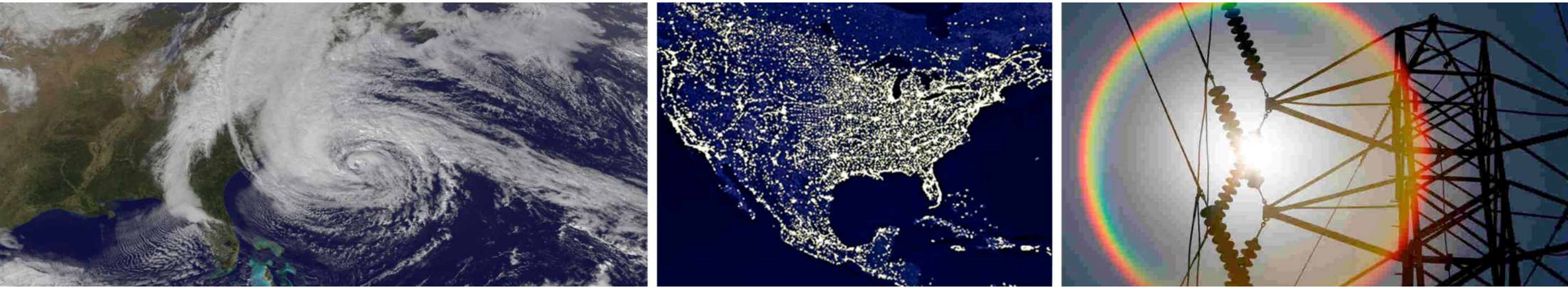
SAND2014-3441P

*Exceptional service in the national interest*

Sandia National Laboratories

energy.sandia.gov



# Sandia's Grid Modernization Programs

General Briefing

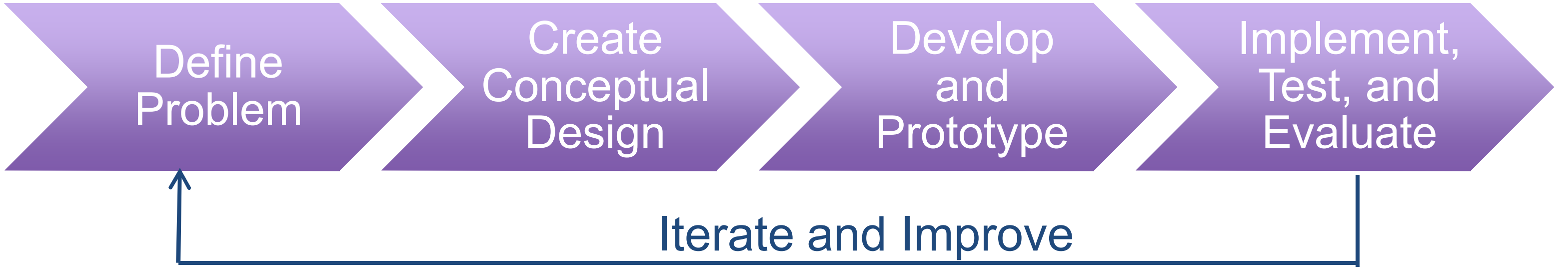
15 April, 2014

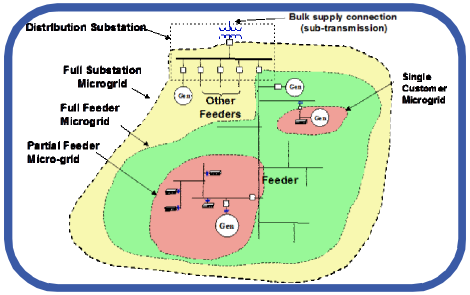
U.S. DEPARTMENT OF ENERGY

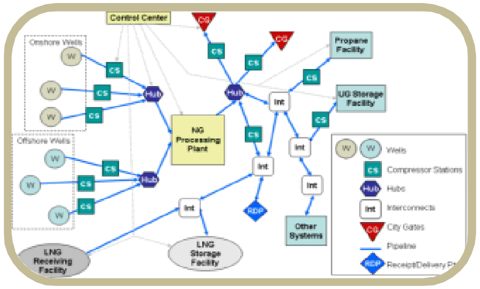
NNSA National Nuclear Security Administration

# Our Value Proposition:

## Integrated Capabilities for Solving The Most Difficult Energy Surety Challenges





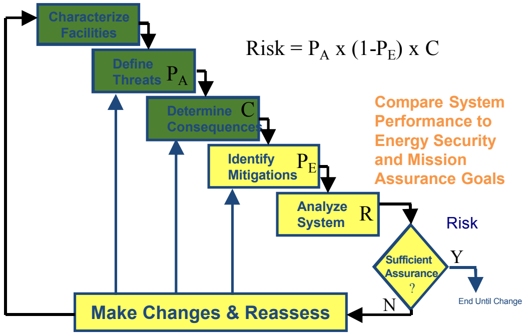


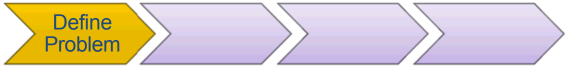
Sandia applies a **comprehensive modeling, analysis, design, development, test and evaluation approach to Energy Surety Systems solutions**

# Addressing Energy Surety Microgrid Challenges

## Energy Surety Assessment

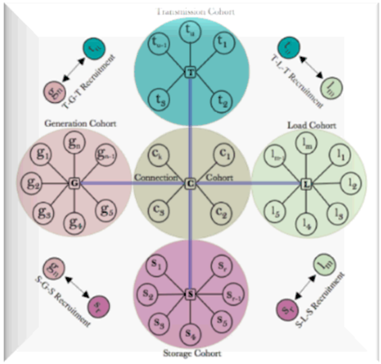
A risk based approach to assess energy surety (safety, security, reliability, sustainability, and cost effectiveness)

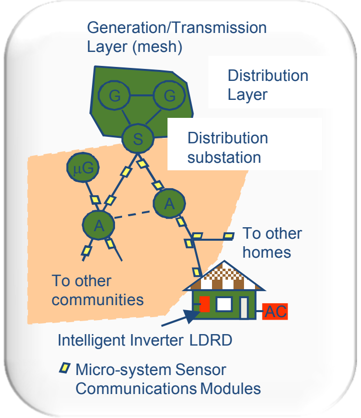




## Agent Based Microgrid Modeling

Control techniques are applied using agent based system of system model techniques. Emergent and complex behaviors can be modeled in microgrid systems.



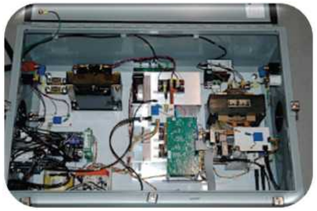


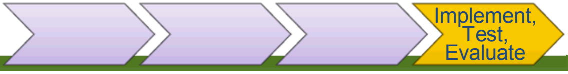
## Secure Scalable Microgrids with High Penetration Renewables

Non-linear component and system models; distributed agent-based control algorithms, software and architectures with secure communications

## Intelligent Power Controllers for Self Organizing Microgrids

Modular Macro Inverter hardware to support agent based control of generators and load devices in microgrids



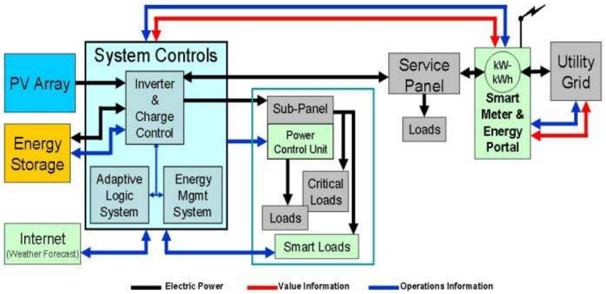


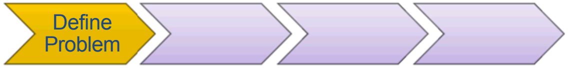
# Addressing High Penetration of Renewable Energy on our Electric Infrastructure

Increasing penetration of variable renewable generation can overstress our current electric grid

80MW Solar Farm in Ontario, Canada

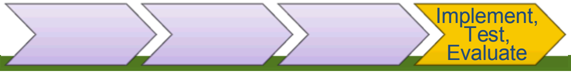
Near-term product concepts to address tomorrow's needs: "Solar Energy Grid Integrated Systems (SEGIS)"





Product developments are verified and optimized at Sandia's DETL

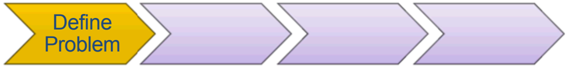
New system controllers and inverter technologies can mitigate negative impacts while providing added value



# Addressing High-Energy Storage Challenges

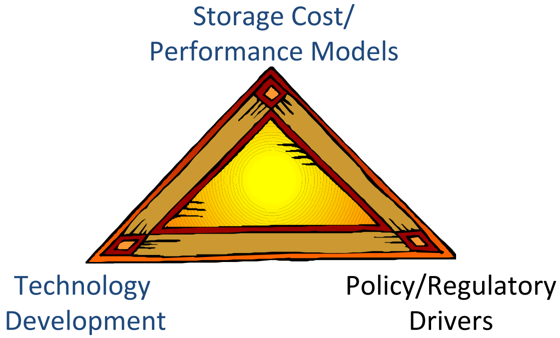
## Grid Variability Caused by Renewable Energy Integration

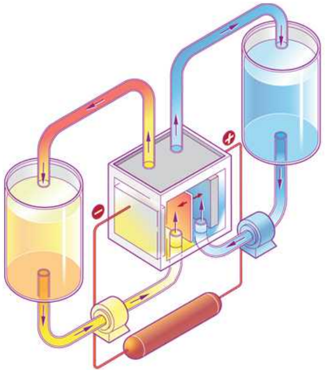
- Energy Storage Solutions Offers Clean and reliable solution
- Energy Capacities are limited in existing battery technologies



## Energy Storage Systems Model Development

(Coordinated Approach)



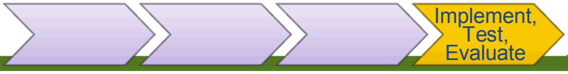


## Flow Battery Development

- Potential for low cost
- Long cycle life
- Deep discharge capability
- Separate power, energy requirements

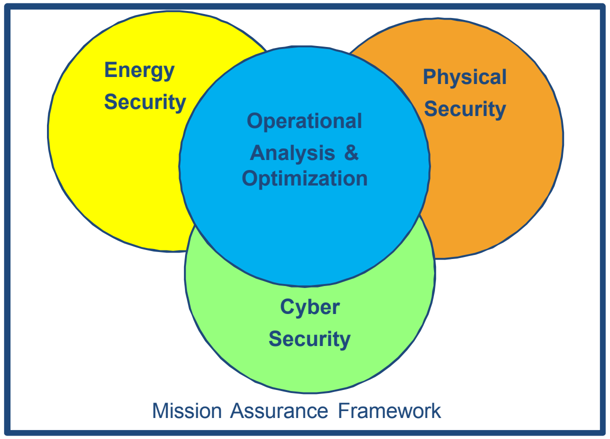
## Energy Storage Systems Testing

- 100KW - 1MW
- Grid and Island Mode
- Testing with renewable sources at DETL

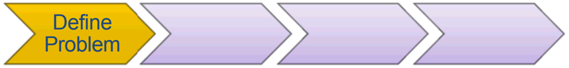


# Forward Operating Base Challenges

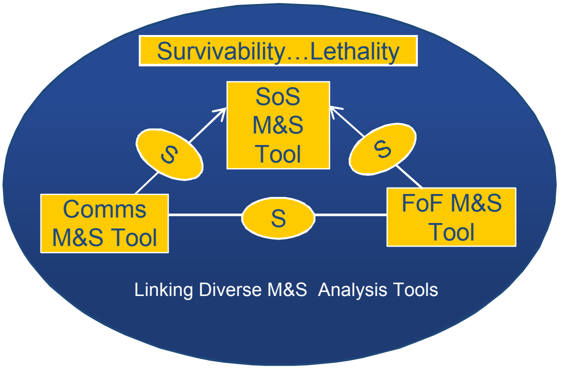
Addressing Forward Operating Base System of Systems Complexity and Overarching Integration & Technology Needs to Effectively Assure National Defense Missions



Mission Assurance Framework



Developing Architecture and Methods for more Effectively Leveraging Analyses and Information Between Heterogeneous Modeling and Simulation Tools



Linking Diverse M&S Analysis Tools

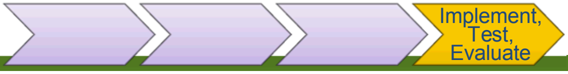
Develop and Prototype Operational Energy Systems to Address Needs and Capability Gaps

**Live**

**Virtual**

**Constructive**

Developed Live, Virtual, and Constructive Environment for Test and Evaluation of Complex System of Systems Solutions



# Field demonstrations drive analytical activities: PNM Smart Grid Project Example

- Full integration of a Renewable Energy and Smart Grid concepts into utility operations
    - PV, Wind, Energy Storage and Demand Response, other DER
    - Residential/Building/Utility scale resources and systems
    - Layers of controls

- Large-scale testbed fully accessible for research, testing & demonstration

- Implemented at Mesa del Sol in Albuquerque

Graphic: EPRI / PNM

# Key Customers

## DOE

- OE
- EERE
- EPSA

## DoD

- Air Force
- Army
- Navy
- PACOM
- NORTHCOM

## DHS

- S&T
- NPPD
- FEMA

# Partnerships are Key to Strategy

AMES LABORATORY

Argonne

BERKELEY LAB

BROOKHAVEN NATIONAL LABORATORY

INL Idaho National Laboratory

JLAB

Los Alamos NATIONAL LABORATORY EST 1943

Pacific Northwest NATIONAL LABORATORY

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

OAK RIDGE National Laboratory

SRNL SAVANNAH RIVER NATIONAL LABORATORY

SMUD Powering forward. Together.

OPAL-RT

OSIsoft

DISTRICT OF COLUMBIA

THE GREAT SEAL OF THE STATE OF NEW JERSEY

VOLNTATIS TVÆ CORONASTI NOS SCVTO BONÆ 1632

VERMONT FREEDOM AND UNITY

GREAT SEAL OF THE STATE OF NEW MEXICO 1912

UNM

The UNIVERSITY of VERMONT

SCHWEITZER ENGINEERING LABORATORIES

NVEnergy

PNM

THE UNIVERSITY OF ARIZONA

UCDAVIS

CASE WESTERN RESERVE UNIVERSITY EST. 1826

ERCOT

THE JOHNS HOPKINS UNIVERSITY BALTIMORE

NM STATE UNIVERSITY

ISO new england

Hawaiian Electric Company

SOUTHERN CALIFORNIA EDISON An EDISON INTERNATIONAL Company

UNIVERSITY OF WYOMING

GT

ARIZONA STATE UNIVERSITY

STATE

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Tucson Electric Power A UniSource Energy Company

California ISO Your Link to Power

WASHINGTON STATE UNIVERSITY

# Sandia Grid Modernization Strategy Pillars

## Renewables Integration

Sandia National Laboratories

Energy, Climate, & Infrastructure Security

### Renewable Energy Grid Integration

Sandia's renewable energy grid integration program is broad and multidisciplinary, recognizing that future evolution of the grid is influenced by multiple factors and technologies.

**Vision**
To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

U.S. DEPARTMENT OF ENERGY

## Grid Resiliency

Sandia National Laboratories

Energy, Climate, & Infrastructure Security

### A National Grid Resiliency Initiative: Securing Our Nation's Electric Grid

**The Need for Grid Resiliency**

Our nation's rise to prominence as one of the world's most productive and innovative economies reflects the broad access to abundant, reliable, and cheap energy. Today it is our electric power system that almost singularly drives our digital economy and elevates our health, safety, and overall standard of living. Without a functioning electric grid, nearly every critical infrastructure in the U.S.—from banking to water to telecommunications—would grind to a halt.

Unfortunately, the threats to our grid, both natural and manufactured, continue to grow. Weather-related and other natural disasters, which cause the bulk of power outages, are projected to increase in intensity and frequency, with a hotter, moister atmosphere primed to trigger disasters.[1] Frightening studies by the National Security Agency and others show that malware directed at the grid continues to evolve and grow.[2] As a consequence, our nation faces significant risk from prolonged electrical outages, which, largely because of storms, have been steadily increasing in frequency since 1995.[3]

The time has come, therefore, to find new ways to plan, manage, and safeguard our nation's electric grid. Much as a massive blackout in 1965 prompted the U.S. Congress to enact the Electric Power Reliability Act of 1967, leading to the formation of the National Energy Reliability Council (NERC) and a standard definition of reliability, the natural disasters of the past few years (including Hurricanes Katrina and Sandy) should prompt a new paradigm for securing the grid against its increased exposure to high-consequence events.

Simply put, a grid defined only by reliability is no longer adequate in our 21st Century world. What our nation needs instead is a grid that can adapt to both large-scale environmental and manufactured events, and remain operational in the face of adversity, thus minimizing the catastrophic consequences that affect quality of life, economic activity, national security, and critical-infrastructure operations. Specifically, the concept of reliability needs to be replaced with a resiliency approach, one that looks at the grid not strictly as a flow of electrons but as a grid that services, interfaces with, and impacts people and societies.

Put another way, *it is the consequences, not the outages per se, that matter.*

**Why Reliability Is Not Enough**

Grid reliability, which is defined by NERC as a combination of grid adequacy (i.e., having sufficient generation to meet load) and grid security (having the ability to withstand disturbances), is

**Vision**
To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

U.S. DEPARTMENT OF ENERGY

EXCEPTIONAL SERVICE IN THE NATIONAL INTEREST

## Grid Cybersecurity

Sandia National Laboratories

Energy, Climate, & Infrastructure Security

### Cybersecurity for the Electric Grid

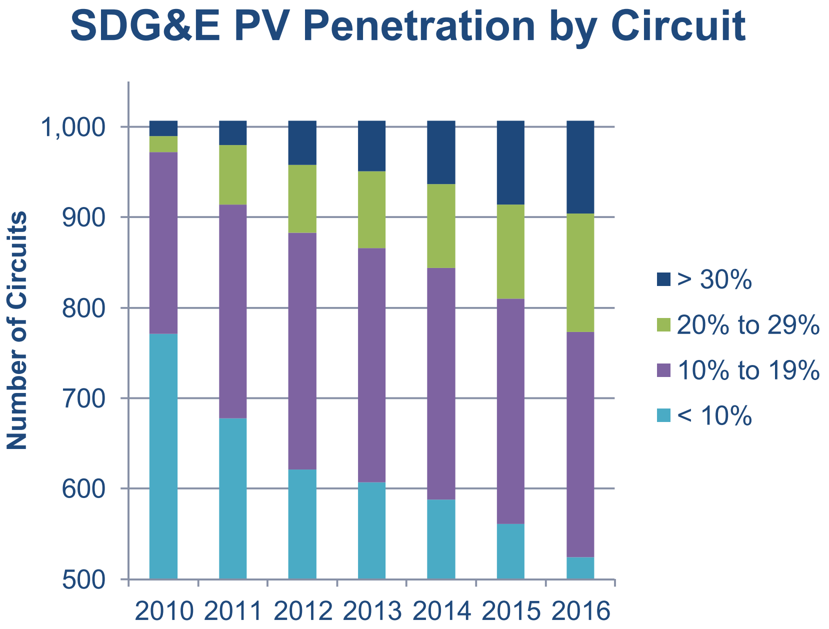
The electric power sector is experiencing rapid growth in controls, telemetry, and automation that necessitates increased awareness of emerging cyber threats that can negatively impact the power grid.

**Emerging Cyber Threats**

**Vision**
To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

U.S. DEPARTMENT OF ENERGY

# High Penetration of Variable Generators Driving Changes

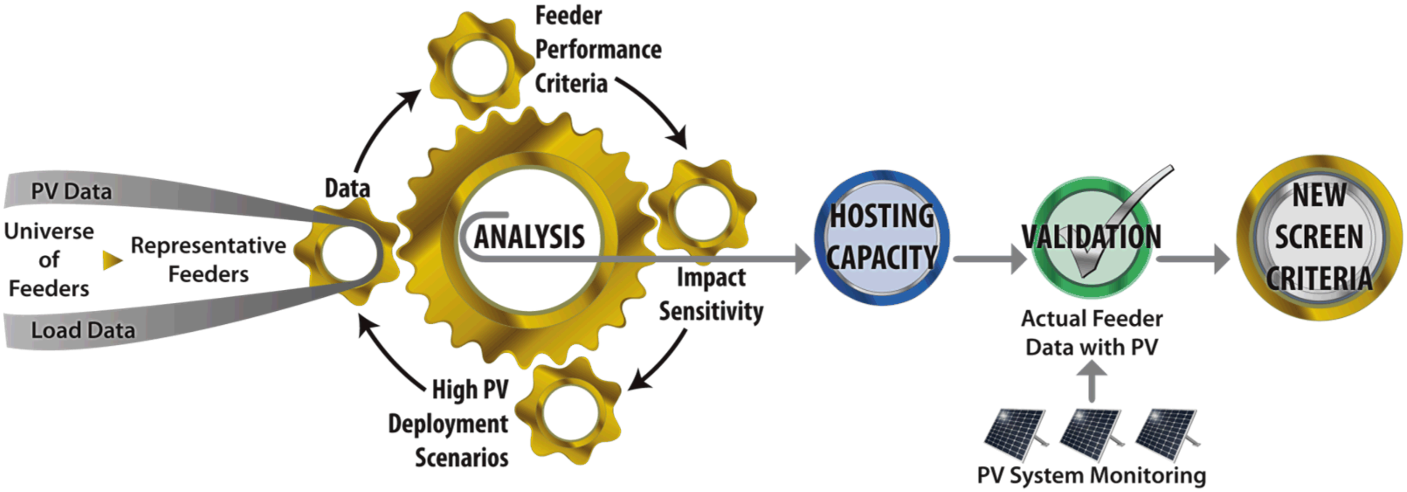


**Predictions show a need for resilience to variability and opportunities for enhance grid functionality.**

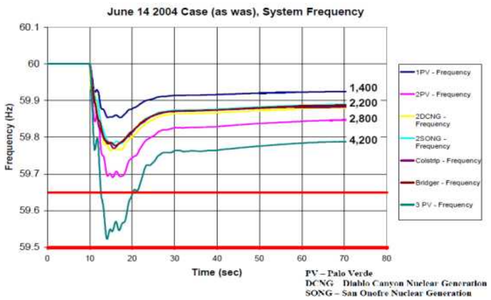
**Sandia's Distributed Energy Technologies Laboratory provides technology solutions for integrated systems**

# Sandia Developing New Screens to Simplify Distribution-Interconnection Processes

- Effort co-funded by USDOE and CA Solar Initiative
- Working with EPRI, CA utilities to develop data-driven technical foundation to support revision to Small Generator Interconnection Procedure (SGIP) screens
- Resulted in revised FERC-approved screening process through scenario analysis



# Sandia Leads Incorporation of CA Rule 21 Revisions in National Standards



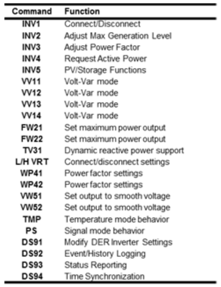
High PV penetrations are leading to grid voltage and frequency stability concerns.

IEC/TR 61850-90-7

Edition 1.0 2013-02

TECHNICAL
REPORT

Communication networks and systems for power utility automation –
Part 90-7: Object models for power converters in distributed energy resources (DER) systems



| Command | Function |
|---|---|
| INV1 | Connect/Disconnect |
| INV2 | Adjust Max Generation Level |
| INV3 | Adjust Power Factor |
| INV4 | Request Active Power |
| INV5 | PV/Storage Functions |
| VV11 | Volt-Var mode |
| VV12 | Volt-Var mode |
| VV13 | Volt-Var mode |
| VV14 | Volt-Var mode |
| FW21 | Set maximum power output |
| FW22 | Set maximum power output |
| TV31 | Dynamic reactive power support |
| L/H VRT | Connect/disconnect settings |
| WP41 | Power factor settings |
| WP42 | Power factor settings |
| VW51 | Set output to smooth voltage |
| VW52 | Set output to smooth voltage |
| TMP | Temperature mode behavior |
| PS | Signal mode behavior |
| DS91 | Modify DER Inverter Settings |
| DS92 | Event/History Logging |
| DS93 | Status Reporting |
| DS94 | Time Synchronization |

Based on EPRI and SNL research, advanced interoperability DER functions are standardized in IEC 61850-90-7.

*California Energy Commission*
*&*
*California Public Utilities Commission*

Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources

*Smart Inverter Working Group Recommendations*

January 2014

California Public Utilities Commission (CPUC) considers updating Rule 21 to require inverters to have advanced grid functions.

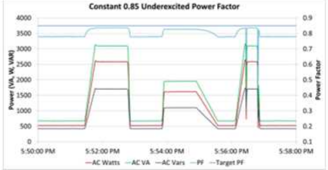
**SANDIA REPORT**
SAND2013-9880
Unlimited Release
Printed November 2013

**Test Protocols for Advanced Inverter Interoperability Functions – Main Document**

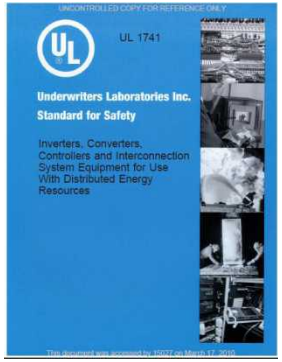
Jay Johnson, Sigifredo Gonzalez, Mark E. Ralph, Abraham Ellis, and Robert Broderick

Sandia National Laboratories

In Nov 2013, Sandia releases the Advance Interoperability Test Protocols matching the IEC functions.



Sandia and other laboratories begin exercising the test protocols to refine the procedures, parameter selection, and number of tests.



UNCONTROLLED COPY FOR REFERENCE ONLY

UL 1741

**Underwriters Laboratories Inc.**
**Standard for Safety**

Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

This document was accessed by 15027 on March 17, 2010

Based on recommendations from Sandia and other industry experts, UL 1741 is updated to cover inverters required by CPUC Rule 21.

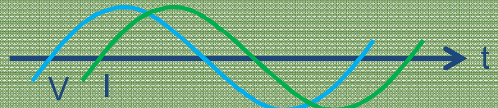
Same effort underway for updates to IEEE 1547

# Types of Advanced Inverter Functions

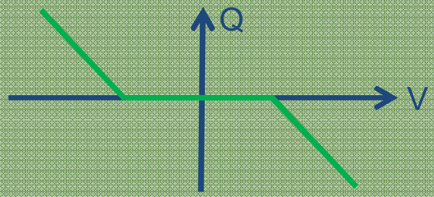
Advanced functions defined in IEC Technical Report 61850-90-7:

### Voltage Support

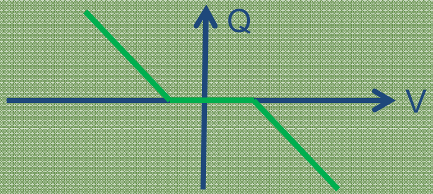
- Adjust Power Factor (INV3)



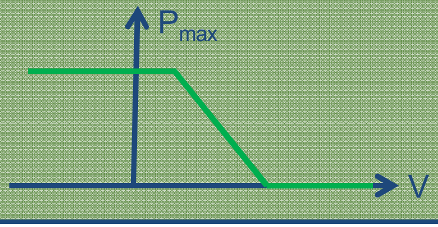
- Volt-Var Mode (VV11, VV12, VV13)



- Dynamic Reactive Power (TV31)

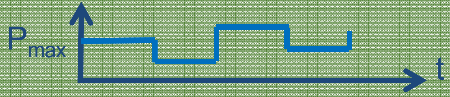


- Volt-Watt Mode (VW51; VW52)

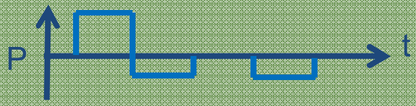


### Frequency Support

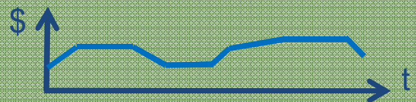
- Adjust Maximum Active Power (INV2)



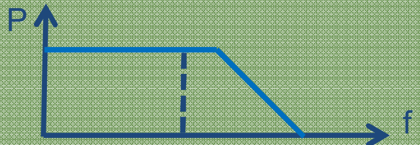
- Request Active Power from Storage (INV4)



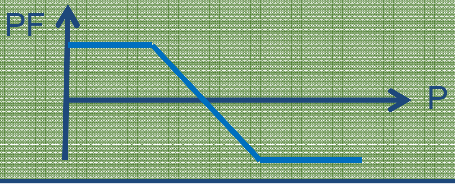
- Signal for Charge/Discharge (INV5)



- Frequency-Watt Mode (FW21, FW22)

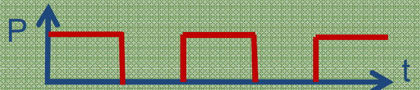


- Watt-Power Factor (WP41, WP42)

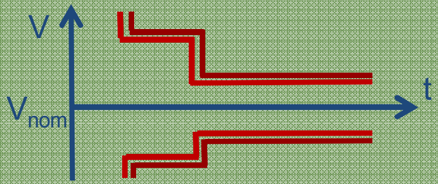


### Grid Protection (Response to Disturbances)

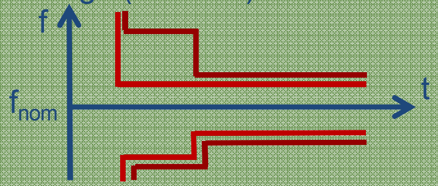
- Connect/Disconnect (INV1)



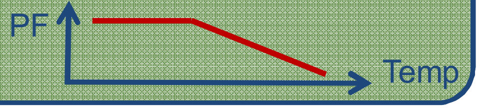
- Low and High Voltage Ride Through (L/HVRT)



- Low and High Frequency Ride Through (L/HFRT)*



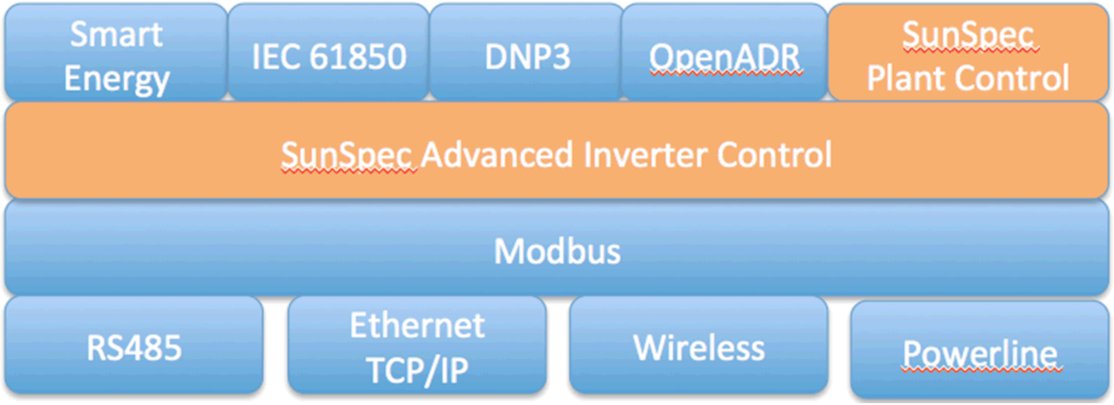
- Temperature Mode Behavior (TMP)



*FRT not included in IEC 61850-90-7, but is included in Rule 21 SIWG recommendations and Sandia Test Protocols.

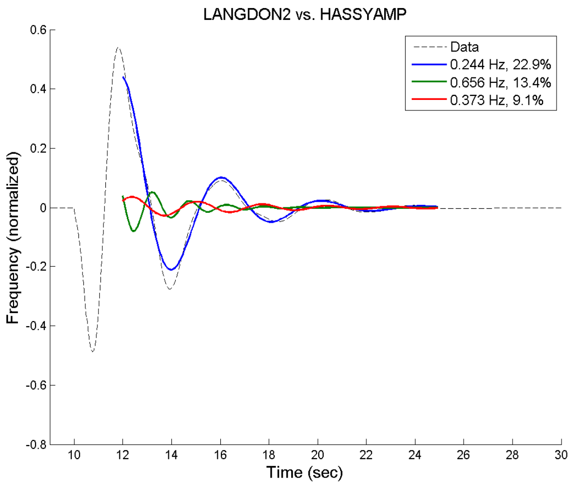
# Current California Solar Initiative (CSI) Proposal* Increases Impacts

- Adapt test protocols for the certification/conformance of CA Rule 21 inverter control and interoperability requirements.
- Address cybersecurity concerns by establishing the underlying rules for the utility-to-DER interoperability.
- Partnered effort with EPRI, SMA, Fronius, SCE, SMUD, and SunSpec Alliance

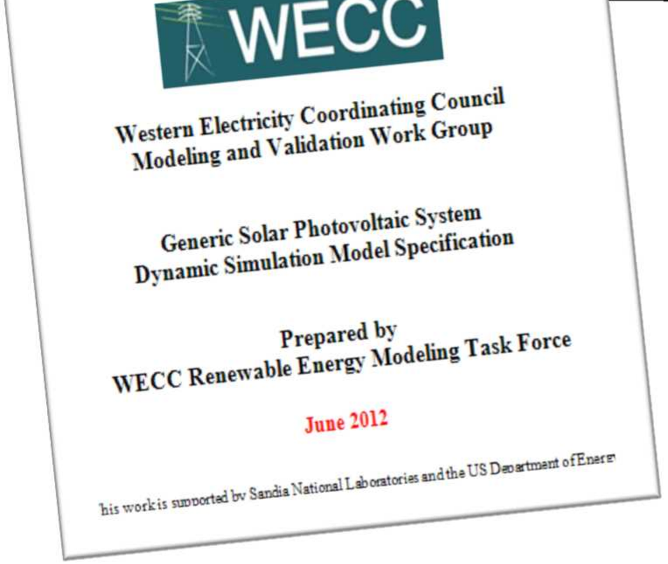


*"Standard Communication Interface and Certification Test Program" to develop communications specifications for the utility-to-DER interchange over Modbus, SEP 2.0, and Zigbee gateways.

# Sandia Addressing Transmission-Level Variability



**Small Signal Stability analysis covers Western US**


WECC

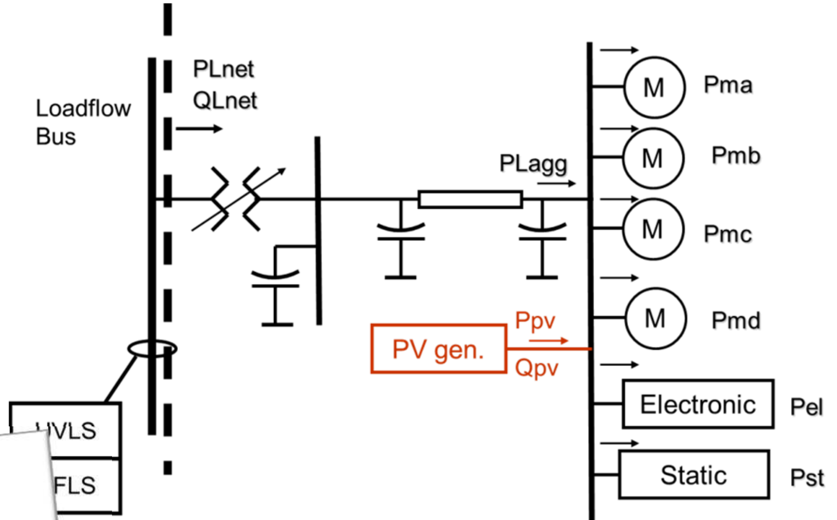
Western Electricity Coordinating Council
Modeling and Validation Work Group

Generic Solar Photovoltaic System
Dynamic Simulation Model Specification

Prepared by
WECC Renewable Energy Modeling Task Force

June 2012

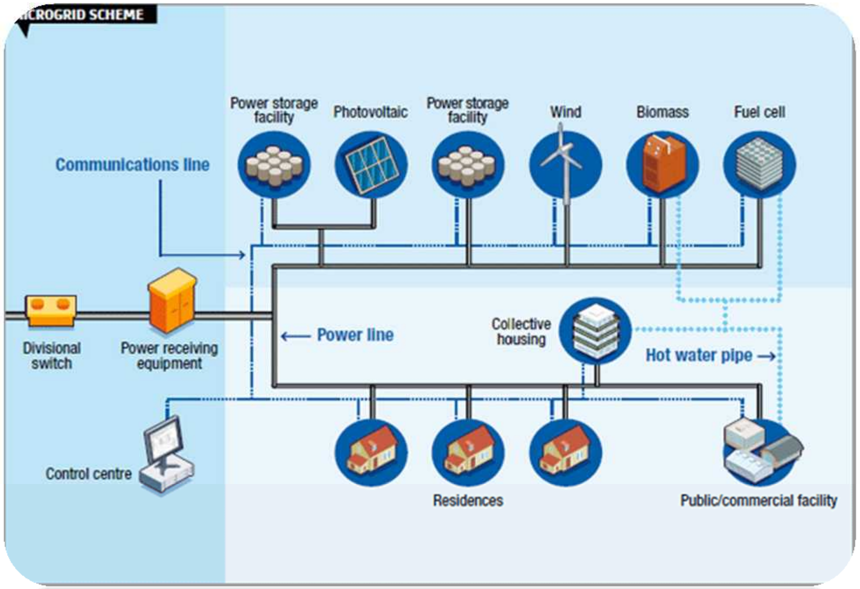
his work is supported by Sandia National Laboratories and the US Department of Energ



**New Models: PV as a Generation Source for Utility Engineers – in use by over 90% of market.**

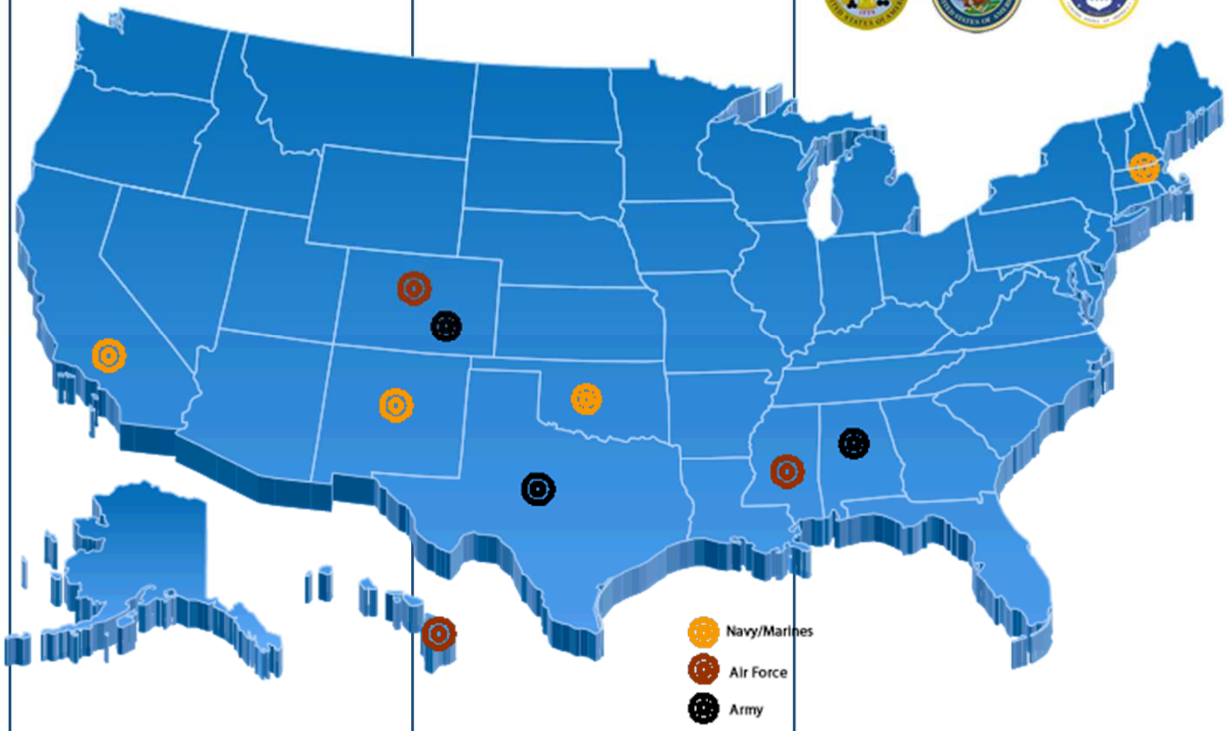
# Grid Modernization via Sandia's "Energy Surety Design Methodology"

- Optimized integration of source, load, storage and sensing technologies
- Microgrids are a key component
- Advanced control systems
- Enhanced cyber security architecture
- "Single entity" view to bulk grid – ability to island

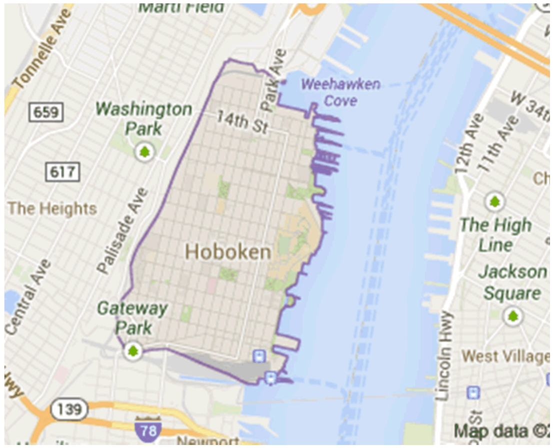


# DoD Energy Surety Microgrid R&D

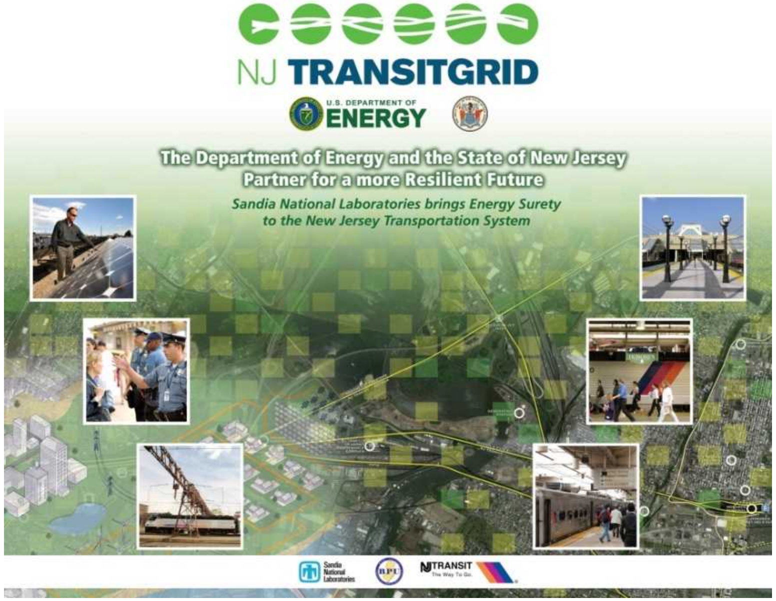
| Conceptual Designs/Assessments | Small Scale Microgrid Demos | Large Scale Microgrid Demos | Operational Prototypes |
|---|---|---|---|
| • Philadelphia Navy Yard – FY11, DOE OE/PIDC<br>• Camp Smith – FY10, DOE FEMP<br>• West Point FY12, DoD/DOE/OE<br>• Indian Head NWC – FY09, DOE OE/DoD<br>• Ft. Sill – FY08, Sandia LDRD<br>• Ft. Bliss – FY10, DOE FEMP<br>• Ft. Carson – FY10, DOE FEMP<br>• Ft. Devens (99th ANG) – FY09, DOE OE/DoD<br>• Ft. Belvoir – FY09, FY12 DOE OE/FEMP<br>• Cannon AFB – FY11, DOE OE/DoD<br>• Vandenberg AFB – FY11, DOE FEMP<br>• Kirtland AFB – FY10, DOE OE/DoD<br>• Manwell AFB – FY09, DoD/DOE<br>• Osan AFB – FY1, DoD<br>• Soto Cano – FY12, DoD<br>• Creech AFB – FY12 DoD<br>• Alaska Villages – FY12 DOE | • Manwell AFB – FY09, DoD<br>• Ft. Sill – FY09, DoD w/ SNL serving as advisor | • SPIDERS JCTD – FY11, DOE/DoD<br>○ Camp Smith<br>○ Ft Carson<br>○ Hickam AFB | • H.R. 5136 National Defense Authorization Act |



# Sandia Addresses Resilience in Post-Sandy Rebuilding



- Resilient ESDM microgrid designs were developed for NJ Transit and Hoboken
- Broad partnerships include transit; utilities; municipal, state, and federal government
- Approach is being applied to other municipalities, islands, nationally



NJ TRANSITGRID

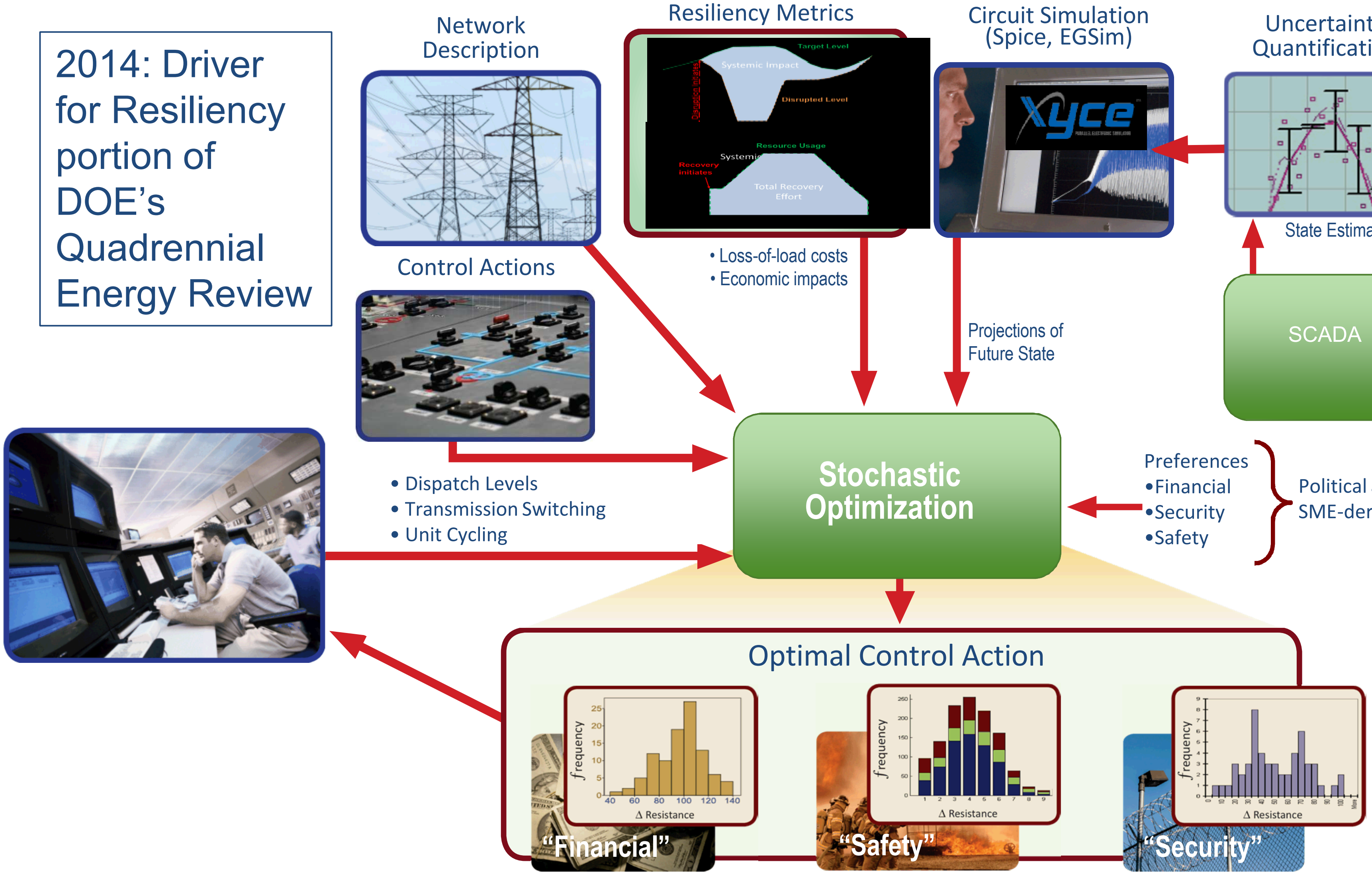
U.S. DEPARTMENT OF ENERGY

The Department of Energy and the State of New Jersey Partner for a more Resilient Future

*Sandia National Laboratories brings Energy Surety to the New Jersey Transportation System*

# Lab-Directed Research and Development - Advanced Metrics and Control Strategies for Grid Resiliency

2014: Driver for Resiliency portion of DOE's Quadrennial Energy Review



Network Description

Resiliency Metrics

- Loss-of-load costs
- Economic impacts

Circuit Simulation (Spice, EGSim)

Uncertainty Quantification

State Estimation

SCADA

Projections of Future State

Control Actions

- Dispatch Levels
- Transmission Switching
- Unit Cycling

**Stochastic Optimization**

Preferences
- Financial
- Security
- Safety

Political and SME-derived

Optimal Control Action

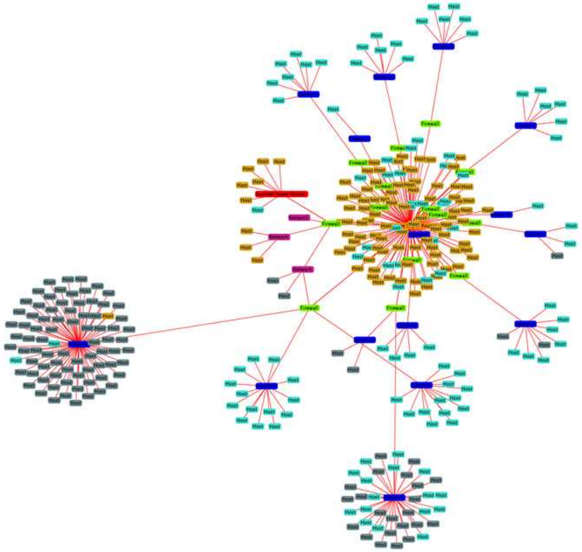
# Grid Cyber Vulnerability and Assessments

- Leverage a $150M classified program to investigate cyber security for the electric grid
    - Have built upon Sandia's NW assessment heritage to conduct vulnerability assessments for the grid
    - Developed Information Design Assurance Red Team (IDART) methodology and custom assessment tools
- Use IDART to perform cyber security vulnerability / risk assessments on power grid control systems and networks
    - Including transmission, distribution, and campus level grids for utilities across the country
- Conduct cyber security vulnerability and risk assessments on power grid hardware (e.g., smart meters, PLCs and PMUs)

IDART
Information Design Assurance Red Team

# Grid Cyber Vulnerability and Assessments (Cont.)

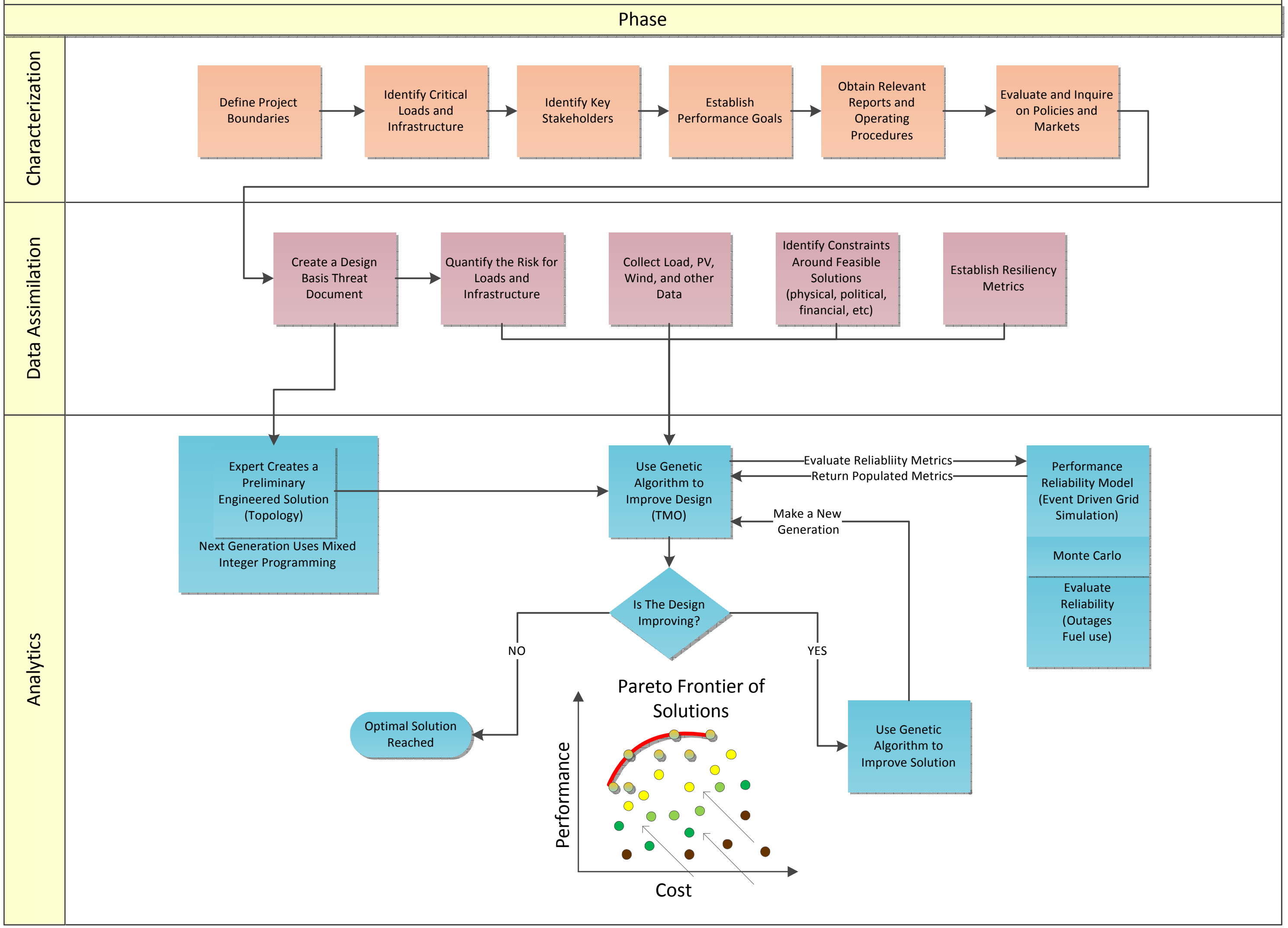
- Ant Farm passively maps existing grid control system networks for vulnerability assessments
- OPSAID provides a design basis for vendors to build add-on security devices for legacy power control systems
- Cyber tools have been employed in multiple smart grid and microgrid deployments via several Sandia programs (e.g., SPIDERS)



ANTFARM mapping output

# extras

# Energy Surety Design Methodology



Phase

**Characterization**

Define Project Boundaries

Identify Critical Loads and Infrastructure

Identify Key Stakeholders

Establish Performance Goals

Obtain Relevant Reports and Operating Procedures

Evaluate and Inquire on Policies and Markets

**Data Assimilation**

Create a Design Basis Threat Document

Quantify the Risk for Loads and Infrastructure

Collect Load, PV, Wind, and other Data

Identify Constraints Around Feasible Solutions (physical, political, financial, etc)

Establish Resiliency Metrics

**Analytics**

Expert Creates a Preliminary Engineered Solution (Topology)

Next Generation Uses Mixed Integer Programming

Use Genetic Algorithm to Improve Design (TMO)

Evaluate Reliablity Metrics

Return Populated Metrics

Performance Reliability Model (Event Driven Grid Simulation)

Monte Carlo

Evaluate Reliability (Outages Fuel use)

Make a New Generation

Is The Design Improving?

NO

YES

Optimal Solution Reached

Use Genetic Algorithm to Improve Solution

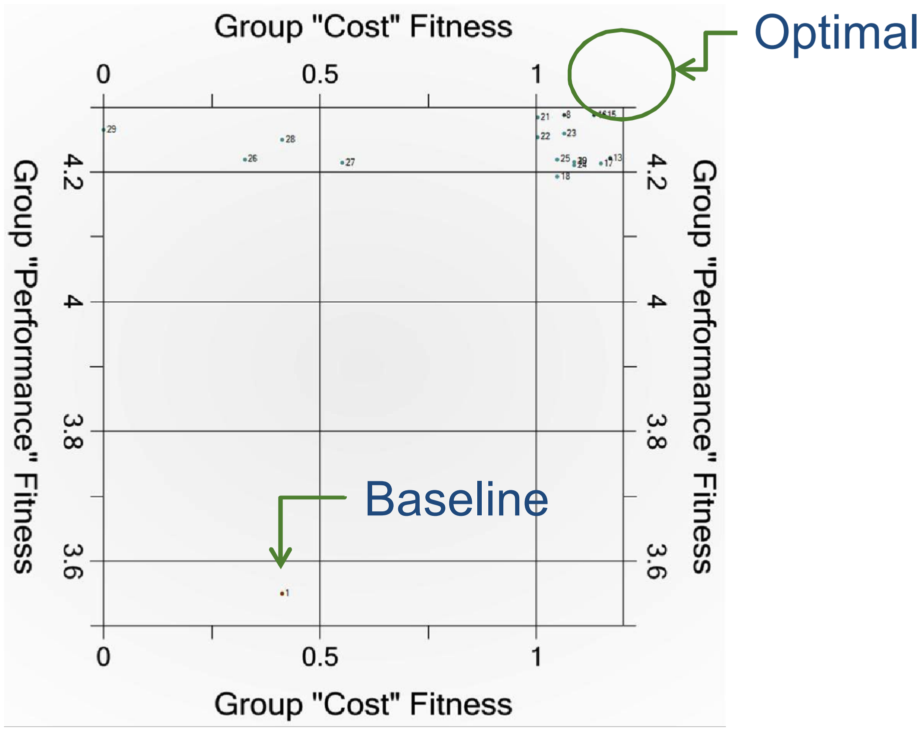
Pareto Frontier of Solutions

# TMO-PRM: Smith

## Availability:

| | | |
|---|---|---|
| Baseline | Tier 1A | 0.995805 |
| | Tier 1B | 0.995341 |
| | Tier 2 | 0.000000 |
| With Tier 2 | Tier 1A | 0.999861 |
| | Tier 1B | 0.999844 |
| | Tier 2 | 0.999808 |
| Without Tier 2 | Tier 1A | 0.999998 |
| | Tier 1B | 0.999976 |
| | Tier 2 | 0.000000 |

## Pareto Chart

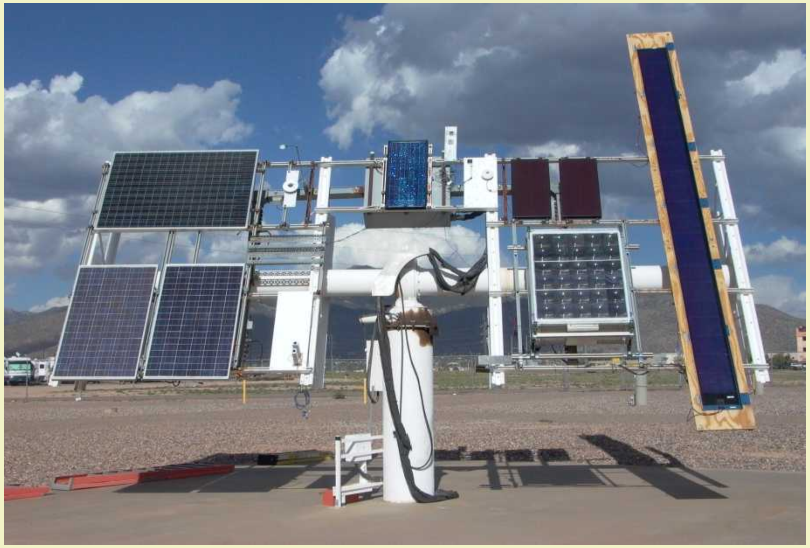


## Performance:

| Option | Variable Cost | Avg. Diesel Consumption (gal/hr) | Avg. Gen Efficiency | Average Tier 1 A Not Served (Tier 1 A Outages) (kWh/h of outage) | % of Outages where Tier 1 A Not Served > 0 | Average Tier 1 B Not Served, (Tier 1 B Outages) (kWh/h of outage) | % of Outages (Post-startup) where Tier 1 B Not Served > 0 | Tier 2 Load Served (kWh/h of outage) |
|---|---|---|---|---|---|---|---|---|
| Base Case | $0 | 75.25 | 0.318 | 49.25 | 0.04167 | 37.83 | 0.05984 | 0.0 |
| Option 6 (Highest fitness Solution w/Tier 2) | $1.1M | 111.58 | 0.367 | 17.95 | 0.00378 | 16.60 | 0.00392 | 1275.0 |
| Option 13 (Highest fitness Solution w/o Tier 2) | $1.1M | 56.34 | 0.348 | 0.68 | 0.00109 | 1.57 | 0.00045 | 0.0 |

# PV Technology Validation Facilities

PV Systems Evaluation & Optimization Lab (PSEL)



- Full-scale cell and module performance characterization laboratory
- Controlled side-by-side system and component characterization
  - PV Arrays
  - All other BOS components
- Fully configurable test platforms for indoor, outdoor and long-term testing

Distributed Energy Technology Lab (DETL)

- Simulate micro-grid, commercial, and community-scale energy systems, including
  - PV
  - Storage
  - Fuel Cells
  - Microturbines
  - Diesel gensets
- R&D testbed for advanced power conversion hardware, controls (including EMS)

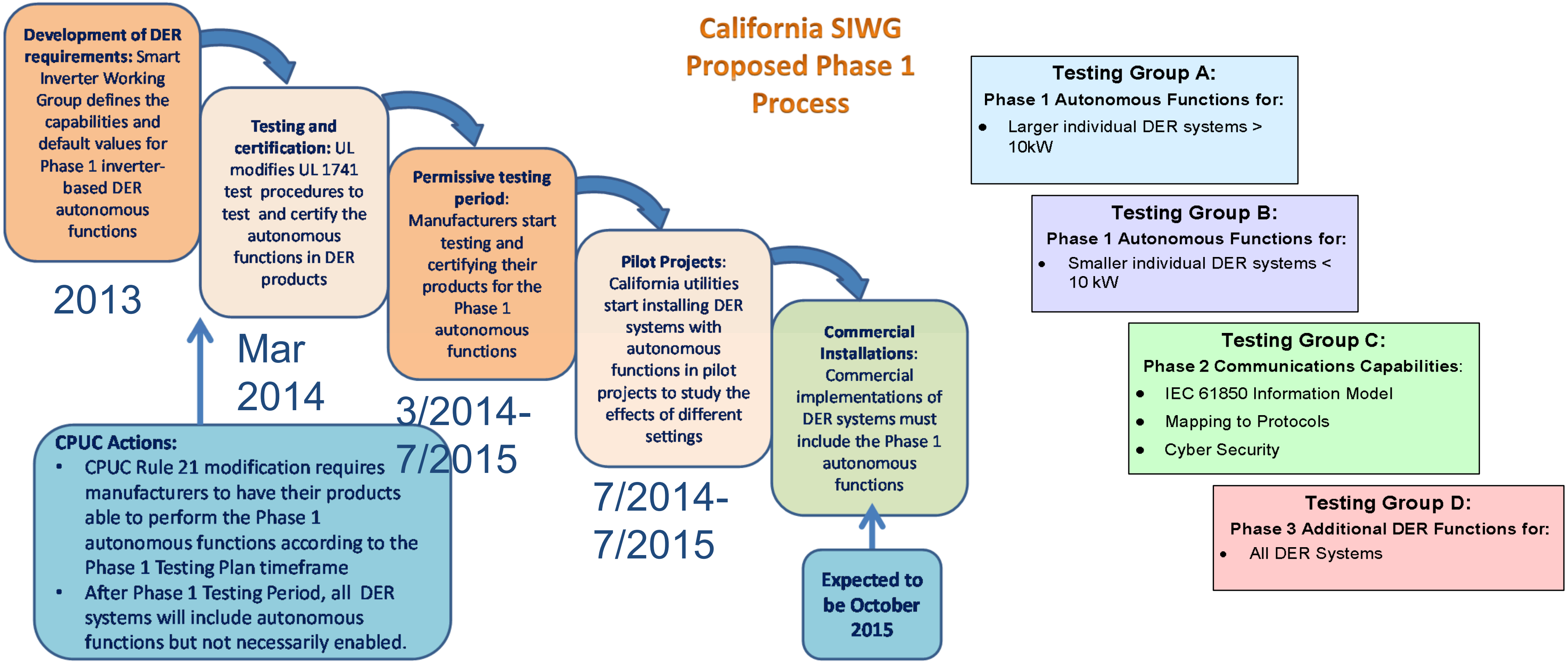
# PV Regional Test Centers: Large-Scale System Evaluation at SNL

Conceptual Rendition of Sandia PV Regional Test Center, Located at the So

- Up to 2MW of systems to be studied in different climates, in partnership with industry
- 5 Locations: Sandia’s Solar Tower, Florida, Vermont (smart grid), Nevada (CPV), NREL
- Stong partnership with industry
- Focus on “bankability” of large PV systems for finance community
- SNL leading effort on infrastructure and analysis
- Opportunity for international replication

# CPUC Proposed Rule 21 Rollout

- CPUC Smart Inverter Working Group (SIWG) recommendations for gradually phasing in the advanced functions.



**California SIWG Proposed Phase 1 Process**

**Development of DER requirements:** Smart Inverter Working Group defines the capabilities and default values for Phase 1 inverter-based DER autonomous functions

2013

**Testing and certification:** UL modifies UL 1741 test procedures to test and certify the autonomous functions in DER products

Mar 2014

**Permissive testing period:** Manufacturers start testing and certifying their products for the Phase 1 autonomous functions

3/2014-7/2015

**Pilot Projects:** California utilities start installing DER systems with autonomous functions in pilot projects to study the effects of different settings

7/2014-7/2015

**Commercial Installations:** Commercial implementations of DER systems must include the Phase 1 autonomous functions

**Expected to be October 2015**

**CPUC Actions:**

- CPUC Rule 21 modification requires manufacturers to have their products able to perform the Phase 1 autonomous functions according to the Phase 1 Testing Plan timeframe
- After Phase 1 Testing Period, all DER systems will include autonomous functions but not necessarily enabled.

**Testing Group A:**

**Phase 1 Autonomous Functions for:**

- Larger individual DER systems > 10kW

**Testing Group B:**

**Phase 1 Autonomous Functions for:**

- Smaller individual DER systems < 10 kW

**Testing Group C:**

**Phase 2 Communications Capabilities:**

- IEC 61850 Information Model
- Mapping to Protocols
- Cyber Security

**Testing Group D:**

**Phase 3 Additional DER Functions for:**

- All DER Systems

# IEEE 1547 undergoes Revisions -- California (CPUC) introduces Paradigm shift to Rule 21

IEEE 1547 Interconnection Standard Revisions target

- Voltage and frequency regulation
- Voltage and frequency ride-through capabilities

Revision **issues** include: (1) Level of ride-through, (2) method of implementation, (3) effectiveness of utility support functions, (4) effect on anti-islanding

Multiple CA Programs aimed at achieving the 12,000 MW of DER by 2020:

- High level of DER has resulted in significant changes to interconnection requirements and practices.
  - Requires V/F RT capabilities for new installations
  - Requires voltage support function (VV11– volt-VAr function that has watt priority)

Concerns about effects on protection and loss of utility detection

# Revisions to IEEE 1547 and CPUC Rule 21 require rational implementation

**Sandia Sponsors Ride-Through Study :** ***Implementation Voltage and Frequency Ride- Through Requirements in Distributed Energy Resources Interconnection Standards***

- V/FRT should be based on rational needs for
  BES security
- not unnecessarily onerous on industry  and allowing compliance

Propose minimum voltage ride-through requirements with allowances to meet distribution compatibility requirements

Sandia leading anti-islanding revision to UL test procedure for Rule 21 smart inverter working group (SIWG)

- Develop anti-islanding test plan per California R21 Phase 1
- Evaluate inverters response per AI test procedure
- Assess support function criteria for compliance

# Sandia sponsors studies for Recommendation for interconnection standard revision

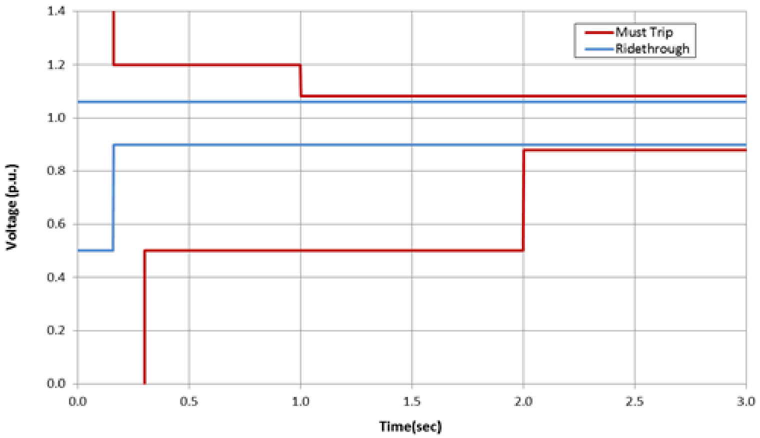
**Proposed VRT are Excessive[6]**

- LVRT-- 0 volts (.16-2 sec)
- LVRT-- .5-.7 (10 sec)
- HVRT – 1.2 (12 sec)

These requirements will/can cause:

- Loss of auxiliary power (controls, fans, pumps, contactors)
- Activation of surge arresters and varistors used to protect equipment

Imposition of unduly onerous VRT requirements on DR could exceed the capabilities of current designs, increasing equipment costs.



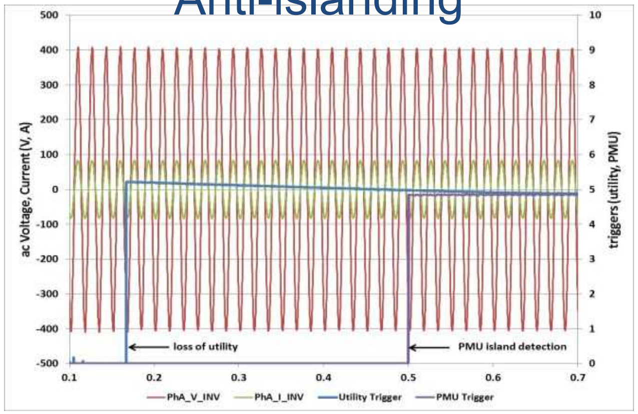
IVGTF 1-7 Recommended Ride-Through and Must-Trip Requirements for DER [7]

Communication based Anti-Islanding

These anti-islanding methods are to meet utility interconnection req while allowing the utility stabilizin and utility support functions to be

- Sandia investigating low cost PLC and SP Communication based Anti-Islanding
- Sandia investigating autonomously implemented collaborative controls

Synchrophasor-based Anti-islanding



# CPUC Smart Inverter Working Group Functions

- Sandia leading the mapping of functions into a Certification Test Standard for implementation in California. Testing will be performed at UL using the SunSpec Advanced Inverter Control Tool.

## Phase 1 Autonomous Functions

| | Function | Description |
|---|---|---|
| 1 | Anti-Islanding Protection | Modified L/HVRT and L/HFRT settings. |
| 2 | Low/High Voltage Ride-Through | Defines “Stay Connected Until” and “Disconnect By” areas. |
| 3 | Low/High Frequency Ride-Through | Expands frequency range for remaining connected over WECC settings |
| 4 | Dynamic Volt/Var Operations | Default Volt-Var curve with dead-band |
| 5 | Ramp Rates | Establishes default ramp up and ramp down rates for:<br>a. Normal<br>b. Emergency<br>c. Soft disconnect |
| 6 | Fixed Power Factor | New allowed PF ranges. |
| 7 | Reconnect by “Soft Start” | Ramp up and/or random start time after 15 seconds of V&F in range. |

## Phase 2 Communication-Related Functions

| | Function | Description |
|---|---|---|
| 1 | Control | Adjustment of default parameters associated with the functions identified in Phase 1 above. |
| 2 | Monitoring | Ability to read the identified set of parameters (see SWIG document) |
| 3 | Functionality upgradeability | Ability to download new firmware to inverter |
| 4 | Emergency direct control | Ability to directly set functions |

## Future Phase 3 Functions

Not yet defined. Could include:

- Emergency Alarms
- Current status
- Commanded Max power limit
- Connect/disconnect
- Optional/alternative settings configurations
- Self-test of new software
- Dynamic frequency-watt
- Dynamic volt-var
- Preset Max power limit
- Volt-watt curves
- Set power level
- Schedule power level
- Dynamic frequency-watt
- Schedules for energy and ancillary services