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Configurable PV Solutions and Resultant Impacts to our Ever - Changing Electrical Grid

August 2nd 2013

IEEE Sustainable Technologies Conference

AESOLARENERGY

Presentation Overview

- PV Penetration Impacts on Electrical Infrastructure
  - Interconnection Variation and Configurability Needs
  - Power Electronics and Inherent Capabilities
- Deterministic Solution Set
  - Features / Functions
  - Control Modes
  - Asset Coordination

- Case Study
  - Modeling, Lab Validation, Field Deployment
  - Baldock Solar Site

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PV Penetration and Existing Electrical Infrastructure

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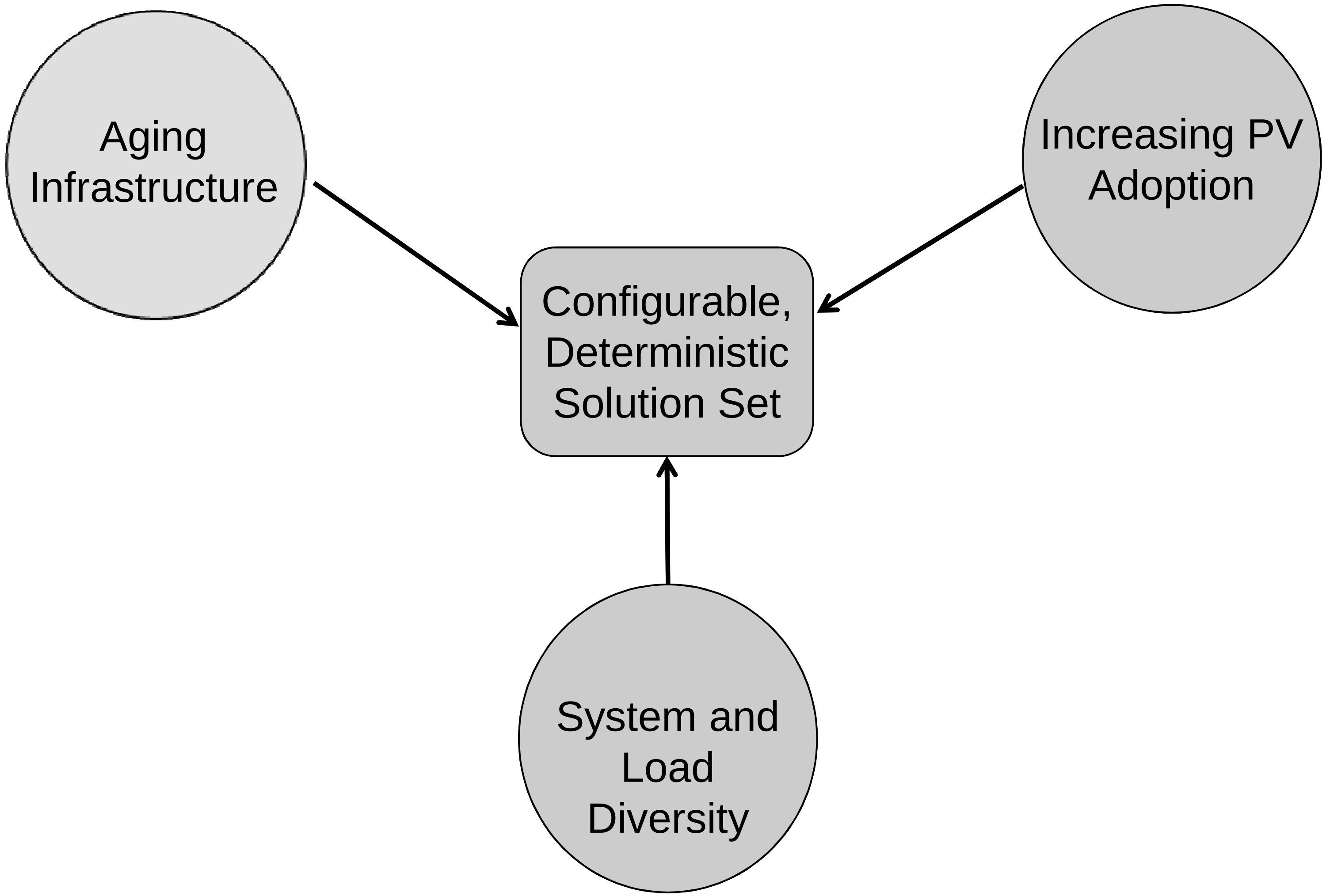
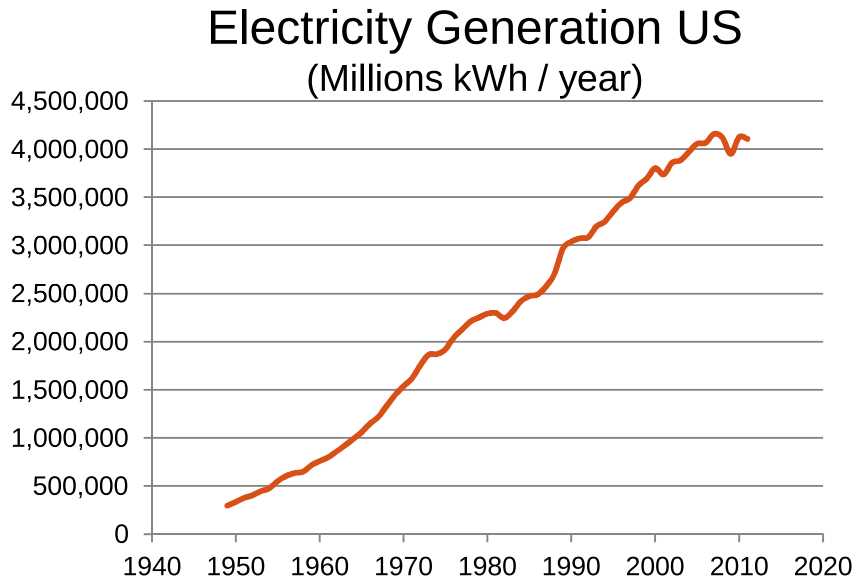
Distributed Generation Resource Management



Electrical Distribution Systems

- One of the "Supreme Engineering Achievements of 20th Century"
  - Reliably
  - Safely
  - Economically

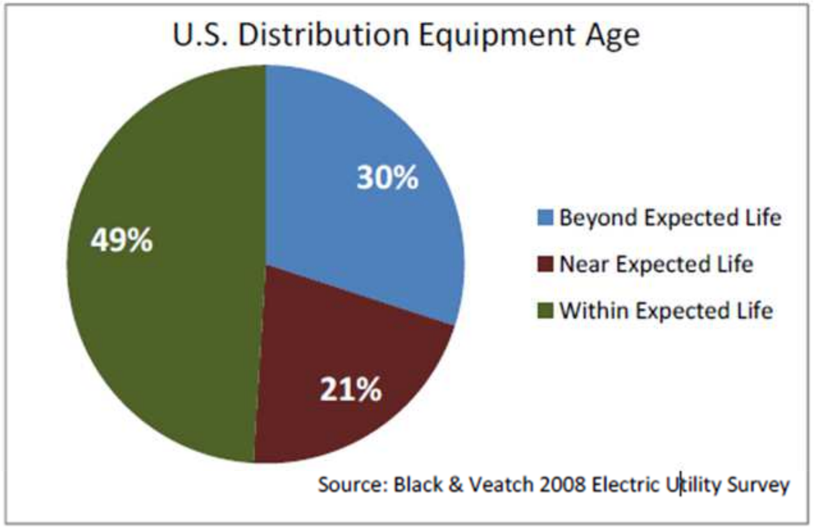
- Significant Technology Developments
  - Automatic circuit re-closers
  - Automated sectionalizing and tie switches
  - Digital metering infrastructure
  - Digital relays
  - PMU capability for system analysis



** Data for graph courtesy of US Energy Information*

The Aging Electrical Infrastructure

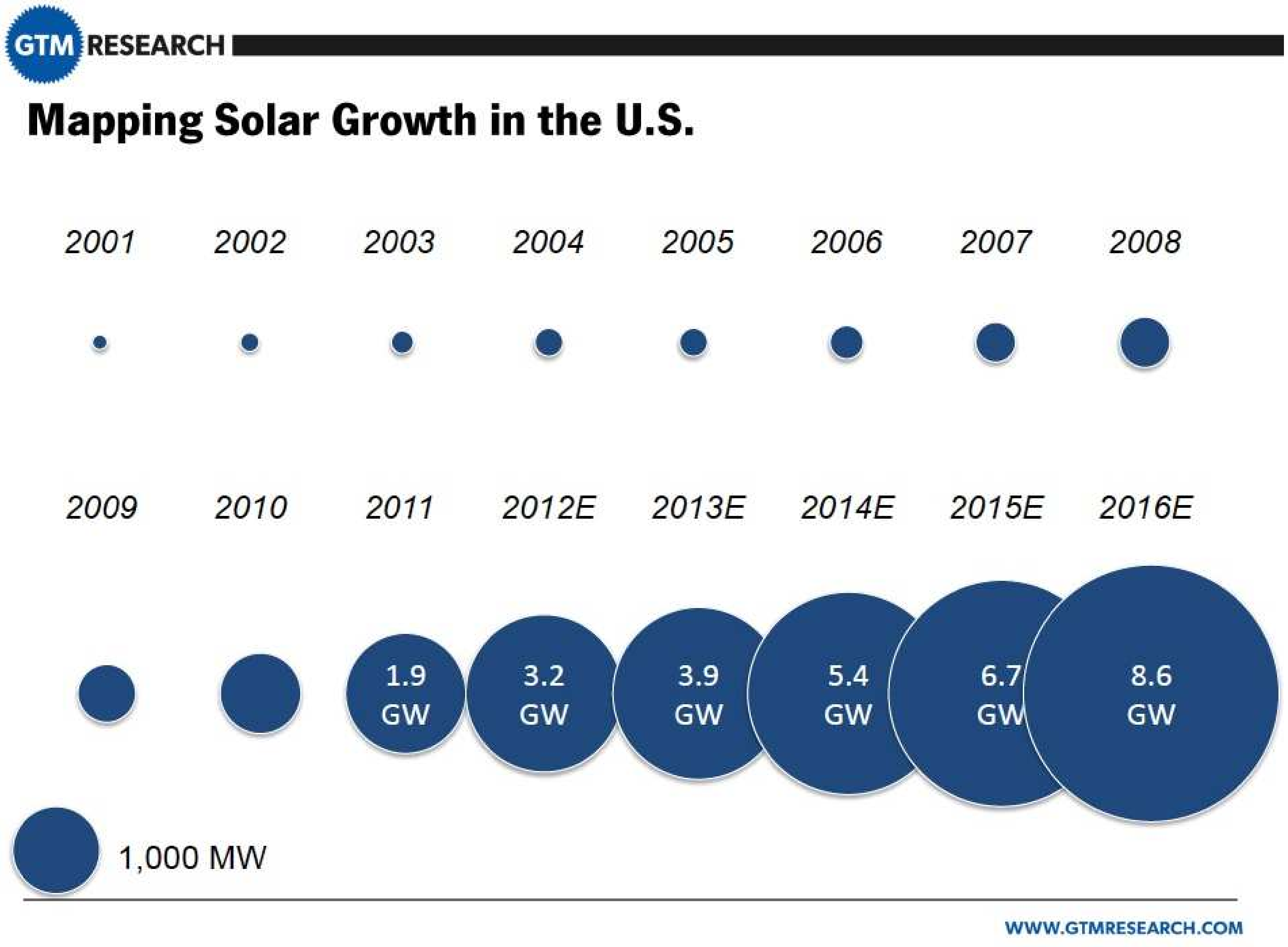
- "Deterministic" System Design
  - Short / long term forecasting
  - VR equipment settings
  - Protection settings



Distribution Engineering Factors	
Traditional	Additional Factors Today
Voltage levels	Voltage Stability
Phase balance	Minimum load for DG
Maximum demand	Net load/supply variability
Load factor	Load & DG Harmonics
Power Factor	System Transients
Short Circuit Current	Protection coordination
Deterministic Modeling	Stochastic Modeling

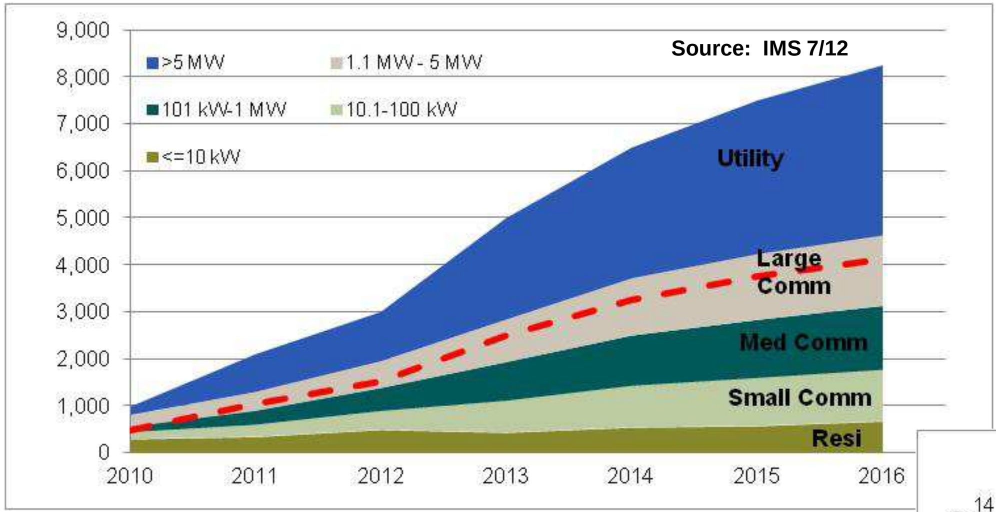
Evolving Customer Loads
- Digital era
- Agricultural – consolidation
- Demand response
- Energy conservation

US Solar Market Growth

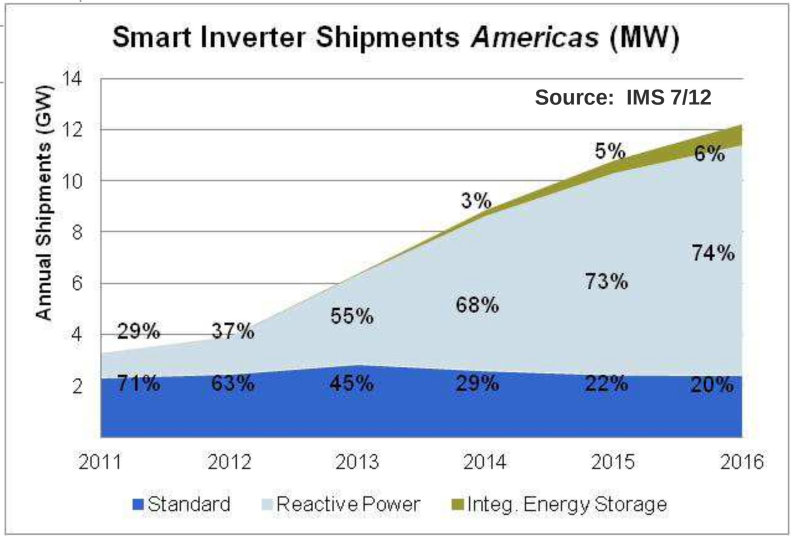


**charts courtesy GTM*

PV Integration Projections



- Increasing # installations
- Increasing system size
- Geography and adoption



- High penetration
  - Capacity / min load
  - Output / nameplate
- Advanced services
  - Intermittency mitigation
  - Fault handling
- Capacity factor
  - Reliability

**charts courtesy of IMS 7/12*

Obstacles | Barriers to PV Growth

Short Term

- Interoperation with VR Equipment
  - Cap banks
  - LTC's
- Coordination with Protection Schemes
  - TOV
  - Re-closer events
- kWh vs. kVAr
  - Incentive programs
  - Voltage support

Medium Term

- System Level Impacts
  - Storage Integration
  - Forecasting
  - Protection Enhancements
- Economic Comm's Network
  - Function Management
  - Reliable / Robust
- Capacity Factor
  - System Overdesign
  - Burst Operation
  - Storage integration

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Inverter Capabilities:

Power Electronics Enabled Features and Functions

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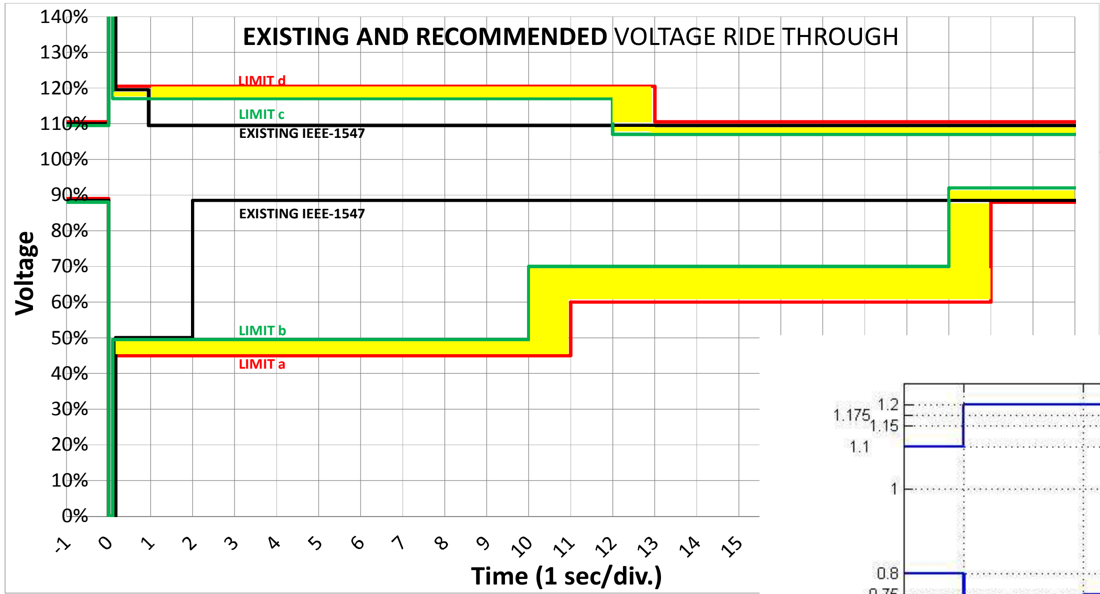
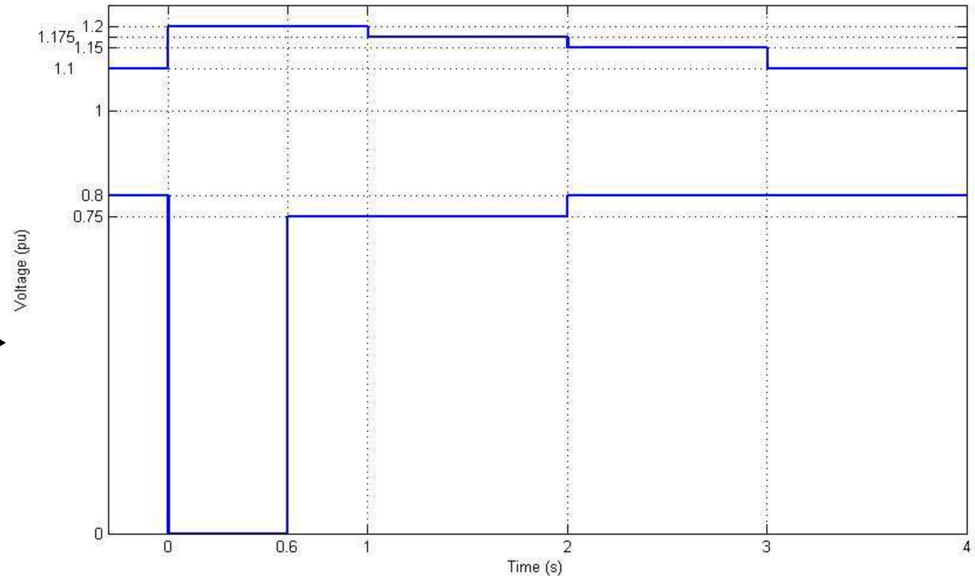
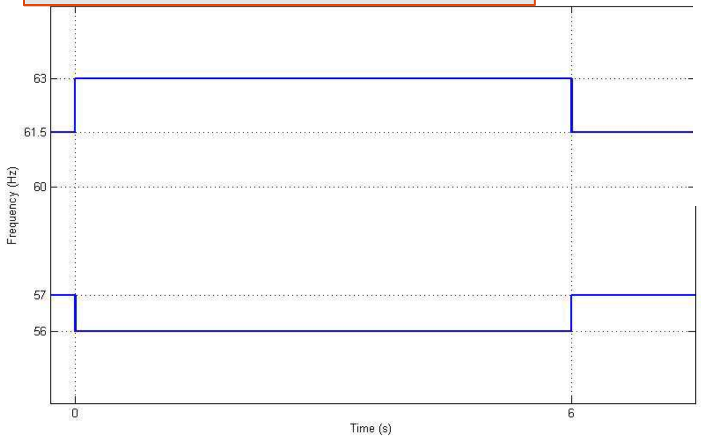
Voltage and Frequency Trip Points



Proposed CEC/CPUC Voltage Ride-Through Profile

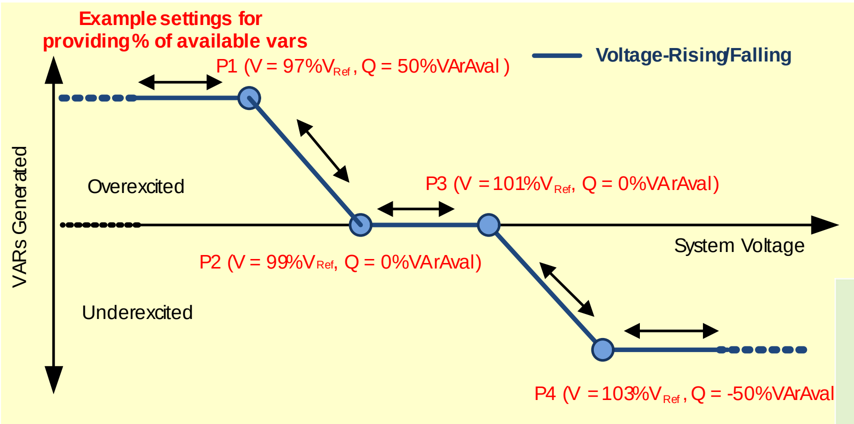


HECO Proposed Voltage Ride-Through Profile



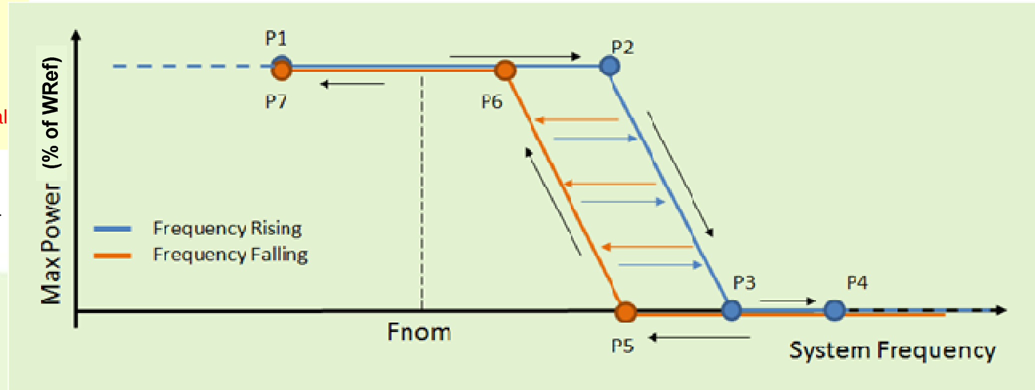
HECO Proposed Frequency Ride-Through Profile

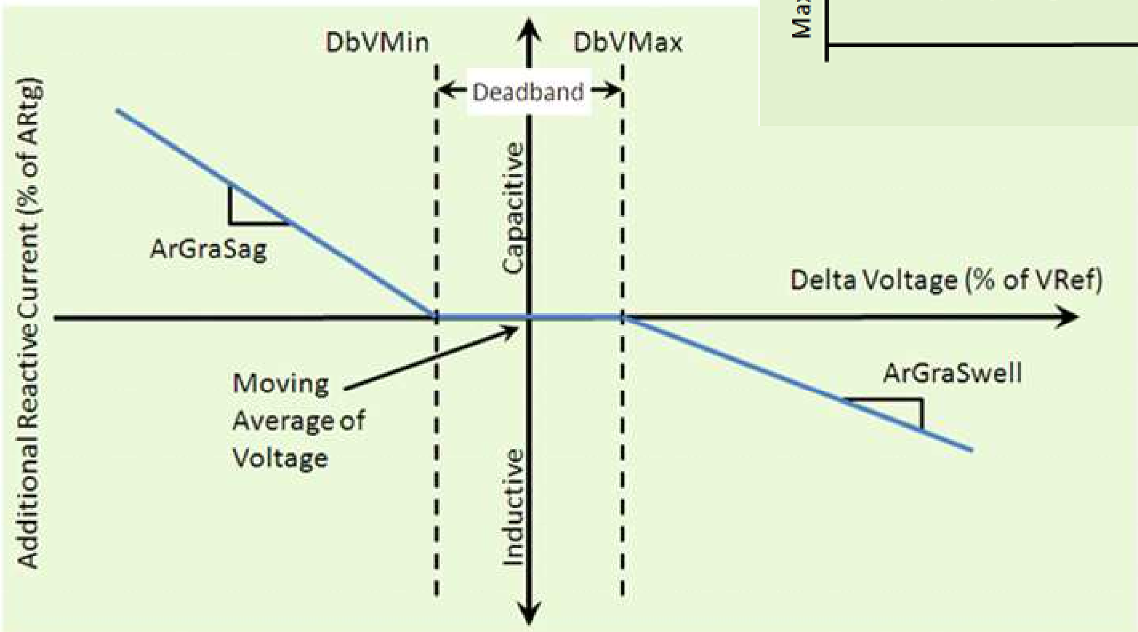
Inverter Response to Grid Transients



VAr response (reactive power)

Watt response (real power)

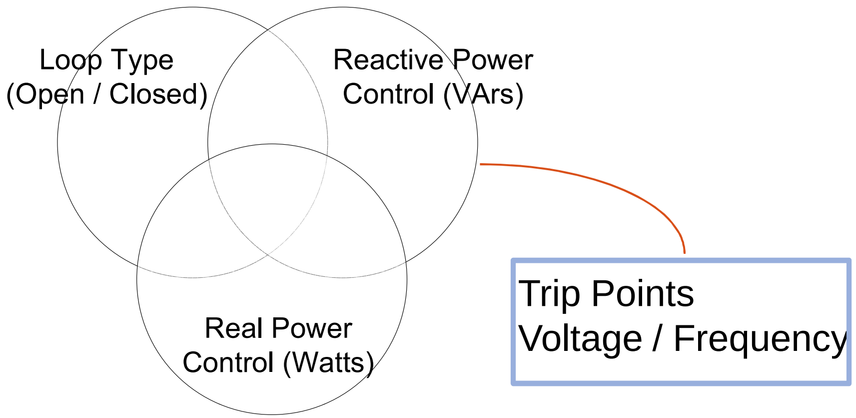




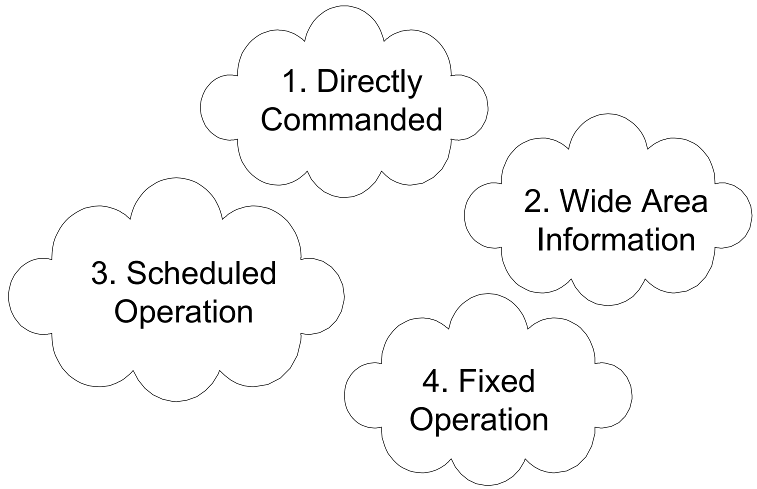
VAr response (dynamic)

Configurable Platform of Solutions

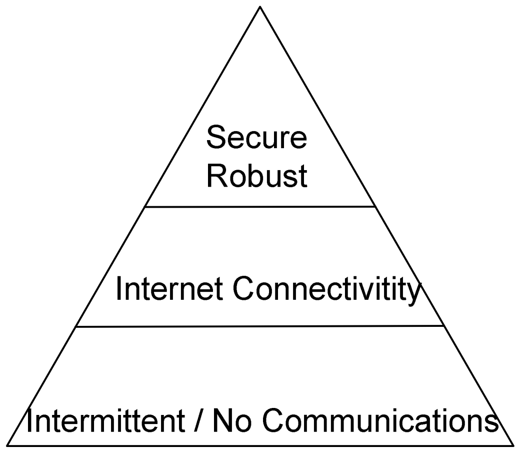
- Voltage Support Functions



- Priority Control Structure

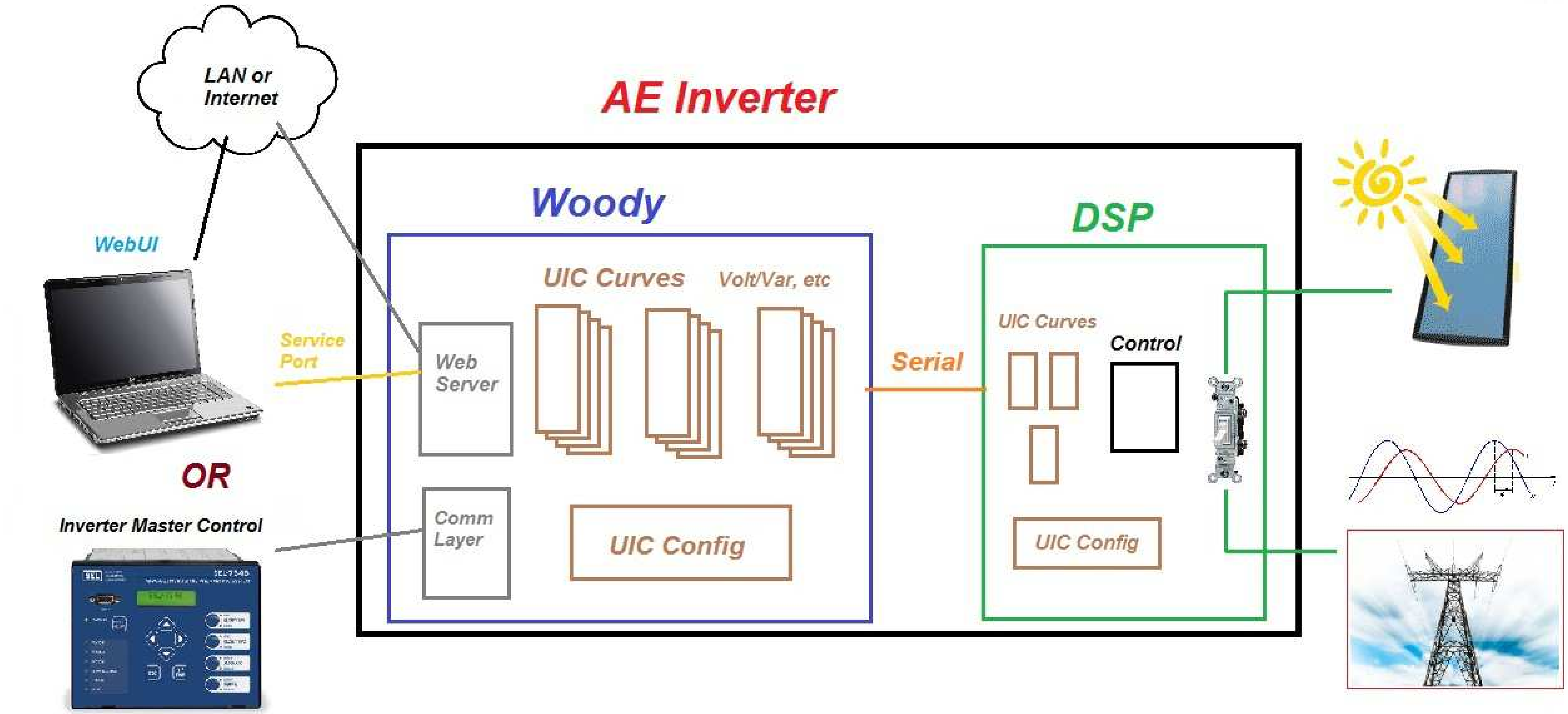


- Degree of Communications



- Management / Configuration Tools
  - Deterministic
  - User configurable
  - Authentication and authorization
  - IMC vs. Stand-alone

Inverter Architecture Function Management



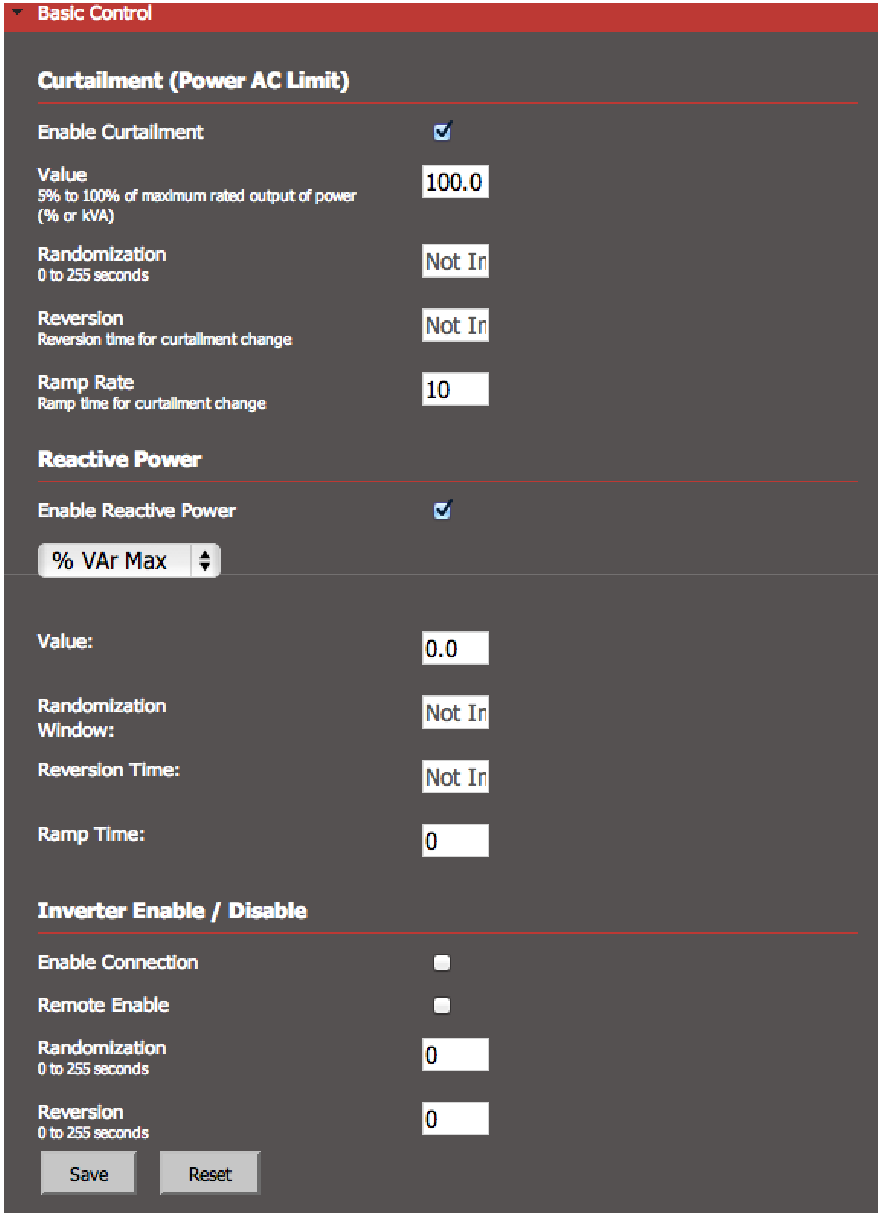
- Service / Support
- User Interaction
- Configuration / mgmt

- Pre-stored operating conditions
- Function Management
- Data aggregation / communication mgmt

- Output current
- Safety functions
- MPPT / Active UIC

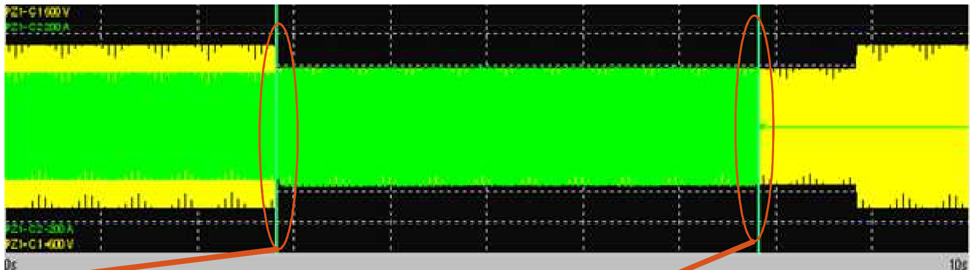
Basic Inverter Controls / Inverter Management

- Real Power Curtailment
  - Managing watt output
- Reactive Power Management
  - % Nameplate VAr's
  - % Available VAr's
- Global Control Variables
  - Ramp time
  - Reversion
  - Randomization
- Enable / Disable
- Network Configuration

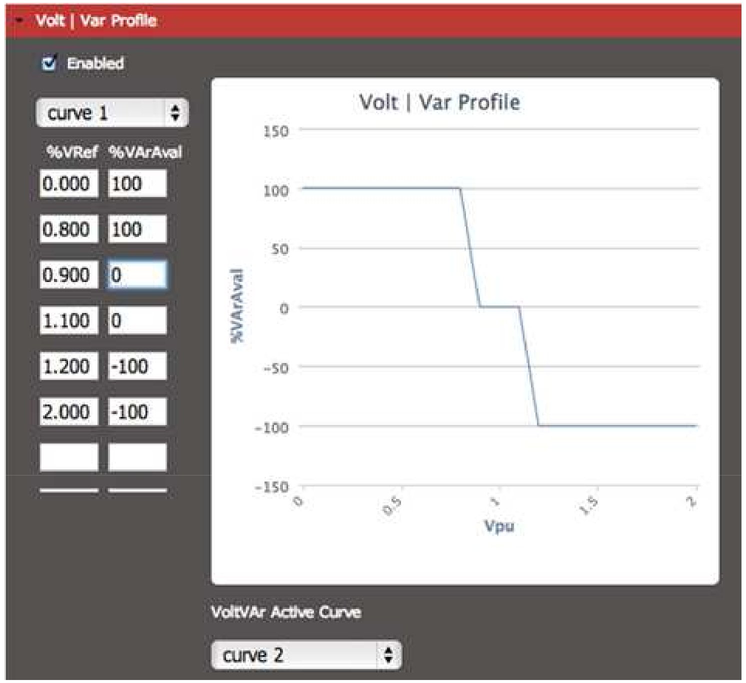


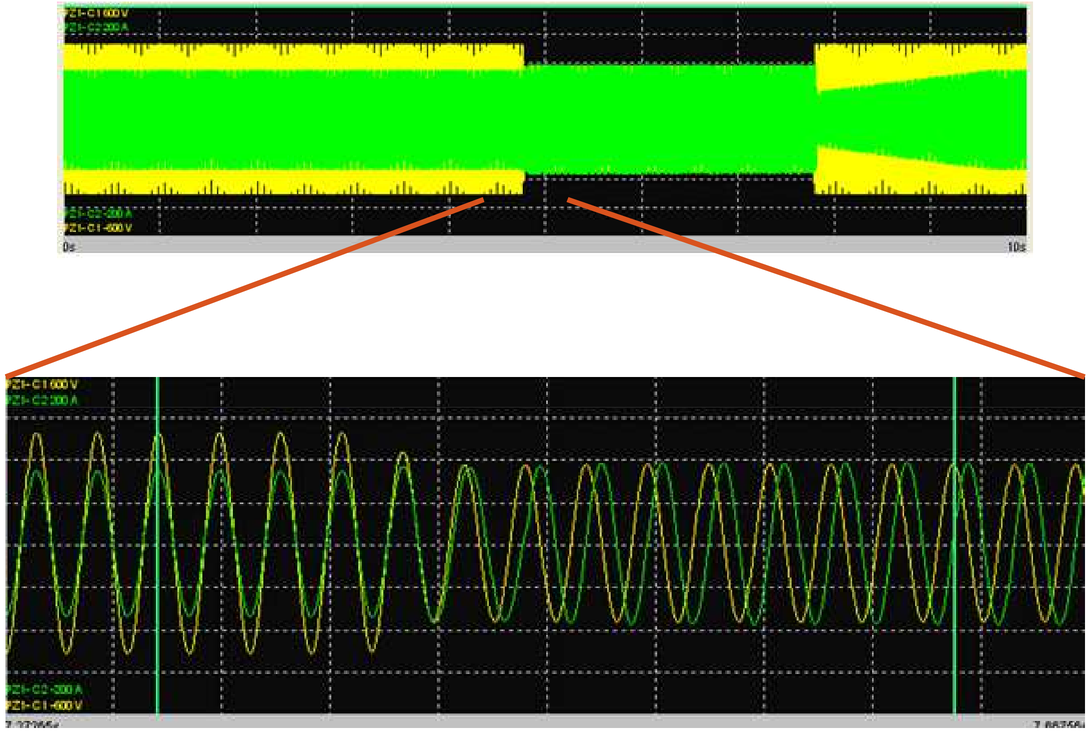
User Configurable Voltage Trip Points

- Curve Settings:
  - LVRT envelope allows 0.3 to 0.75 p.u. for <= 5 sec
- RS90 (Grid Event)
  - Voltage sag to 0.7 p.u. for 6 sec



Volt – VAr Response to Grid Transient

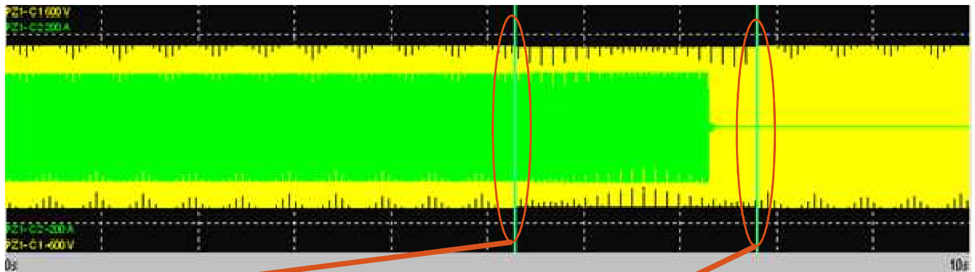




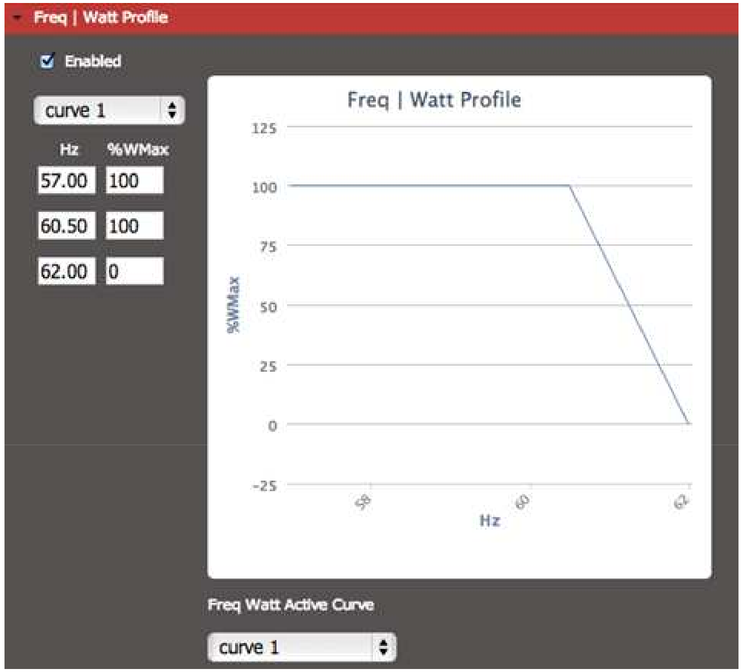
Device Configuration —— Grid Event —— Inverter Response

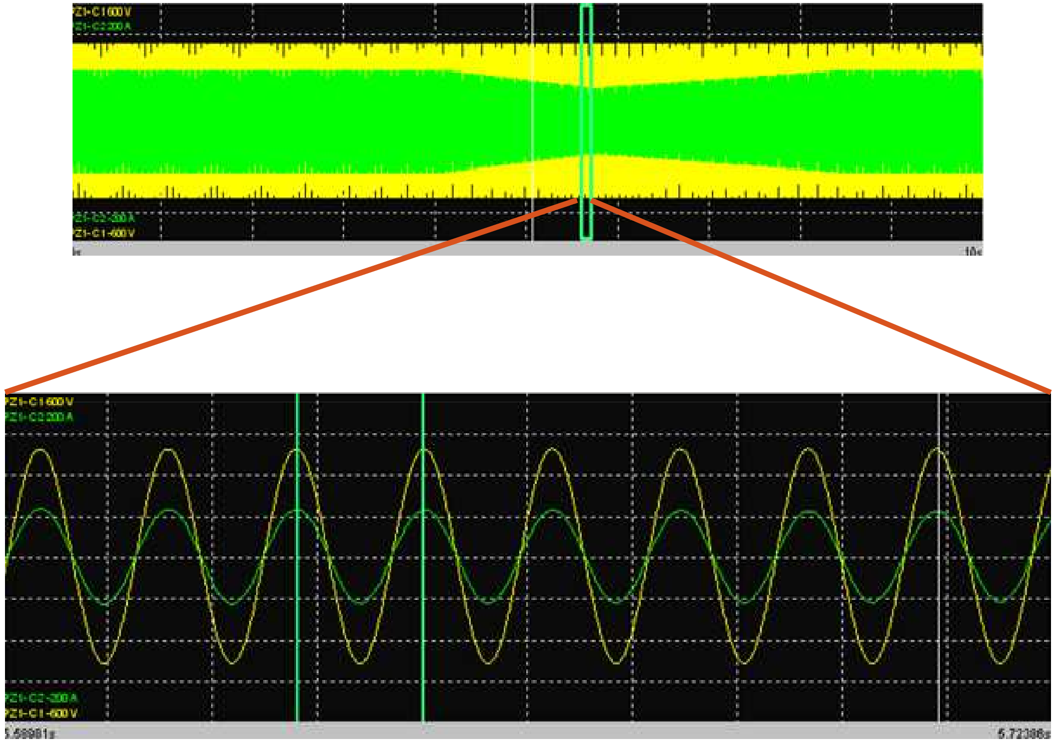
User Configurable Frequency Trip Points

- Curve Settings:
  - Trip envelope allows 57 – 59.5 Hz for <= 2 sec
- RS90 (Grid Event)
  - Go to 58 Hz for 2.5 sec (for clarity, voltage will go to 0.98 p.u. as well)



Frequency–Watt Response to Grid Transient





Device Configuration ——— Grid Event ——— Inverter Response

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Case Study:

Baldock PV Site

Modeling, Lab Verification and Field Validation

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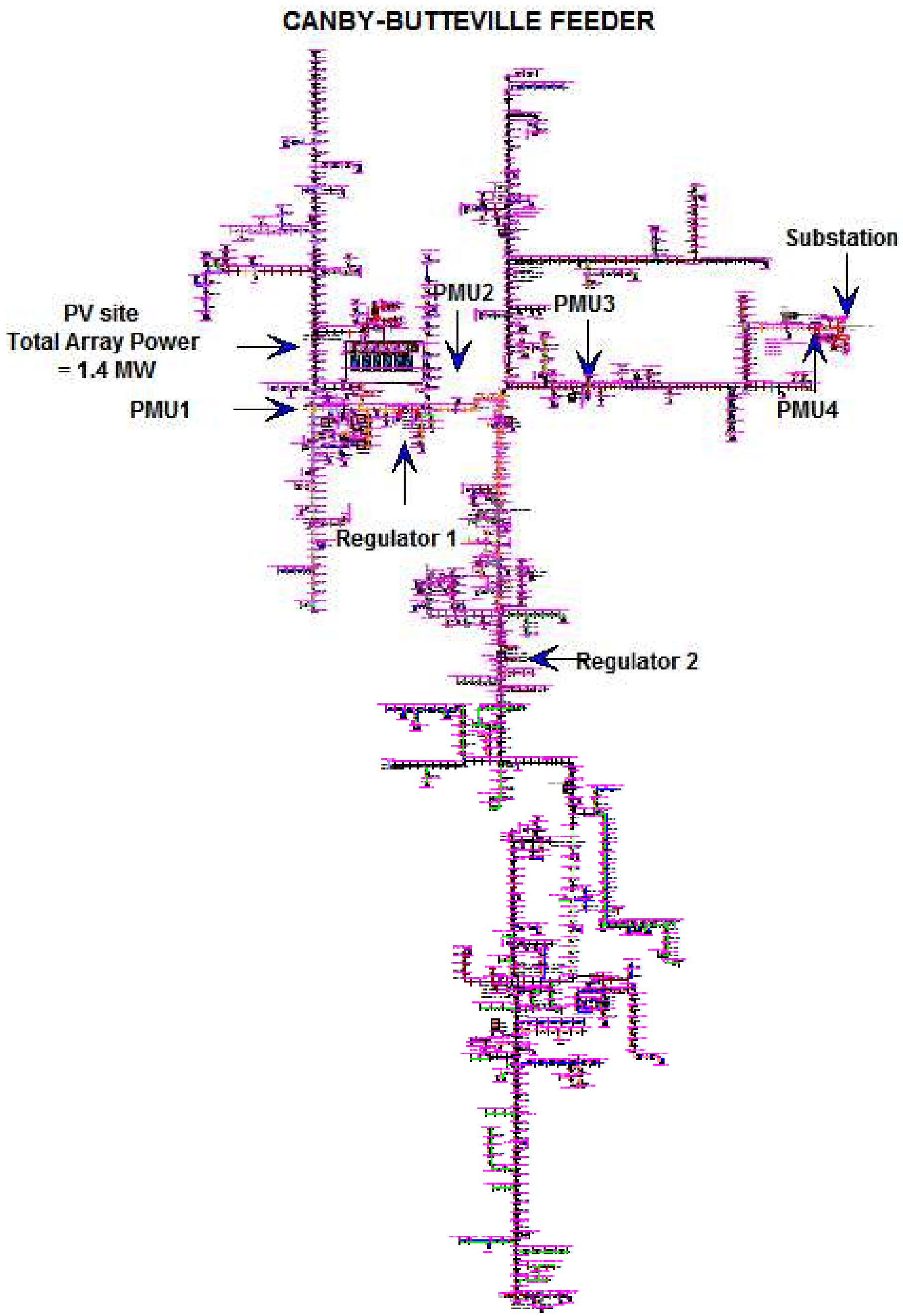
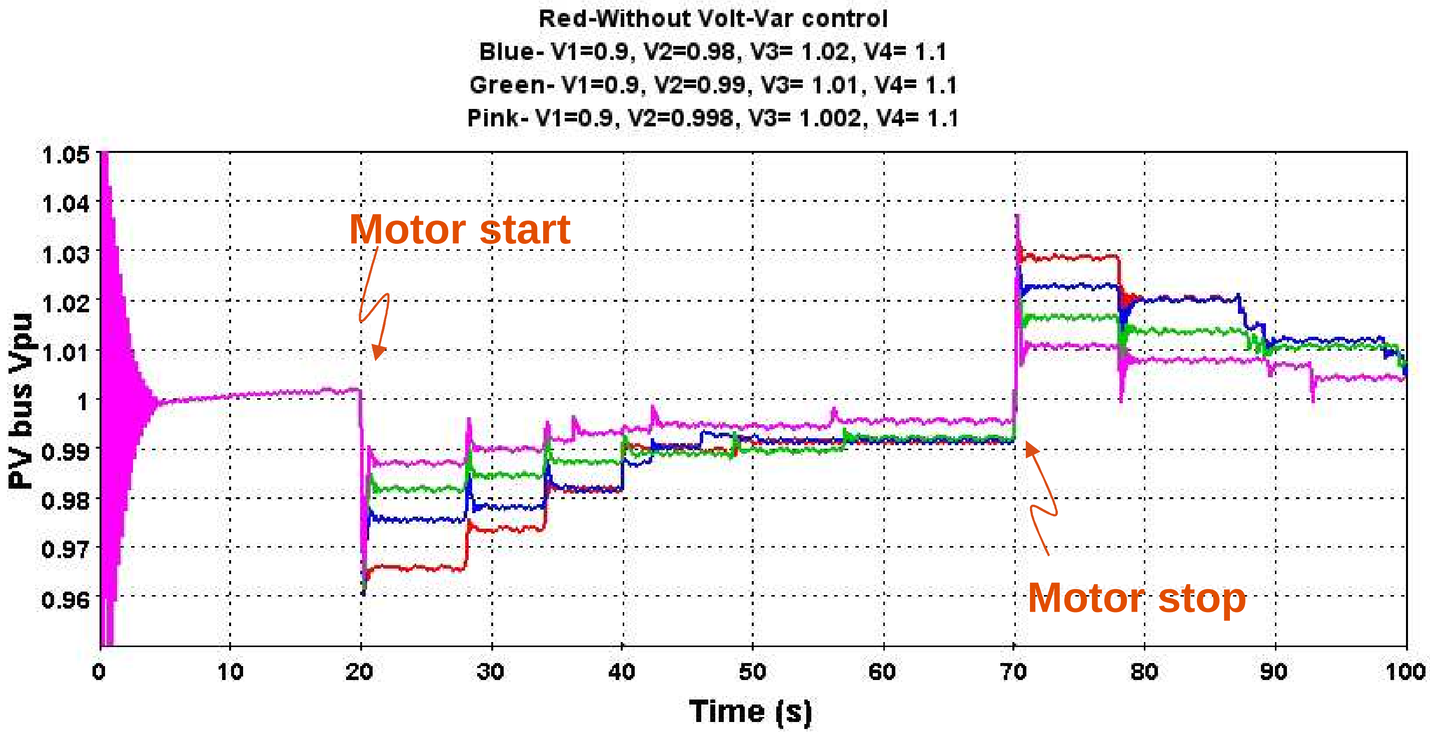
Modeling and Simulation

- Data gathering / Modeling
  - ➢ Detailed models built of all of the selected PGE and PEPCO feeders
  - ➢ AE transient inverter model detailed and leveraged with volt-VAr and frequency-watt functions implemented.
  - ➢ Complete feeder level model analyzed for sub-transient, transient and steady state response.



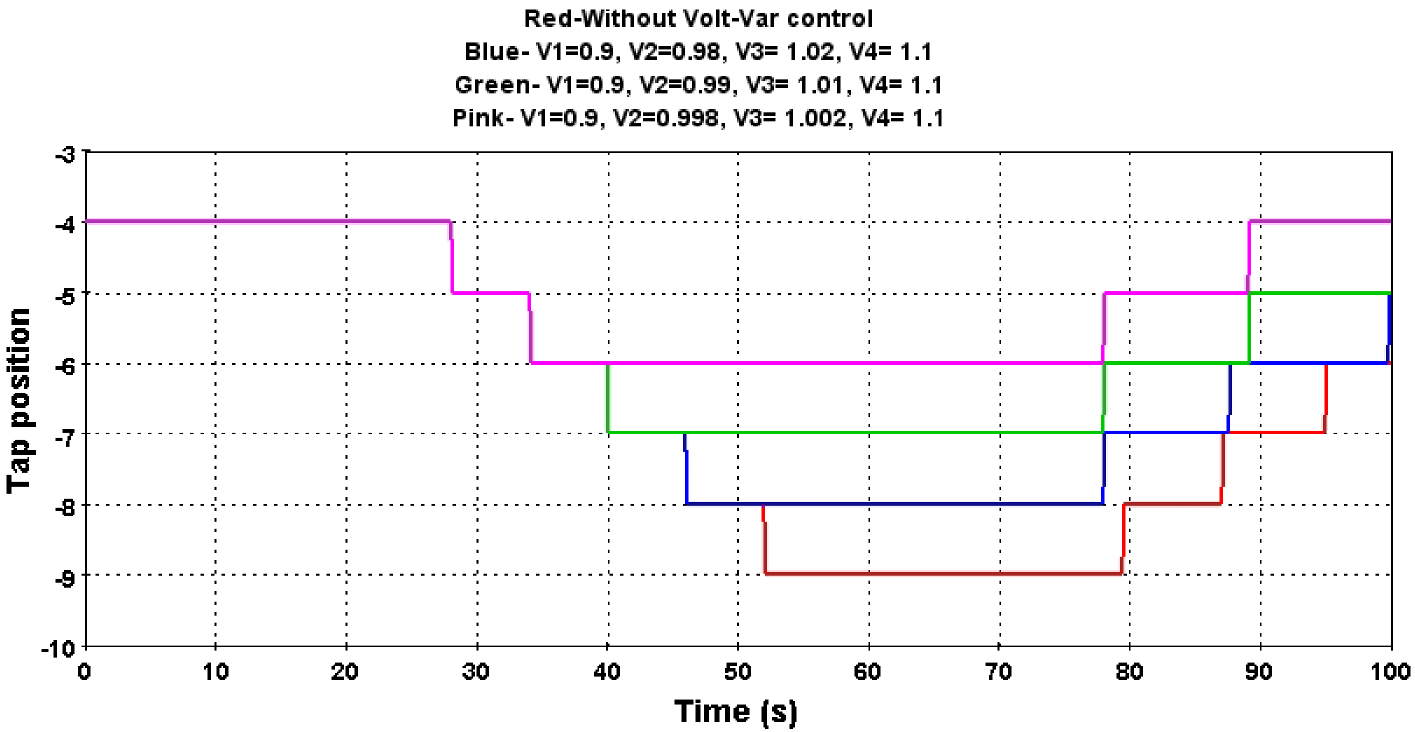
AC Voltage Response to Motor Start Event

- Simulation results to date: Canby-Butteville



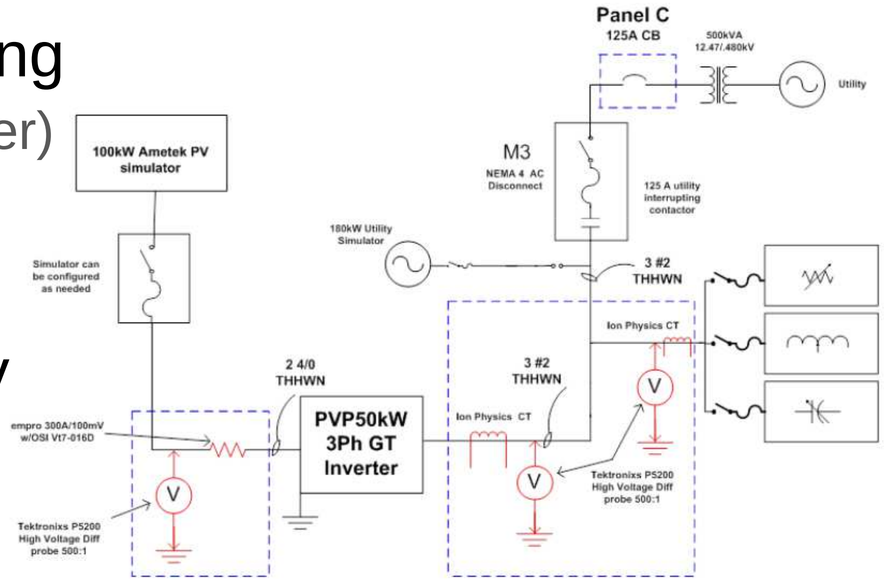
Voltage Regulator Response to Motor Start Event

- Canby-Butteville (simulation)



Laboratory Testing and Validation

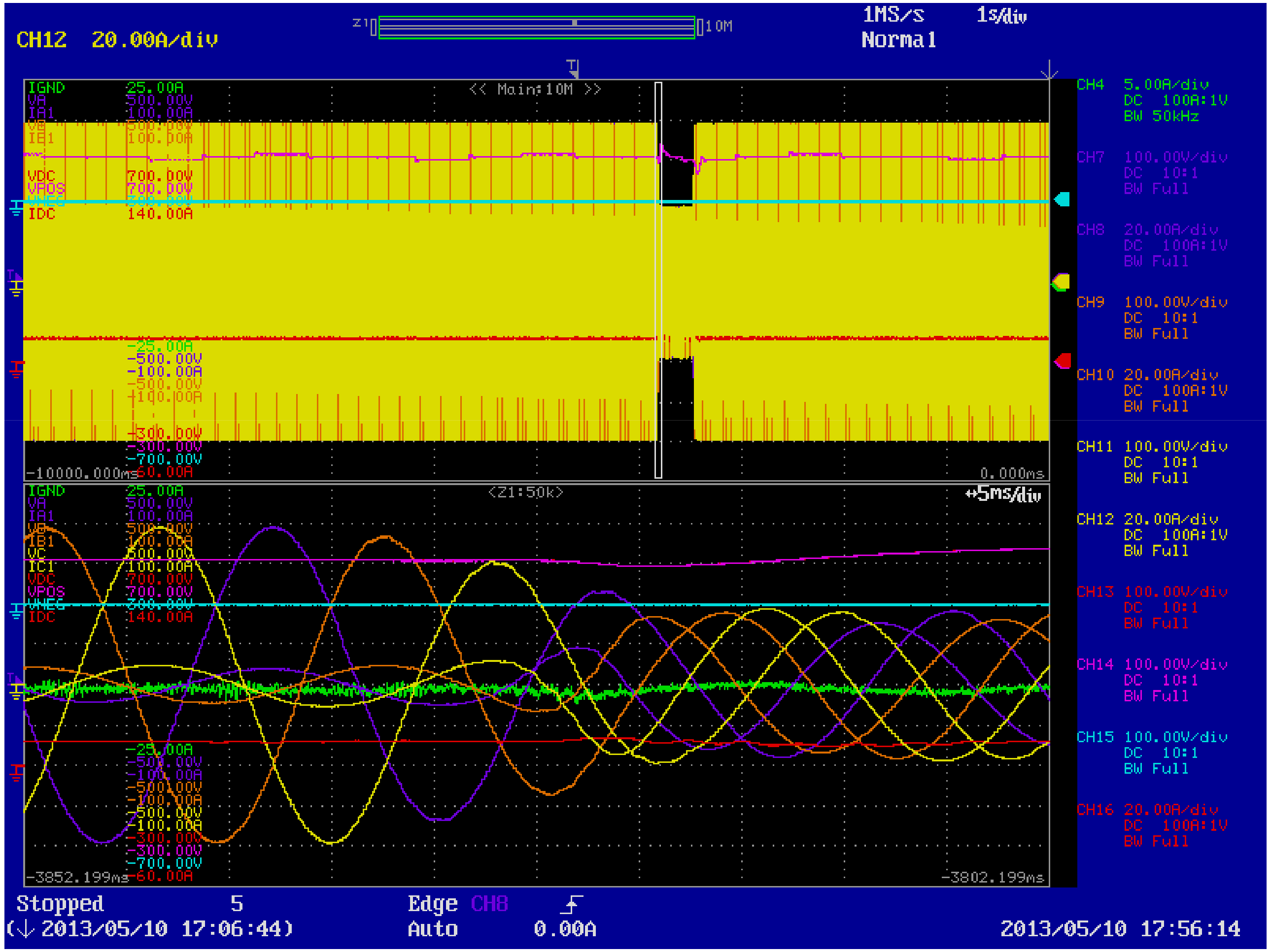
- Sandia National Laboratories
  - Scaled testing (50 kVA inverter)
  - Preliminary functions
- Advanced Energy Lab Testing
  - Scaled testing (50 kVA inverter)
  - 500 kVA preliminary tests
  - User interface testing
- National Renewable Energy Laboratories (ESIF)
  - 500 kVA full power testing
  - Full system tests "black box"
  - HIL and PHIL Testing



Battery Configuration Enclosure

3-Phase Grid-Tied Test Rack each ph monitored individually on inverter and load (load can be replaced with another inverter)

Inverter Response to Grid Sag Event



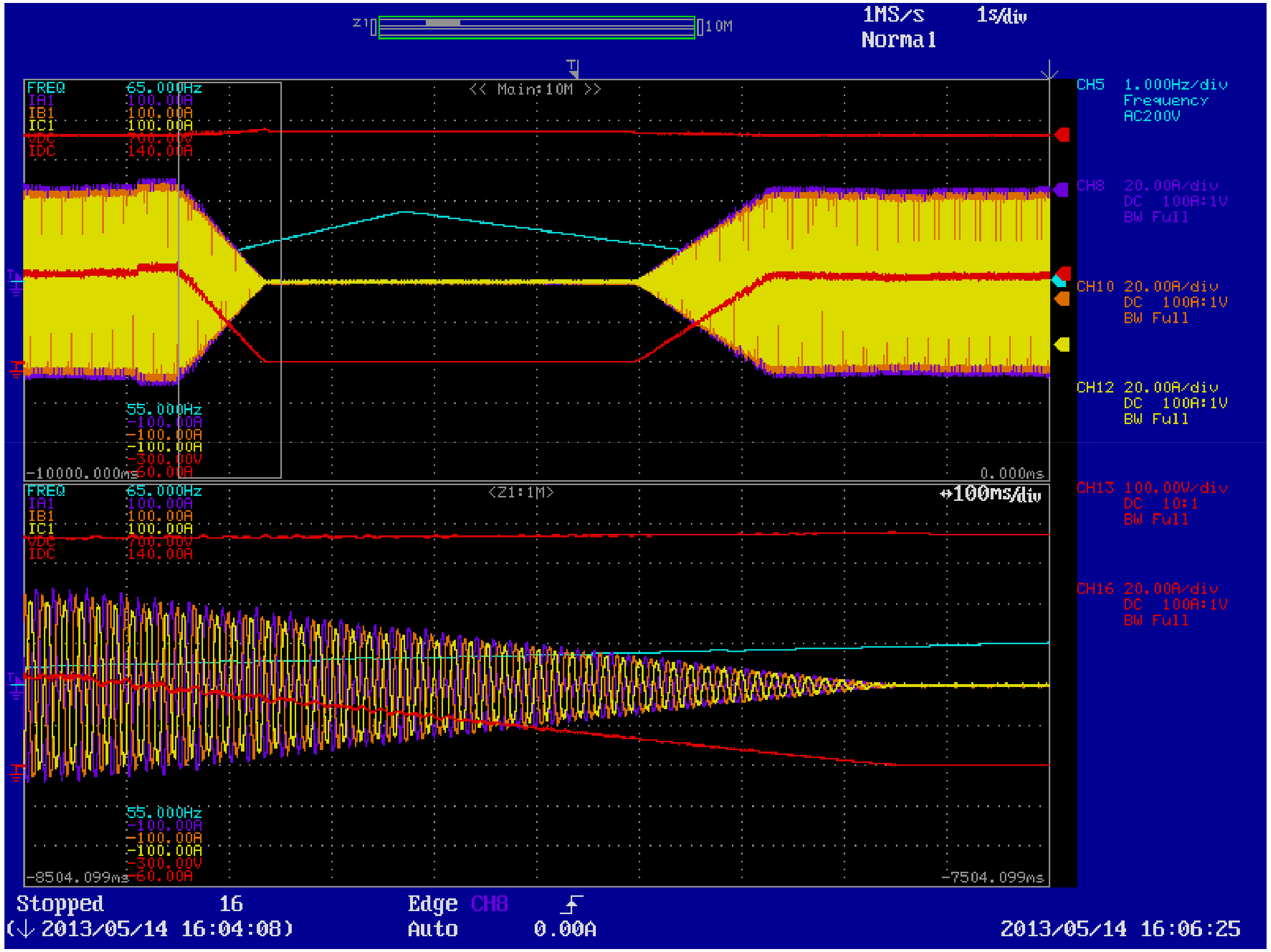
<u>Grid Sag Event</u>

1) Step change from 1.0 per unit to 0.7 per unit

<u>Inverter Response</u>

Transition to VAr source per defined user configurable profile and maintain until sag ends or trip point envelope is reached.

Frequency Ride-Through and Inverter Response



<u>Frequency Ramp:</u>

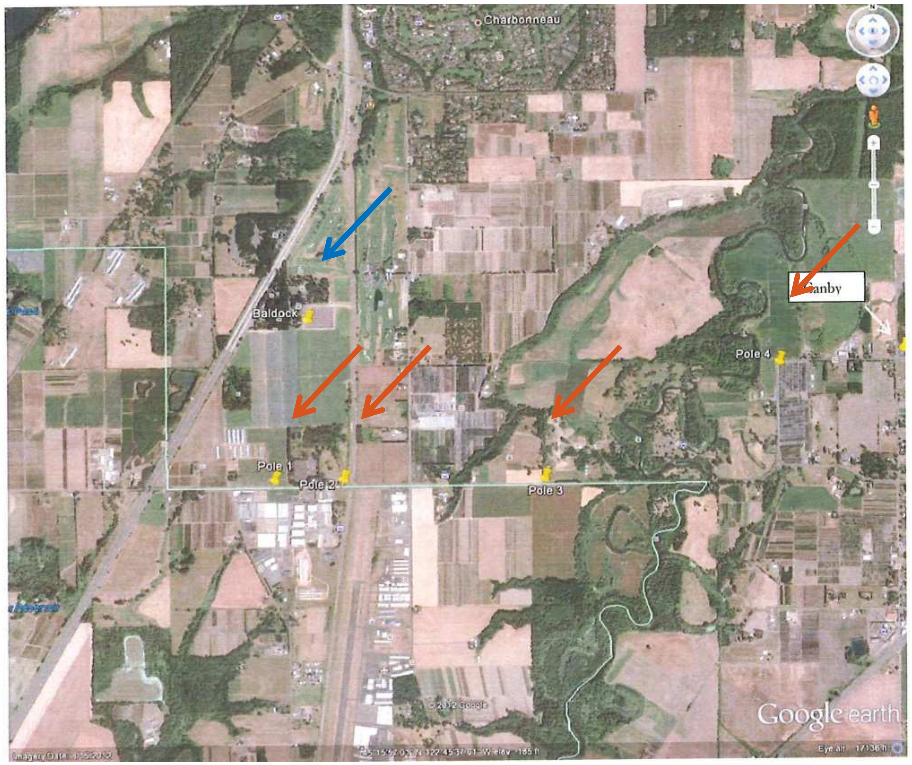
1) Start 60 Hz
2) Ramp to 61.5 Hz (2s)
3) Ramp to 60 Hz (3s)

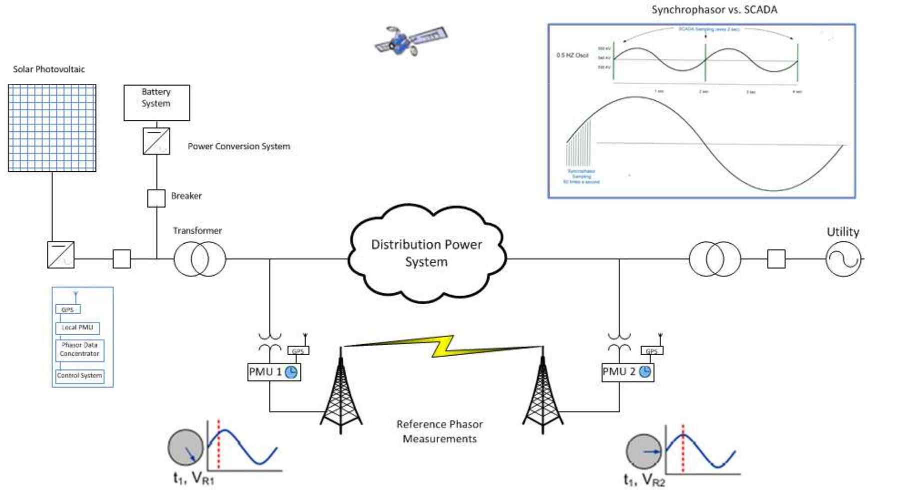
<u>Inverter Response</u>

Curtail output to rising frequency according to defined watt-frequency curve

Feeder Performance – Equipment Installation

- West Coast: Canby-Butteville Feeder
  - Installed 5 PMU's along service feeder
  - PMU with GPS clock, Radio, Logging Capability
  - Transmitting data to Baldock PV site





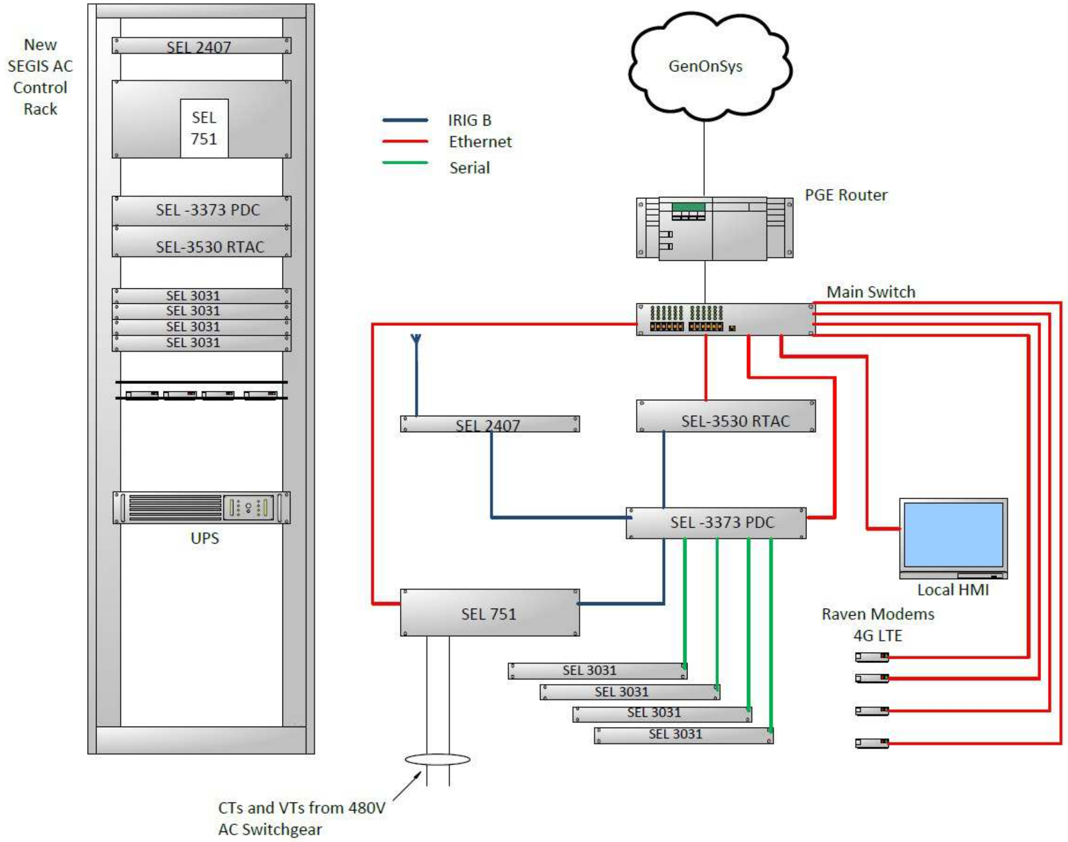
Baldock PV Site Equipment Installation

All equipment for long term demonstrations installed at site

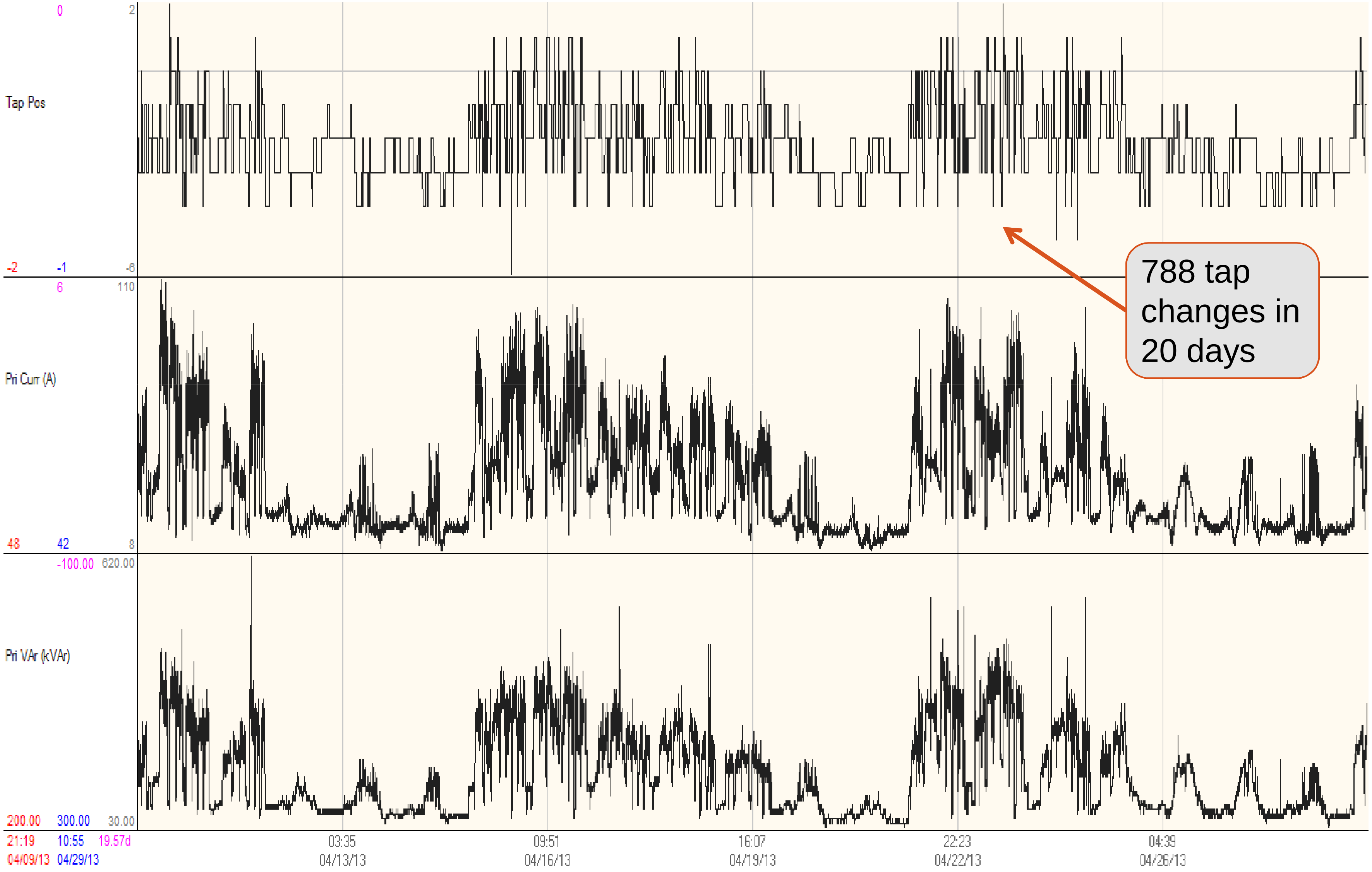
- IMC, meter, radio receivers, inverter connections, etc.

Data collection and analysis ongoing to validate models

- Volt/VAr response, ramp rate controller response, island detection validation



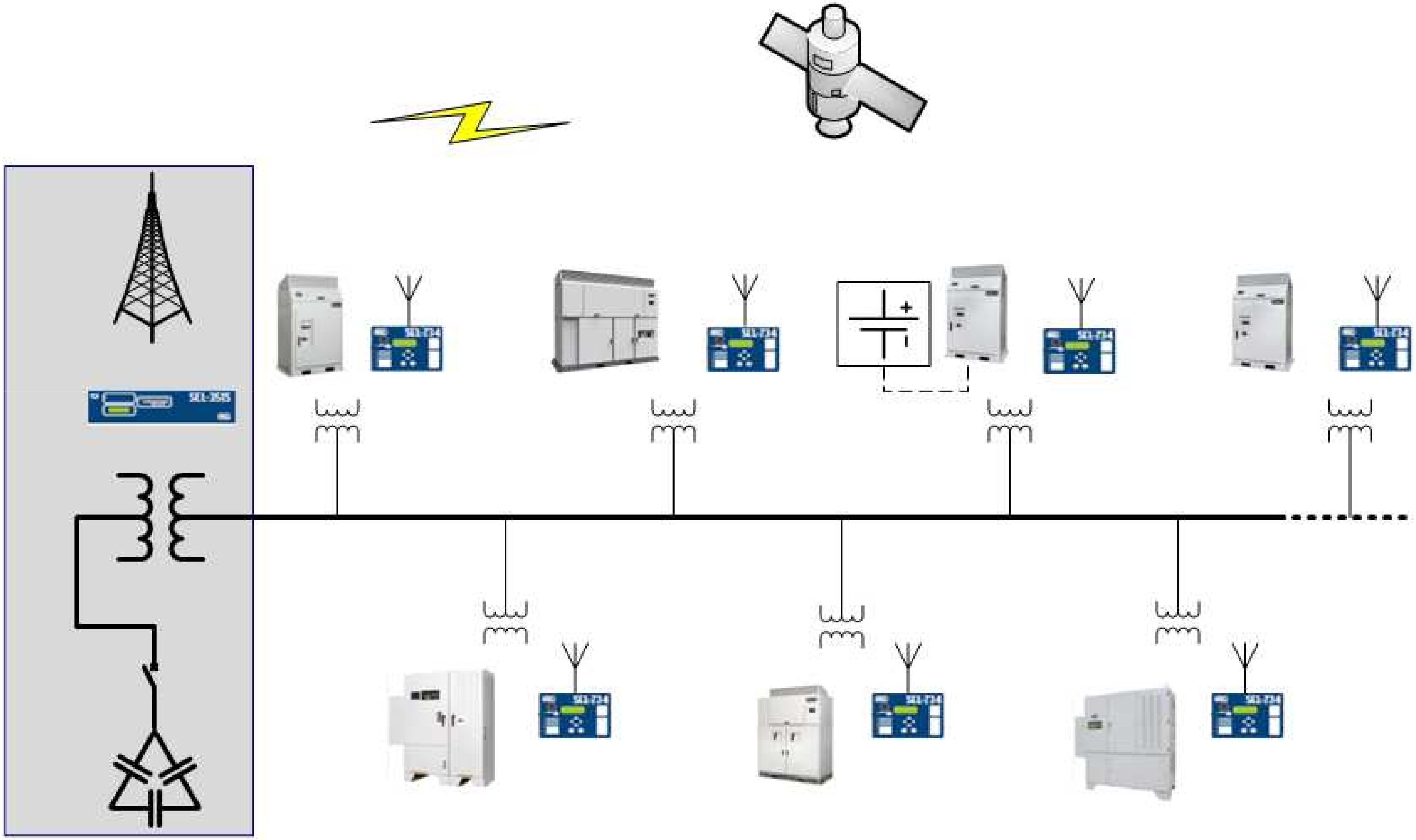
Butteville Regulator Response (April)



Results of System Study (to-date)

- In summation, the volt-VAr functions ~can~ provide major benefits on feeders
  - Definitely effective in mitigating the local impacts of cloud transients
  - Can provide significant benefit in improving the feeder voltage profile under other contingencies, such as large load or capacitor switching
- However, the level of benefit ranges from zero to a lot, depending on the feeder configuration as well as the installation size and location
  - High penetration
  - Distributed model

A Look Ahead -- Wide Area Control



Conclusions

- PV adoption rates driving need for additional grid supportive functions throughout distribution circuits
- Interconnection standards evolving to allow for distributed generators to perform voltage and frequency stability functions.
- Power electronics based inverter solutions offer flexible, deterministic programmable response
- Solution set can be re-purposed to accommodate circuit reconfigurations and load modifications.
- Field tests, and long term case studies ongoing to validate models, simulation results, and opportunities

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Backup Slides

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Practical Implications of Functionality

- Distributed Voltage Stabilization
  - Brown-out mitigation
  - Demand charge reduction / elimination
- Interconnection Rules Conformity
  - Electrical and geographical needs
  - Load forecasting and future control modifications
- Electromechanical Voltage Regulation Equipment
  - Reduce cycle counts (regulators, cap banks, LTC's)
  - Reduce / eliminate need for re-conductoring
- Feeder, Sub-Transmission and Transmission Efficiency
  - VAr source – load match
  - Response time / distance
  - Congestion reduction

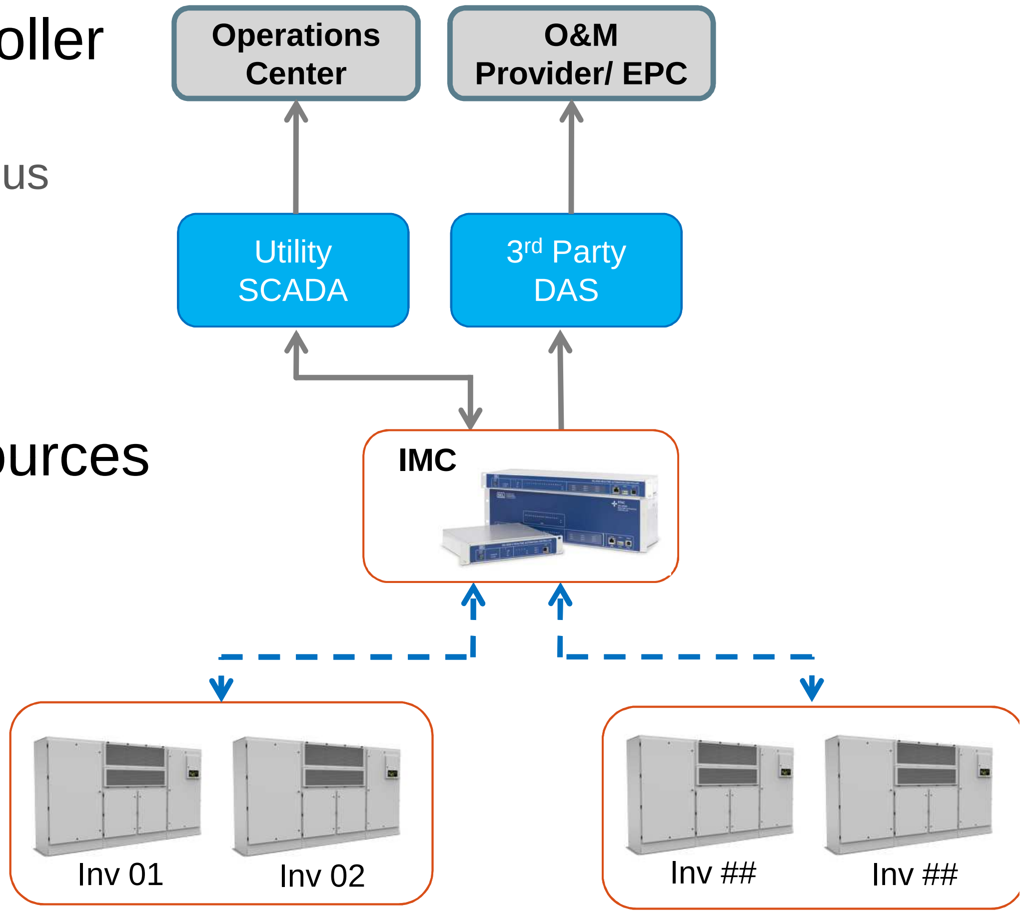
ANYTIME OPERTATION

Practical Implications of Frequency Watt

- Electrical System Inertia
  - Rotating machine impacts
  - Island operations
- Droop Response
  - Programmable to match system requirements
  - Isochronous vs. droop (sharing the “load”)
  - Aggregate plant damping
- Micro-Grid Compliant
  - 4 – quadrant operation finalizes system
  - PLL capabilities scale across platforms
  - Deterministic operation

Inverter Master Controller (IMC)

- Real Time Automation Controller
  - Communications flexibility
    - DNP 3.0, IEC 61850, Modbus
  - Aggregation of controls / monitoring
  - Industry accepted solution
- Coordination of multiple resources
  - Risk mitigation for inverter interaction
  - Extension of system visibility
- Integration of functions
  - Voltage support functions
  - Island detection
  - Ramp rate controller (storage)



Utility Scale Site Mock-Up (IMC Role)