Distributed Energy Communications & Controls (DECC) Laboratory Activities

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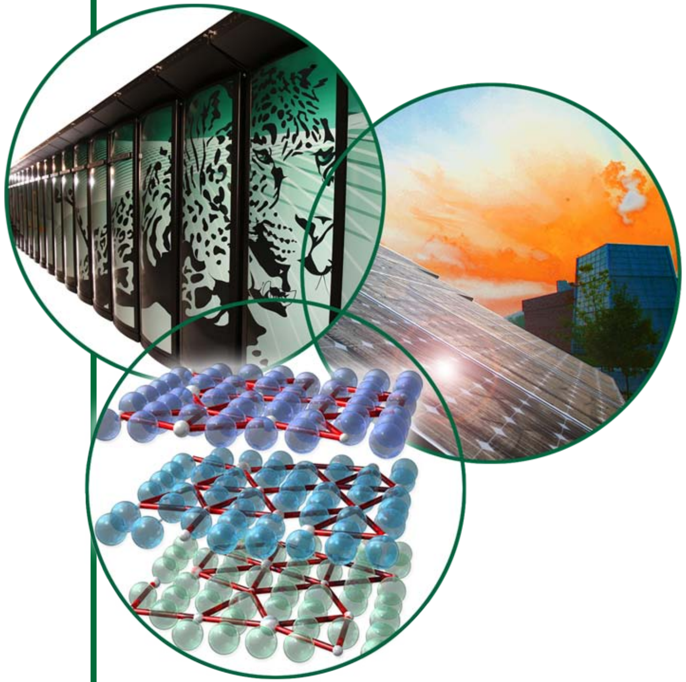
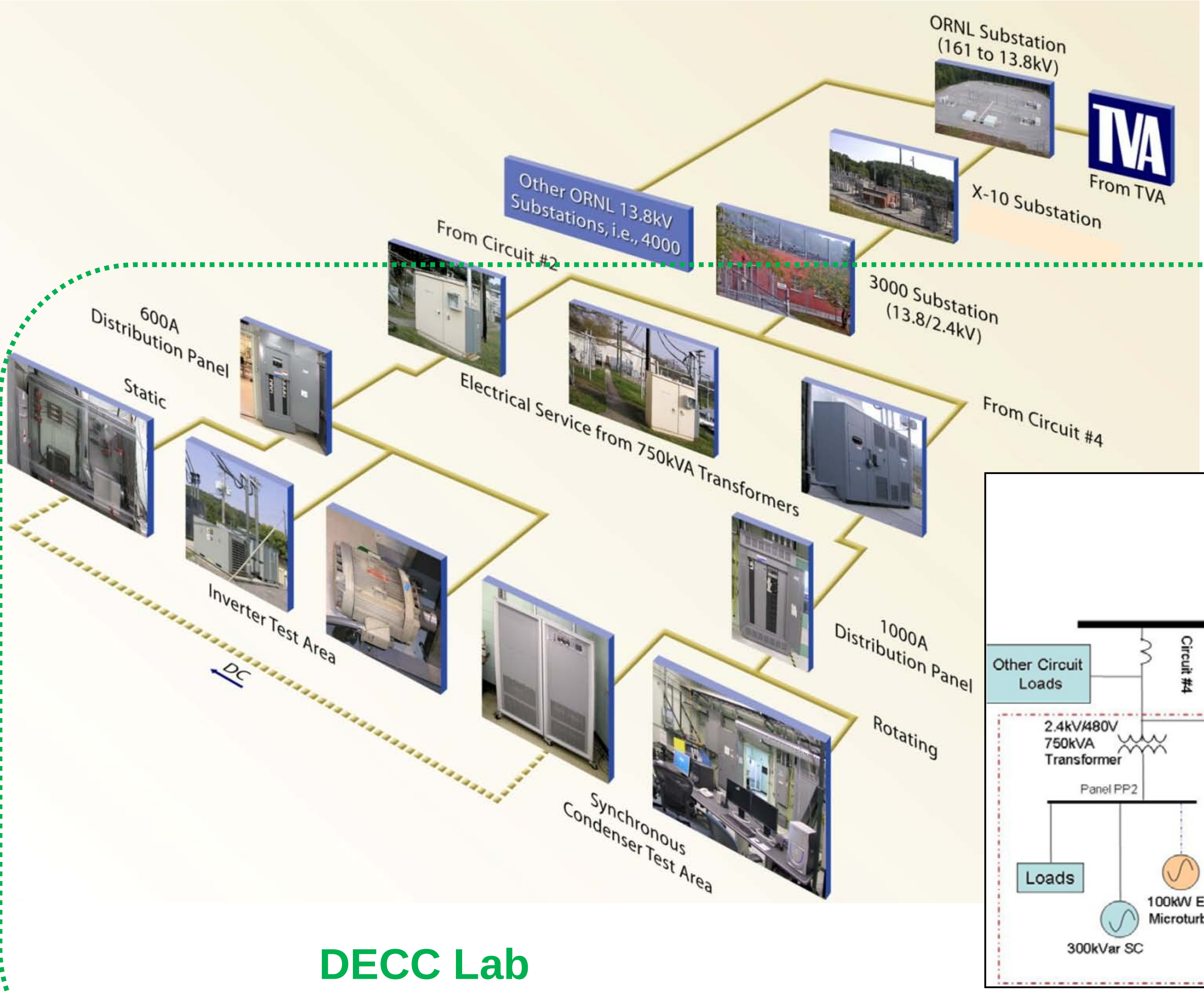
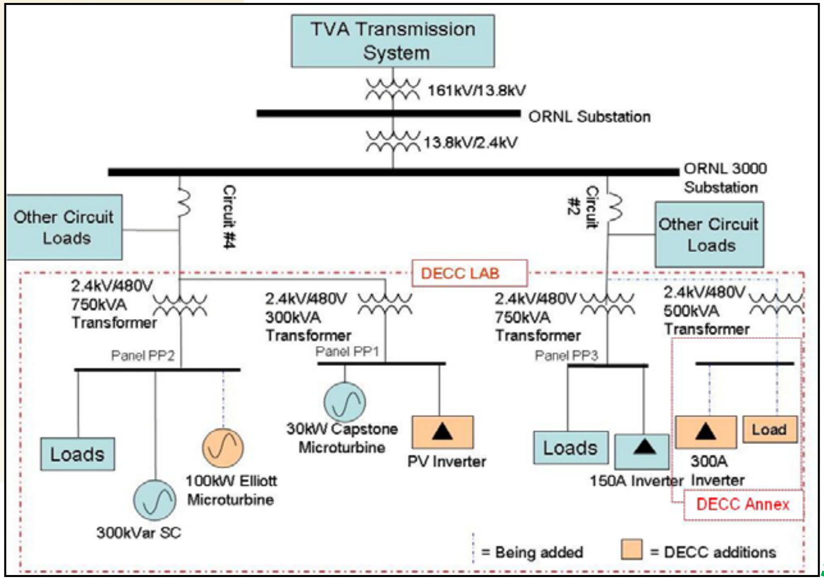


[1]*Oak Ridge Associated Universities*

Evolved from 1943 Manhattan Project

DECC Laboratory is interfaced with ORNL owned and operated distribution system





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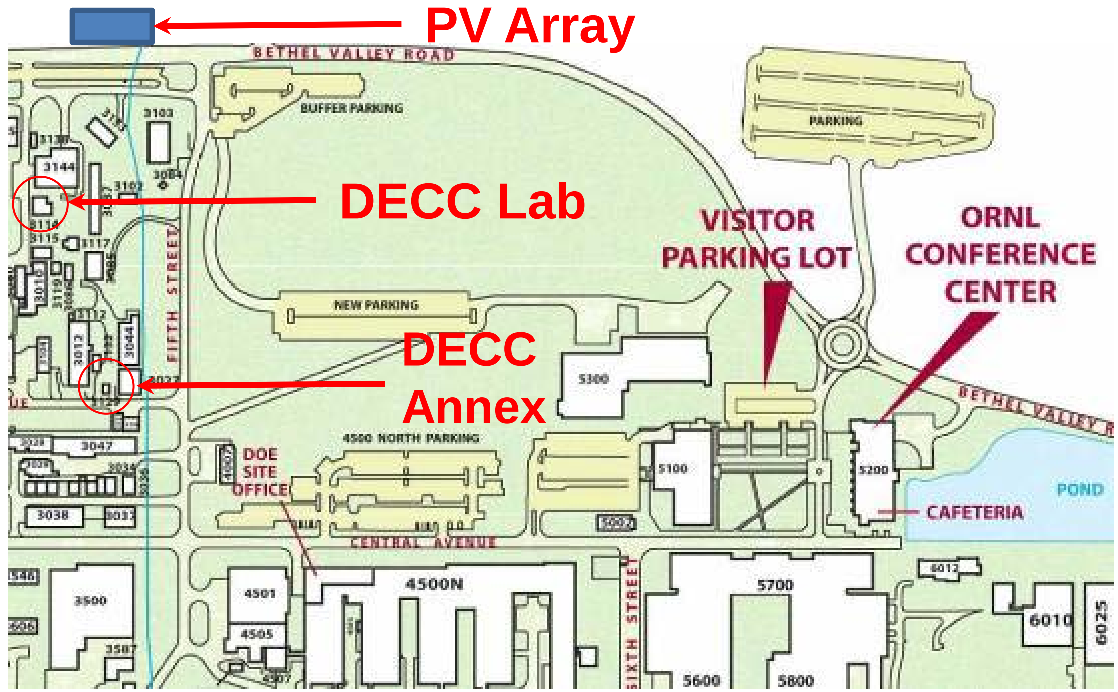
DECC Laboratory (2 locations) is located on the North ORNL Campus



50kW PV Array is connected to the DECC Lab

DECC Laboratory’s Four Test Systems

Rotating-Based DR (SC) Test System

Inverter–based DR Test System

Air Conditioning Stall Test System

Remote Large Inverter-based DR Test System

DECC Lab Relevance to Smart Grid 2030

One of the Smart Grid 2030 Targets*

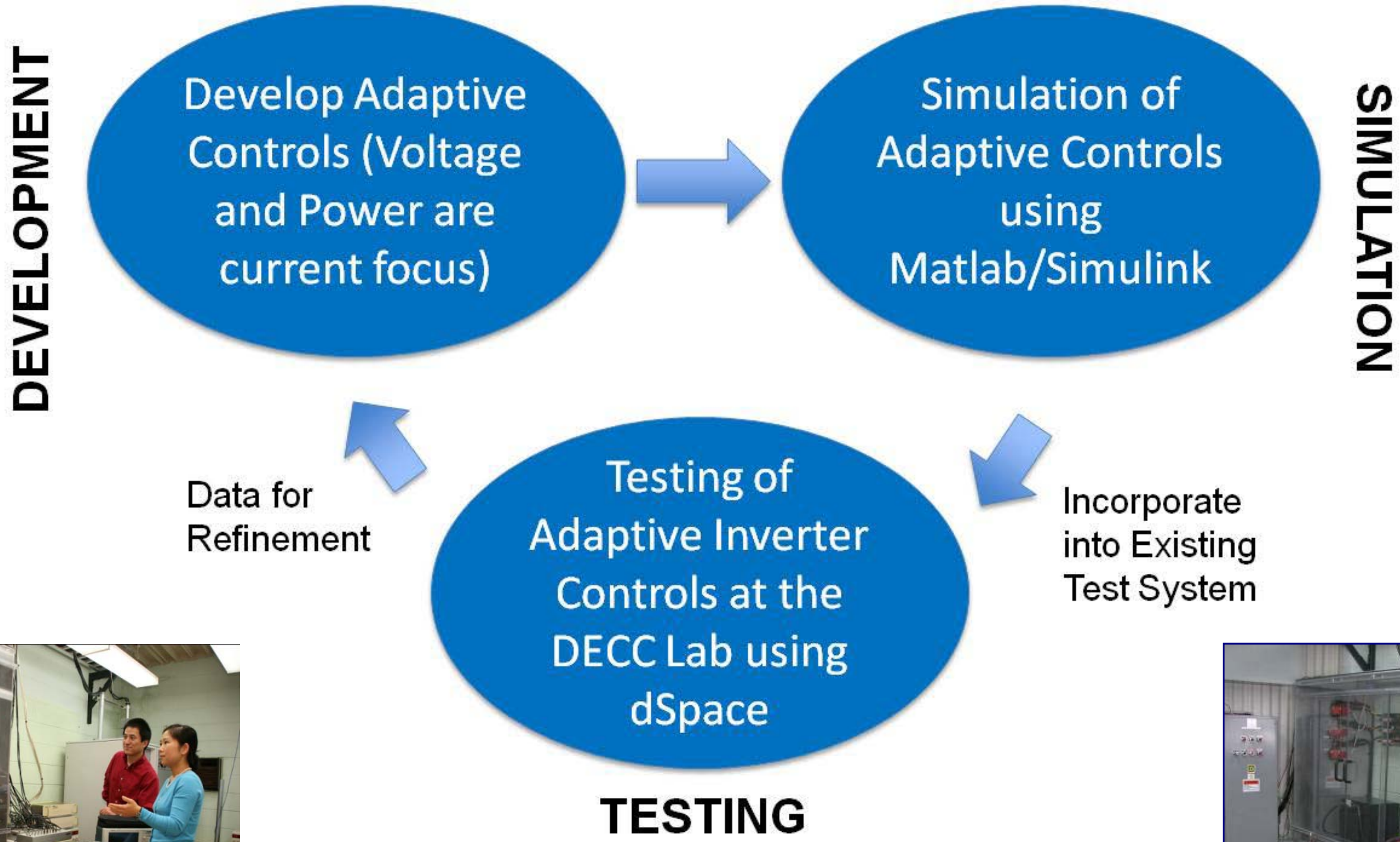
- 20% of electricity capacity from distributed and renewable energy sources
  - 200 GW of DR and Renewables
  - Demonstrate fast voltage regulation and overvoltage protection solutions under high penetration of renewable energy by 2014

- DECC Focus
  - Autonomous Control - develop independent, adaptive, and scalable control of DR
  - Develop rapid local control methods for providing non-active as well as active power
  - Use minimal communications – additional functionality is possible when it is present

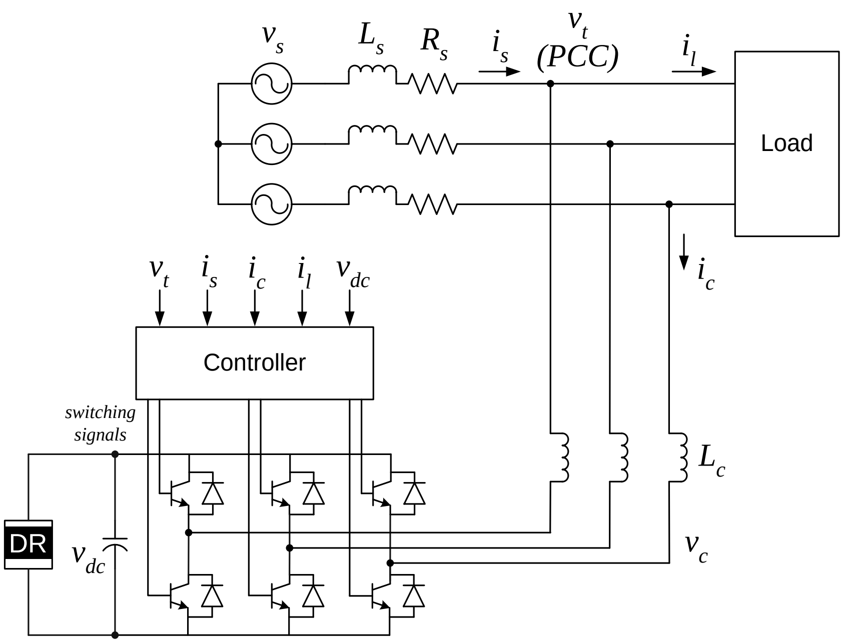
***Per Smart Grid R&D 2010-2014 MYPP, U.S Department of Energy, Office of Electricity Delivery & Energy Reliability.**

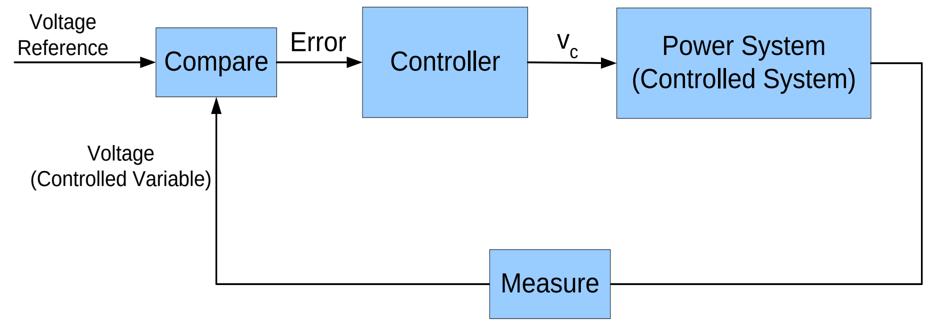
Approach - Inverter-based Test System

Objective: Develop, simulate, and verify with testing autonomous, adaptive controls for inverter-based distributed energy resource (DR) when there are multiple inverters on the same feeder or electrically close.



Approach
Inverter Control Methodology, Fixed vs. Adaptive





DR: **Distributed Energy Resource**

Control variable: **the PCC voltage**

Reference: **the desired value of the PCC voltage**

Error: **difference between reference and measured PCC voltage**

- **Fixed control:**

  PI control with K_p and K_i fixed

  K_p and K_i typically by trial & error

  Incorrect gains result in under-performance, oscillation, or instability

- **Adaptive control:**

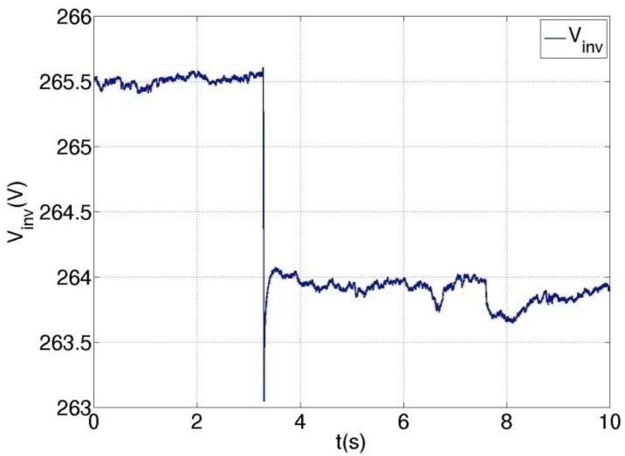
  K_p and K_i values are initially conservative but adjusted in real-time to achieve desired system response time

  Voltage stability is ensured

Technical Accomplishments of Inverter-based Controls

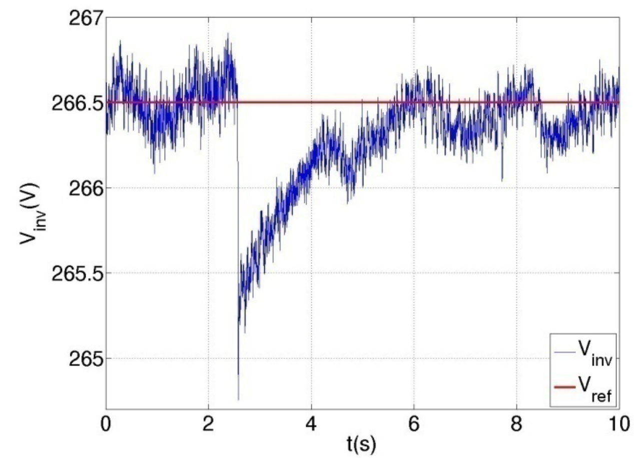
- **Development** of adaptive controls for multiple inverter-based DRs
  - Adaptive voltage regulation controls have been further enhanced.
  - New active (P) and nonactive (Q) power control for controlling P and Q power independently has been developed and is being further refined.
- **Simulation** of multiple inverter-based DR controls on the model of the ORNL system
  - Adaptive voltage regulation controls have been tested on a system similar to the ORNL system and IEEE system models.
- **Testing** of multiple test systems with our adaptive controls
  - A second large inverter-based test system is being completed we have tested controls simultaneously on our rotating and inverter based DR test systems.
  - Expect to have second inverter system operational by year end but simulation of two inverter based systems indicates potential interaction.
- **Implementation** of the adaptive controls in a microcontroller (DSP) at one of the inverter test systems and repeat the multiple inverter testing
  - Focused on a new method for inverter "soft-engagement" to grid due to dc voltage sensitivity.
  - Microprocessor (DSP) control test setup and will be tested at an inverter system in FY11.

Technical Accomplishments
Local Voltage Regulation for Inverter

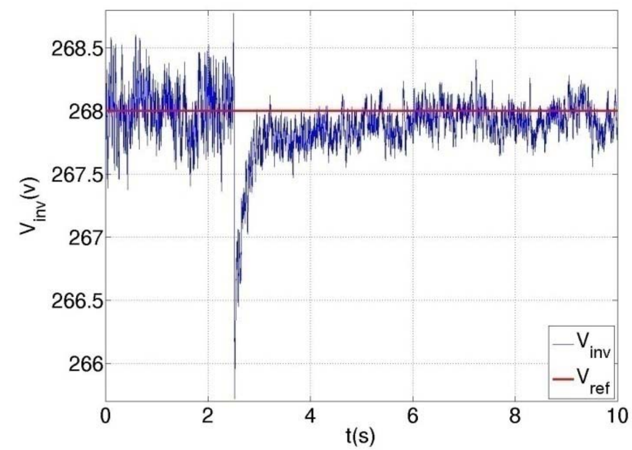


No regulation of PCC voltage (RMS) for 1.5V transient

- Three Plots Compare
  - Transient due to Load Change
  - No Voltage Regulation
  - Non-Adaptive Regulation
  - Adaptive Regulation



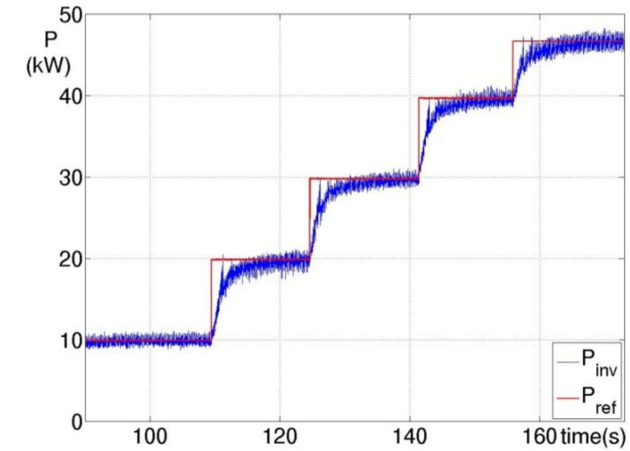
PCC voltage (RMS) with non-adaptive voltage regulation for 1.5V transient



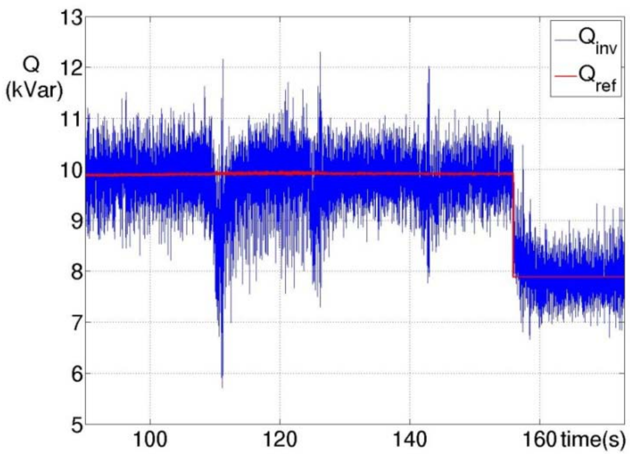
PCC voltage (RMS) with adaptive voltage regulation for 1.5V transient

Technical Accomplishments

Independent Active & Non-Active Power Control

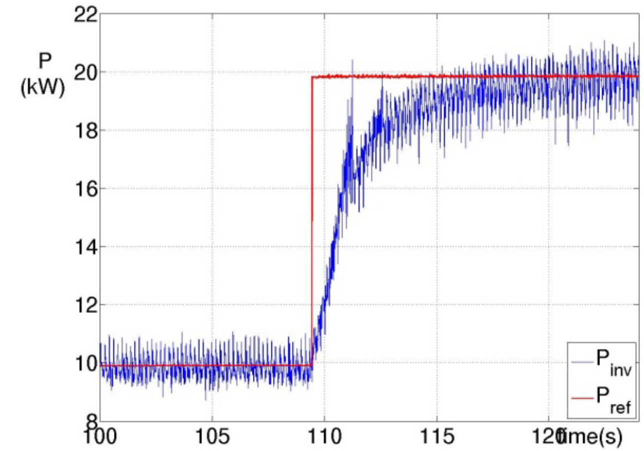


P_{ref} changed from 10 kW to 50 kW

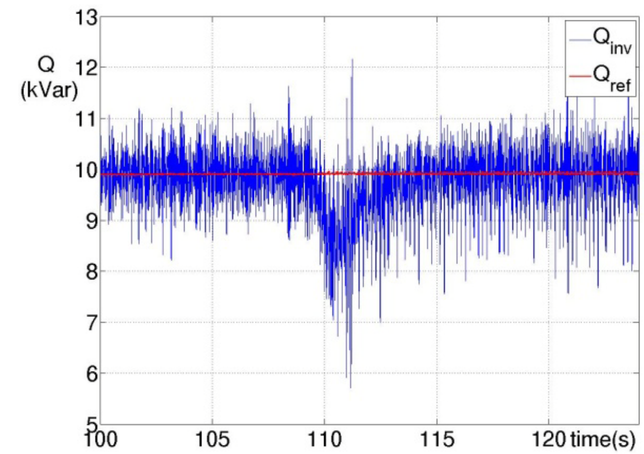


Q_{ref} set to10kVar

- Complete event on left.
- Zoomed in to 10 to 20 kW change on right.
- Active power reference (P_{ref}) from 10 to 50kW.
- Nonactive power reference (Q_{ref}) set to10 kVar.
- P does not reach 50 kW and Q drops because of the inverter current limit (60A).



P_{ref} change from 10 to 20kW



Q_{ref} set to10kVar.

DECC Laboratory Air Conditioning (A/C) Voltage Stall Relevance

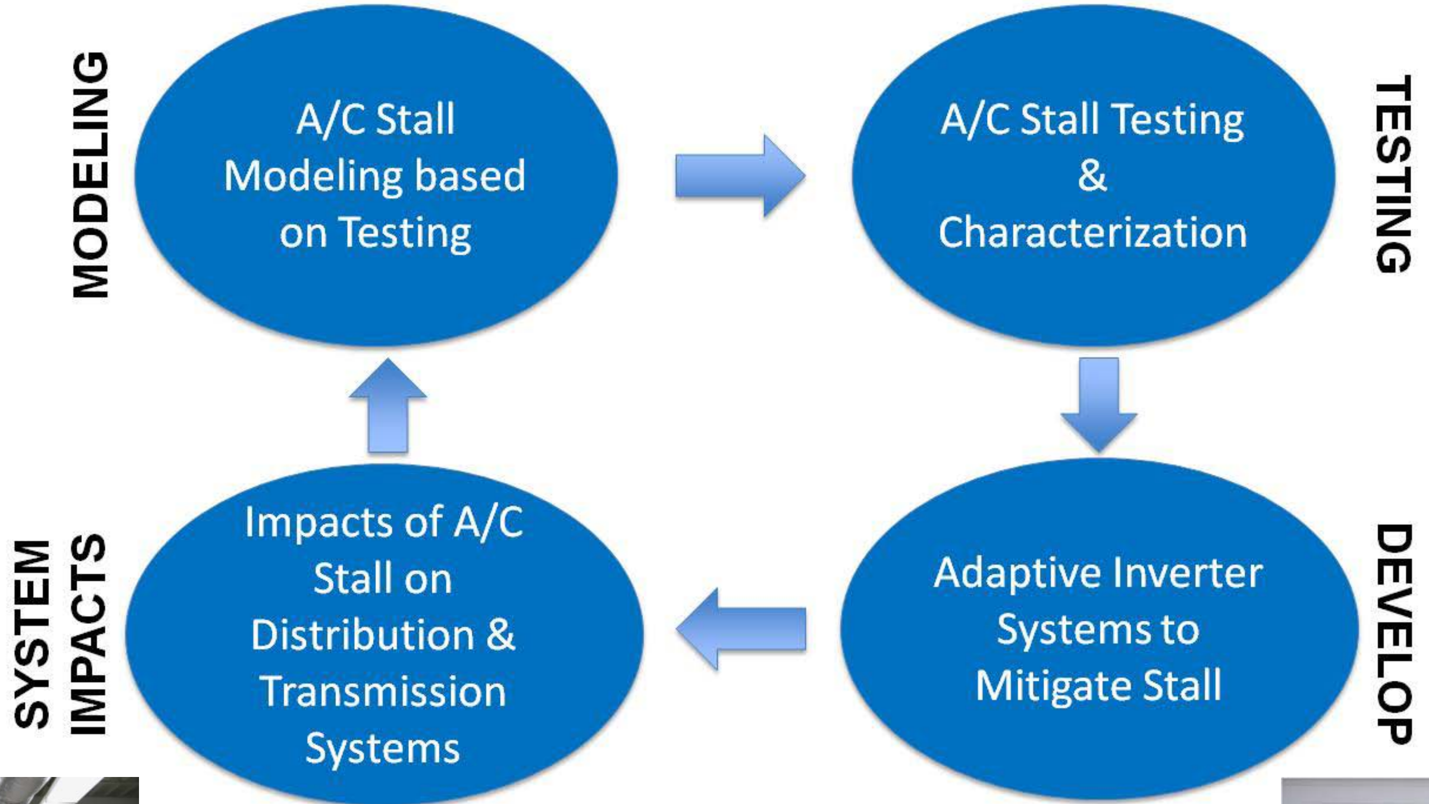
Challenge: Air conditioning stall can occur rapidly and result in high reactive current demand and is a significant challenge to mitigate with DR alone.

Areas of Impact

- Reduced Capacity
  - High penetration A/C stalling causes 4-5 times normal current
  - Increases reactive power demand of the distribution system and can reduce available capacity.
- Degraded Power Quality & Reliability
  - A/C units can stall in 3 cycles (0.05s) following a sub-transmission fault
  - Stall can last for 30s resulting in an extended voltage sag event (FIDVR).
- Reduced Energy Efficiency
  - Increased current of the stalled A/C units can result in 16-25 times the normal current losses.
- Present Operational Problems
  - Volt/Var control is a major concern when an A/C stall event occurs.
  - FIDVR can result in a microvoltage collapse in the distribution system.
  - Ultimately could result in transmission system voltage instability and even voltage collapse.

Approach
Air Conditioning (A/C) Stall Test System

<u>Objective:</u> Explore impact of high penetration high seasonal energy efficiency ratio (SEER) air conditioning (A/C) units on power systems during sub-transmission faults.

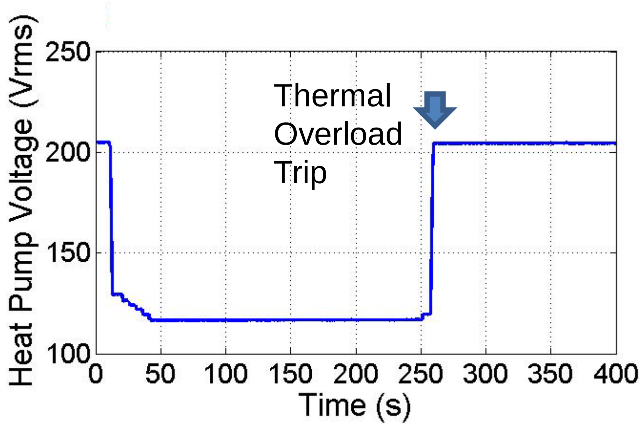


Technical Accomplishments

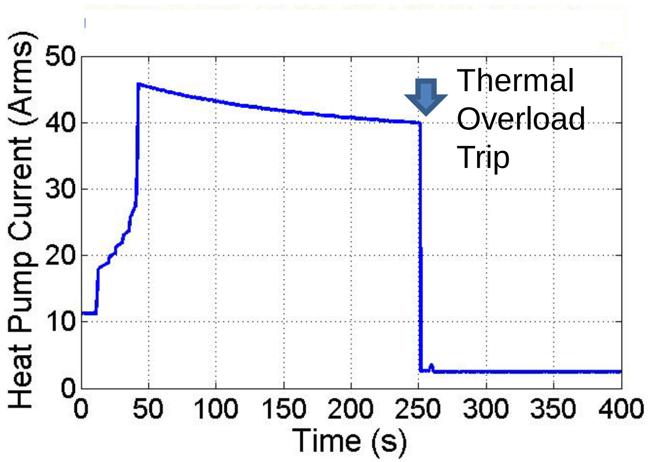
- **Testing System** - Completed the A/C Stall Test System
  - New test system at the DECC Laboratory.
- **Model** - Complete composite load and motor model for EMTP
  - Dynamic model for the A/C compressor operation during normal voltage and stalled voltage was developed.
  - Analysis using the model was completed and a technical paper was presented/published.
- **Testing** – Fine-tune the model with results from A/C Stall testing
  - A/C stall characterization of sustained voltage sags; response too slow for fault response.
  - Completed installation of a fast contactor/switch to implement momentary sags characterization..
  - Model for specific heat pump model still undergoing development based on manufacturer specs, test data and ORNL heat pump design (thermodynamic) model.
- **System Impacts** – Impact of high penetration high SEER A/C
  - Impact on distribution system – initial analysis using the hybrid air conditioner compressor model but plan revisit with specific heat pump model.
  - Impact on transmission system voltage stability - Have a large systems model built in EMTP that will be used and developed a approach.

Technical Accomplishments
A/C Stall Characterization Results

- Sustained Voltage Sag

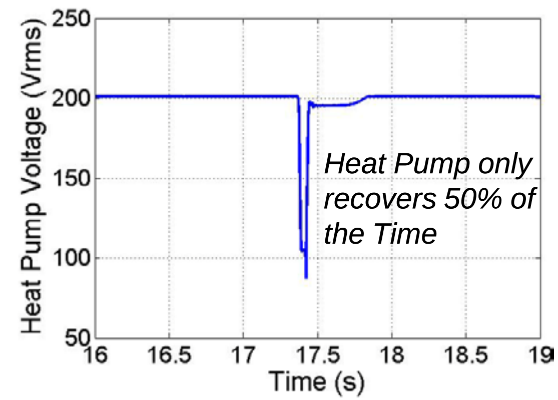


Voltage Sag of 55% for ~250s

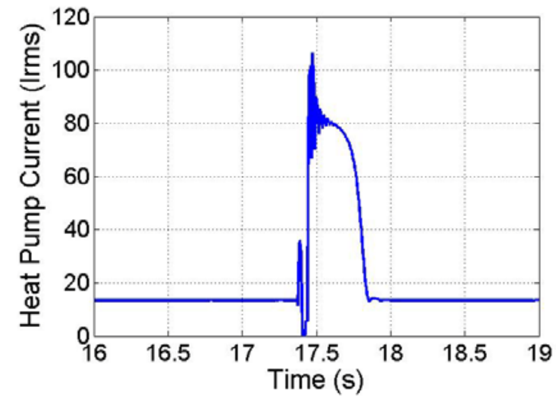


Normal Current = 13.5A
Stalled Current = 46 to 40A, ~3.4 to 3 times

- Momentary Voltage Sag



Voltage Sag of 52% for 0.08s (~1 cycle)
Voltage Recovery takes 0.47s (~7.5 cycles)



Normal Current = 13.5A
Stalled Current = 105A, 8 times normal

Technology Transfer & Collaborations

- DECC Industry Team
  - SCE provided initial air conditioning stall test data, report on SEER (10 to 13) units and data for Catalina Island power system.
  - SCE, TVA & LCUB provided valuable input on their system voltage regulation requirements for adaptive inverter controls.
- IEEE Volt-Var Control Task Force (VVCTF)
  - Formed January 2010 by the IEEE PES Distribution Subcommittee and industry is showing great interest (Tom Rizy is Chair).
- NERC
  - ORNL (Kueck, Dimitrovski) on VAR working group which was assembled from FERC recommendations and hosted 2nd meeting at ORNL
- EETN & KUB
  - Negotiating collaboration agreement with Efficient Energy of Tennessee and Knoxville Utilities Board to implement ORNL adaptive controls at their 1MW PV system.

Conclusions

- DECC activities are addressing voltage problems by extending the functionality of DR, specifically inverter-based systems.
- DECC Lab is a unique testing environment interfaced to an actual distribution system and provides a real-world testing environment.
  - Additional inverter systems need to be considered for A/C stall.
  - Multiple inverter operation interaction and with NIST modes need to be considered.
- Advanced control algorithms have been developed, simulated and verified with testing at the DECC Lab and published.
- Control methods provide a rapid dynamic voltage regulation or active & non-active power regulation by inverter-based DR.
- Local voltage/var regulation is a practical method for expanding the margin-to-local voltage collapse and for providing local power quality.

Selected Publications

“Instantaneous Active and Nonactive Power Control of Distributed Energy Resources with a Current Limiter”, Paper #464, Session 110: Sustainable Energy Applications: Flexible Renewable/Alternative Energy System II**,** *2010 IEEE Energy Conversion Congress & Exposition (ECCE)*, Atlanta, GA, Sep. 2010.

"Adaptive Voltage Control with Distributed Energy Resources: Algorithm, Theoretical Analysis, Simulation, and Field Test Verification,“ *IEEE Transactions on Power Systems*, Vol.25, No.3, pp.1638-1647, Aug. 2010, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5431066&isnumber=5512898.

"Properly Understanding the Impacts of Distributed Resources on Distribution Systems," *2010 IEEE Power and Energy Society General Meeting,* pp.1-5, July 2010, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5589726&isnumber=5588047.

"Local Voltage Support from Distributed Energy Resources to Prevent Air Conditioner Motor Stalling," *2010 Innovative Smart Grid Technologies (ISGT),* pp.1-6, Jan. 2010, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5434728&isnumber=5434721.

"An Adaptive Voltage Control Algorithm with Multiple Distributed Energy Resources," *2009 North American Power Symposium (NAPS), pp.1-6, Oct. 2009,* http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5484035&isnumber=5483979.

"Preventing delayed voltage recovery with voltage-regulating distributed energy resources," *IEEE PowerTech 2009, Bucharest*, pp.1-6, June-July 2009, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5281866&isnumber=5281781.

Q&A

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