DOE Fossil Energy Fuel Cells Program

DG Electrical Test Lab & DOE Inverter Power Quality Functionalities

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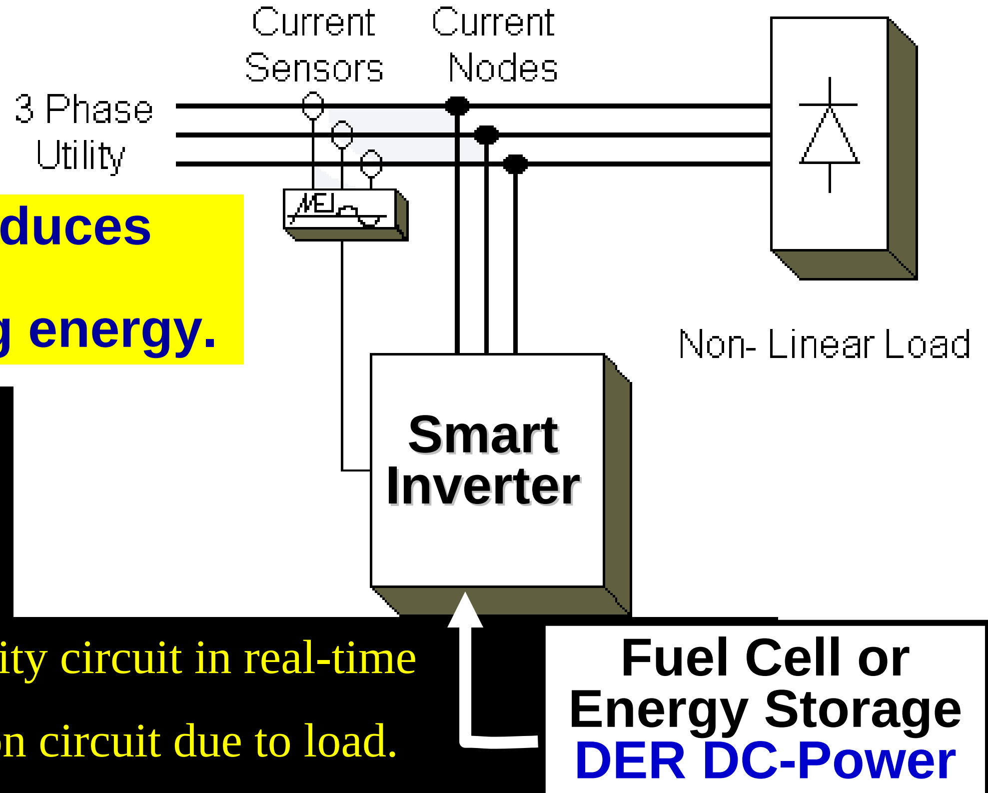
National Energy Technology Laboratory

Intelligent DER Inverter Improves D-Level Power



Supports utility voltage, and also reduces harmonics and phase imbalances whether or not the DER is supplying energy.

Manage Power Quality via DER Inverter

- VAR Support (leading/lagging)
- Harmonics <2.5% THD
- Phase imbalance correction
- DER Voltage & Phase matching to utility circuit in real-time

Utility sees Unity power factor current flow on circuit due to load.

Intelligent priority control algorithm enables Utility or DER owner to emphasize/select order of priority for specific application or operating condition.

Provides flexibility to satisfy the load non-linear current needs during DER Intentional Islanding and MicroGrid operational scenarios.

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SCE DG VAR Support Results at Circuit Location 17

	Lowest Circuit Voltage, kV	MW Loss/ reduction, MW	MVAR Loss/ Reduction, MVAR
No Generation, ‘base line’	11.40 kV	0.56 / -----	1.01 / -----
250 kW Gen @ With VARS., High/600A circuit load	11.46 kV	0.54 / -0.02	0.96 / -0.05
250 kW Gen @ Without VARS, High/600A circuit load	11.42 kV	0.55 / -0.01	0.96 / -0.05
3,000 kW Gen @ With VARS, High/600A circuit load	12.05 kV	0.26 / -0.30	0.40 / -0.61
3,000 kW Gen @ Without VARS, High/600A circuit load	11.72 kV	0.27 / -0.29	0.42 / -0.59

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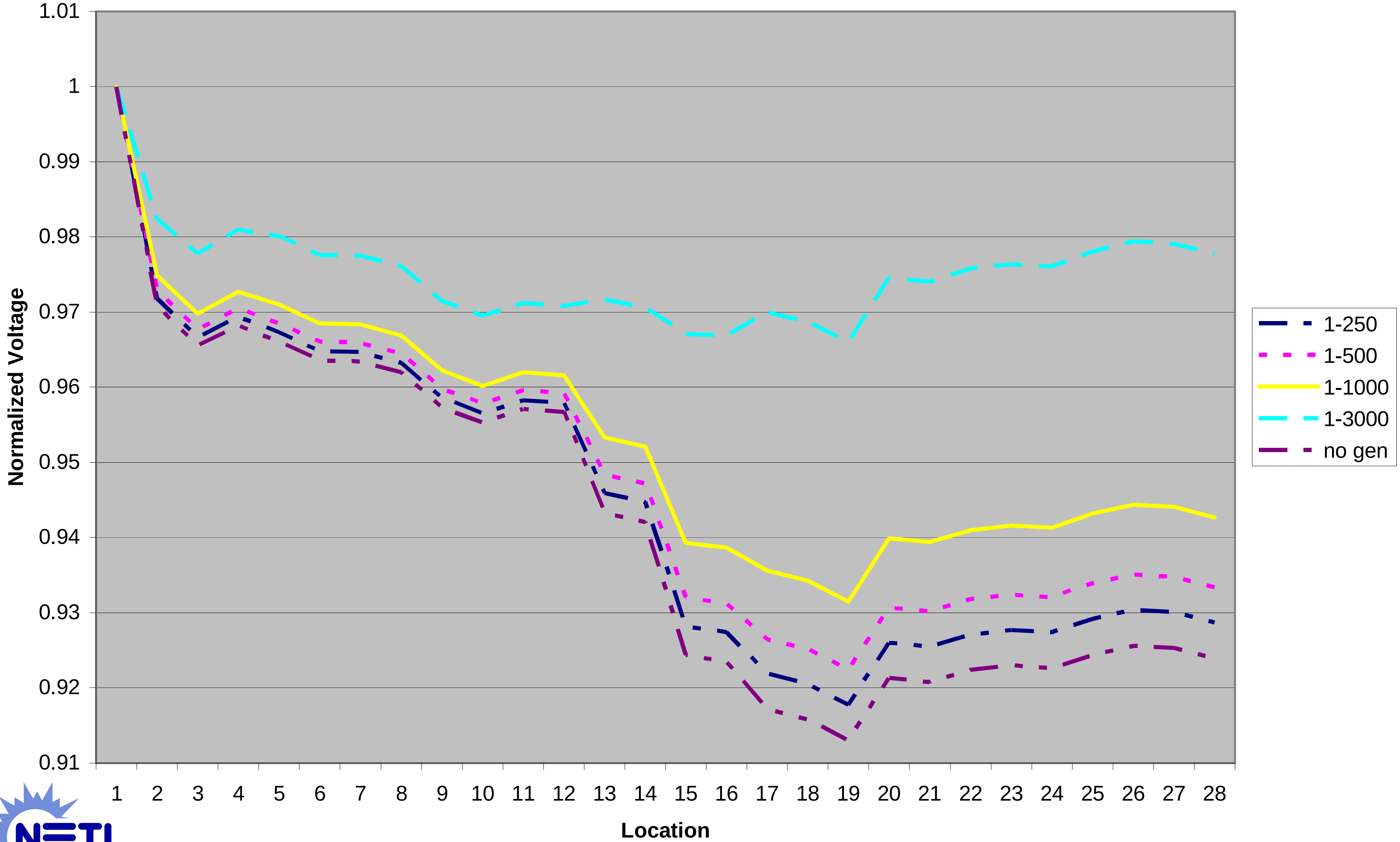
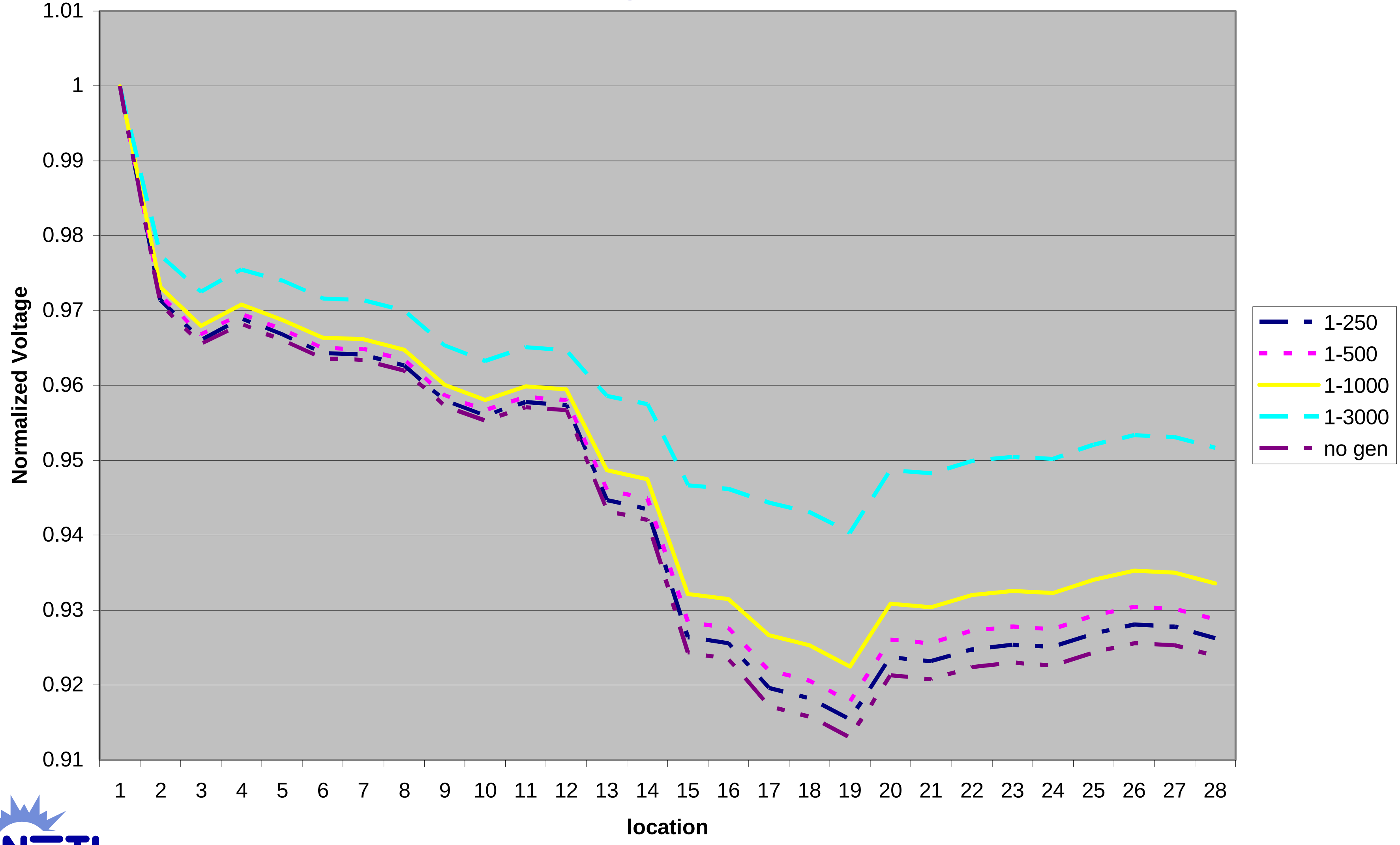
600 amps with VAR Support near Heavy Load Center



Source: C.A. Hessenius, A. Ang and S. Hamilton, "Fuel Cells: A Utility Perspective", ASME Fuel Cell Conference 2006, Irvine, CA

600 amps without VAR Support near Heavy Load Center



Source: C.A. Hessenius, A. Ang and S. Hamilton, "Fuel Cells: A Utility Perspective", ASME Fuel Cell Conference 2006, Irvine, CA

SCE DG VAR Support Results

	Lowest Circuit Voltage, kV	MW Loss / Reduction, MW	MVAR Loss / Reduction, MVAR
3,000 kW Gen @ With VARS, High/600A circuit load at location 17	12.05 kV	0.26 / -0.30	0.40 / -0.61
3 X 1,000 kW Gen @ With VARS, at locations 3, 17, 25	11.93 kV	0.29 / -0.27	0.50 / -0.51
3,000 kW Gen @ With VARS, at location 25	12.05 kV	0.36 / -0.20	0.57 / -0.44
4,000 kW Gen @ shunt cap, at location 17	11.90 kV	0.55 / -0.01	1.0 / -0.01

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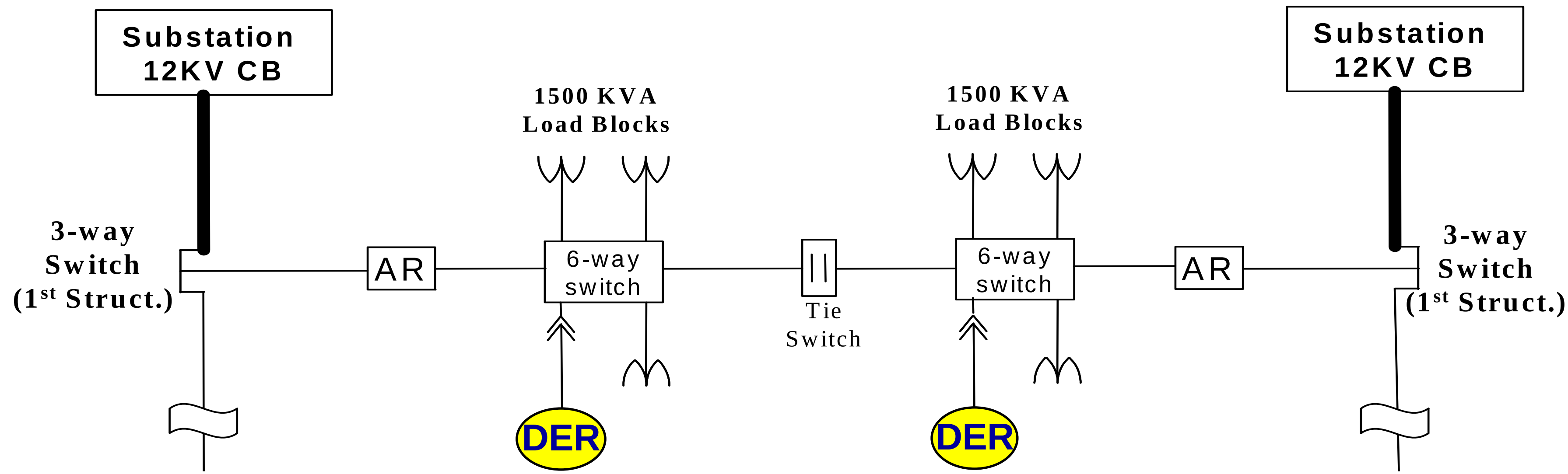
Benefit SCE Distribution Circuit of the Future Initiative



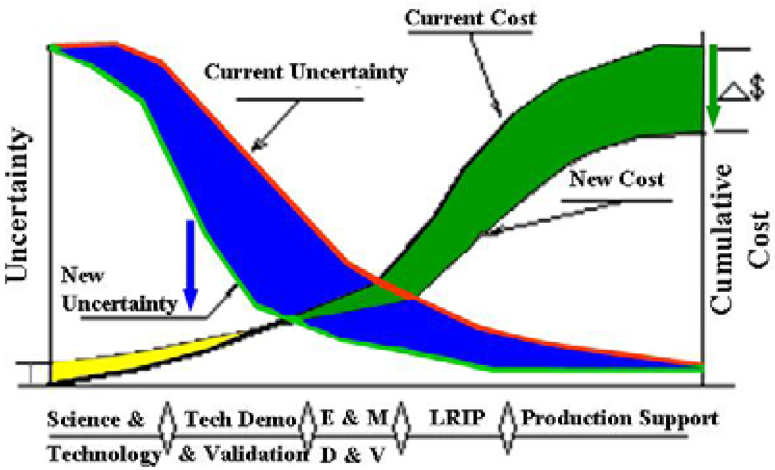
DER, Solar, Wind, Capacitors, Microturbines, Fuel Cells, Energy Storage, Intelligent Controls, Advanced Inverters

- Smart Radial Concept
  - Isolate, Clear and Restore unfaulted line sections automatically
  - Coordination of protective devices
  - Auto-reconfigure with alternate protection schemes
  - Built in DG/DER interconnections
  - Isolation Switches with CL Fuses, and Fault Indicating Devices
  - *Leverage Intelligence & Advance Inverter Capabilities in DER assets to enhance "D-Level" voltage support, efficiency and fault/disturbance "Ride-Thru" capability*

Source: C.A. Hessenius, A. Ang and S. Hamilton, "Fuel Cells: A Utility Perspective", Journal of Power Sources 158 (2006) 436-445. 17 February 2006

R. Neal, Presentations SECA Workshop, Monterey, CA & 2005 Fuel Cell Seminar, Palm Springs, CA

Work with UCI & SCE Drive Out Uncertainty *ASAP*



If the cost of commercializing new technology is generally between 10 & 100 times the cost of developing and demonstrating the technology, *then what can we do to hit 10x*!!!

Product development needs to be complete enough to ensure that products are sufficiently robust to endure all kinds of potential use scenarios they might encounter in all kinds of use and misuse.

This has historically been accomplished through testing designs until they fail, modifying the design, and testing it again. The more test-fix cycles the product goes through before reaching the market, the more expensive the product has to be to cover its development costs.

Notes from: G.Allen & R.Jarman, "Collaborative R&D - Manufacturing's New Tool", Wiley & Sons, NY 1999

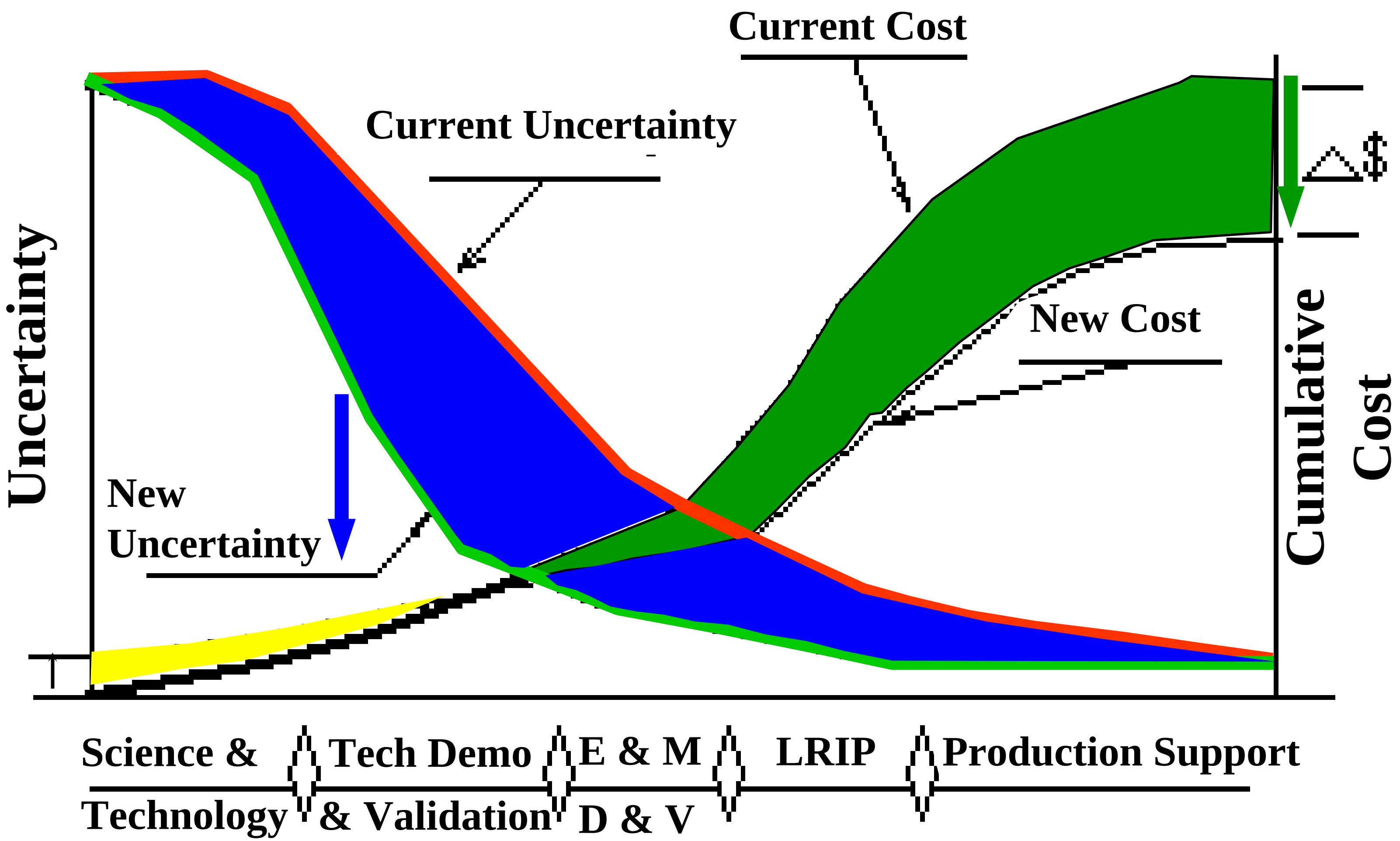
Integrated R&D and Deployment Planning

- Integrate Planning for all Stakeholders in Product Life Cycle
- Maximize Knowledge Creation & Benefits
- Integrate Test, Evaluation & Business Decision Activities

Minimize Serial Processing to Shorten Product Development Cycle

- Controlled Integrated Baselines
  - Business & Marketing Strategy Baseline
  - Delivery & Siting Baseline
  - Production Process Baseline
  - Operational Baseline
  - Product Capability & Functionality Baseline
  - Product Design Baseline
  - Research, Test & Evaluation Strategy Baseline

Driving Out Uncertainty



Inverter Lab & Utility Roles & Contributions

- **Specify and evaluate "Value-Added" power quality management functionalities in addition to real power from distributed generation and/or energy storage technologies.**
  - VAR support and reduced total current flow throughout system
  - Phase Balancing and reduced current flow on the neutral
  - Active Harmonic cancellation/correction
  - Autonomous/Semi-autonomous Intelligent Control
  - Develop requirements for all of the above
    - Individual worse case requirement
    - Simultaneous worse case requirements
- **Assess value of such inverter functions for D-Level circuits.**
  - Technical performance models that enhance T&D system performance
  - Economic evaluation data and models to enable Electric Utility system designers to smartly deploy such inverters to improve system efficiency and power quality while positively impacting the business financial bottom-line.

Inverter Lab and Utility Roles & Contributions

- **Identify and address policy and procedure concerns related to allowing and integrating autonomous VAR, phase balancing and harmonic correction capabilities within distribution feeders.**
  - Discuss testing and evaluating such capabilities with the new control strategies being deployed within the SCE Circuit of the Future during Phase II of project. ***Determine appropriate off-grid test facility.***
  - Discuss potential for future integration of "smart agent" distribution system control techniques for both technical performance management as well as business transaction management.
  - Air potential for greasing skids with CEC concerning funding of demonstration test and evaluation costs for varied SCE circuits, including the CoF. ***Discuss how best to coordinate with CEC.***
- **Keep Project & Technology efforts focused on meeting T&D system needs not just a "Science Project".**

Thoughts for Inverter Lab Test & Evaluation

- **All operating conditions**
  - Normal
  - Dynamic Load Change, VAR need, Harmonic Response, Phase Balance
  - Extreme operating conditions (min, max, worse cases)
  - Emergency, fault scenarios
  - Inverter support of circuit fault ride-thru vs. disconnect
- **Control Response**
  - Autonomous/semi-autonomous load, fault, emergency response
  - Quickness, amplitude, and effect on circuit stability and power quality…
- **Varied DG/DER power input characteristics {Investigate lab capabilities to vary input parameters}**

Thoughts for Distributed Power Study

- **Explore system wide impacts, cost and societal benefits associated with various DG technologies**
  - Initial Capital Investment Risk, Life Cycle Cost, Environmental Impacts & Benefits & Policies, Regulations and Business Practice
  - ***How will CO2 emissions be captured & stored?****
- **Quantify w/SCE the inverter technical performance and economic benefits of:**
  - VAR support (a.k.a. leading/lagging linear displacement)
  - Harmonic active correction
  - Phase Balancing
- **Evaluate merits of load-side technologies to manage VARs, harmonics and non-linear current at the facility and/or load**

* Note the recent Supreme Court ruling that green house gases must comply with the Clean Air Act. Impact on DG technologies?

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Back-up Slides

SCE DG VAR Support Study

Back Ground

- **Generation added to the original circuit model, in the following increments**
  - 250 kW with no VAR support
  - 250 kW with 150 kVAR support
  - 500 kW with no VAR support
  - 500 kW with 300 kVAR support
  - 1000 kW with no VAR support
  - 1000 kW with 600 kVAR support
  - 3000 kW with no VAR support
  - 3000 kW with 1800 kVAR support

Source: C.A. Hessenius, A. Ang and S. Hamilton, "Fuel Cells: A Utility Perspective", ASME Fuel Cell Conference 2006, Irvine, CA

SCE DG VAR Support Study

Back Ground

- Topology for the circuit extracted from SCE's circuit maps
- Capacitor banks present on the circuit, fixed
- Generation added to the circuit is considered a "black box", containing a fuel cell and an inverter. A key assumption is that the fuel cell's inverter can provide VARs to the system
- Assume modeled generators regulate distribution (primary side) voltage
- Balanced 3-phase loading on circuit
- End-point loads were estimated; two total circuit loading scenarios, 'peak' 600 Amps (10.5 MVA), and 'normal' 400 Amps
- Power factor of 0.90 was assumed, uncorrected on circuit

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Source: C.A. Hessenius, A. Ang and S. Hamilton, "Fuel Cells: A Utility Perspective", ASME Fuel Cell Conference 2006, Irvine, CA