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OSIsoft. USERS CONFERENCE 2011

Voltage Regulation of High Penetration PV

Presented by **Dr. Shawn Henry**

Florida State University - CAPS

Agenda

- Center for Advanced Power Systems: An Overview
- Background
- Voltage regulation via line drop compensation
- The role of the PI System
- Future Work

CAPS Overview

FSU Center for Advanced Power Systems

- Established at Florida State University in 2000 under a grant from the Office of Naval Research
- Lead Member of ONR Electric Ship R&D Consortium
  - FSU, MSU, USC, UT-Austin, MIT, Purdue, Naval Academy/Navy Post Graduate School
- Focus on research and education related to application of new technologies to electric power systems
- ~$5 million annual research funding from ONR, DOE, DARPA, Industry

Research Focus

- Electric Power Systems
- Advanced Modeling and Simulation
- Advanced Control Systems
- Power Electronics Integration and Controls
- Thermal management
- High Temperature Superconductivity
- Electrical Insulation/Dielectrics

–36,000 square feet laboratories and offices located in Innovation Park, Tallahassee; about $20 million specialized power and energy capabilities funded by ONR, DOE

–Employs 74, including

–50 scientists, engineers and technicians, post-doc.'s and supporting staff,

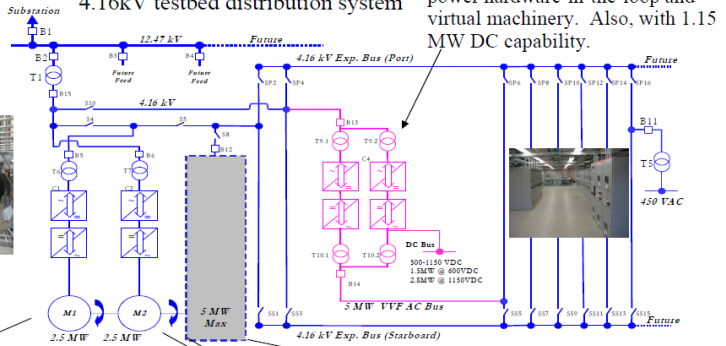
–9 FAMU-FSU College of Engineering faculty

–24Students

An Advanced Prototype Integrated Development, Test, and Evaluation Facility

7500 MVA stiff connection to utility, supplying 12.47kV and 4.16kV testbed distribution system

5 MW AC Variable Voltage and Frequency Converter for high-power waveform generation for power hardware-in-the-loop and virtual machinery. Also, with 1.15 MW DC capability.



5 MW Dynamometer – (2) 2.5 MW induction machines w/4Q drives

"An important aspect of the new results obtained at CAPS on the 5-MW motor is the validation of AMSC's electromagnetic, mechanical and thermal analytical models for HTS ship propulsion motors - a vital step in the development cycle for advanced electrical machines."

-- American Superconductor Corp., 6/28/2005

CAPS Capabilities

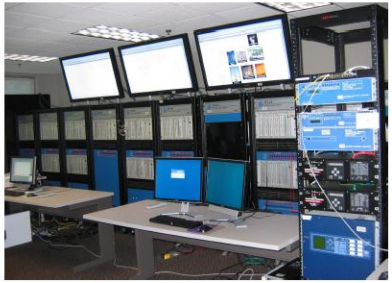
Power Systems Simulation

REAL-TIME – using RTDS

- Large-scale electromagnetic transient simulator
- EMTP type simulation covers load-flow, harmonic, dynamic, and transient regime
- 111,200 MFLOPS; 14 "racks", parallel processing
- Real-time simulation, with time steps down to <2 µs.
- Real-time simulation of 756 electrical nodes, plus hundreds of control and other simulation blocks
- Extensive digital and analog I/O for interfacing hardware to simulation (>2500 analog, >200 digital). Can connect in real-time to any electrical node within the simulation.
- MODBUS TCP, DNP 3.0 and IEC 61850 interfaces also available.
- Capability for remote access over VPN link

Other simulation tools in-use at CAPS:

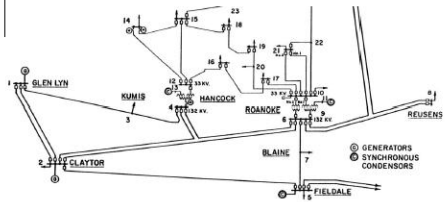
- PSS/E, PSCAD/EMTDC, MATLAB/Simulink, ATP, PSPICE, ANSYS, DSPACE



14 rack RTDS at CAPS

Example: IEEE 30-bus System

- 5 racks, dt=65 µs
- 6 machines incl. governor & v-regulator
- 36 transmission lines
- 70 breakers



Other *Unique* Research, Test, and Demonstration Capabilities

High Voltage Cryogenic Dielectric Testing

Impulse voltages to 140 kV, 250 J. Standardized 1.2/50 µs impulse lightning strike waveform

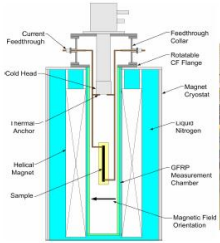
140 kV DC at up to 11.2 mA, 100 kV AC up to 50 mA, with 5 kVA transformer for partial discharge measurements

pressure range from Torr to atmospheric

temperature ranges from 30 K to 293 K.

high voltage feed-through is rated at 150 kV and 7 A.

Machines and Converters Control Laboratory



Transport Current to 650A DC and 500 A AC

Magnetic field: DC to 250 mT, AC from zero to 200 mT

DC – 10 kHz

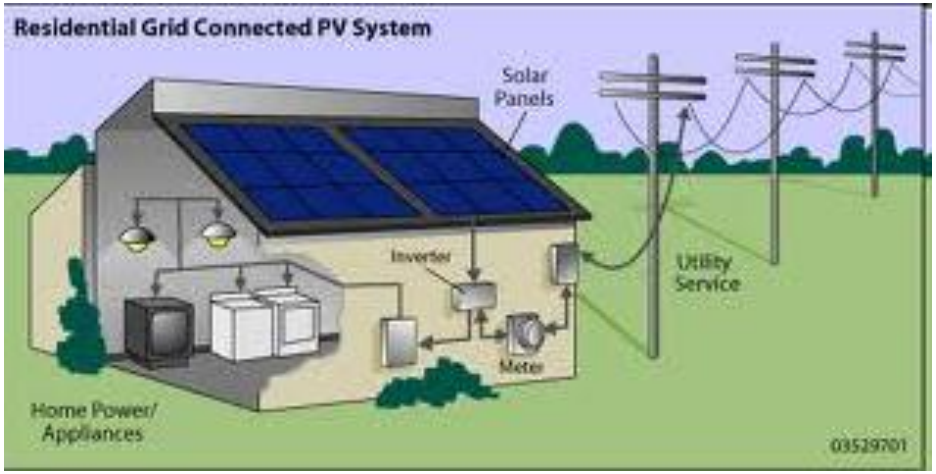
25 – 100 deg. K

0-90° field orientation

Superconductor AC Loss Measurement, Quench Stability & Propagation Testing

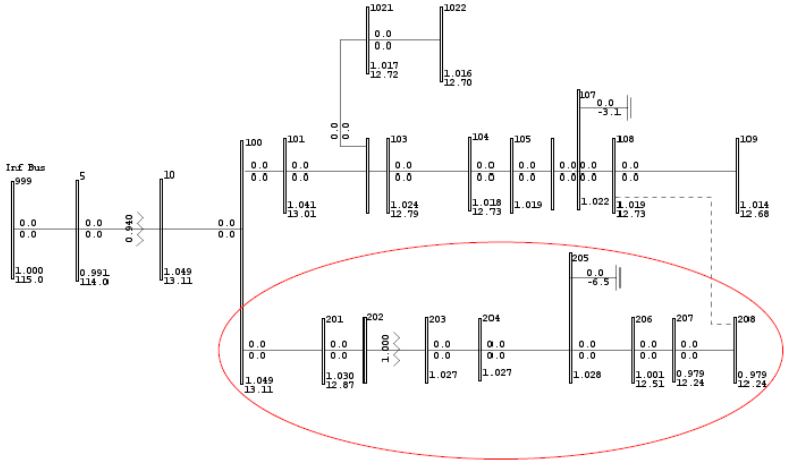
Research Objective

- Explore the impact of high-penetration PV on the distribution grid
  - Over-voltages along distribution feeder
  - Operational issues caused by reverse power flow
  - Various feeder topologies
- Develop solutions to overcome PV integration challenges
  - Reconcile existing feeder voltage control techniques with high penetration of distributed PV



Radial Distribution System Model

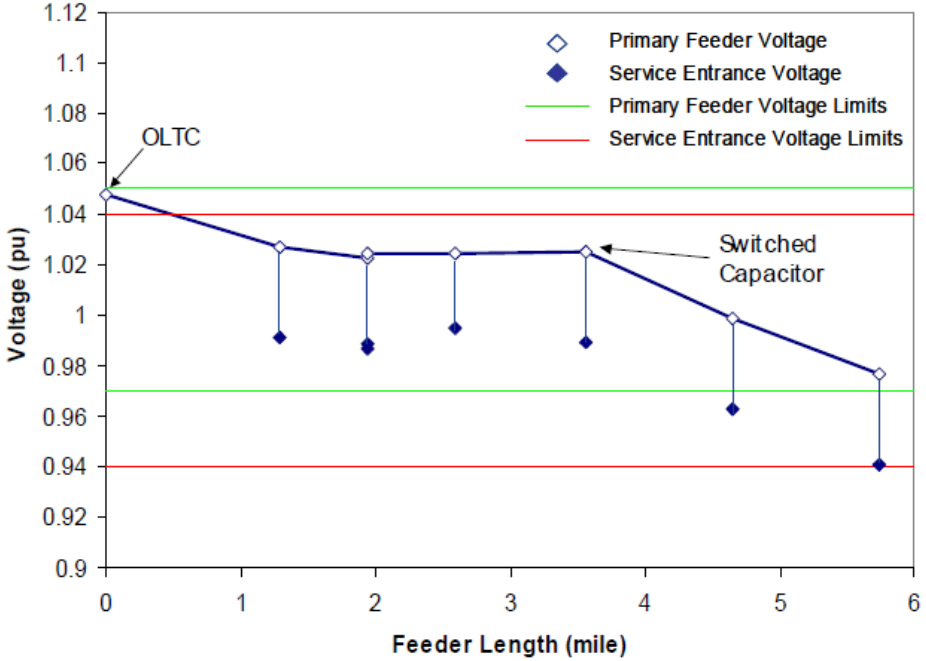
- 6 miles in length
- Mixture of residential load and commercial loads ranging from 0.3 MW to 5 MW. The total load is 11 MVA.
- Primary feeder voltage is 12.5 kV. Secondary voltages are 240 V for residential loads and 600 V for commercial loads.
- Two voltage regulators are employed – one in the substation and another at 2.6 miles from the substation



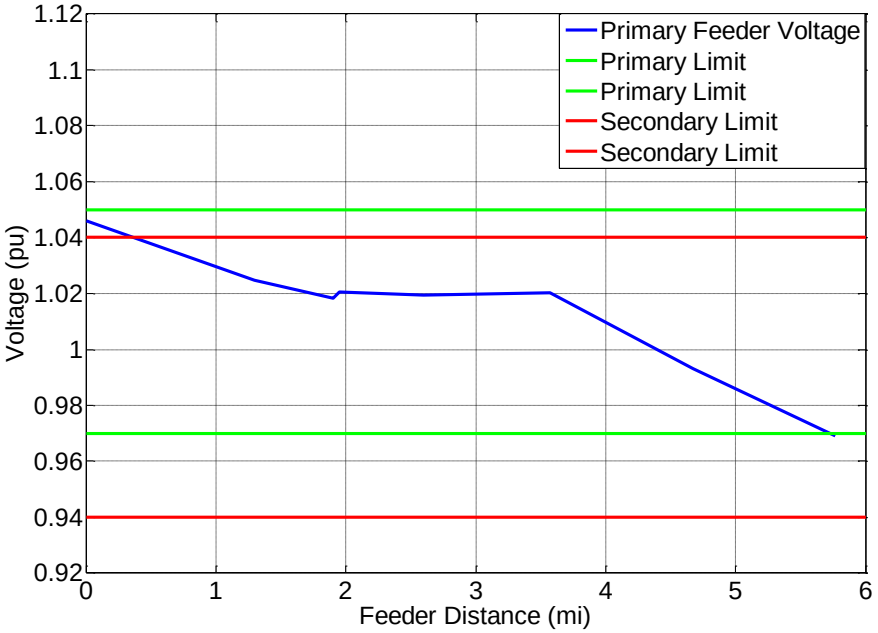
Taken from NREL study: Distribution System Voltage Performance Analysis for High-Penetration PV

Feeder Validation

Sandia Results



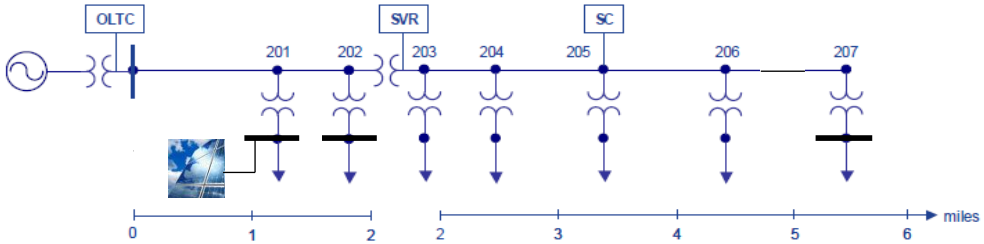
PSCAD Results

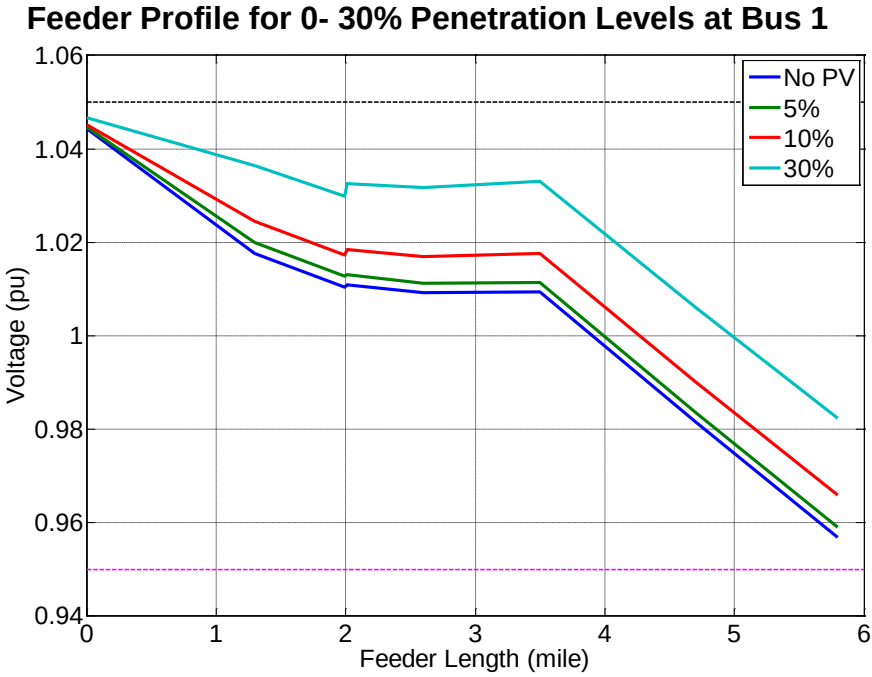


Impact of Penetration Level on Voltage

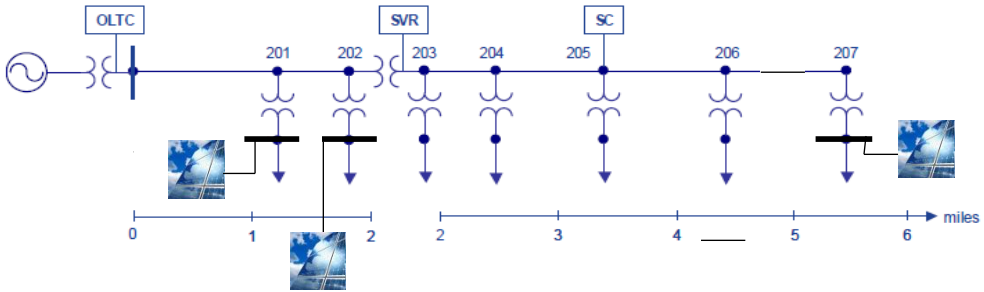
Penetration is defined as:

$$\sum_{i}^{n} P_{i,PV,DC}$$

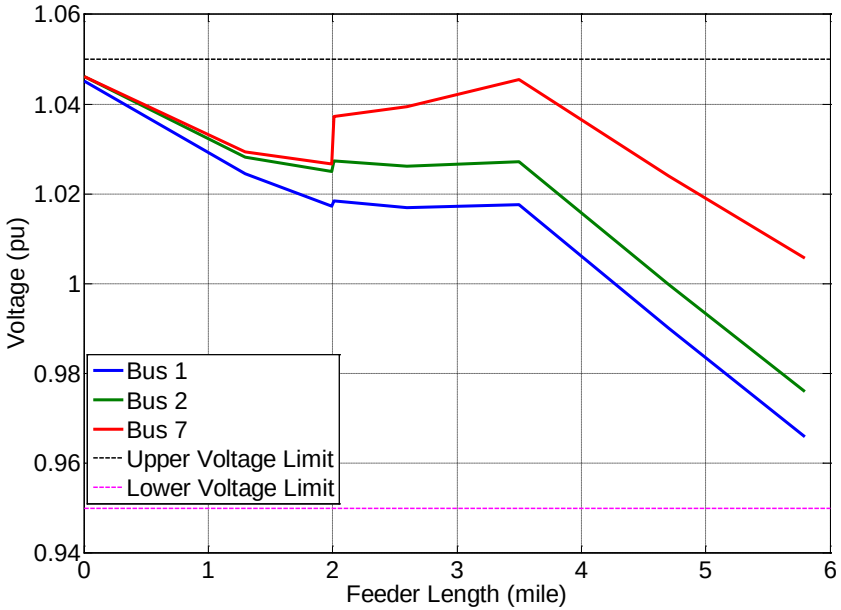




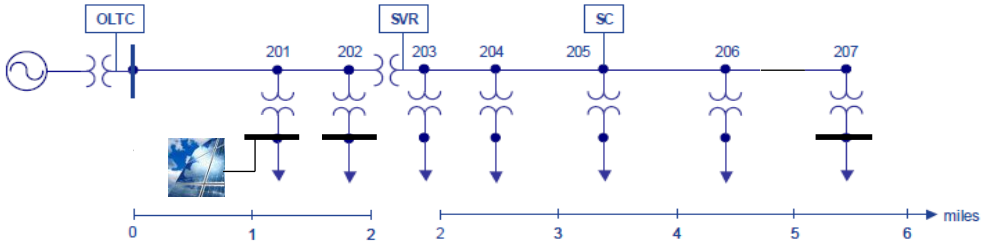
Impact of PV System Location on Voltage

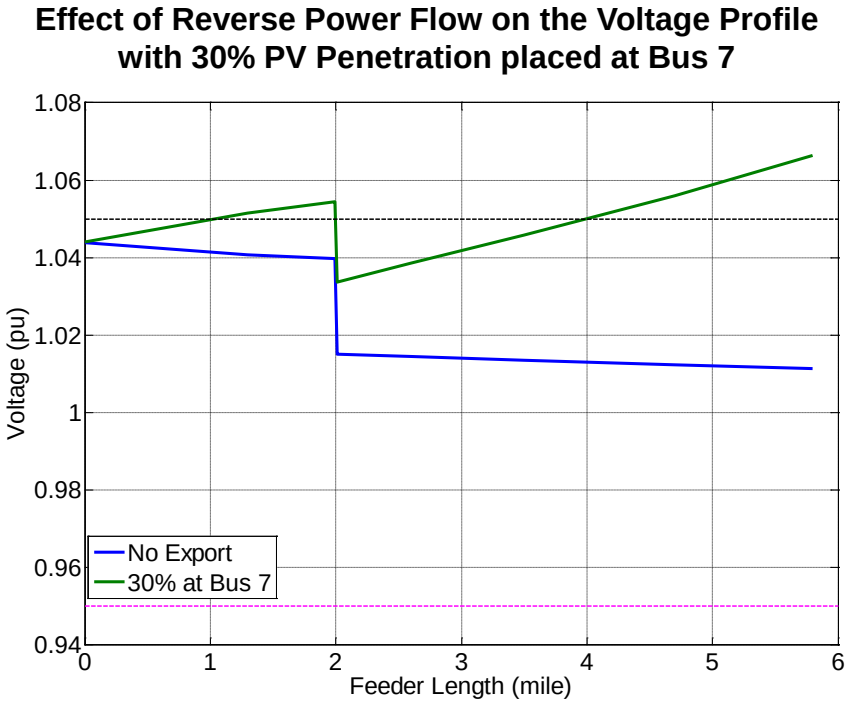


Feeder Voltage Profile for a 10% Penetration Level at Bus 1, Bus 2, and Bus 7

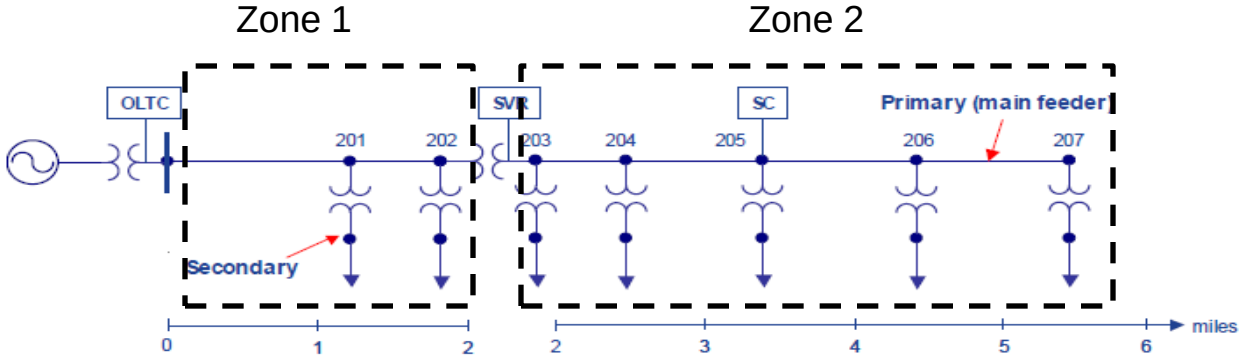


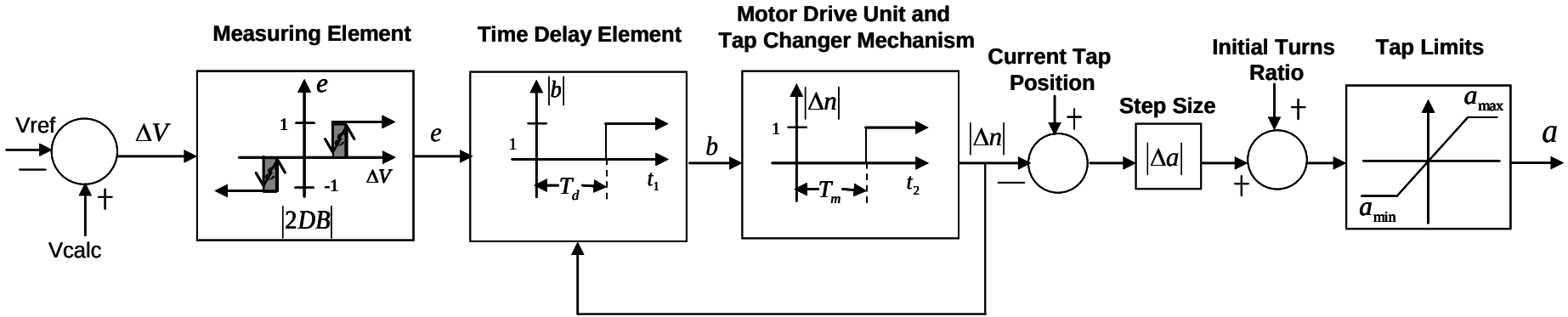
Impact of Reverse Power Flow on Voltage



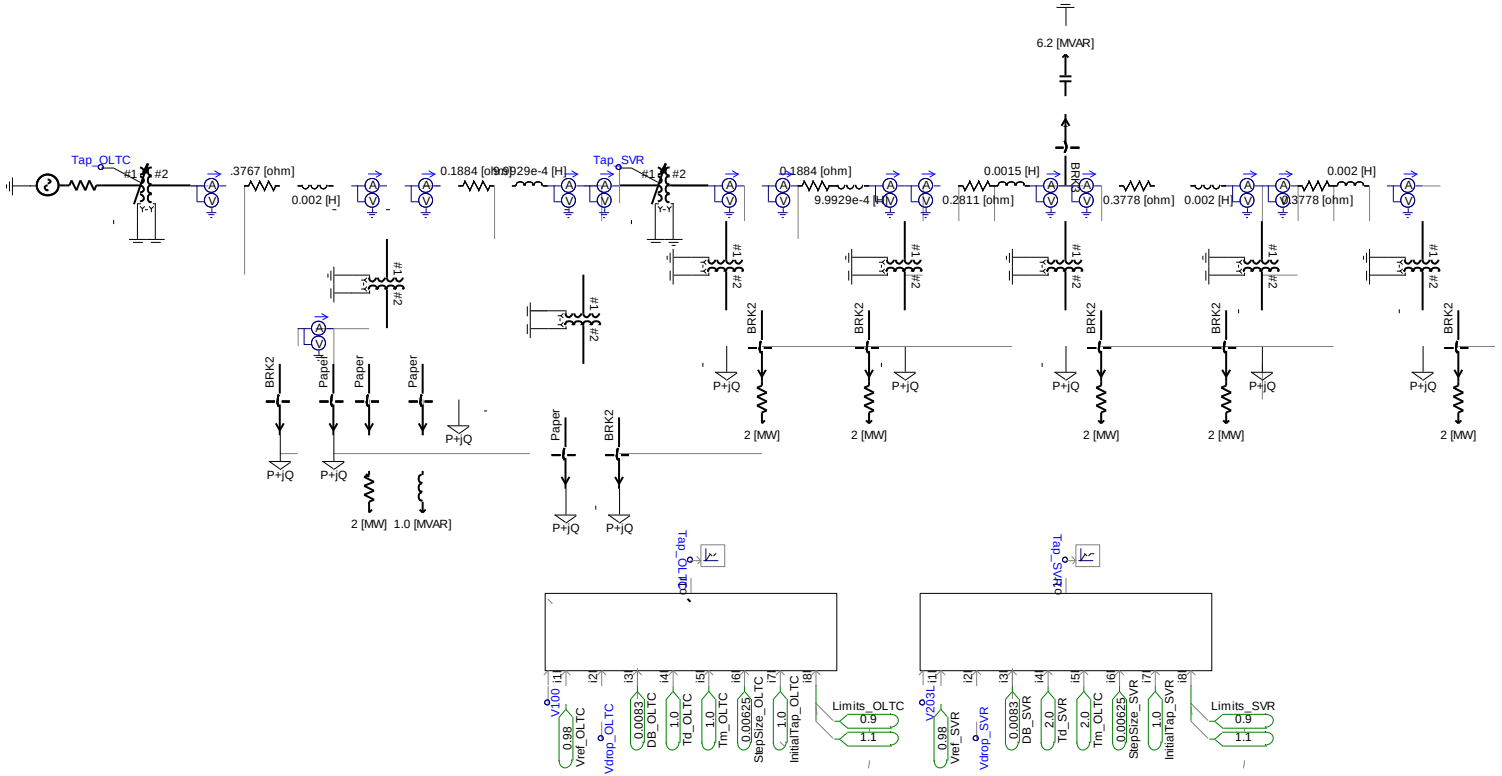


Line Drop Compensation Method

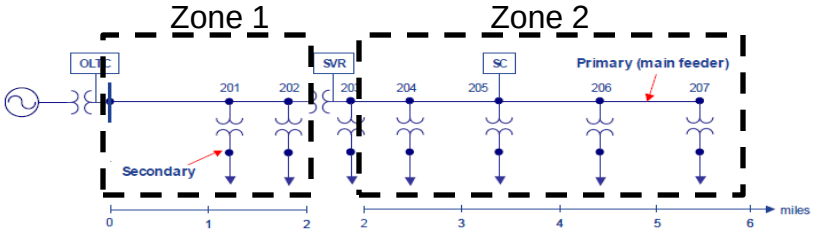


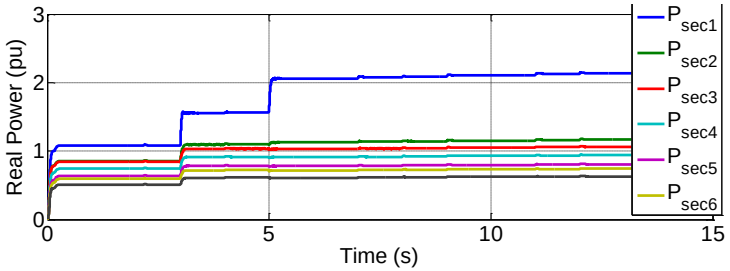


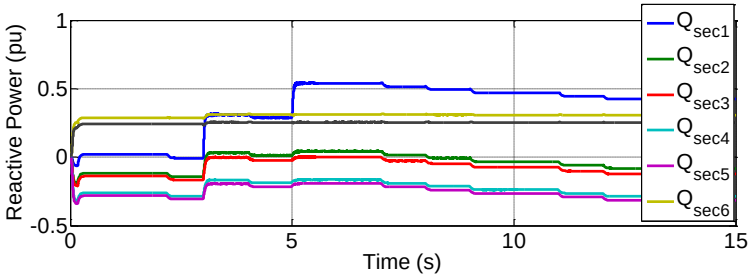
PSCAD Feeder Model



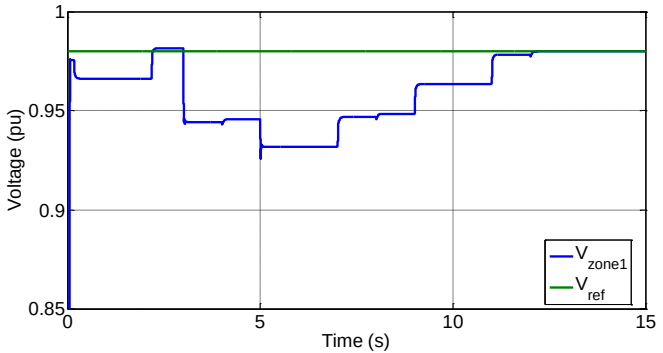
Feeder Zone Dynamics



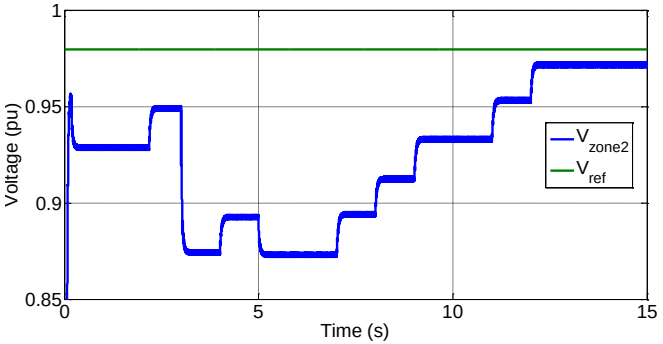




Bus 202

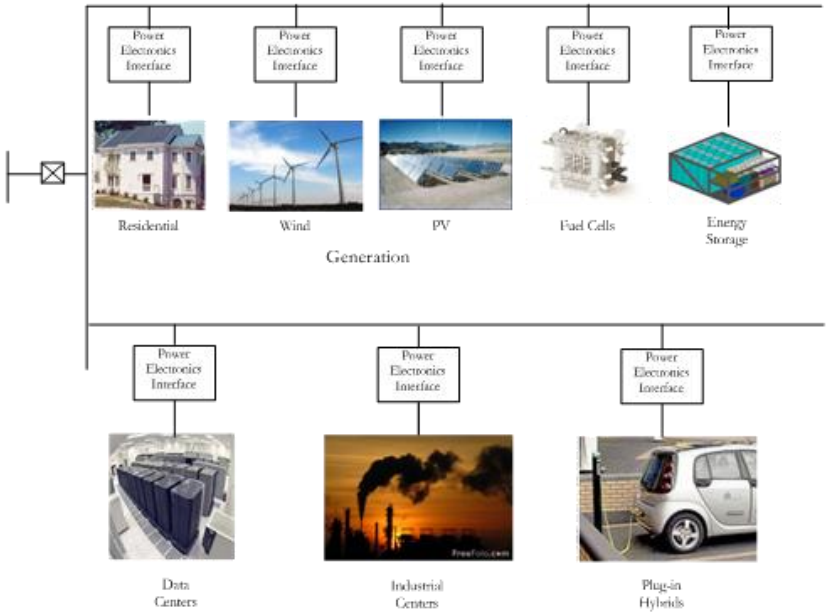


Bus 207



The PI System's Role in Extending Research

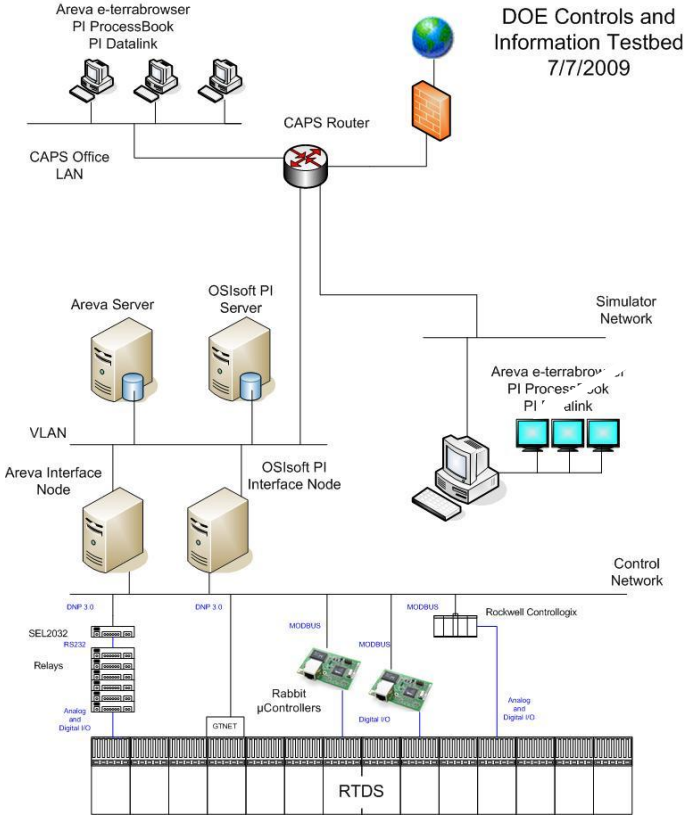
Microgrids for a Sustainable Energy Future



Potential Benefits of a PI System

- Provides for a "smarter" grid system that can produce better power management
- Development of control systems that allow utility companies to communicate with consumers to create the most efficient means of distribution and consumption of power
- Supervisory control capability for intelligent system protection operation schemes
- Allows for the mass infiltration of plug-in hybrid electric vehicles

Lab Implementation of the PI System



Future Plans and Next Steps

- Explore the performance of several voltage regulation schemes for realistic inputs
  - Solar irradiation data
  - Loading profiles
- Investigate the system protection operation in high penetrated PV systems

Questions

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Thank you