each roll set with a base inertia of 45,000 lbs. with the addition of a large flywheel. The dynamometer applies appropriate loads to a vehicle to simulate factors such as the friction of the roadway and wind resistance that it would experience under typical driving. A driver accelerates and decelerates following a driving trace while the vehicle is driven in place.



Working with CARB and the California Energy Commission, CE-CERT has developed and utilizes specific testing protocols for EVs

In addition to standard vehicle performance measurements of velocity and acceleration, CE-CERT is able to measure battery SOC, system voltage and current, energy efficiency per mile (kWh/mile) and gradeability.



Electric Vehicle Drive Cycle Testing

Through extensive vehicle activity studies, CE-CERT has developed a number of "drive cycles" specific for electric vehicles and trucks. These drive cycles, in addition to certification drive cycles, can be tested repeatedly in a controlled environment.

Electric Drive Vehicle Testing Laboratories

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Technology Type	Testing Capabilities
Heavy Duty Chassis Dynamometer	Capable of testing any electric truck in a wide range of configurations
Light Duty Chassis Dynamometer	Capable of testing any light-duty electric vehicle in a wide range of configurations
EV Data Acquisition System: **Real-Time Monitoring System Software and Sensors**	Capable of measuring dynamometer physical loads, battery SOC, vehicle voltage, current, energy efficiency

Sustainable Integrated Grid Initiative (SIGI) Testbed

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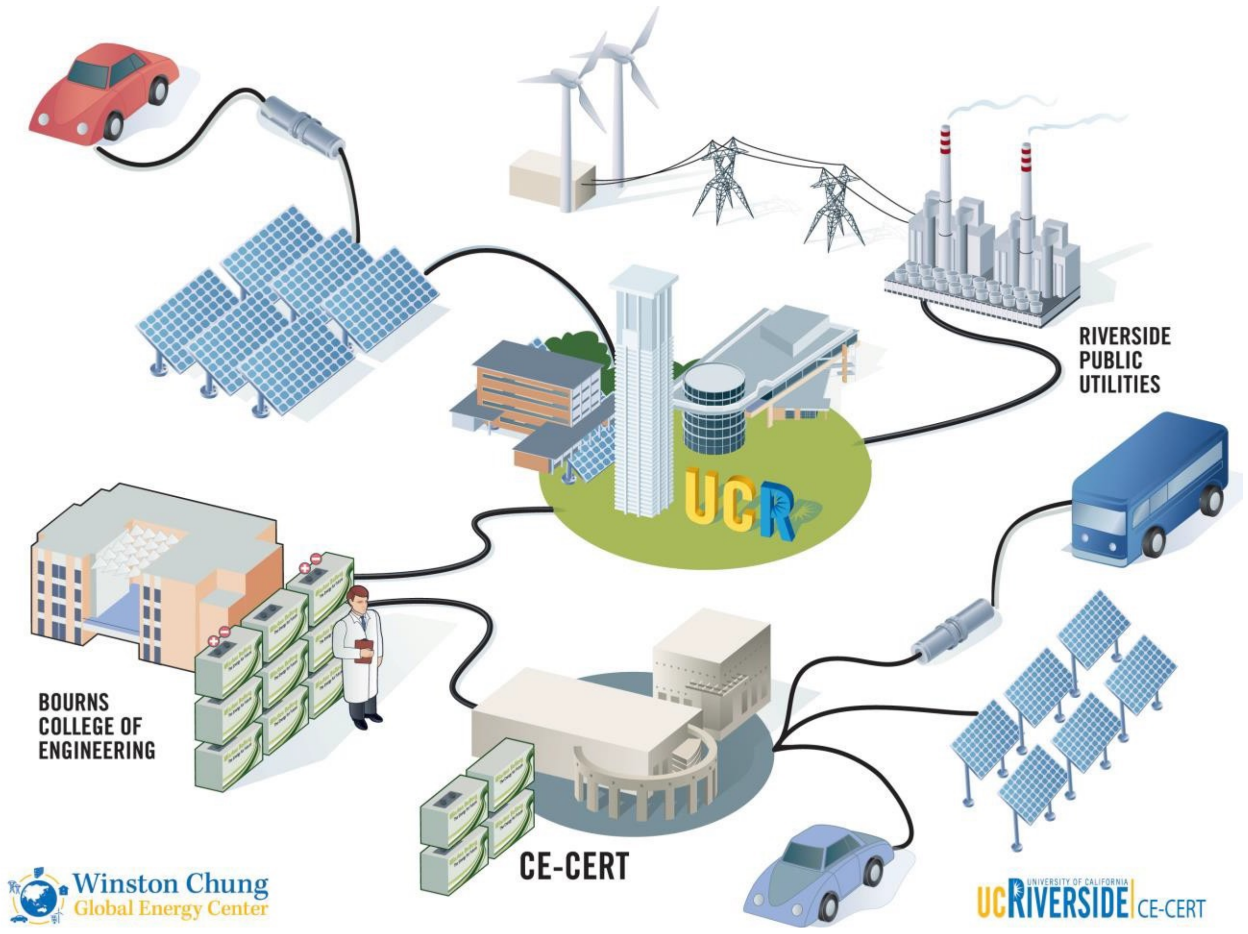

UCR has well established microgrid testbeds and laboratories for pre-commercial testing of new technologies in a "living lab" environment. Over the last seven years, UCR researchers have designed and implemented numerous microgrid systems including 2.2 MWh of battery energy storage, over 11 MW solar PV, 8 MW of Thermal Energy Storage (TES) for chiller operations, and multiple electric vehicle chargers including supervisory control and data acquisition systems.

These unique microgrid/smartgrid testbeds with plug and play capabilities possess the ability to validate various Hardware in Loop (HiL) scenarios. In addition to energy system modeling, UCR can utilize its microgrid testbed for evaluating specific microgrid designs that will be placed elsewhere.

Sustainable Integrated Grid Initiative (SIGI) Testbed

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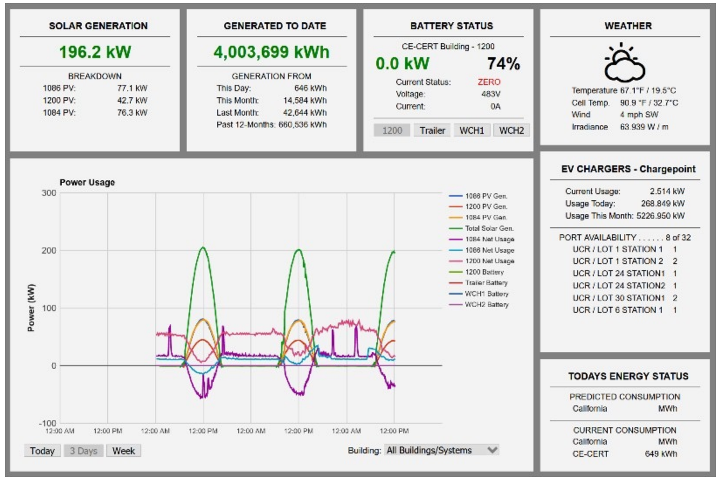
Battery Storage

- 2 MWh integrated battery energy storage
- Stationary and mobile battery platforms
- 10 MW of controllable loads
- Load shifting and peak shaving algorithm optimization
- Demand response

Renewable Energy Generation

- 8 MW of PV solar capacity islanding operation and control
- Curtailment optimization & Soiling evaluation
- Fixed vs. tracking characterization
- Zero net energy microgrid demonstration with storage and load control integration



System Integration

- SCADA microgrid controller development
- Power quality monitoring and analysis with load monitoring and control
- Microgrid optimization
- EV charging with microgrid integration
- Anomaly detection and response

Sustainable Integrated Grid Initiative (SIGI) Testbed

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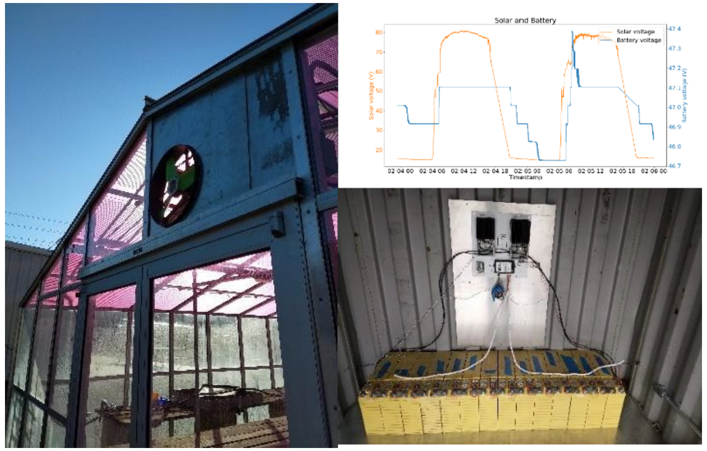

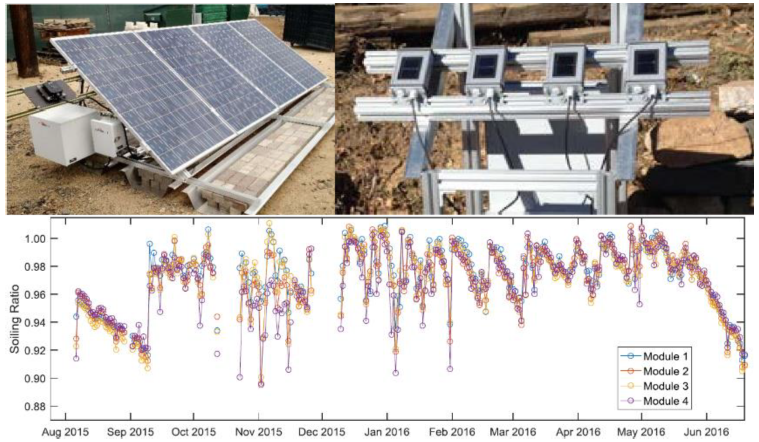

Off-Grid Solar Energy Systems

- Stand-alone (off-grid) system deployment, demonstration, and measurements
- Testing of control algorithms for managing self consumption, loads, and energy storage
- Greenhouse energy management systems (load controller, charge controller, microcontrollers, and battery management systems)

Mobile Renewable Energy Power Systems

- Modular and deployable solar-plus-battery system demonstration and testing
- Portable battery performance cycling and testing
- Solar energy generation, inverter, and load data monitoring, reporting, and analysis
- Versatile and adaptable testbed system

Soiling Testing Stations

- Testbed for testing different module types, coatings, designs, and cleaning cycles
- Soiling, light induce degradation (LID) studies, and potential induced degradation (PID)
- Performance metrology and environmental equipment
- Data collection and analysis methodologies

Sustainable Integrated Grid Initiative (SIGI) Testbed

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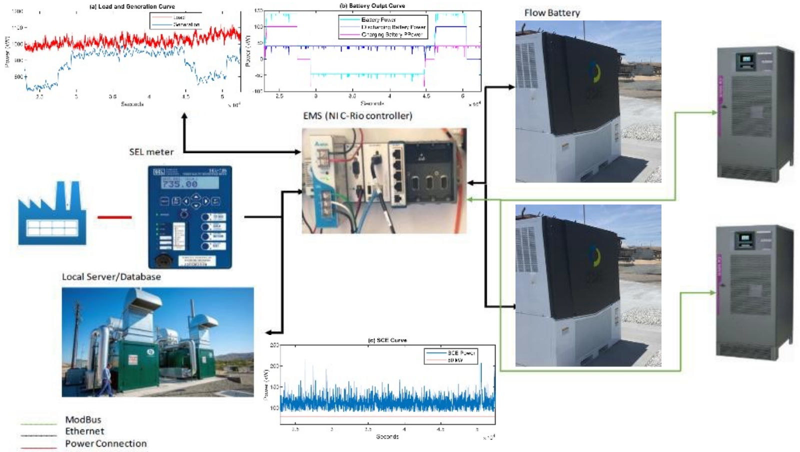
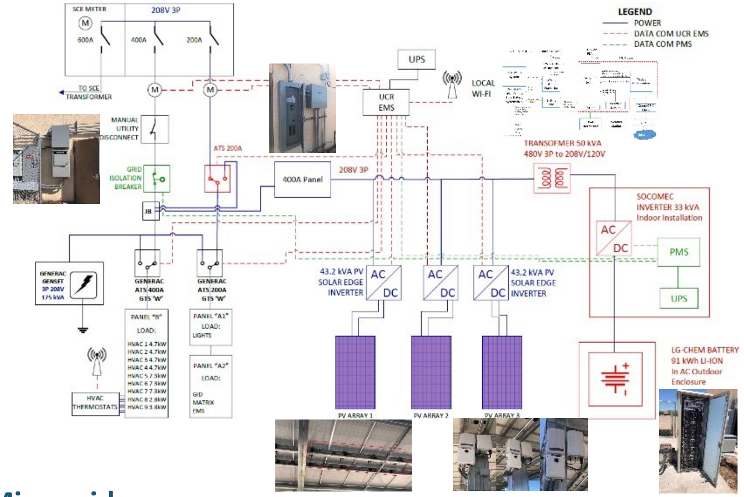


Batteries to Prevent Minimum Import Violation

- Large scale integration of ZnBr flow batteries
- Real time load forecast and dynamic control
- Energy management system and control algorithm development
- Benefit-to-cost analysis
- Minimum import interconnection agreement

Flow Batteries Integration

- Rule 21 and NFPA compliance
- Demonstration of peak shaving, load shifting, demand response, and emergency back-up power
- Energy, economic, and emissions savings analysis
- System optimization based on operational constraints and requirements



Microgrids

- Islanding studies and demonstration Increased grid stability, robustness, and reliability
- Advanced data and energy management systems
- Optimized utilization of solar energy and stored energy
- Implementation of use cases and scenarios
- Measurement and verification (M&V) analysis

Sustainable Integrated Grid Initiative (SIGI) Testbed

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Technology Type	Testing Capabilities
Solar Panels	Soiling, efficiency, curtailment, performance, microgrid integration, islanding
Inverters	Efficiency testing (5kW to MW+), curtailment, islanding, voltage support, reactive power control, grid ancillary services
Battery Energy Storage	Microgrid integration, control optimization, Battery Management System (BMS), performance, islanding
Microgrid Control and Integration	System architecture, net zero configuration, controls, distributed generation, load management
Load Management	SCADA, islanding, microgrid integration, control optimization, energy profiling
Supervisory Control and Data Acquisition (SCADA)	System optimization, system configuration, energy measurement, load management, performance monitoring
Vehicle to Grid	As of 2019, SIGI now offers testing of vehicle-to-grid algorithms using the latest V2G inverter systems.

Field Testing and HiL Testing of Smart Grid Monitoring and Control Technologies

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UC Riverside's Department of Electrical and Computer Engineering, in collaboration with Winston Chung Global Energy Center (WCGEC) and the Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT) has the unique capabilities to test various smart grid sensor technologies (e.g., synchrophasors, synchowaveforms, grid asset sensors, line sensors, substation SCADA systems, behind-the-meter sensors, building sensors, fault location, isolation, and service restoration (FLISR), etc.); as well as various smart grid control technologies (e.g., Volt-VAR control and Volt-Watt control based on inverter-based distributed energy resources (DERs), voltage and frequency ride-through control, DERMS, Advanced Distribution Management Systems (ADMS), distribution-level Flexible Alternating Current Transmission System (FACTS), building energy management, frequency regulation, demand response, etc.). The available field test capability is at medium voltage and low voltage three-phase systems; including a collection of multiple 12 kV power distribution feeders; with various types of loads and DERs.

In addition to true-scale field testing capabilities, UC Riverside also has the capabilities to conduct lab-scale (i.e., pre-field-test) assessment of smart grid monitoring and control technologies by using its state-of-the-art hardware-in-the-loop (HIL) testing facility; including both performance and cyber-security assessment.

Field Testing and HiL Testing of Smart Grid Monitoring and Control Technologies

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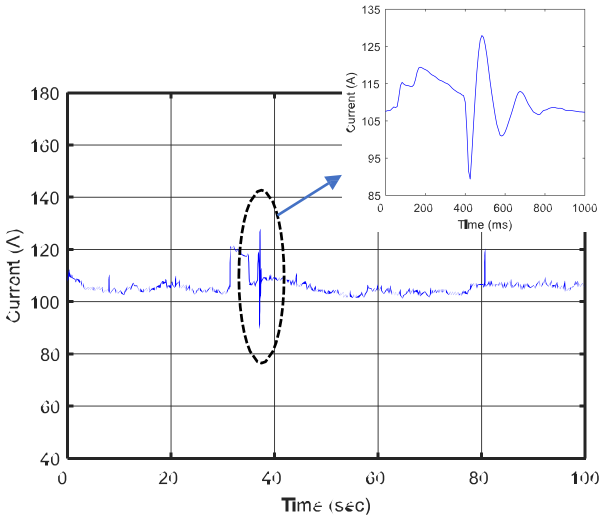
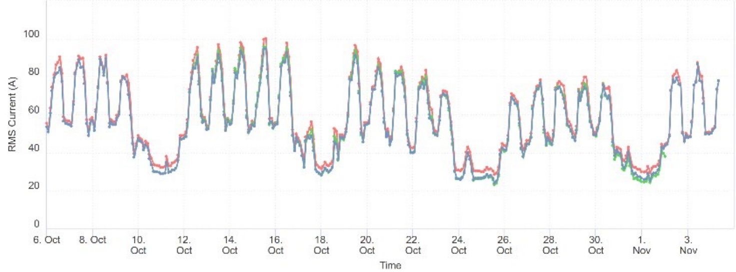
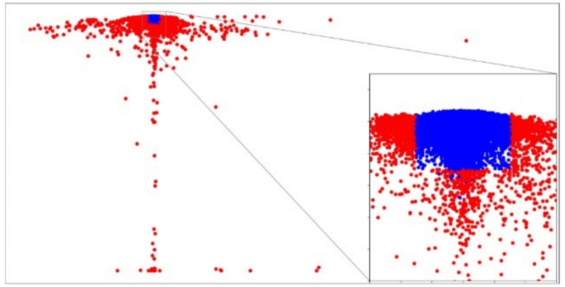


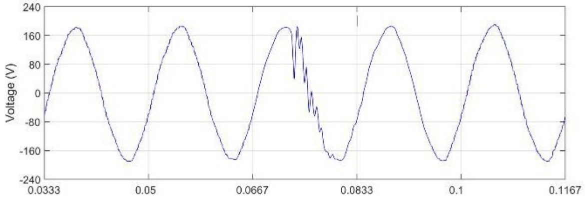


Non-contact Line-Mounted Current Sensors and Fault Indicators (Sentient Line Current Sensors)

GPS-time-synchronized High-resolution Phasor Measurements (PSL Micro-PMUs)

Big-data Analytics





Power quality and waveform sensors (PMI PQ Sensor - Revolution)

Field Testing and HiL Testing of Smart Grid Monitoring and Control Technologies

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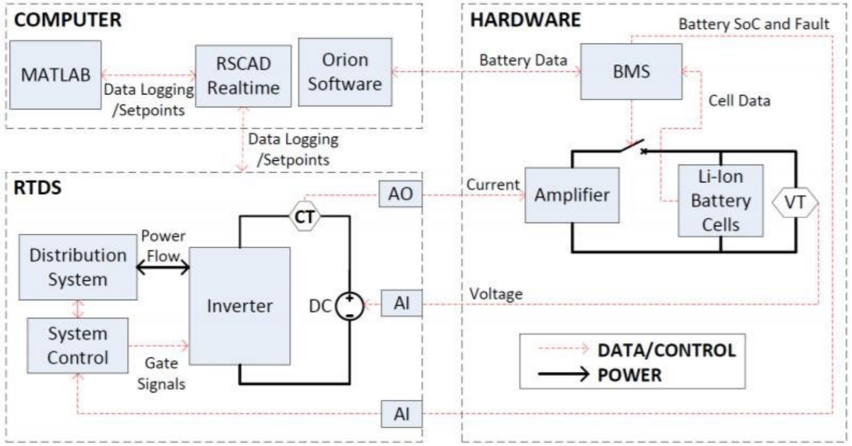
DERMS: DER Management System (SGS DER Controller); supporting inverter-based Volt-VAR and Volt-Watt control

Lab-scale Hardware-in-the-Loop (HIL) testbed with a Real-Time Digital Simulator (RTDS) for Power Grid Simulation.



Vehicle to Grid (V2G) Testing

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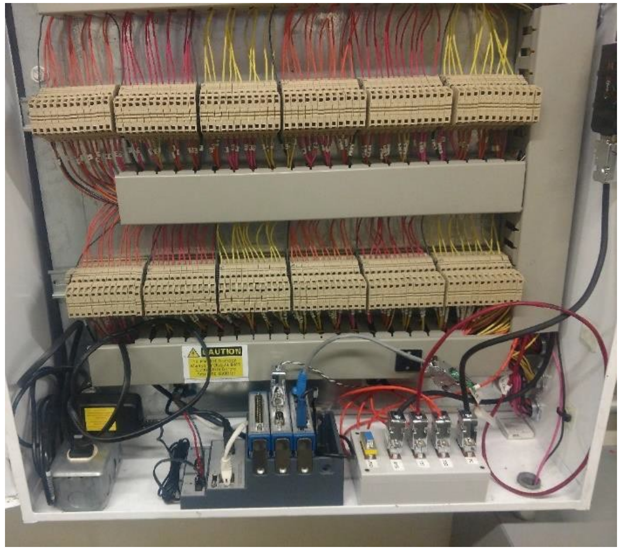

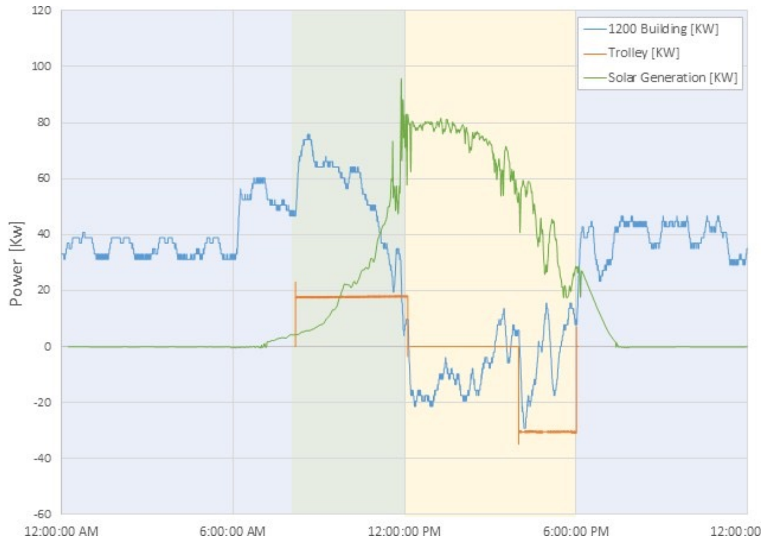

Diesel to Electric Conversions

- Equipped for bi-directional energy transfer
- Light duty and transit vehicle platforms
- 100 kW V2G capability
- Load shifting and peak shaving algorithm optimization
- Demand response

Battery Energy Storage with V2G Integration

- Load management utilizing V2G algorithms
- Smart charging based on distributed generation
- Aggregation algorithm development
- Vehicle activity monitoring
- Carbon based pricing for EV charging

EV charging Monitoring and Control

- Peak shaving and shifting
- Energy cost optimization
- Zero net energy algorithm development
- Utility integrated demand response

Vehicle to Grid (V2G) Testing

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Vehicle to Grid (V2G) architectures allow grid connected vehicles to transfer power from the vehicle back to the electric supply infrastructure. The optimization of V2G requires properly configured vehicles and electric vehicle supply equipment (EVSE).

UC Riverside has created a microgrid testbed with Integrated V2G capabilities. The system utilizes both light duty passenger EVs and larger transit vehicles.

Research is focused on system architectures, controls, optimization, energy management, and communications.

Shown in Picture: Electric Vehicle supplying power to the storage bank (inside trailer) which is connected to the building microgrid

Vehicle to Grid (V2G) Testing

UC Riverside

Technology Type	Testing Capabilities
Electric Vehicle Supply Equipment (EVSE)	V2G capability, performance, measurement, access control, billing, communications
V2G capabilities	Energy measurement, capacity, vehicle connectivity, protocols
Microgrid Control and Integration	System architecture, net zero configuration, controls, load management
Load Management	SCADA, islanding, microgrid integration, control optimization, energy profiling
Vehicle Activity	Energy profiles, trip activity, charging activity, GIS based analysis, vehicle energy monitoring

Materials Synthesis, Device Fabrication and Testing

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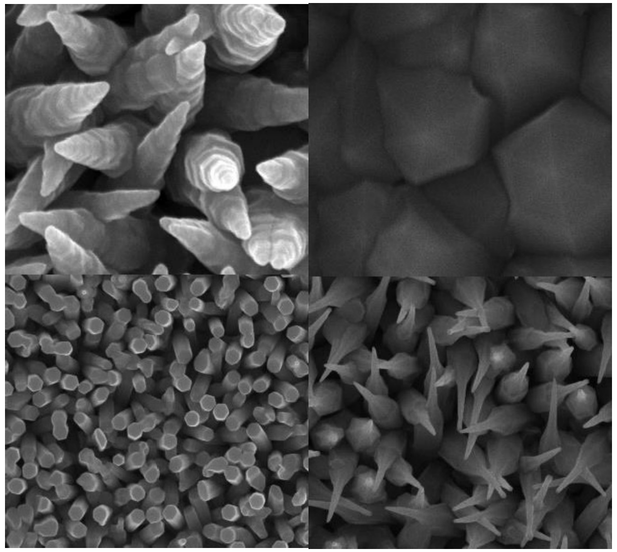
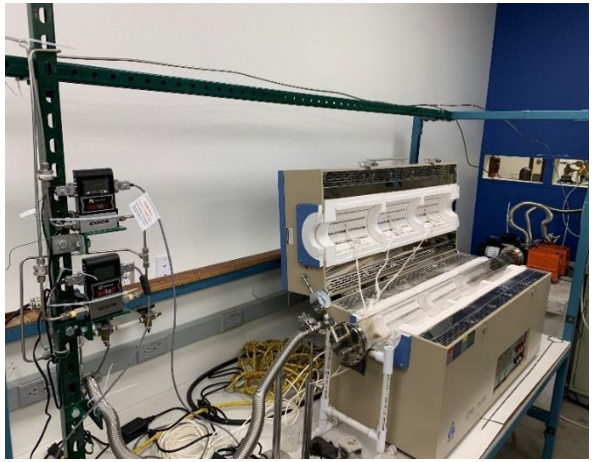


The Advanced Materials and Energy Devices Laboratory (AMEDL) specializes in renewable energy generation and energy storage. The AMEDL group has expertise in the extensive testing of materials and devices for photovoltaic, photoelectrochemical, piezoelectric, delivery platforms, and battery applications. AMEDL's research is focused on experimental work including high quality synthesis of materials, characterization, device fabrication, measurement and testing. Testing includes electrochemical measurements photoresponsive measurement under diverse light sources including a solar simulator and UV lamps.



Materials Synthesis, Device Fabrication and Testing

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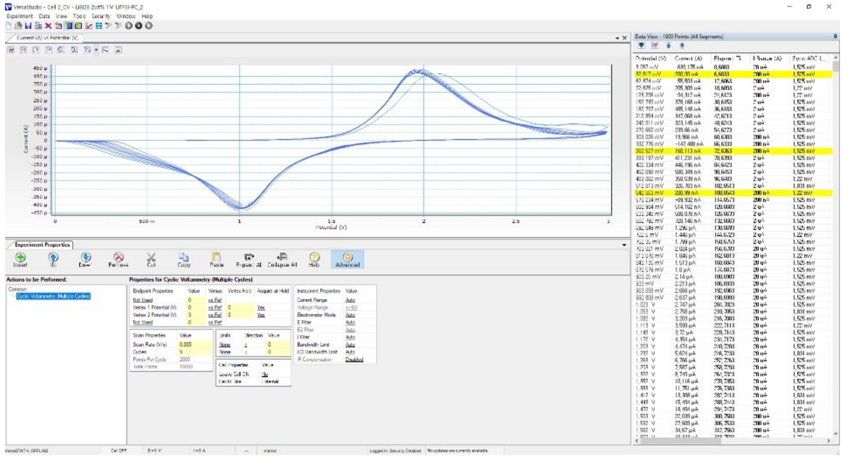

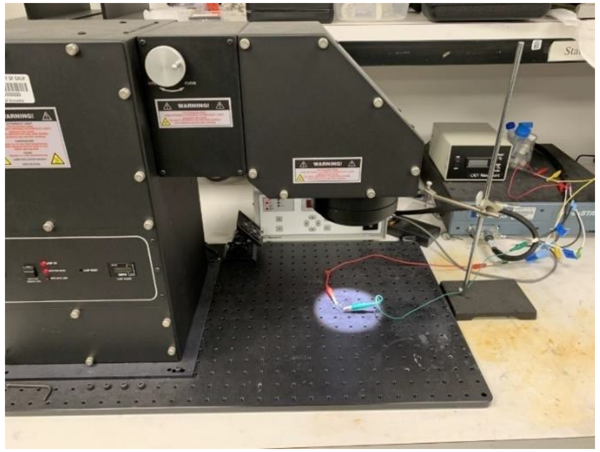

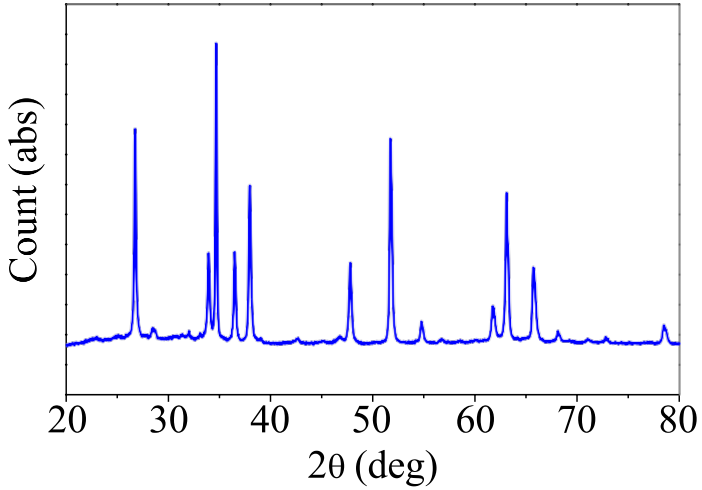

Battery Fabrication and Testing

- Electrochemical depositions and measurements
- Potentiostatic/Galvanostatic and programmed cyclic techniques
- Voltammetry and Electrochemical Impedance Spectroscopy (EIS)
- Current sensitive sensing, corrosion and inhibitors studies, combined with frequency response analyzer (FRA), coating technologies

Solar Cell Fabrication and Testing

- 450 W Xe Class AAA solar simulator
- Calibrated with a Certified IEC 60904-9 Edition 2 (2007) spectral match with a thermocouple
- 0.1 to 1 Sun irradiation power adjustment
- Horizontal and vertical beam path
- UV and visible light filters

Material Synthesis and Characterizations

- Diverse material synthesis and nano-engineering system
- Extensive materials characterization equipment and tools
- Large selection of deposition and etching systems including e-beam physical vapor deposition (EBPVD), sputter, atomic layer deposition (ALD), focused ion beam (FIB) milling and photolithography

Battery and Solar Energy Materials and Device Testing

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Technology Type	Testing Capabilities
Renewable Generation	Solar Cells - Efficiency, stability, testing under artificial environment, and testing of next-generation solar cells
Energy Storage	Batteries - Charging/discharging, cyclic performance, long-term stability, and rate performance
Material-Based	Electrochemical Cells - Cyclic/linear/chrono voltammetry, coulometry and potentiometry, and electrochemical impedance spectroscopy
Material-Based	Materials Characterization - Electron microscopy, optical spectroscopy, crystallographic analysis, elemental analysis, and surface topography
Material-Based	Materials Synthesis - Chemical vapor deposition (CVD), hydrothermal and solvothermal synthesis, and electrodeposition
Material-Based	Device Fabrication - Thin-film devices, solar cells, photoelectrochemical cells, electrochemical cells, and coin-cell batteries

Shared, Electric, Connected, and Automated Vehicle Testing

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When considering how to get to zero-carbon mobility, there are generally four strategies to consider: 1) build more efficient vehicles that emit less carbon (e.g., HEVs, BEVs, and fuel-cell EVs); 2) utilize low- or zero-carbon fuel such as electricity or hydrogen; 3) implement programs that reduce overall VMT; and 4) employ ITS and automation technology to improve transportation system efficiency. UC Riverside has set up testbeds to evaluate Shared Mobility (addressing strategy 3), Transportation Electrification (addressing strategies 1 & 2), and Connected and Automated Vehicles (addressing strategy 4).

Shared, Electric, Connected, and Automated Vehicle Testing

UC Riverside

A key vehicle testbed, the *Innovation Corridor,* located in Riverside, California, consists of a six-mile section of University Avenue between the main UCR campus and downtown Riverside. This arterial corridor has been outfitted with traffic signal controllers that broadcast signal phase and timing, employ video analytics, and is used for experimentation with shared, electric, connected and automated vehicle (e.g., cars, buses, and trucks).

https://www.cert.ucr.edu/transportation-systems-vehicle-infrastructure-interaction/city-riverside-innovation-corridor

Shared, Electric, Connected, and Automated Vehicle Testing

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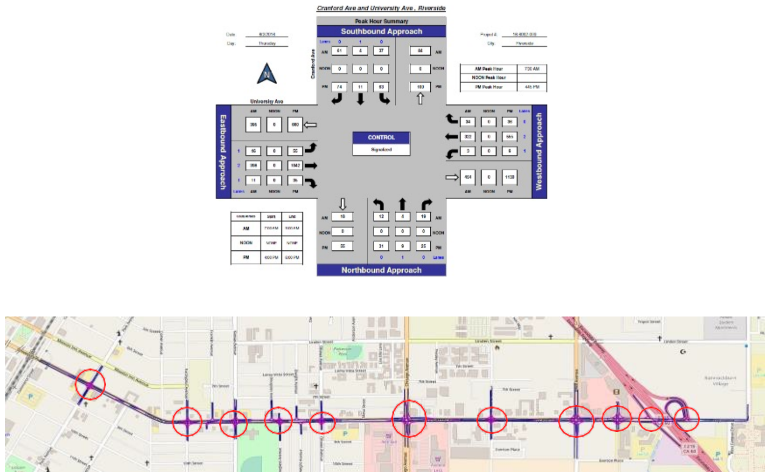

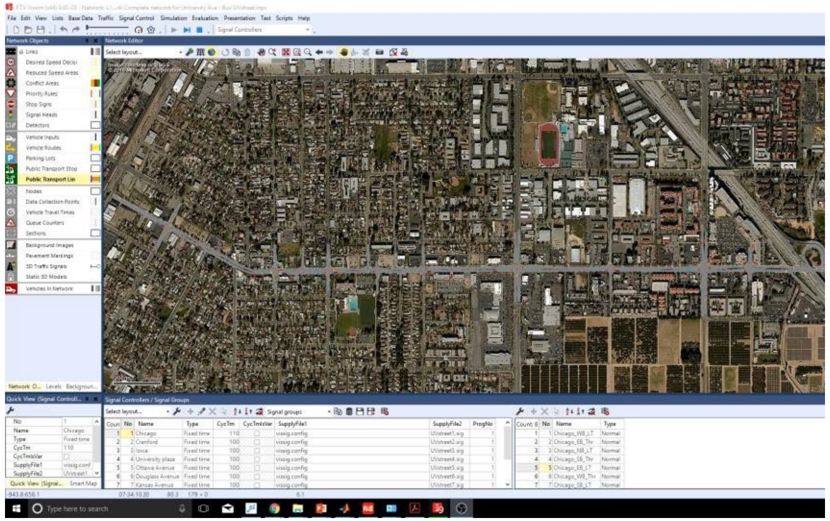

Innovation Corridor

Consists of 10 instrumented intersections along a 4-lane urban arterial. Intersections utilize modern traffic signal controllers that broadcast signal phase and timing and employ video analytics; Corridor also has multiple air quality monitors.

Example connected vehicle application

The corridor is used to conduct Eco-approach and departure studies at signalized intersections. Vehicles can “listen” to an upcoming signal’s phase and timing and adjust their speed to reduce energy consumption and improve throughput.

Demo at: https://youtu.be/j9Tg2g9YTjc

Simulation and testing platforms

Complementing real world testing, modeling enables the projection of mobility and environmental benefits from the wide-scale adoption of shared, electric, connected and automated vehicle technologies.

Shared, Electric, Connected, and Automated Vehicle Testing

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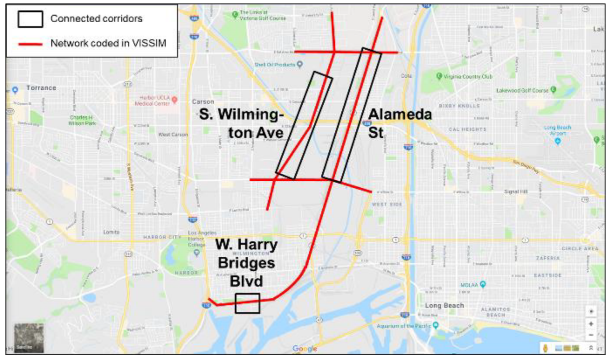
Southern California CAV Testbed



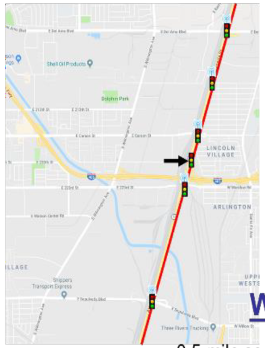
Los Angeles Testbed

UCR has set up three arterial corridors with 15 connected traffic signals nearby the port of Los Angeles to support a variety of connected truck applications such as Eco-Approach and Departure, freight signal priority.

See demo at: https://youtu.be/1CR4vMh8ufE

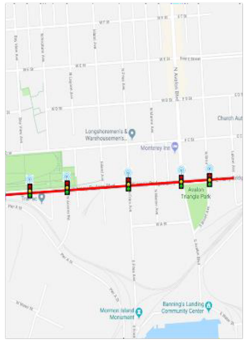
Alameda St

- 3-mile segment
  - 2-3 lanes per direction
  - 45 mph speed limit
- 6 traffic signals
  - 5 connected
  - Actuated signal control



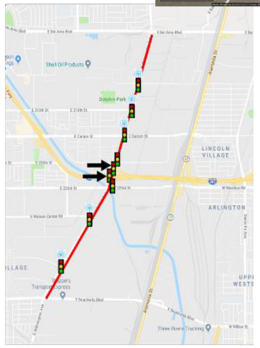
W. Harry Bridges Blvd

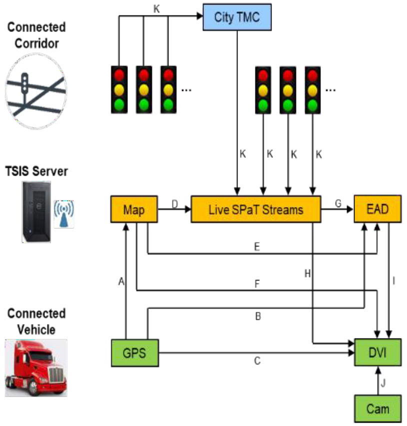
- 0.5-mile segment
  - 2 lanes per direction
  - 35-40 mph speed limit
- 5 traffic signals
  - 5 connected
  - Fixed-time signal control



S. Wilmington Ave

- 2-mile segment
  - 2 lanes per direction
  - 40 mph speed limit
- 9 traffic signals
  - 5 connected
  - Actuated signal control





Component	Description
City TMC	Traffic management center
Map	Digital map of Southern California
Live SPaT Streams	Real-time SPaT from connected intersections
EAD	Eco-Approach and Departure algorithm
GPS	GPS for identifying truck position
Cam	Camera for detecting preceding vehicle
DVI	Driver-vehicle interface on tablet

ID	Data Elements	Update Frequency (Hz)
A	Latitude, longitude, & heading	1
B	Veicle speed (GPS)	1
C	Veicle speed (GPS)	10
D	Upcoming intersection & direction	1
E	Distance to intersection	1
	Roadway speed limit	1
F	Distance to intersection	1
	Roadway speed limit	1
G	Upcoming SPaT	1
H	Upcoming SPaT	1
I	Recommended driving speed	10
J	Preceding vehicle detection signal	10
K	Real-time SPaT	1

Traffic Signal Information System (TSIS)

The connectivity of these connected traffic signals is enabled by 4G/LTE cellular communication where real-time signal phase and timing (SPaT) information is sent to the Traffic Signal Information System (TSIS) server at UCR. Vehicles traveling on the testbed can request and receive the SPaT information from the TSIS server through the same cellular communication. Currently, the testbed is being used to test and evaluate an EAD application for heavy-duty trucks, developed by UCR.

Shared, Electric, Connected, and Automated Vehicle Testing

UC Riverside

Technology Type	Testing Capabilities
Shared Mobility Evaluation	Using LBNL's BEAM model, travel demand activity can be evaluated for a number of shared mobility scenarios, measuring a variety of performance metrics
Evaluating Connected and Automated Vehicles (CAVs) in Simulation	Using a wide range of simulation tools (e.g., VISSIM, PARAMICS, SUMO) and specific APIs, a wide range of CAV scenarios can be tested
Evaluating Connected and Automated Vehicles (CAVs) using Hardware in the Loop testing	A unique hardware-in-the-loop testing system for CAVs has been developed, combining traffic simulation and a real-world vehicle on a dynamometer
Evaluating Connected and Automated Vehicles (CAVs) on the road	UCR has developed several CAV testbed sites in Riverside California, and Carson California, installing communication infrastructure on the road

Electrical Motor Systems Testing Laboratory

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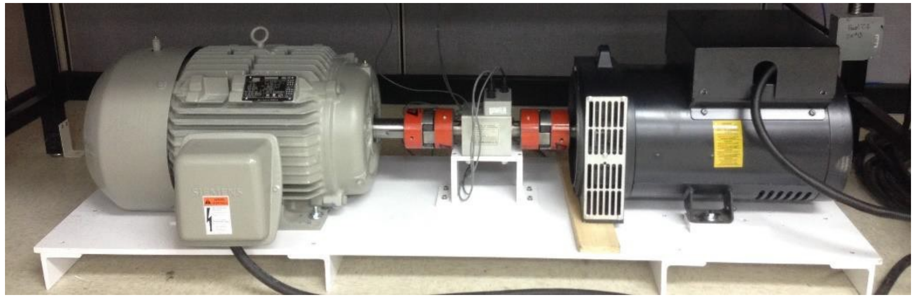
This testing facility, developed with California Energy Commission (CEC) funding, is capable of efficiency and load testing of electric motors and Adjustable Speed Drive (ASD) up to 100hp. The facility can also measure electric system harmonics.

This is the first independent electric motor testing center in the state of California capable of providing unbiased evaluation of motor efficiency at various operating conditions. This facility is available for the use by the industry professionals, academics, and other stakeholders.

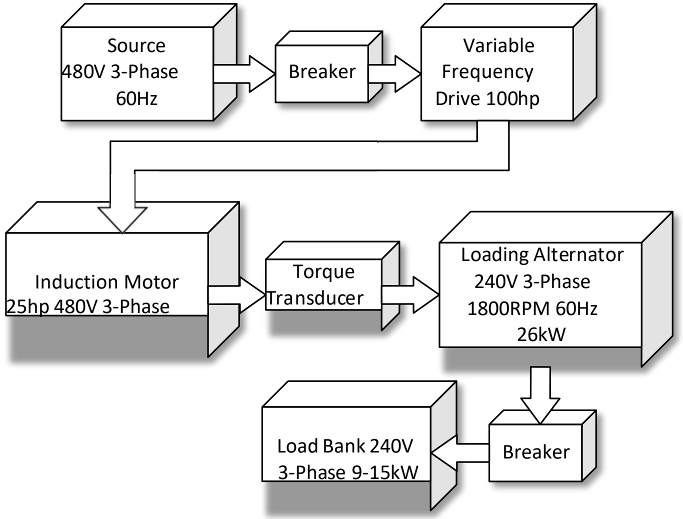
Electrical Motor Systems Testing Laboratory

UC Riverside



motor torque transducer loading generator

power analyzers



Motor Efficiency Measurement & Verification

Output power is monitored and measured using the torque transducer, which separates the load from the motor to isolate output measurement at the shaft of the motor.

External portable Fluke Power Analyzers enable the accurate measurement of both input and output power necessary to find operational efficiency of a motor. This used to verify efficiency of an electric motor.

Improving Software for Efficient Motor Selection

- Many commercial and in-house software used by architectural and engineering firms design HVAC systems with inflated safety factors used in calculating three-phase motor sizes for buildings
- UCR quantifies energy waste due to the: (i) use of lower efficiency motors, (ii) use of oversized motors in existing buildings, and (iii) selection of oversized motors in the architectural and engineering design stage of new buildings.

Electrical Motor Systems Testing Laboratory

UC Riverside

Technology Type	Testing Capabilities
Industrial Electric Motors	Zero to Rated Torque, Efficiency at Various Loading Condition, Quantification of Voltage and Current Harmonics, Range 0-100hp
Variable Frequency Drives	Efficiency at Various Loading Condition, Quantification of Voltage and Current Harmonics, Range 0-100hp
Wind Generators	Zero to Rated Torque, Efficiency at Various Loading Condition, Quantification of Voltage and Current Harmonics, Range 0-100hp
Custom Designed Special Purpose Electric Motors	Zero to Rated Torque, Efficiency at Various Loading Condition, Quantification of Voltage and Current Harmonics, Range 0-100hp

Water Energy Nexus

UC Riverside

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CE-CERT
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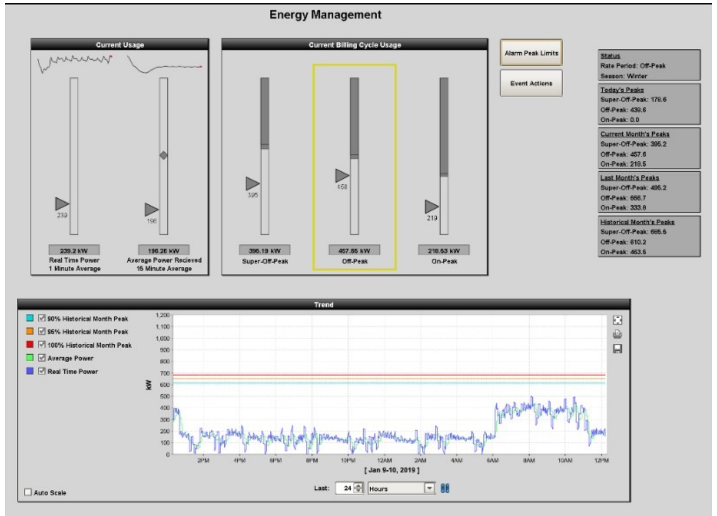
About 20% of electricity use in California is treating, pumping, and distribution of water. With funding from California Energy Commission (CEC), College of Engineering – Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside (UCR) has demonstrated and deployed an energy management and data acquisition and supervisory control strategies that reduce peak loads and electricity costs in the delivery and treatment of water at each of the three water district locations. The three deployments utilize existing on-site SCADA architecture and implement the Energy Management System (EMS) within the existing architecture.

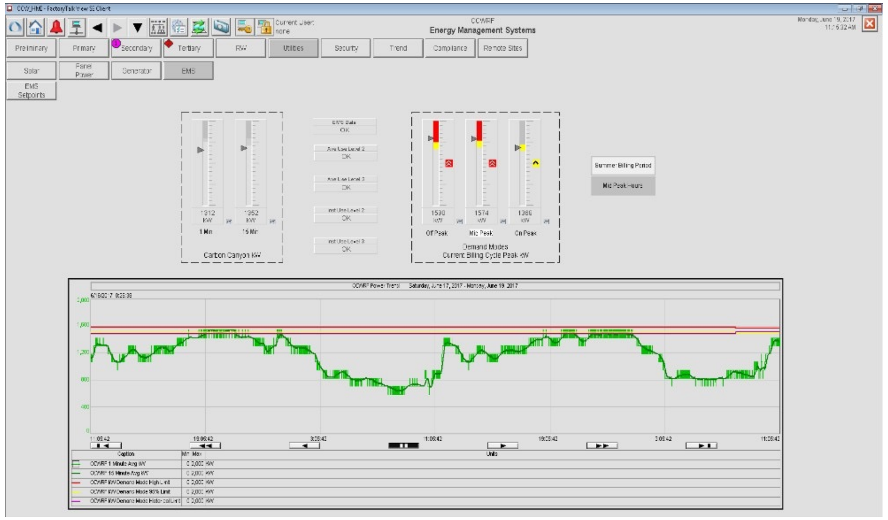
This demonstration project highlights a pathway for water agencies in California to reduce their peak energy consumption substantially with no decrement in service or reliability. The project also identifies "real world" Implementation issues that have not emerged in previous proof-of-concept research.

California Energy Commission
Olivenhain Municipal Water District
Cucamonga Valley Water District
Inland Empire Utilities Agency — A Municipal Water District
OSIsoft
OPTO 22
SDGE — A Sempra Energy utility
Southern California Edison — An Edison International Company

Water Energy Nexus

UC Riverside





Water Delivery Optimization

Integration of software and hardware at water delivery pumping, storage, or treatment facilities that enable the integration and transmission of data from energy meters directly or indirectly into Supervisory Control and Data Acquisition (SCADA).

Reducing Peak Energy Consumption

This demonstration project highlights a pathway for water agencies in California to reduce their peak energy consumption substantially with no decrement in service or reliability.

The project also identifies “real world” implementation issues that have not emerged in previous proof-of-concept research.

Individual SCADA System Integration

Combined with historical energy use integrated with real time SCADA control displays, operators can manage systems in real time to monitor and control peak demand.

Real time energy usage monitoring provides both instantaneous and 15min average relative to Time of Use (TOU) rate schedules, and alarm notifications optimized to provide operators with real time energy demand and the current existing peak load that has been recorded to date.

Water Energy Nexus

UC Riverside

Technology Type	Testing Capabilities
Energy Management System (EMS)	Customized Development and Validation
Supervisory Control and Data Acquisition (SCADA)	Customized Development and Validation
Real-Time Monitoring System Software and Sensors	Development, Testing, and Validation

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