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UNIVERSITY OF CALIFORNIA, SAN DIEGO
Jacobs School *of* Engineering

ARPA-E Cycling Hardware to Analyze and Ready Grid-Scale Electricity Storage (CHARGES) University of California - San Diego

EESAT Conference

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arpa·e
CHANGING WHAT'S POSSIBLE

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UC San Diego 42 MW Microgrid

UC San Diego Operates a 42 MW_{peak} Microgrid

Campus Quick Facts

With a daily population of over 45,000, UC San Diego is the size and complexity of a small city.

As a research and medical institution, we have **TWO** times the energy density of commercial buildings

12 million sq. ft. of buildings, $200M/yr of building growth

Self generate 92% of annual demand

- **30 MW natural gas Cogen plant**
- **2.8 MW of Fuel Cells installed**
- **2.2 MW of Solar PV installed, with another 0.8 MW planned in 2013**

UCSD Energy Storage Projects

Operational

- 10 kW, Sunverge, Scripps Institute of Oceanography
- 108 kW, 180 kWh BMW, demonstration of application of 2 nd use EV batteries, coupling to 330 kW PV, and Fast EV Level 2
- 3.8 Million Gallon Thermal Energy Storage Tank (Adding two TSE 2x1.2 MG)

To be operational 2015

- 2.5 MW, 5 Mwhr, SGIP Advanced Energy Storage, Lithium-ion from BYD
- 25 kW / 40 kWh Amber Kinetics, Flywheel energy storage
- 28 kW, Maxwell Labs, Ultracapacitors, Smoothing of PV intermittency, coupled with solar forecasting
- MCV 35 kW, 35 kWh Compact Li-Ion energy storage system
- NRG 100 kWh Li-ion, PV integrated energy storage with EV DC Fast Charging

Future Planned

- 730 kW, 1460 kwhr SGIP PV Integrated, five off campus sites

ARPAE CHARGES Project

Objective: Accelerate the commercialization of electrochemical energy storage systems developed in current and past ARPA-E-funded research efforts.

- Evaluate energy storage performance in both laboratory controlled and grid connected conditions.
- Conduct economic valuation of performance under real-world islanded and grid connected conditions.
- Use actual energy markets to determine charge/discharge duty cycles and test protocols

ARPAe CHARGES Project AT UCSD

- Test protocols defined by simulation and modeling of battery energy storage system based on actual market pricing
- Test Protocols based on 5 Energy Storage Use Applications
  - Load Shifting
  - Congestion Relief
  - Area Regulation
  - Demand Charge Management
  - Frequency Regulation & Ramping
- Stacked use cases application to be also tested
- Economic valuation to be conducted for each energy storage system performance
- Cell Level Testing
- Module Testing, Laboratory and Grid Connected

UCSD ARPAE CHARGES Overview

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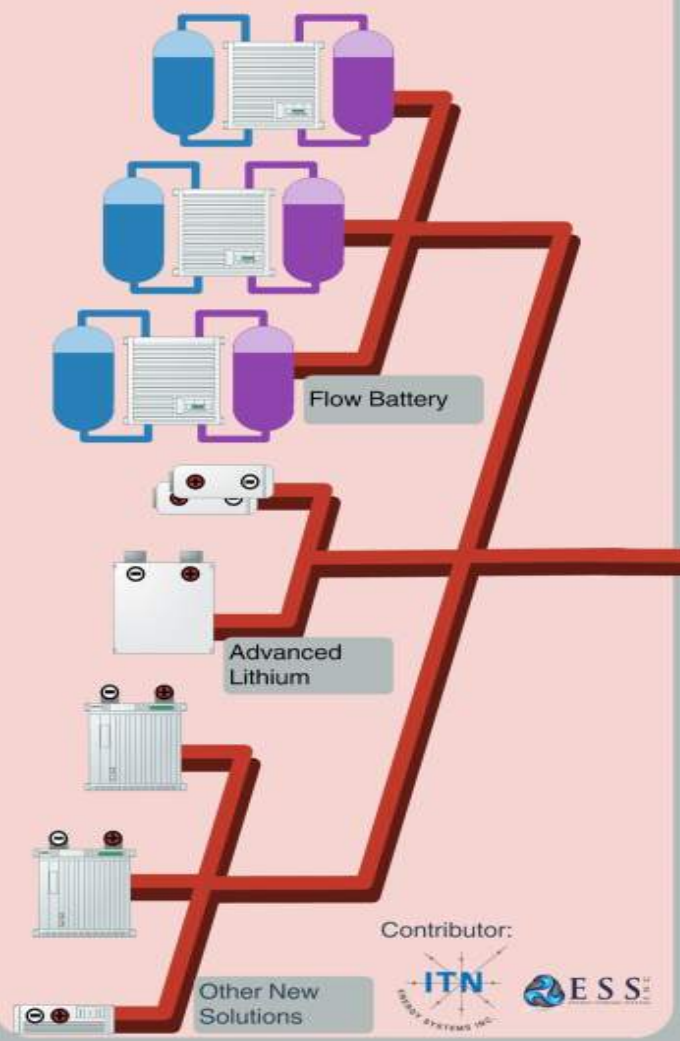
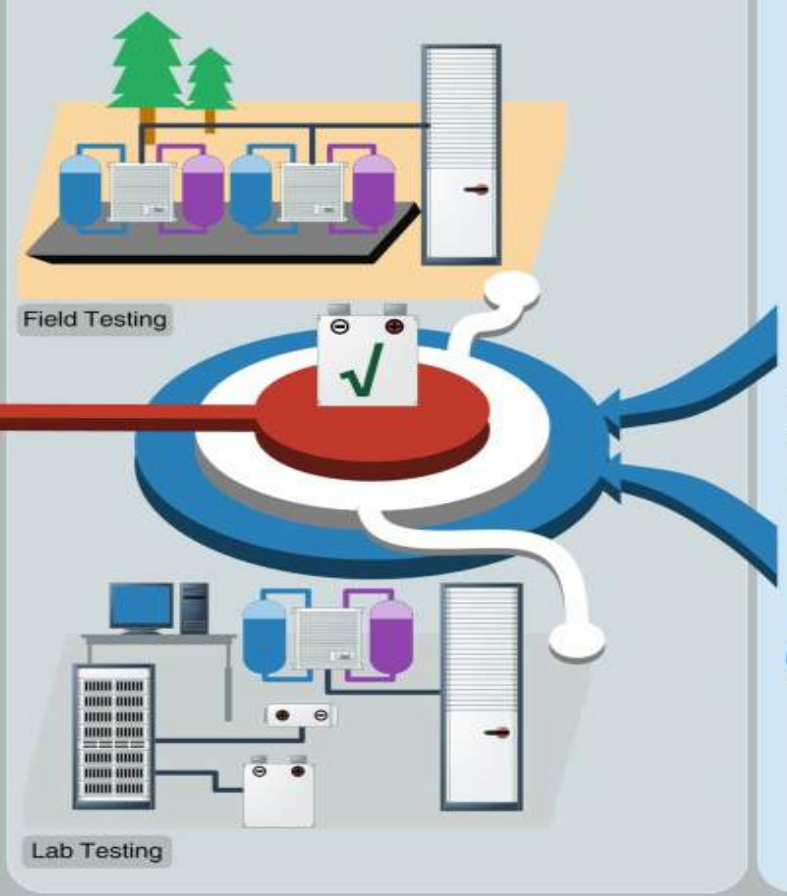
ARPA-E CHARGES ADVANCED ENERGY STORAGE MODELING, PERFORMANCE EVALUATION and TESTING

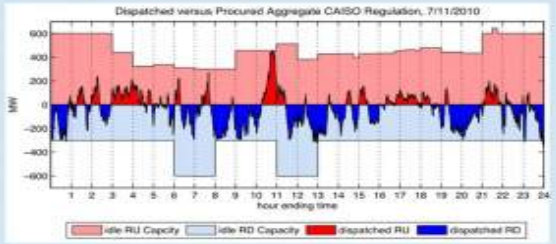
State of the art ESS solutions



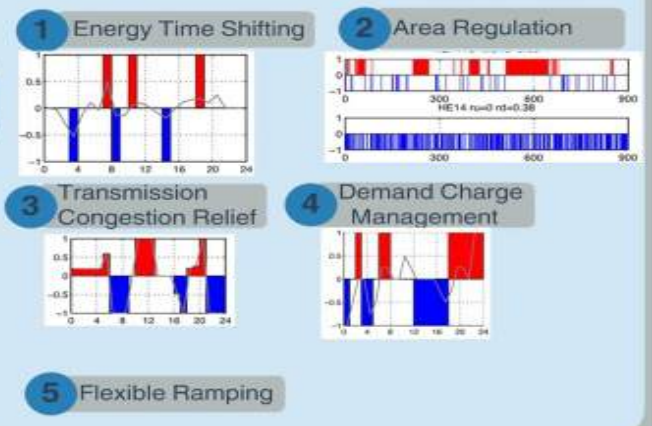
Comprehensive cell and module testing, and grid connected field testing



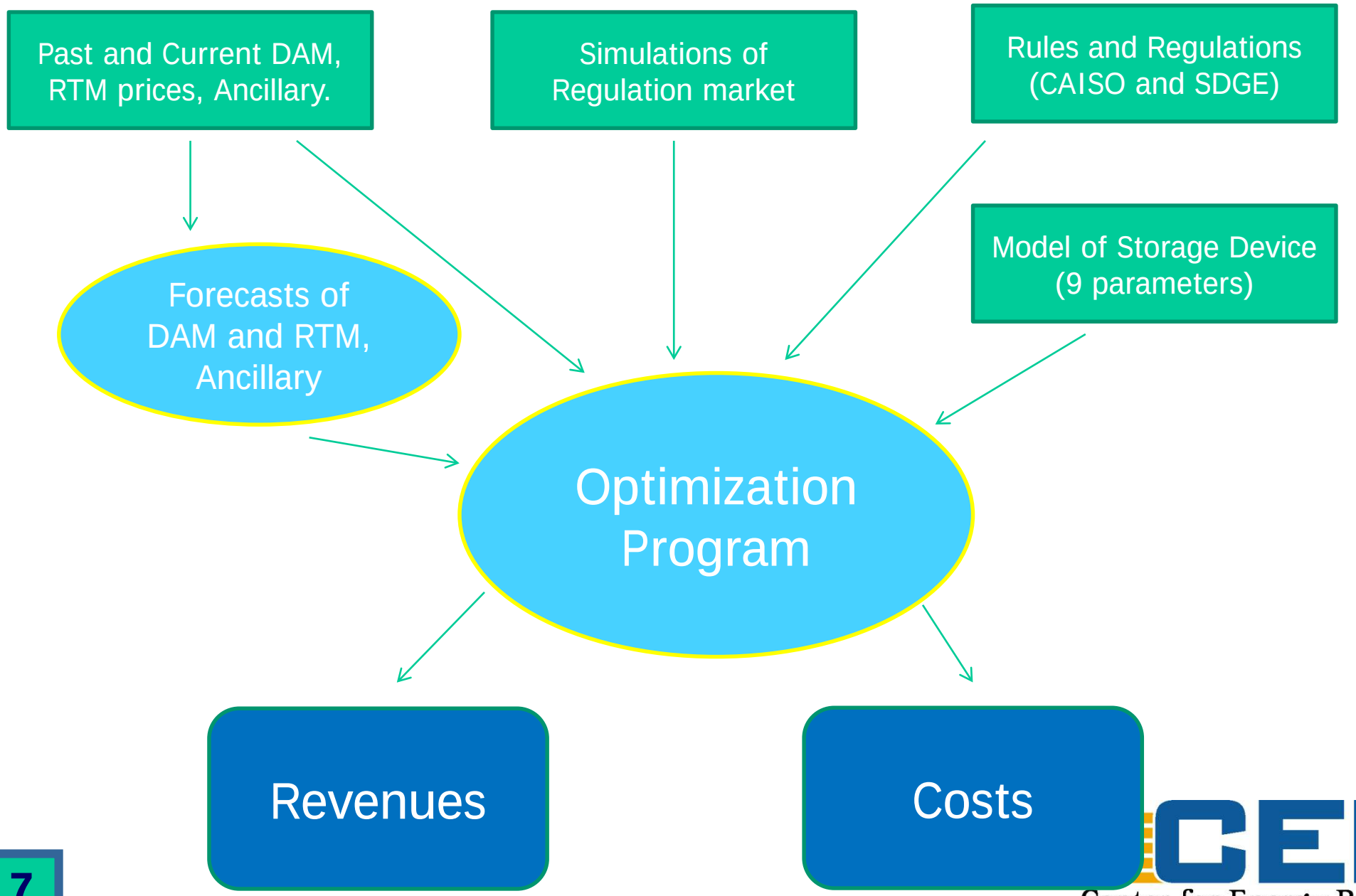
Economy modeling based on real market



Testing protocols reflecting real grid system challenges



Economic Modeling and Valuation



Basic Parameters

Electric Energy Time-Shift

Congestion Relief

Demand Charge Management

- Capacity ratings
- Round trip efficiency
- Stability
- Power capability

Area Regulation

Fast Ramping & Frequency Regulation

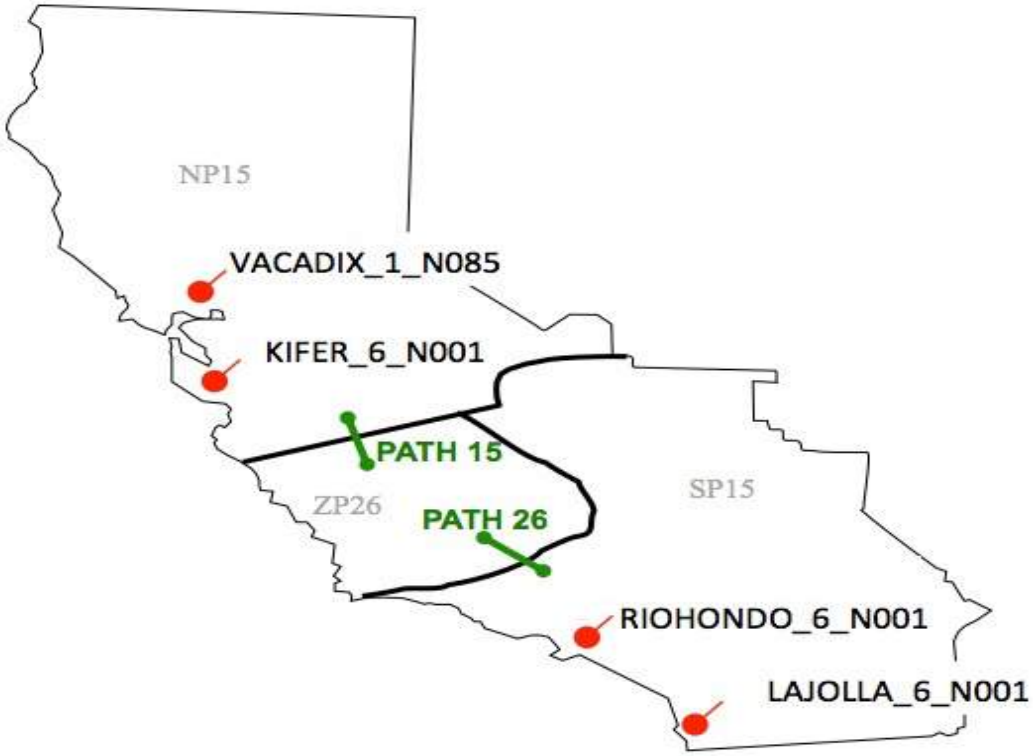
- Response time
- Duty cycle efficiency
- Rate performance

Actual Nodal Pricing Used For Economic Valuation

- Economic valuation of individual and combinations of stacked applications was performed at the following pricing nodes:

LAJOLLA_6_N001
VACADIX_1_N085
RIOHONDO_6_N001
KIFER_6_N001

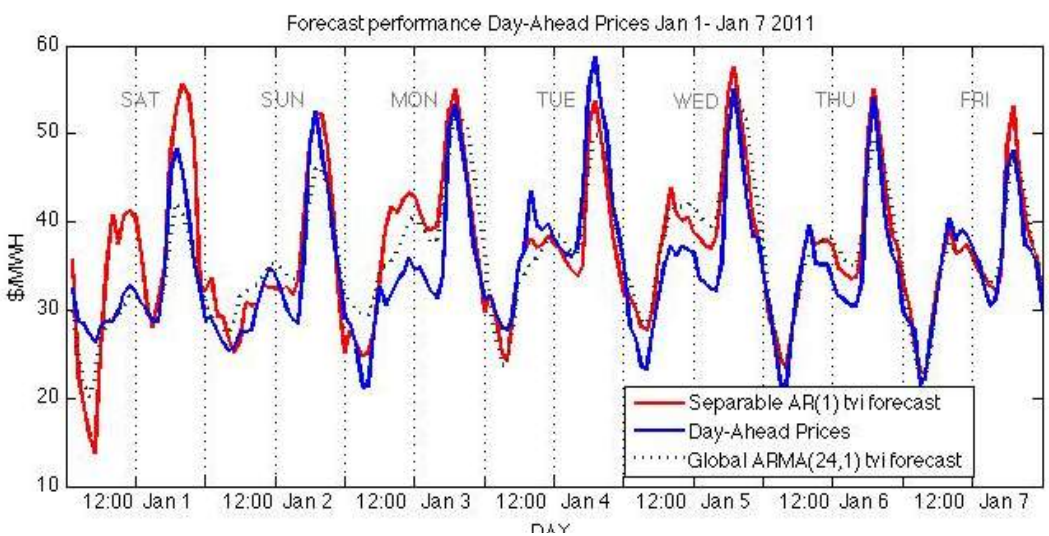
- Selection based on congestion patterns observed in CAISO



Valuing Electric Energy Time Shift

Forecast Models for DAM-RTM Electricity Price

Simple models using load forecasts and past prices



RTM prices (particularly the timing of spikes) are more difficult to forecast.

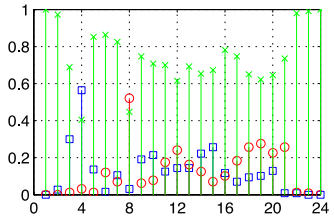
Test Protocol Developmental Assumptions

- Test protocols developed for all five use case applications based on energy market pricing.
- Fast Ramping market not fully developed within CAISO, some assumptions on the expectation of the market were made.
- Long term AGC and frequency regulation data is difficult to obtain and make it difficult to model market conditions.
- Test protocols are adjusted to match individual ARPAe battery performer's batteries (power/energy ratio, and round trip efficiency)

Regulation Markets

- Minimum requirement to receive payments for either energy or regulation services is ability to ramp up/down to a dispatched power level within 10min
- Ramp Rates and “flexibility” of resource when following 4 sec AGC is rewarded via Mileage Payments, depending on how close is the actual power output to the dispatched level
- From economic dispatch perspective only quantity of energy charged/discharged is a choice variable, i.e. Mileage Payments do enter Linear Optimization Programs
- One-week trials for each technology will be run using available AGC snapshots

Load Shifting Test Protocol Developed

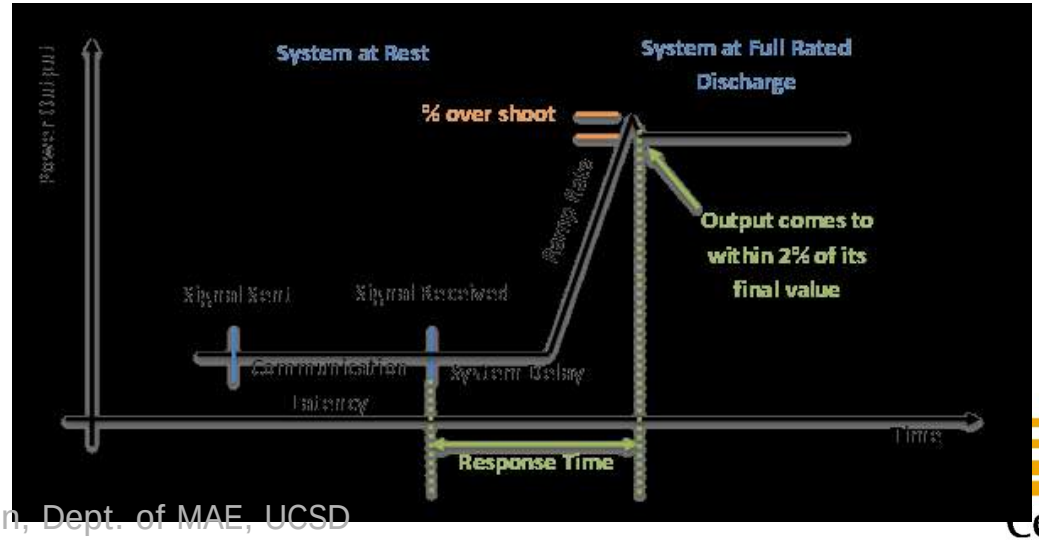


Battery Module Testing Procedures

- The "**Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems"** Sandia Labs (SAND2013-7084) will be used to ensure uniformity of testing
- **Data Recording:** All measurements of charge rate, input current and voltage, output current and voltage, thermal output, system temperatures, ambient conditions, and other parameters shall be collected simultaneously at a temporal resolution applicable to the function of the system application.
- **Reference Performance Test:** A reference performance test will be performed at the beginning of battery testing to establish a baseline for battery performance. And will be performed periodically through testing. (Capacity test, efficiency test, response time test).
- **Capacity Test:** After the initial charge to the ESS, the system shall be discharged to the minimum storage level specified by the manufacturer. Recorded values of energy input to the system shall be obtained by recording them at regular intervals of time or at step or percentage variances at a rate that is documented by the manufacturer to provide adequate resolution.

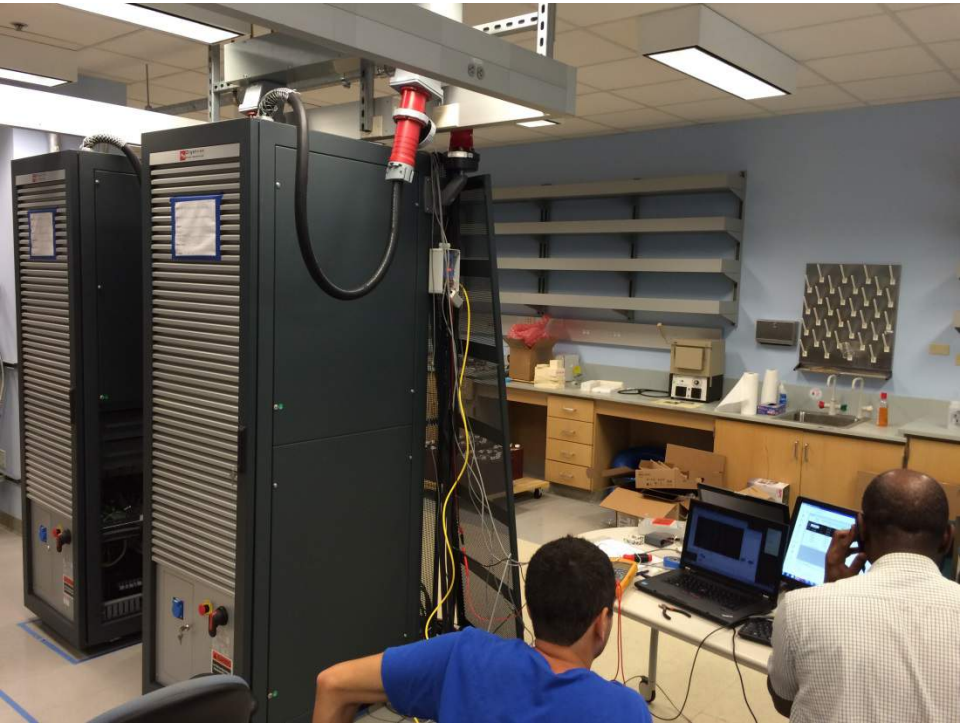
Battery Module Testing Procedures

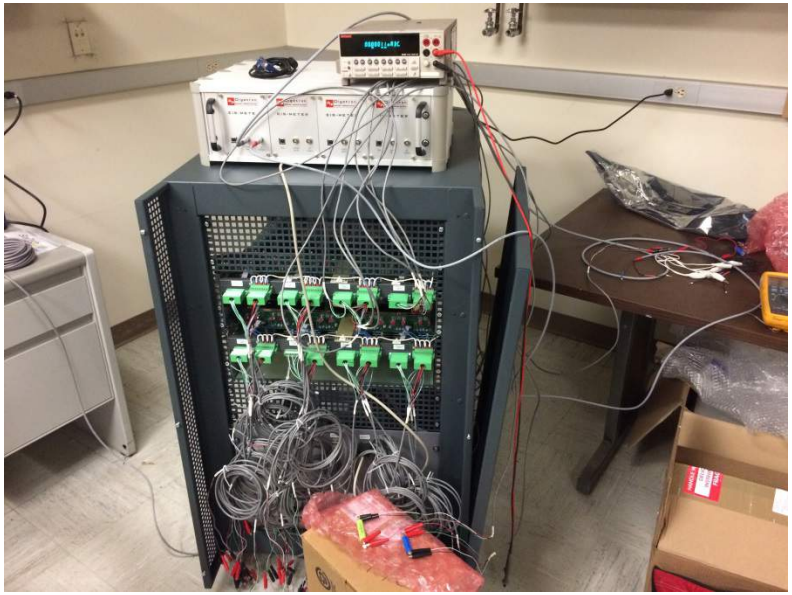
- **Roundtrip Efficiency Test:** A roundtrip energy efficiency test shall be conducted to determine the amount of energy that an energy storage system can deliver. This test shall be performed using the energy test routine and the applicable duty cycle for the intended application of the system.
- **Response Time Test:** The response time shall be measured in accordance with figure below starting when the signal is received at the system boundary, to when the system begins to discharge within 2 percent of the rated power of the system.



State of the Art Laboratory Battery Testing

- Bi-Directional battery module testing equipment placed with 10 Channels with 10 kW each capacity, voltage range of 0 – 100 V DC
- Can be ganged together to test batteries up to 100 kW
- One channel with voltage range 0 – 150 V
- Options to interface BMS and Data Logger
- Interface developed to stream data to UCSD's OSI PI historian
- 16 channel cell testing, and impedance scanning system





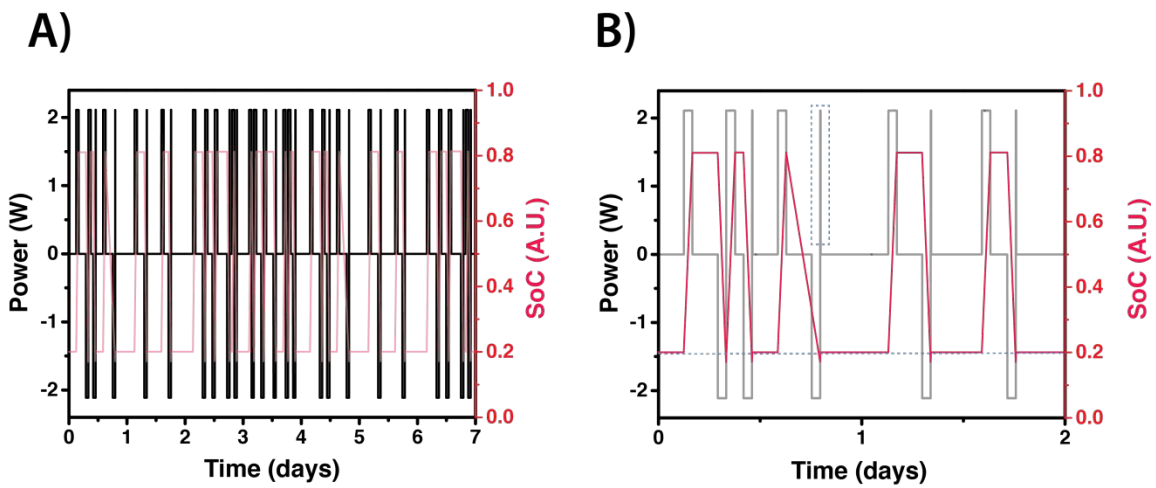
ITN Battery Vanadium Flow Battery Testing

- 1 kW/ 3 kWhr rating
- Vanadium Redox
- Control system interfaced with UCSD's data collection system

Initial Testing Results

- Constant power testing, round trip efficiency measurements completed.
- Replication of factory testing completed
- Impedance pulse testing completed, impedance model of battery system developed.
- Reference Performance Test (per testing procedure 7.3 established by Sandia and PNNL) completed
- First cycling using economically driven load shifting application test protocol to begin this week.

Lithium-ion Baseline Testing

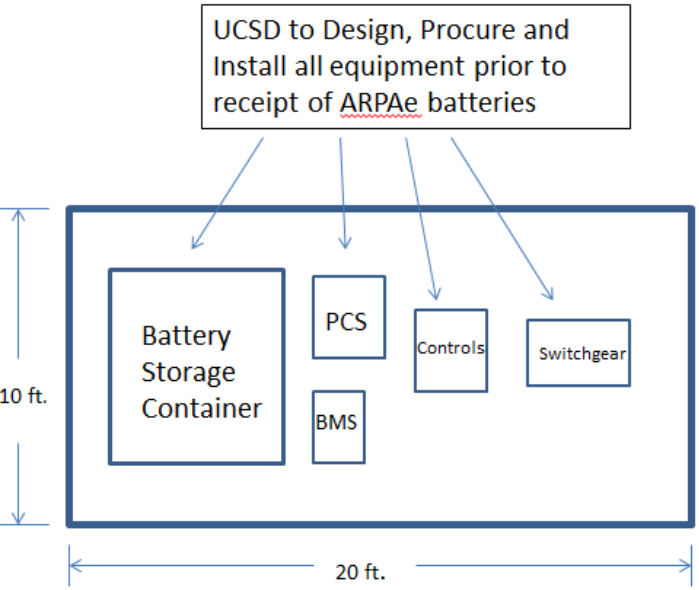


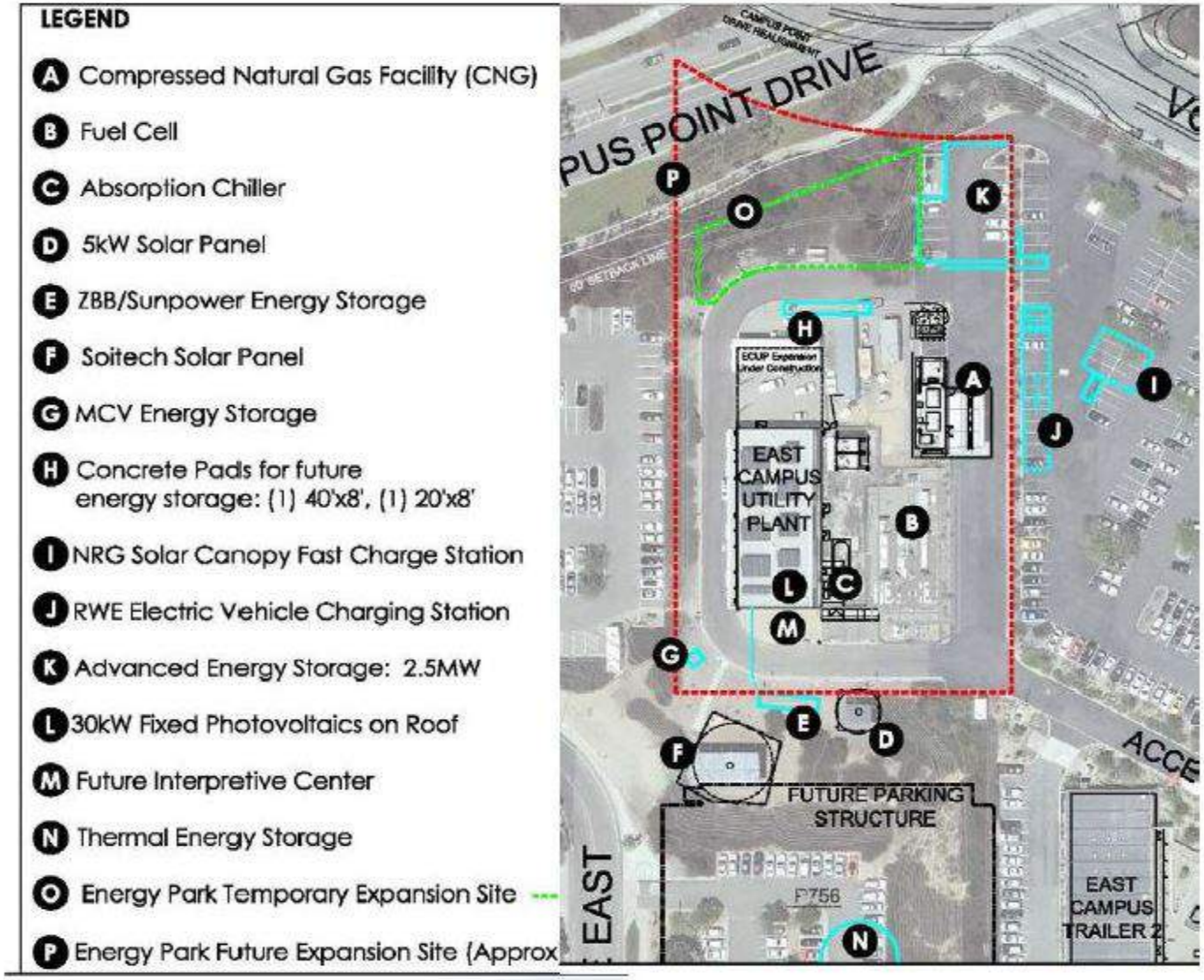
Lithium-ion battery performing energy time-shift at P_{max} for seven days. (B) Zoomed in region of first two days highlight top-off step (blue).

- Feasibility of test protocols initially evaluated by testing on commercial lithium-ion batteries at cell level
- Plan to continue baseline evaluation using larger 1-10 kW lithium-ion battery system, and use for performance comparison

Grid Connected Testing

- Individual test stands with Inverters and BMS
- Design completed
- Civil Construction Completed
- Equipment ordered





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Grid Connected Test Stand Development

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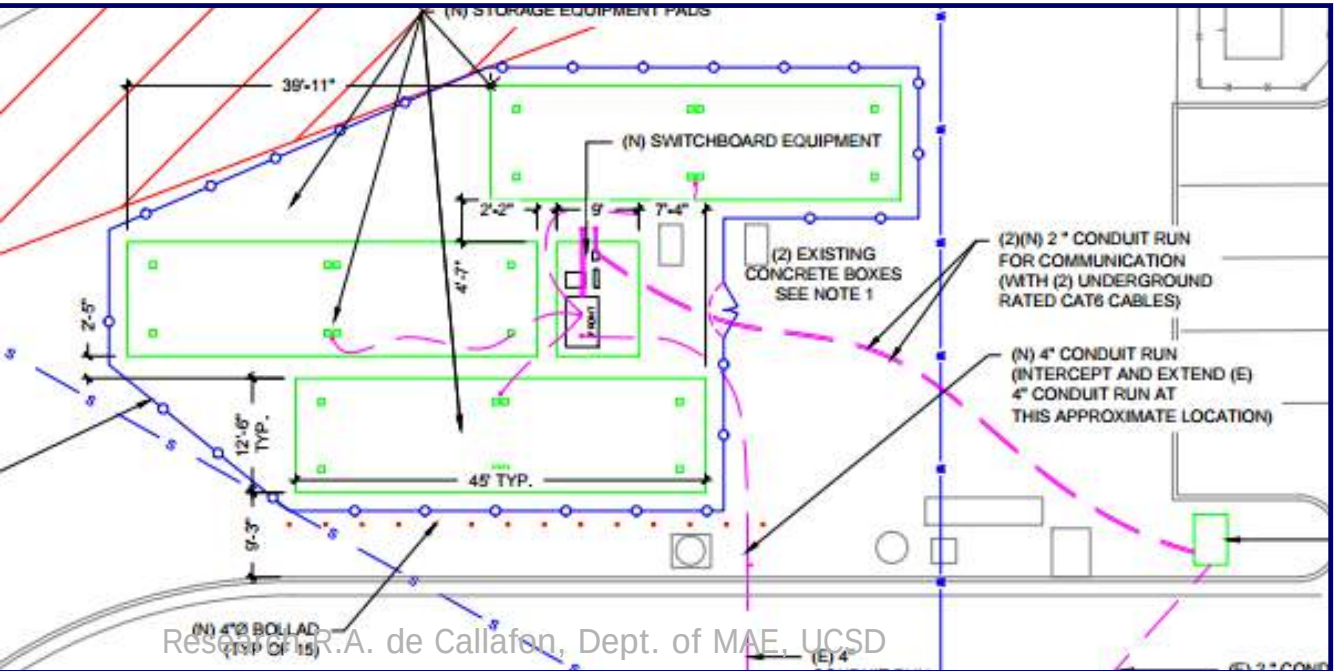

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Grid Connected Testing Capability

- UCSD owns and operates power grid
- Significant renewable energy penetration
- High speed data acquisition system available allowing remote access and detailed analysis
- Initial two 40 ft. pads will accommodate four test stands up to 100 kW energy storage systems each, depending on physical characteristics of systems.
- Third 40 ft. pad planned in the future.
- Test stands capable of remote operation and monitoring, with full bi-directional converters capable of testing any test protocol.
- Future expansion of energy research park planned

ARPAE CHARGES UCSD Project Schedule

- Task 1 – Economic modeling and evaluation: Q1 – Q4, 2015
- Task 2 – Establish Test protocols and procedures: Q1 – Q3, 2015
- Task 3 – Cell level and Module level testing of ARPAe Advanced battery energy storage:
  - Facility Preparation , Q1 – Q3, 2015
  - Module Level Testing, Q3, 2015 – Q4, 2017
  - Cell Level Testing, Q4, 2015, Q4, 2016
- Task 4 – Microgrid testing of energy storage:Q4, 2015 – Q4, 2018
- Task 5 – Commercial Development Pathway: Q2, 2017 – Q4, 2018

Summary of Status of UCSD ARPAe CHARGES Status

- All project tasks and deliverables on schedule
- Economic valuation method and development of market driven test protocols has been completed
- Laboratory module level testing of advanced ARPAe batteries has started at UC San Diego
- Testing infrastructure for grid connected testing is being installed at UC San Diego

Thank You!