High Penetration Solar Forum

March 2011

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Sunshine State Solar Grid Initiative (SUNGRIN)

Presenter:

Rick Meeker

Florida State University (FSU)

Center for Advanced Power Systems (CAPS)

Project Sponsors and Partners

Universities

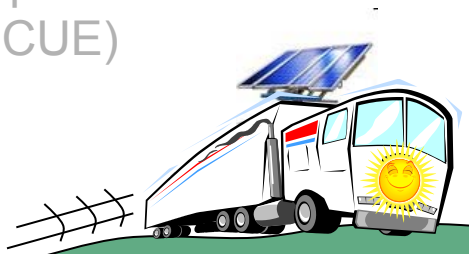
- FSU Center for Advanced Power Systems (CAPS) *(lead institution)*
- University of Central Florida, Florida Solar Energy Center (FSEC)
- University of South Florida, Power Center for Utility Explorations (PCUE)

Utility Industry

- Florida Power and Light (FP&L)
- Florida Municipal Power Agency (FMPA)
- Florida Reliability Coordinating Council (FRCC)
- Gainesville Regional Utilities (GRU)
- Jacksonville Electric Authority (JEA)
- Lakeland Electric
- Orlando Utilities Commission (OUC)

Industry Suppliers

- AMEC
- Satcon Technologies



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University Teams

Focused Working Groups

Data Collection and Analysis
(Dave Click, UCF FSEC)

Distribution Level Modeling
(Chris Edrington, FSU CAPS)

Transmission Level Modeling
(Mischa Steurer, FSU CAPS)

FSU CAPS **Rick Meeker, P.E.** Steinar Dale, Ph.D., FIEEE	Project leadership and direction
FSU CAPS – Power Systems Group **Mischa Steurer, Ph.D.** Omar Faruque, Ph.D. Karl Schoder, Ph.D. Peter McLaren, Ph.D., FIEEE Harsha Ravindra	Transmission and distribution level PV grid integration, hardware-in-the-loop (HIL) modeling, simulation, and analysis.
FSU CAPS – Energy Conversion Group **Chris Edrington, Ph.D., P.E.** Saritha Balathandayuthapani, Ph.D. Shawn Henry, Ph.D.	Distribution level PV grid integration, modeling, simulation, and analysis.
FSU CAPS – Power Electronics Group **Liming Liu, Ph.D.** Hui Li, Ph.D. Yan Zhou XiaoHu Liu	Grid-connected PV inverter with integrated energy storage – development, simulation and testing.
UCF FSEC **Dave Click** Bob Reedy, P.E. Charlie Cromer, Ph.D. Kris Davis	Solar PV data, PV variability. PV inverter and controls, panel and inverter data and testing
USF PCUE **Arif Islam** Alexander Domijan, Ph.D. Adedamola Omole, Ph.D. Aleksandar Damnjanovic, Ph.D. Mujahidul Islam	PV variability, PV grid integration, modeling and simulation

Sungrin team leader names in blue

Project Collaboration Portal

THE FLORIDA STATE UNIVERSITY

All Sites | Enter search words

Center for Advanced Power Systems > SUNGRIN

SUNGRIN

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- Tasks
- SUNGRIN Team Contacts

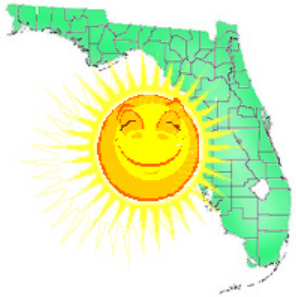
Discussions
- Team Discussion

Sites

People and Groups

Recycle Bin

Sunshine State Solar Grid Initiative (SUNGRIN)



Meeting Materials

December 1 Kick-Off Meeting
Materials from the December 1 meeting in Tallahassee, FL

Calendar of Events

3/1/2011 8:00 AM	DOE/CPUC High Penetration Solar Forum The DOE/CPUC High Penetration Solar Forum will bring together industry experts to present on interim findings of current demonstration and modeling projects simulating high penetrations of solar. http://www1.eere.energy.gov/solar/solar_forum.html
3/8/2011 12:00 AM	Renewable Energy World Conference & Expo http://www.renewableenergyworld-events.com
3/8/2011 8:00 AM	CMU Emerging Phenomena in Changing Electric Energy Systems http://www.ece.cmu.edu/~electriconf/
3/8/2011 2:00 PM	SUNGRIN Project Team Meeting
3/20/2011 12:00 AM	2011 IEEE PES Power Systems Conference & Exhibition (PSCE) http://www.pscexpo.com/
3/22/2011 2:00 PM	SUNGRIN Project Team Meeting
3/28/2011 12:00 AM	OSIsoft's Users Conference 2011 http://www.osisoft.com/microsoft/index.html
4/3/2011 12:00 AM	PV America 2011 Conference for buyers, technology experts and industry leaders sponsored by SEIA and SEPA. https://www.pvamericaexpo.com/PVA11/Public/Enter.aspx
4/5/2011 2:00 PM	SUNGRIN Project Team Meeting
4/19/2011 2:00 PM	SUNGRIN Project Team Meeting

(More Events...)

Add new event

News and Announcements

Work In Progress

Project Team Workspace

Presentations

Type	Name	Modified By
	SUNGRIN Project Phase1 Dec21	arifi@eng.usf.edu

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Type	Name	Modified By
	SUNGRIN_2010report_Q2	Ippolito, Tracy
	SUNGRIN_2010report_Q3	Ippolito, Tracy

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Proposal and Award Documents

Type	Name	Modified By

Focus Areas

- **Characterizing and understanding the variability** of the solar resource in Florida, and, particularly at the output of the inverter.
- **Understanding the effects of variability on distribution and transmission grid** operation, protection, and control at high PV penetration, under diverse integration scenarios.
- **Modeling and simulation tools and approaches** to support the analysis and standards needed for successful integration of high-penetration PV.
- **Extracting additional value from the resource** – ancillary services; voltage support, frequency regulation, etc. (no longer just a low priority negative load).
- **Innovations in conversion and control** – grid connected PV system with integrated energy storage.
- **Outreach, education, and stakeholder Support** – Enhance public and stakeholder community awareness and understanding of PV integration opportunities and challenges.

Key Deliverables

- Analysis of solar PV output variation, temporal and spatial, for sites across Florida.
- Analysis of potential impacts of variation on a variety of grid integration cases based mostly on actual utility circuits.
- Validated models of utility circuits and PV systems.
- Guidance on modeling and simulation approaches.
- New integrated converter with storage and converter control concepts.
- Workshops, training, input to standards bodies, and public information portals or kiosks.

Florida

- 5 IOUs
  - FPL*, PEF, TECO, Gulf Power, FPU
- 34 Municipals
  - JEA* & OUC* the largest
- 18 Rural Co-ops
- 9.6 M consumers (all sectors)
- NERC Regions:
  - All of FRCC and portion of SERC
  - 10 Balancing Authorities in FRCC region
- No. 1 in U.S. electric utility capacity and generation [EIA]

** SUNGRIN Partners*

Peak Demand [firm MW]

	Summer	Winter
2010	45,743	48,887
2019	51,226	56,363

System Capacity [MW] (2009)

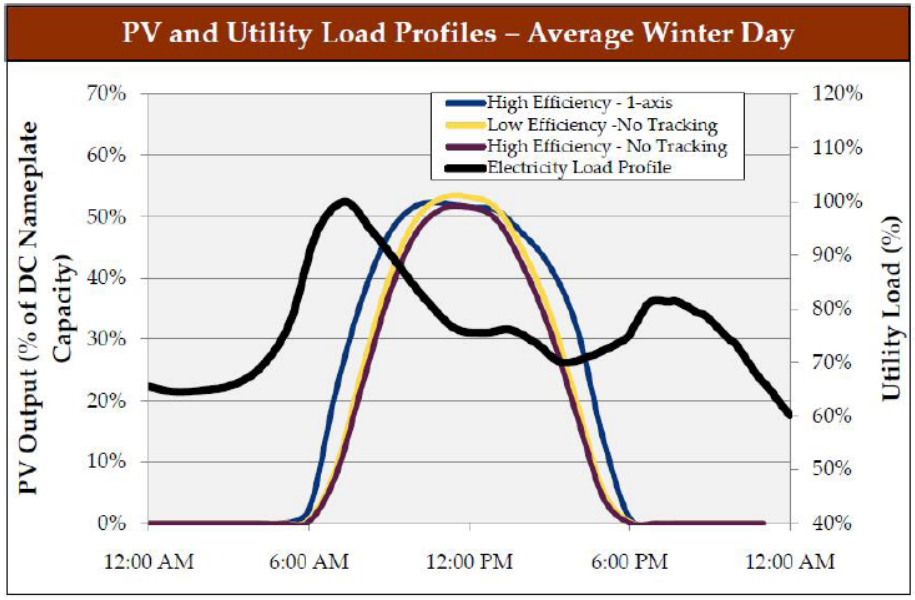
	Summer	Winter
Generating	61,156	56,793
Import	3,600	3,800
Export	1,000	1,900

	Existing	Planned
Solar Energy [MW]	~50	>275

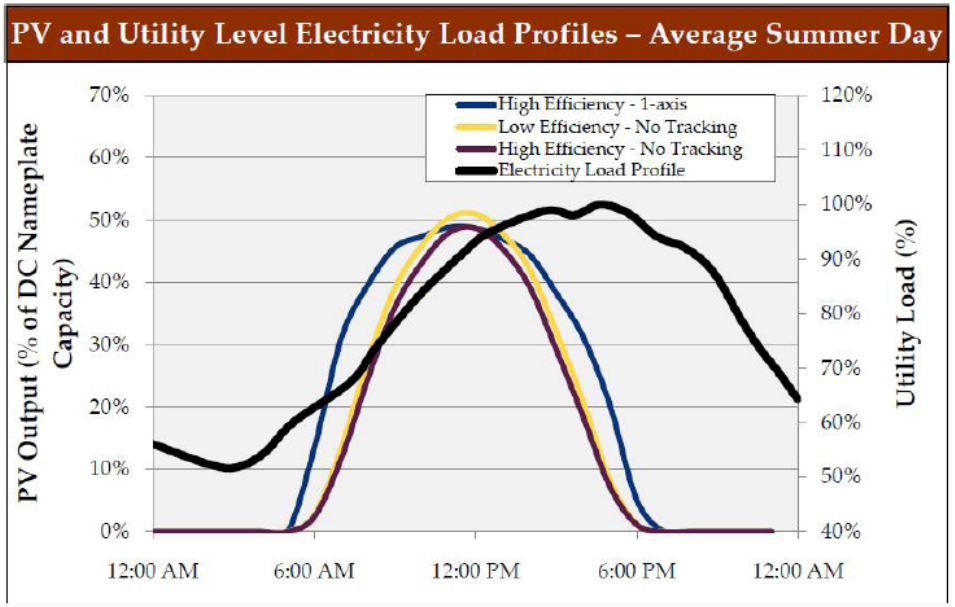
- FPL prepared to begin construction on >500 MW additional solar, pending state renewable legislation. [2]
- PEF plans 127 MW

[1] FL PSC, "Review of the 2010 Ten-Year Site Plans", October 2010.
[2] FPL information presented to FL House Energy & Utilities Subcommittee Meeting, Feb. 8, 2011.

Florida



Typical FL Daily Load Profiles



[1] FL PSC, "Review of the 2010 Ten-Year Site Plans", October 2010 (PSC extracted from Navigant Consulting report).

Solar PV Variability

Timescales

Power system operation, protection, and control

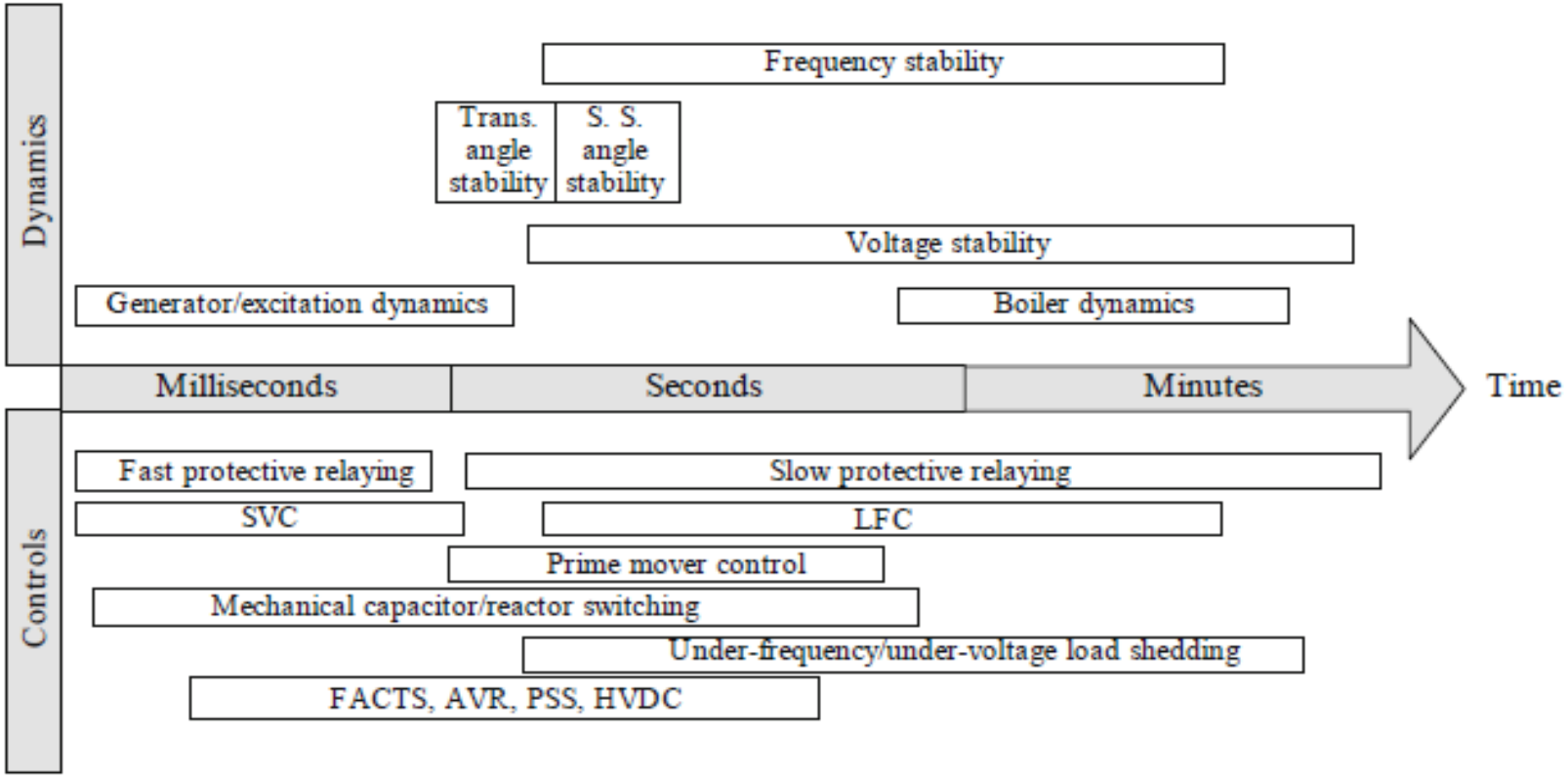
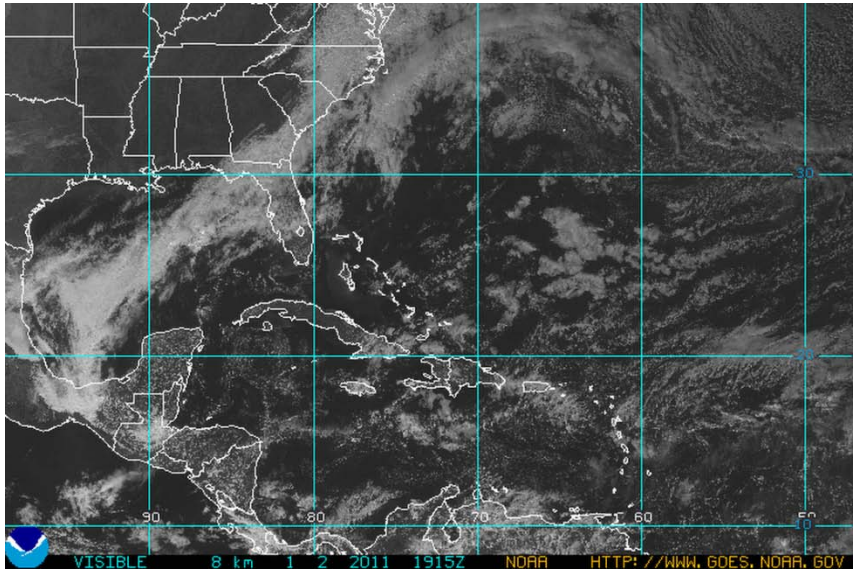


Fig. 1.4 Schematic diagram of different timescales of power system dynamics and controls [3]

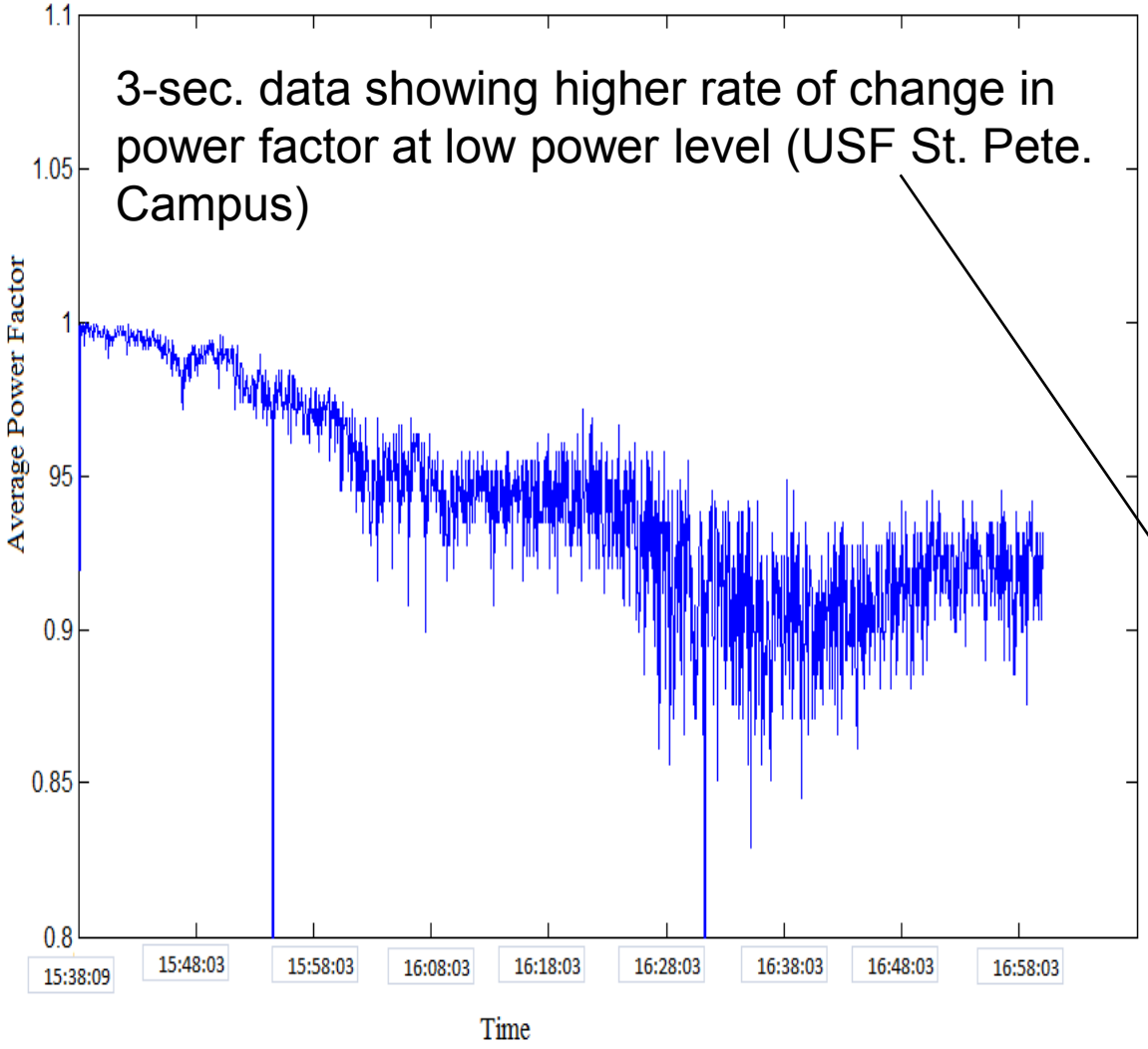
[3] Berani, H., "Robust Power System Frequency Control", Springer Science+Business Media, LLC, NY, 2009.

Solar Input Variations Across Florida

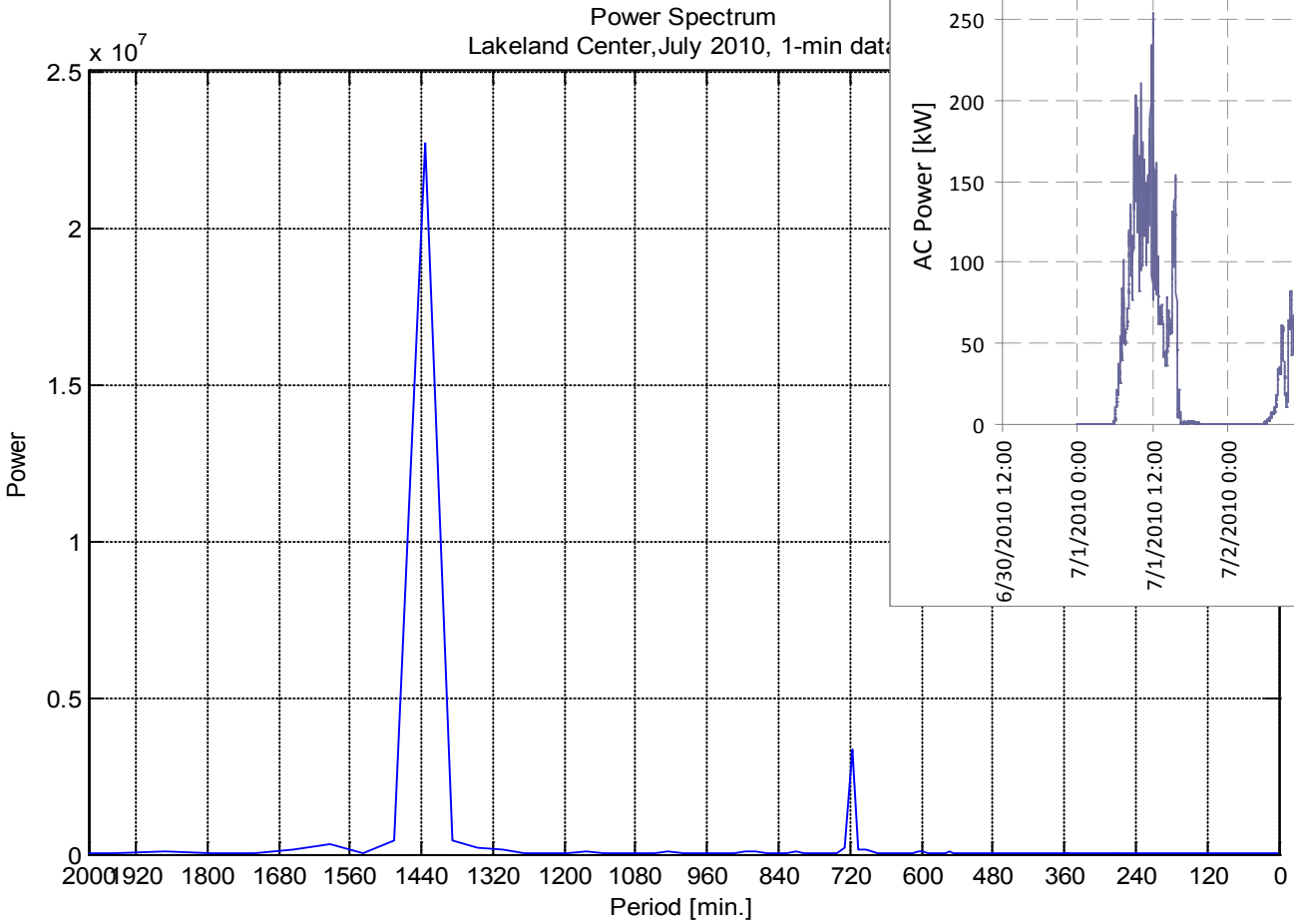
- NOAA GOES satellite data
- One pixel = 5x5 mile grid

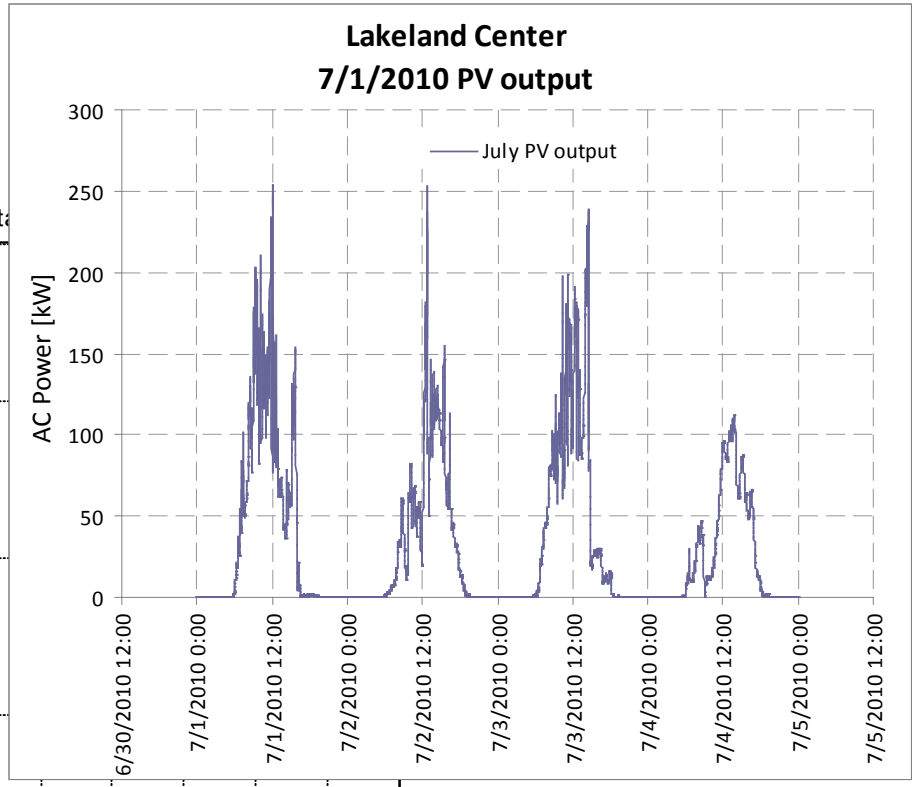


Short term (1/4 & 3 s)



Mid & Long-term (1-min)





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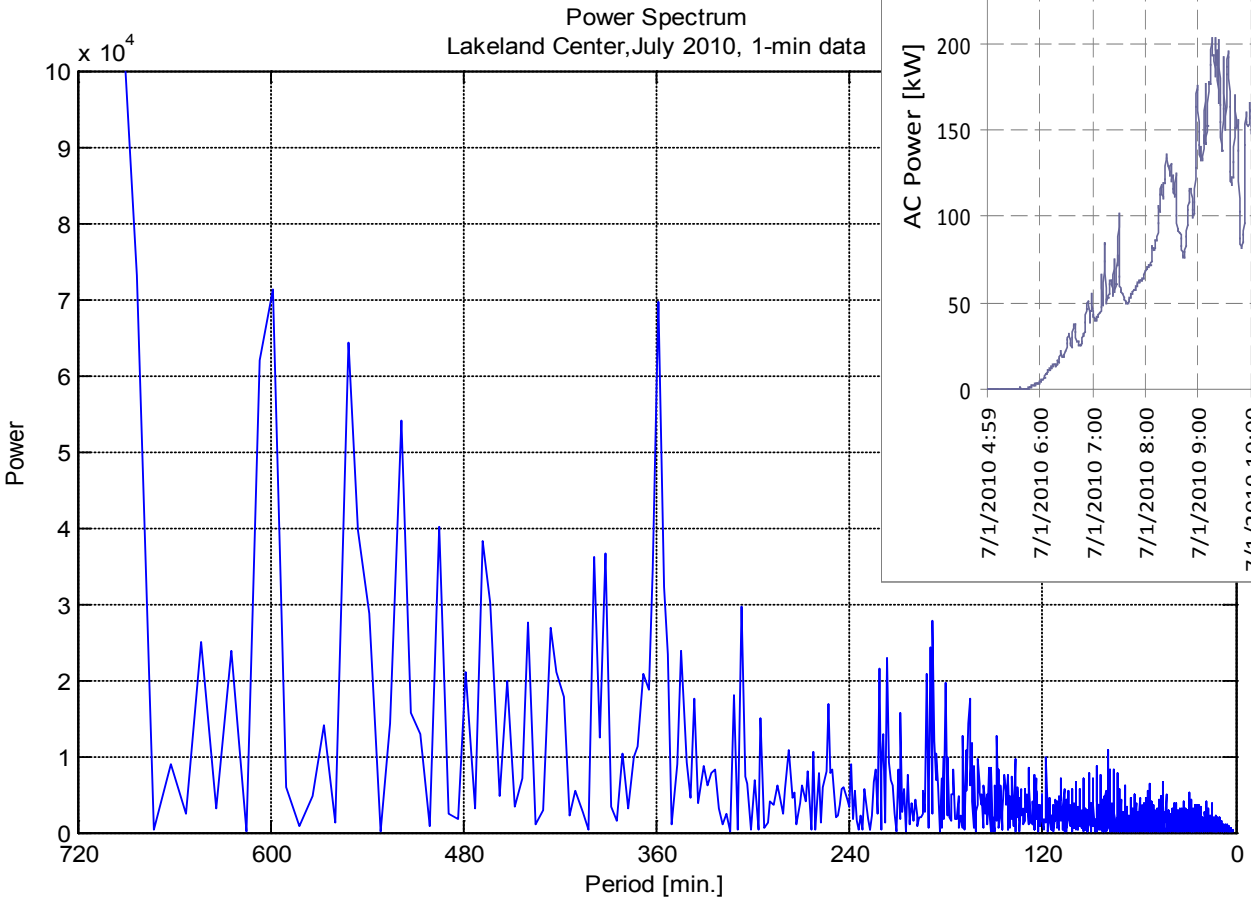
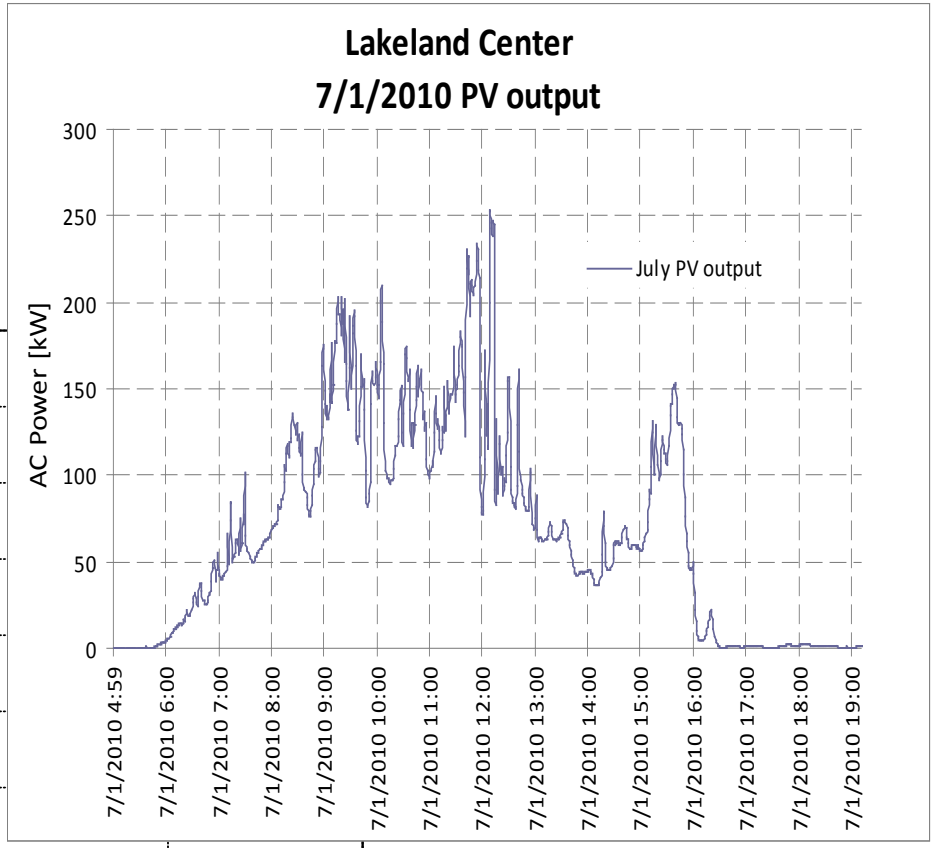
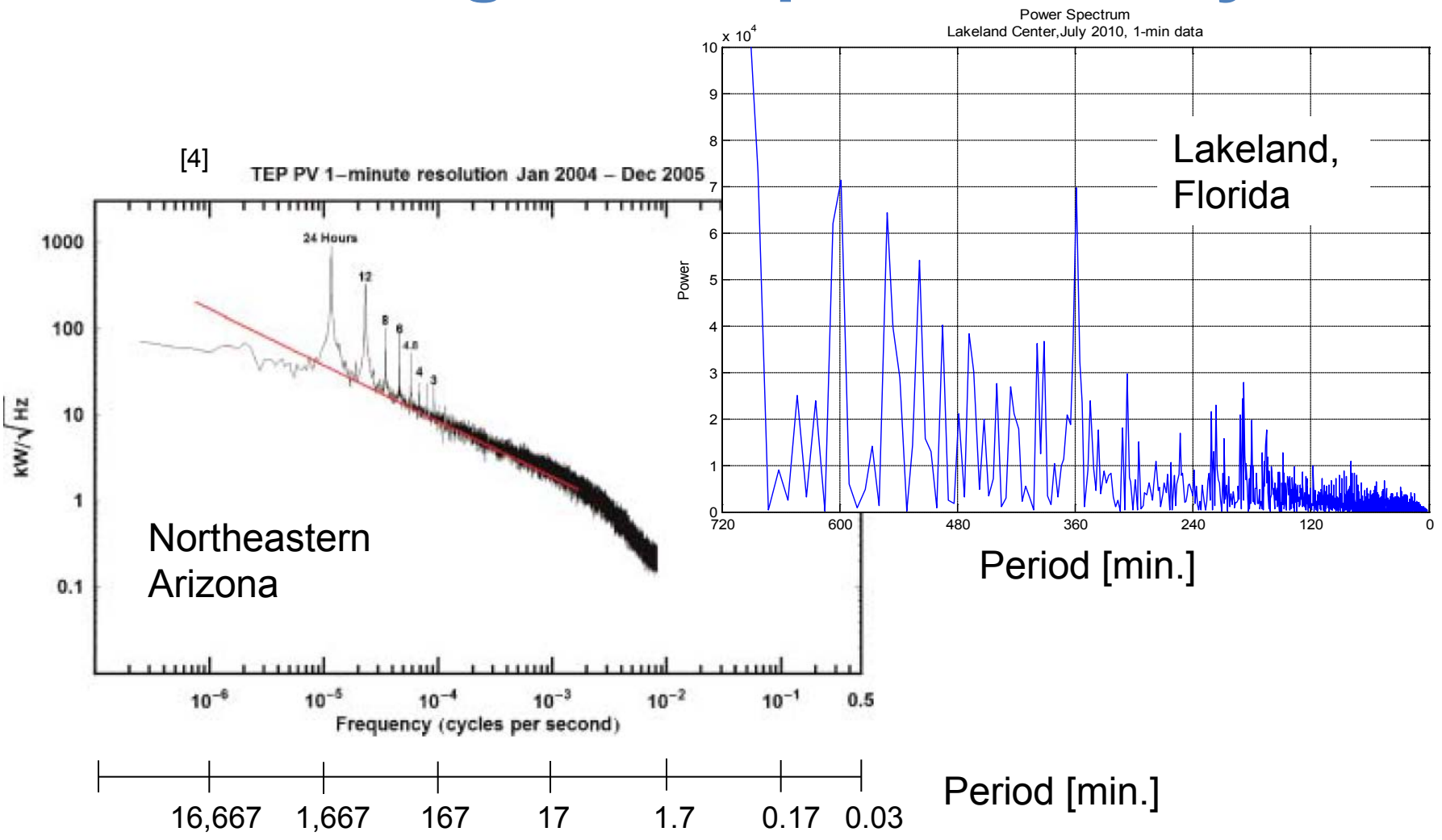




Mid & Long-term Spectral Analysis



[4] Curtright, A.E., Apt, J. "The Character of Power Output from Utility-Scale Photovoltaic Systems", Prog. Photovolt: Res. Appl. 2008.

Timescales

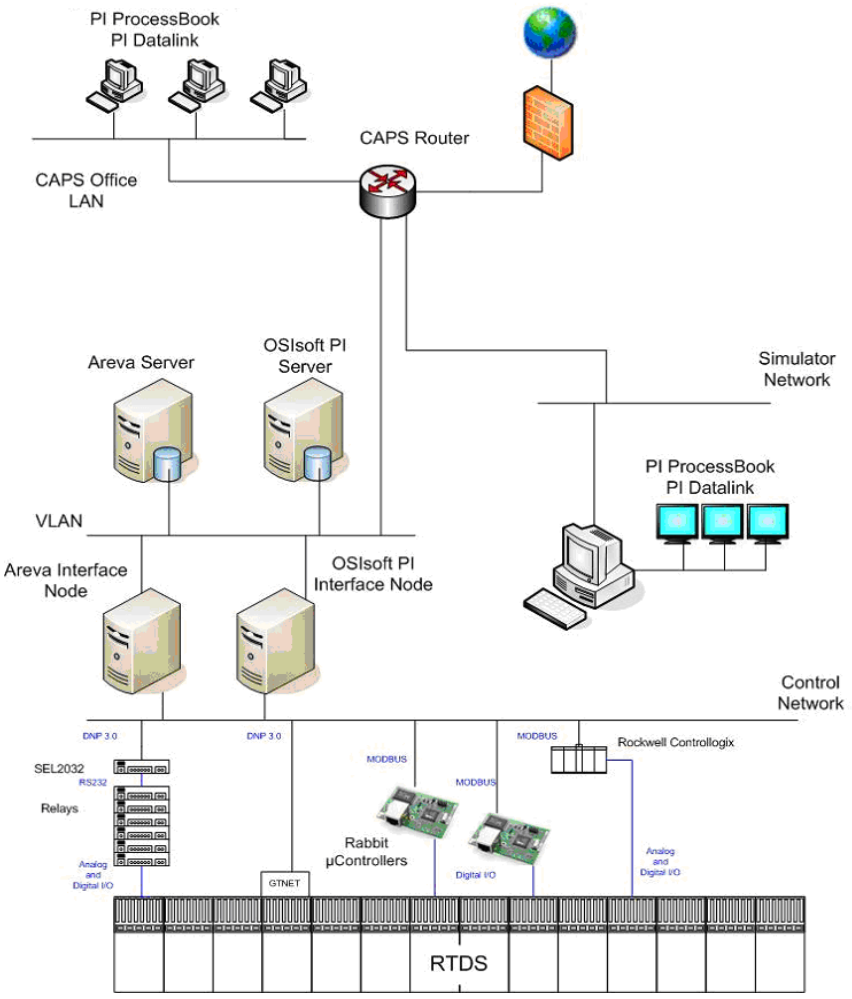
- PV data collection initiative
  - 250 ms, 1 s, 3 s, 1 min., 15 min.

    (& some faster data from PQ meters)
    - AC & DC power, current, voltage
    - AC freq., real & react. pwr or PF
    - Irradiance, weather/climate data
    - Batch & continuous data

Process Information System

OSI PI system

- PI Interfaces:
  - MODBUS Ethernet (TCP)
  - DNP 3.0
  - Campbell Scientific Loggernet®
  - C37.118 (synchrophasor / PMU communications)
  - Areva e-terra® Habitat
  - OPC
  - HTML
  - Universal File and Stream Loader (UFL)
- Two 6 kW systems at FSU Innovation park supplying real-time data currently at 1-min, via Campbell Scientific Loggernet.



Control and information network architecture

PV Projects in SUNGRIN Partner Service Areas

SUNGRIN Utility Partner - PV Project Info

Plant / Project Name	Utility	Map ID Number	System Power Rating	Approx. Area [acres]	Circuit Average Load	Penetration (based on avg. load)	Connection Type	Feeder Length	Power System Connect. Volt.	Project Status	Project Start Date
Keys Eco-Discovery Center	FMPA	1	30 kW	0.11	300 kW	10%	Distribution	0.9 miles	480 V	Operational	Dec. 14, 2009
DeSoto	FPL/Nextera	2	25 MW	235			Transmission			Operational	Oct. 2009
Kennedy Space Center PV Site (PKS)	FPL/Nextera	3	900 kW AC	5.4		70%	Distribution		13.2 kV	Operational	Sept. 2009
Space Coast	FPL/Nextera	4	10 MW AC	60			Transmission		13.8 kV / 115kV	Operational	Apr. 2010
Various	GRU	5	47 proj.'s, 10 kW - 500 kW, ~ 3 MW total online				Distribution			Various stages, ~3 MW operational	
6th Street Solar Energy Park of Gaineseville	GRU	5	2 MW				Distribution		12.8 kV	In construction	4th qtr., 2011
Butler Plaza	GRU	5	2.6 MW 2011 3.8 MW 2016				Distribution		12.8 kV	Phase I Operational	Ph. I: 2011 Ph. II: 2016
Distr. Circuit 435	GRU	5	2 MW		7 MW	29%	Distribution		7.2 kV	Operational	
Jacksonville Solar (JSI)	JEA	6	15 MW DC 12.6 MW DC	100			Distribution	5.64 miles	24 kV	On-line	Nov. 2009
The Lakeland Center	Lakeland Electric	7	250 kW AC	1	2,798 kVA	11%	Distribution	4.7 miles	480 V	Operational	Mar. 24, 2010
CNL/City of Orlando Parking Garage	OUC	8	500 kW	1.7	190 A - 4.1 MW	12%	Distribution	1.55 miles	12.47 kV	Request for Proposals	Summer 2011
Orange County Convention Center	OUC	8	1 MW	4.6	40 A - 864 kW	116%	Distribution	1.42 miles	12.47 kV	Completed	Oct. 2008
Pershing Facilities	OUC	8	149 kW	0.22	230 A - 5.0 MW	3%	Distribution	3.3 miles	12.47 kV	Request for Proposals	Summer 2011
Stanton Energy Center Solar Project	OUC	9	5.91 MW	30	26.5 A - 572 kW	1033%	Distribution	7.13 miles	12.47 kV	Design Permitting	Mar. 3, 2011

Grid Integration Analysis

- Distribution Level
- Transmission Level

Modeling and Simulation Approaches and Tools

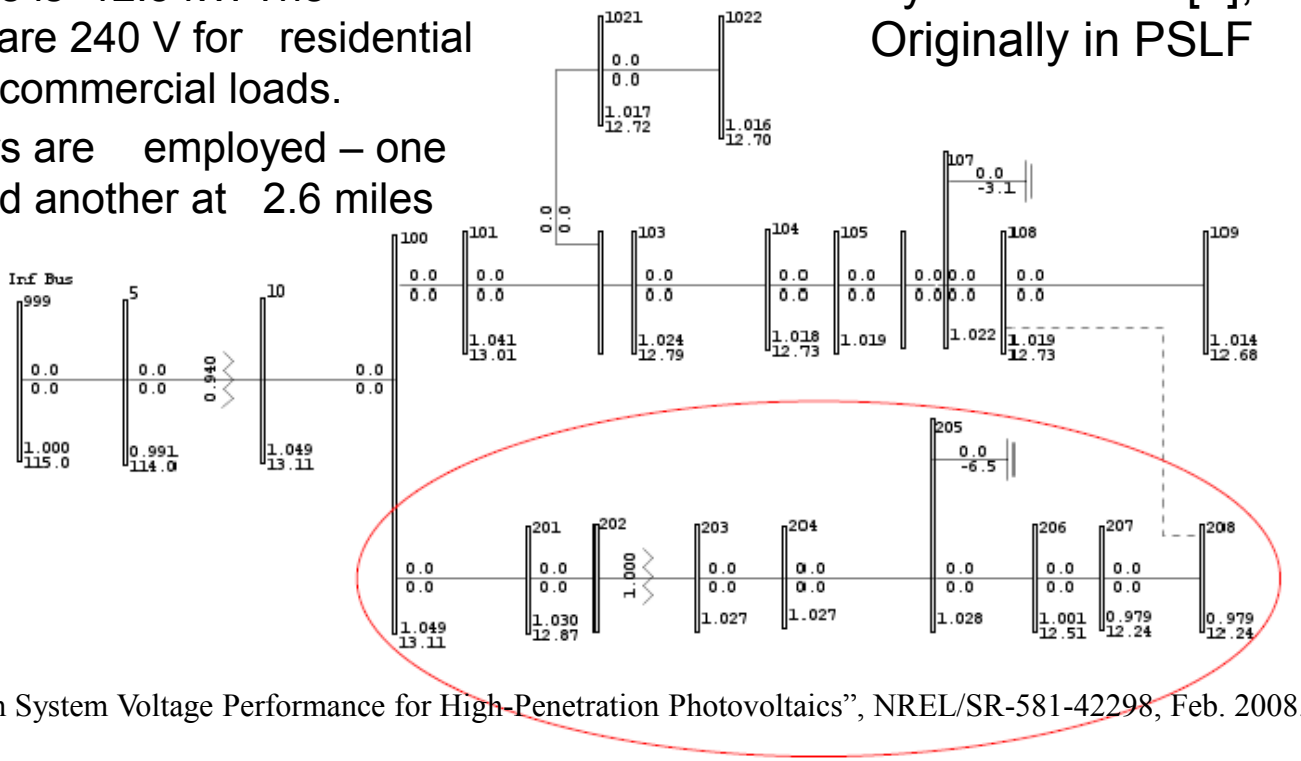
A Distribution System Model

for Renewable Systems Interconnection (RSI) studies

System Description

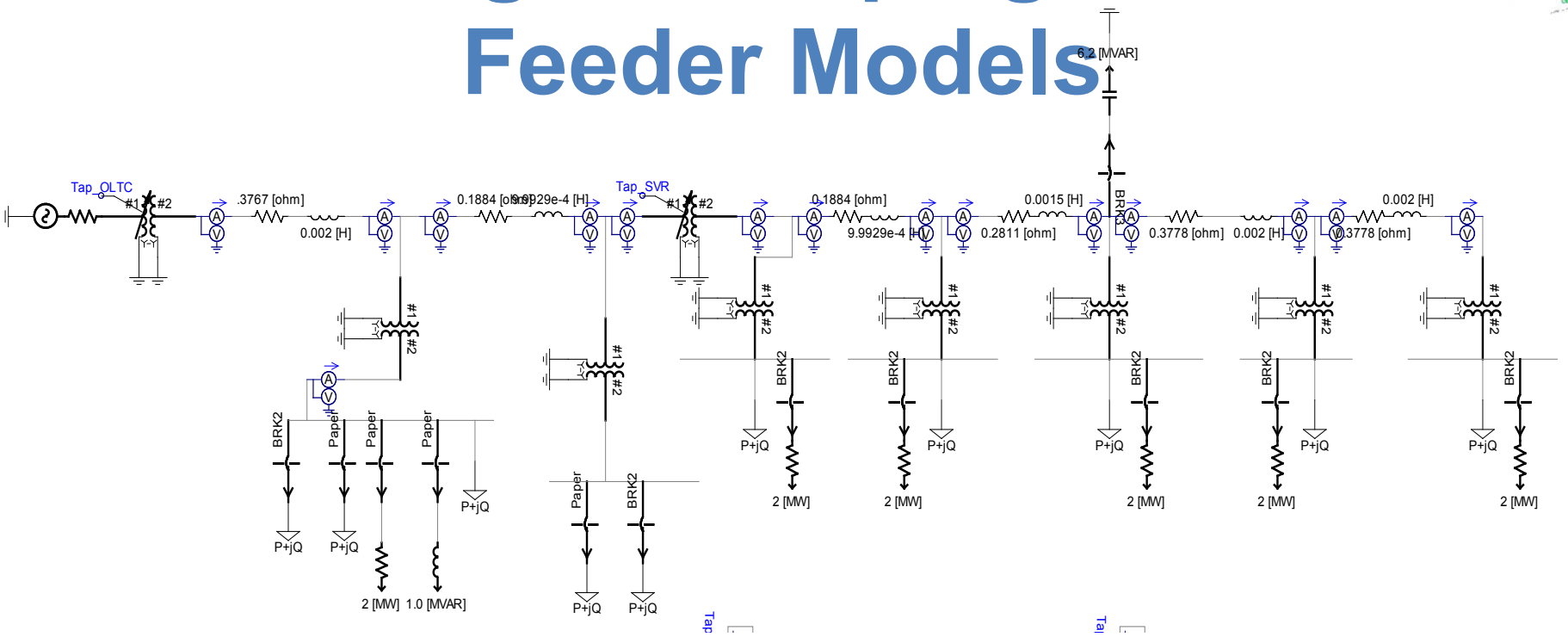
- 6 miles in length
- Mixture of residential load and commercial loads ranging from 0.3 MW to 5 MW. The total load is 11 MVA.
- Primary feeder voltage is 12.5 kV. The secondary voltages are 240 V for residential loads and 600 V for commercial loads.
- Two voltage regulators are employed – one in the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

Radial Distribution System Model [5]; Originally in PSLF



[5] Liu, E., Bebic, J., "Distribution System Voltage Performance for High-Penetration Photovoltaics", NREL/SR-581-42298, Feb. 2008.

Deriving/Developing PSCAD Feeder Models

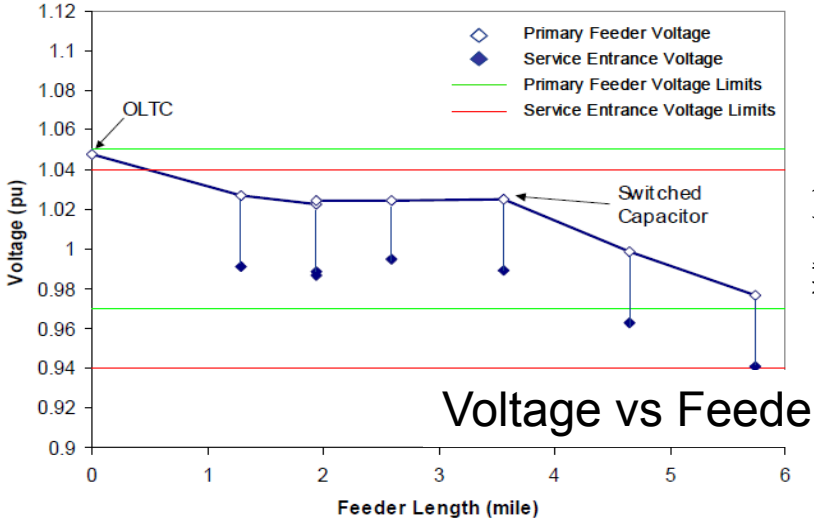


- Full transient time domain simulation platform as opposed to 1-phase equivalent (dynamic) “load flow” type
- 3 individual phases + neutral
- Typically 50 µs time-step (smaller dt possible)
- Allows adequate study of voltage regulation, protection, control of multiple PV converters, etc., to analyze the various details that are typically omitted by other tools

PSCAD Feeder Model Validation

Voltage vs Feeder Length Comparison

Sandia Results



PSCAD Results

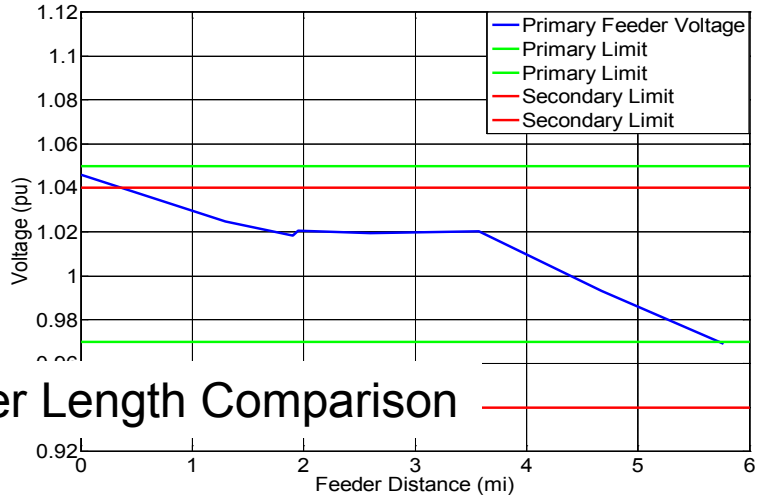
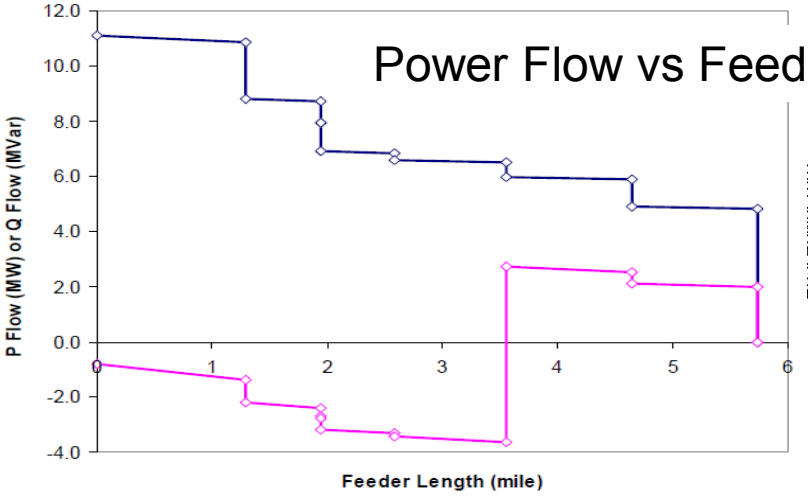


Figure 5. Baseline 1: voltage profile at peak load with the switched capacitor

Power Flow vs Feeder Length Comparison

Sandia Results



PSCAD Results

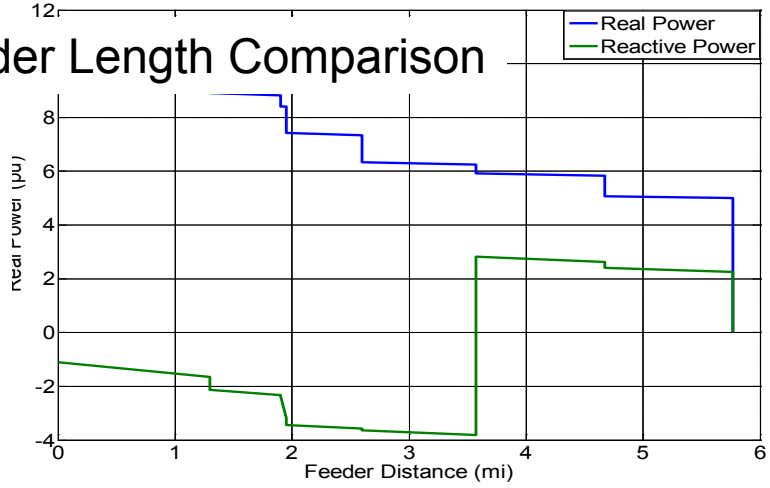
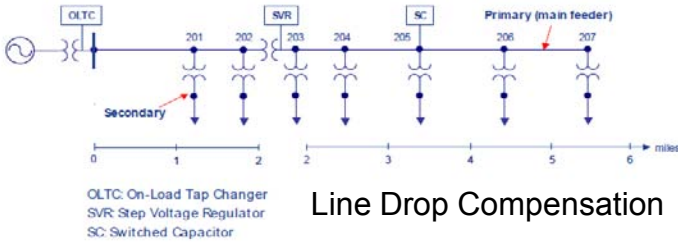


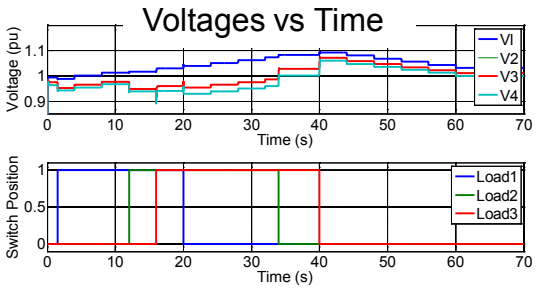
Figure 6. Baseline 1: power flow at peak load with the switched capacitor

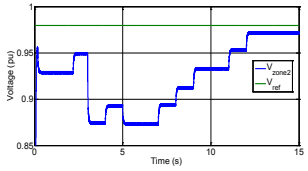
Studies with RSI Dist. Model

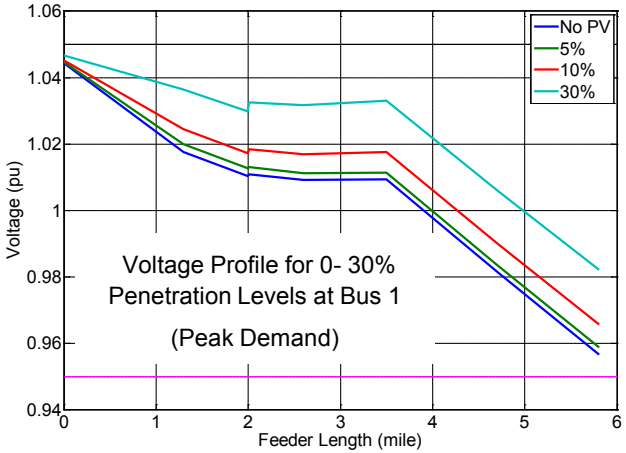
- Voltage regulation dynamics
- OLTC coordination
- Static PV (varying) penetration studies
- Static PV (varying) location studies
- Distributed vs. concentrated PV location
- High-penetration, no-load

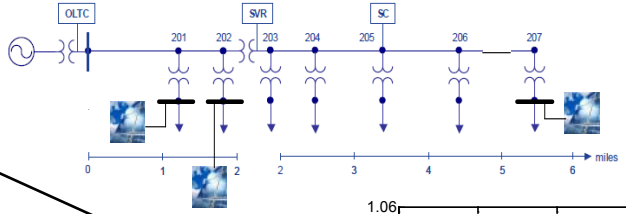


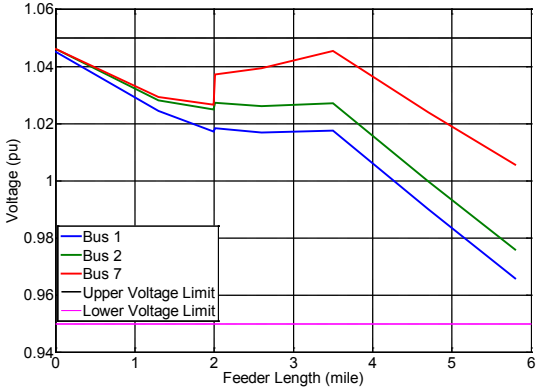
Line Drop Compensation





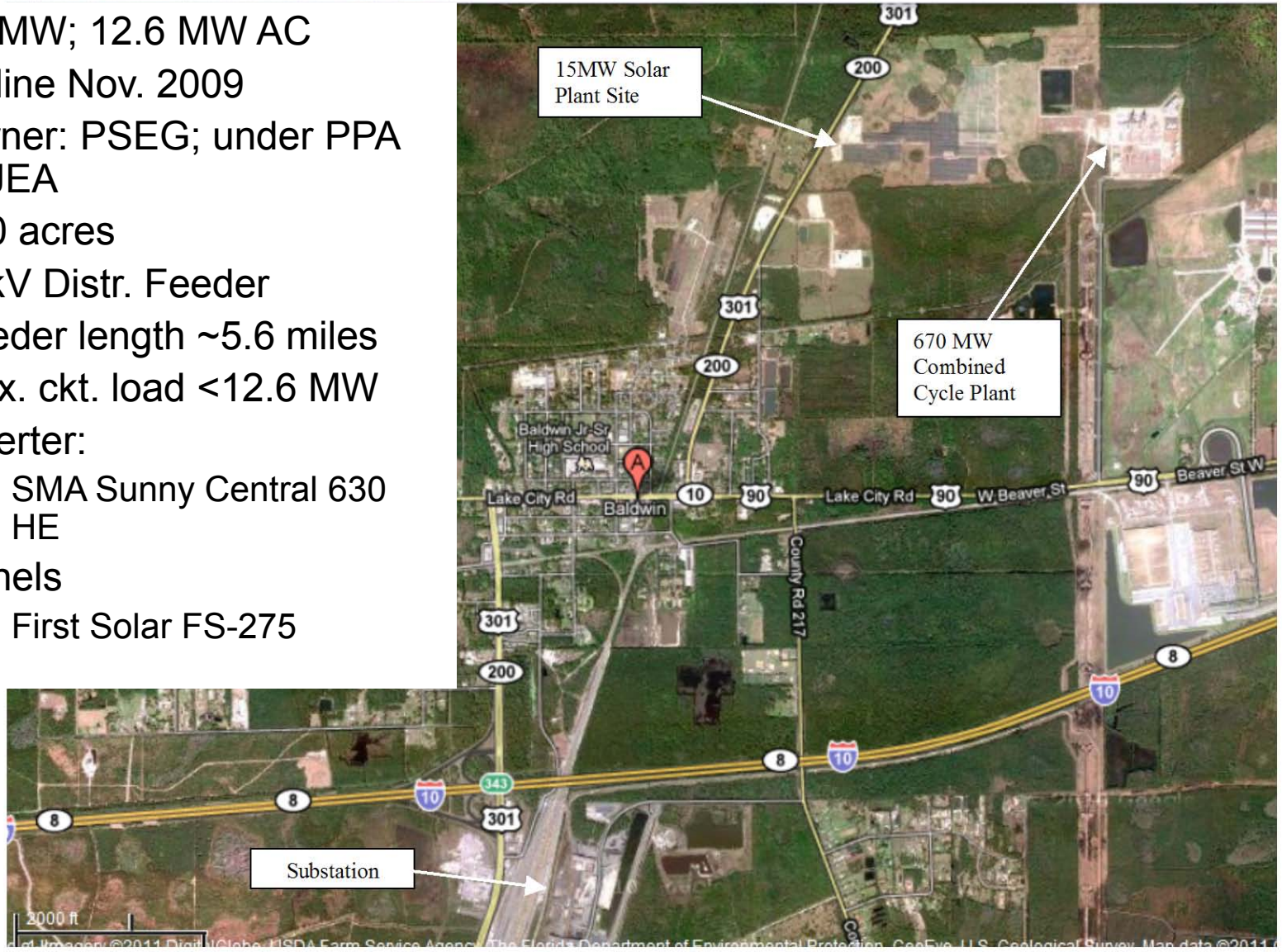






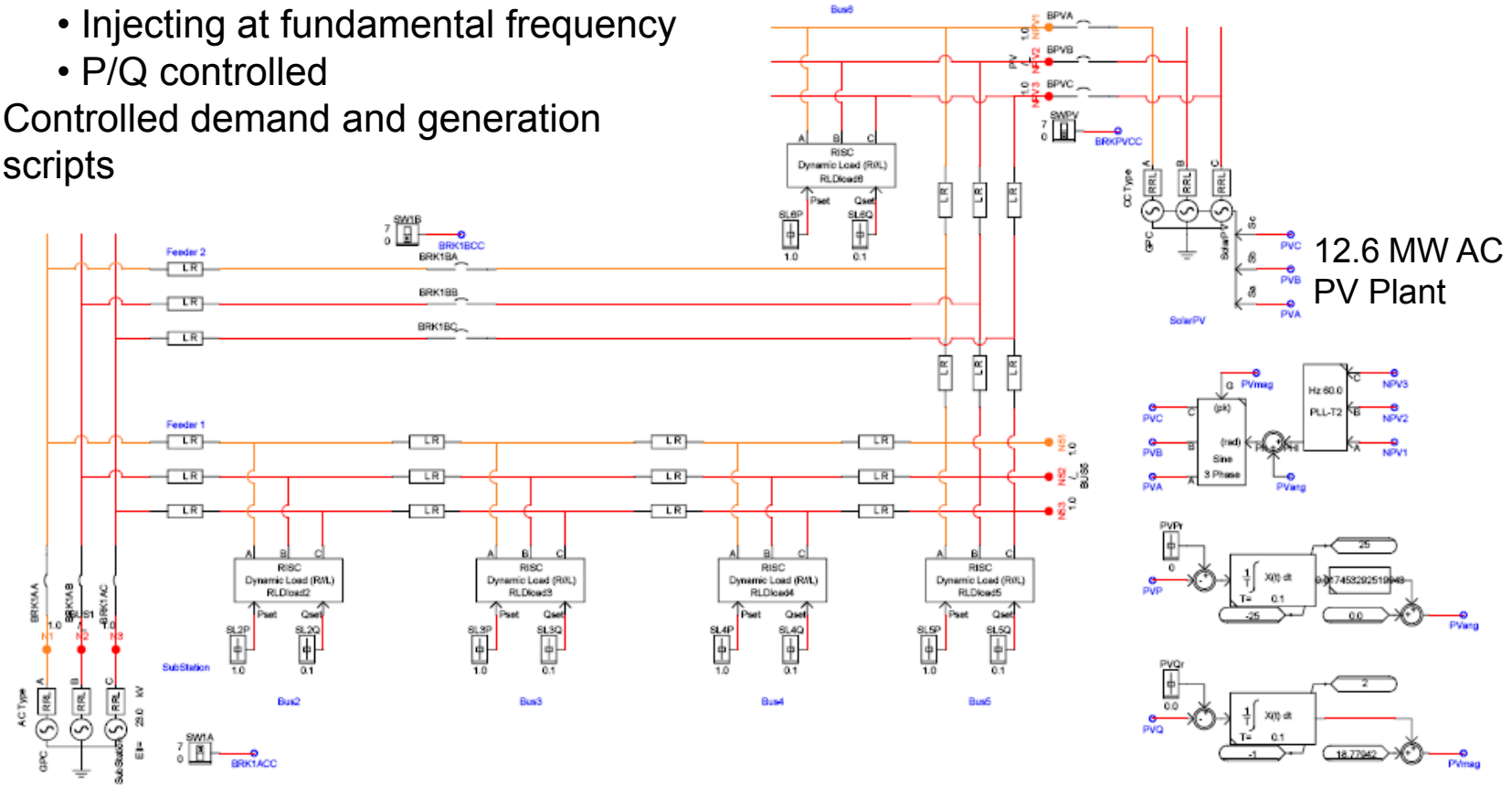
JEA – Jacksonville Solar

- 15 MW; 12.6 MW AC
- Online Nov. 2009
- Owner: PSEG; under PPA to JEA
- 100 acres
- 24kV Distr. Feeder
- Feeder length ~5.6 miles
- Max. ckt. load <12.6 MW
- Inverter:
  - SMA Sunny Central 630 HE
- Panels
  - First Solar FS-275

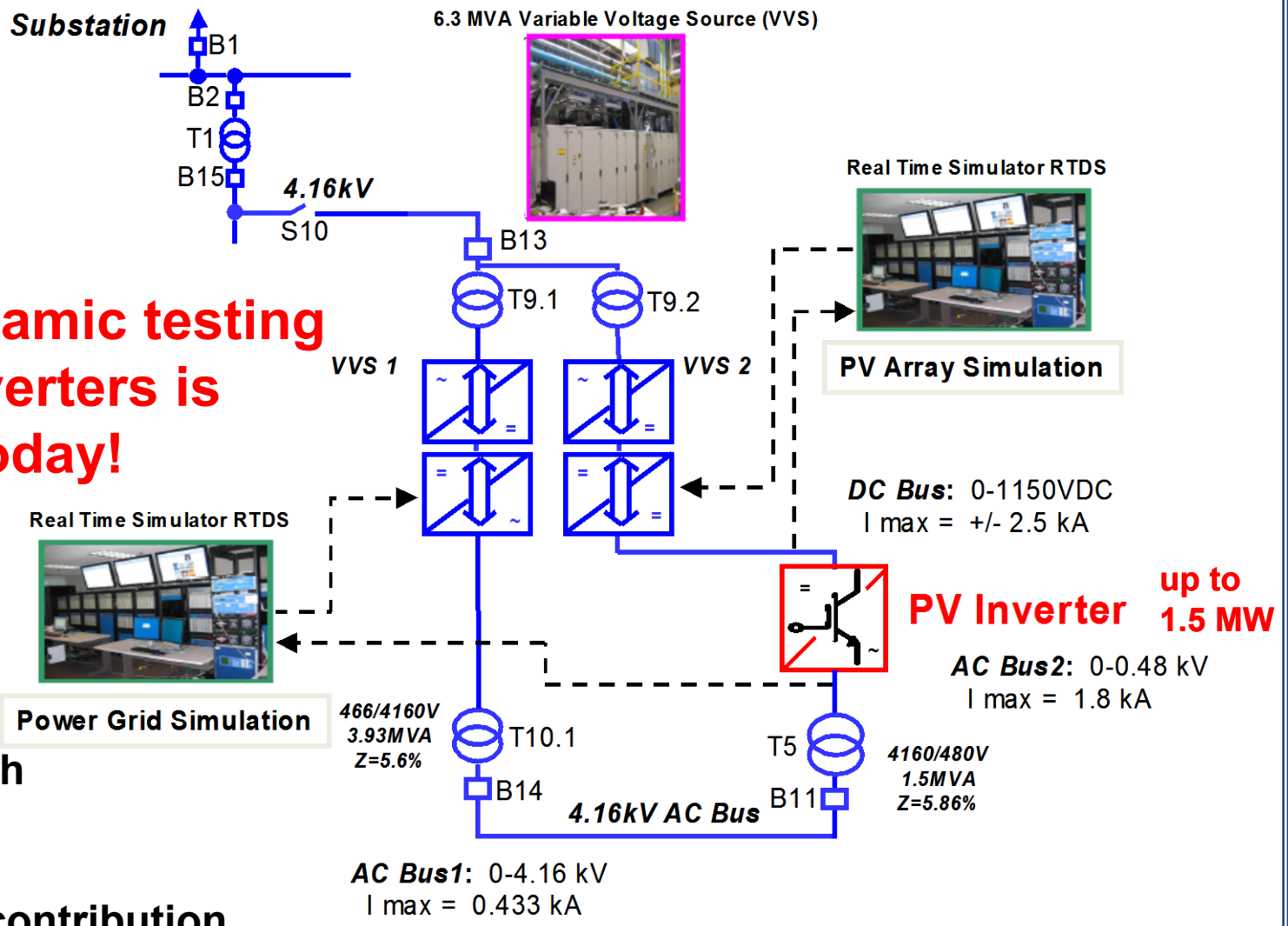


RTDS Model – Jacksonville Solar, Distribution Feeder Circuit from Substation

- Substation
  - Back-up feeder
- 5 P/Q-load buses
- Solar PV
  - Injecting at fundamental frequency
  - P/Q controlled
- Controlled demand and generation scripts



Dynamic HIL Testing of large PV Inverters



Highly dynamic testing of PV converters is possible today!

LV ride through

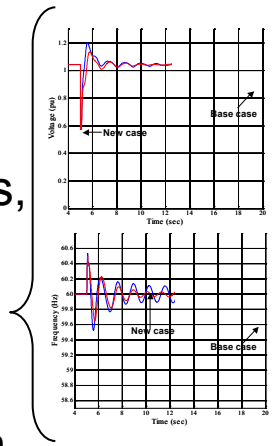
Anti islanding

Fault current contribution

Unbalanced voltage condition

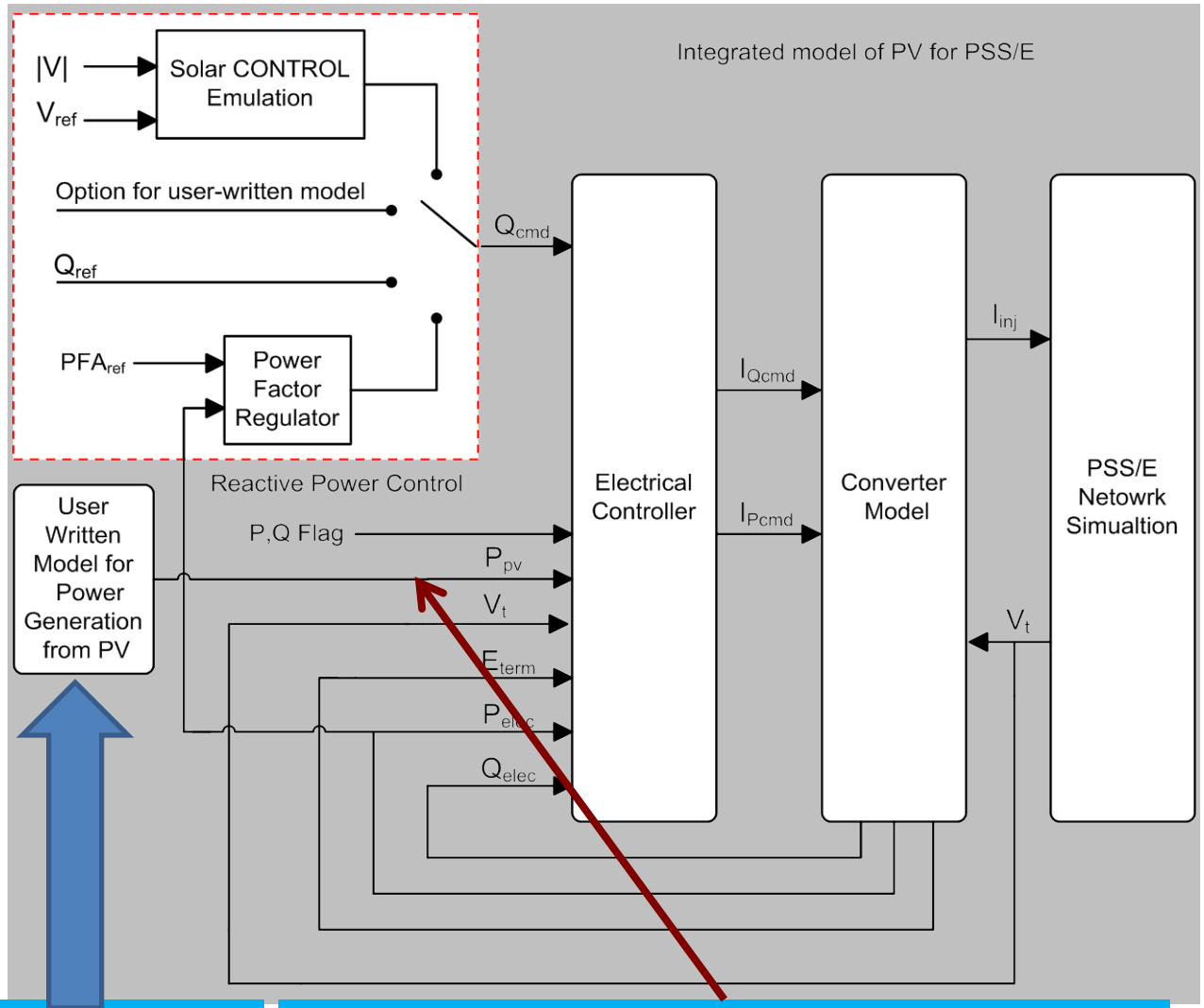
A Transmission Level Model - the Florida Grid

- 154-bus notional Florida grid model developed in PSS/E (State of FL, FESC funded)
- Useful for regional high penetration PV integration studies
- Bus voltage levels are at 500, 230 and 138 kV
- 76 Generators with a scheduled 48049.72MW
- 116 Loads totaling 47704.2MW, 7999.2MVar
- Dynamic data for machines, governors, exciters and stabilizers (recent improvements)
- Cooperation with FRCC on validation and application



A PV Model for use in PSS/E

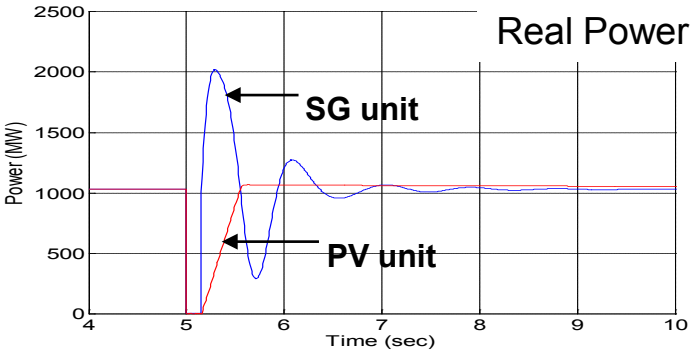
- PV Output is varied to change the penetration level.
- Selective replacement of Synchronous Generator (SG) units with PV generation
- The PV model and MPPT code are written in FLEX/FORTRAN and scripted in the CONEC File
- The model is then incorporated with the electrical control and converter model of Type 4 wind turbine model available in PSS/E (since they both use the same power electronic configuration)

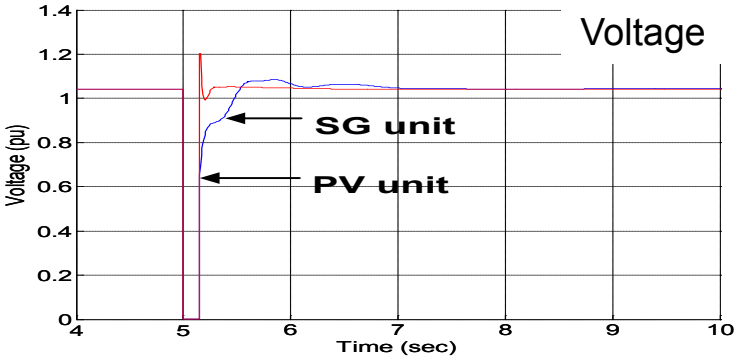


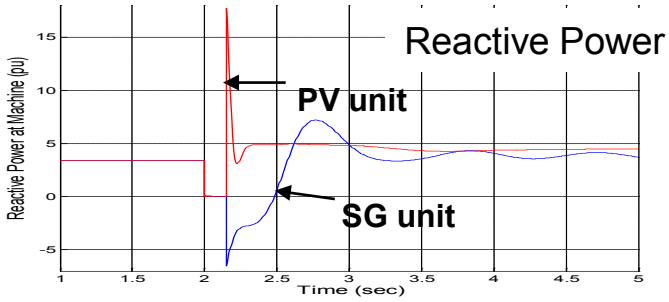
Simulation of a Fault at a Bus

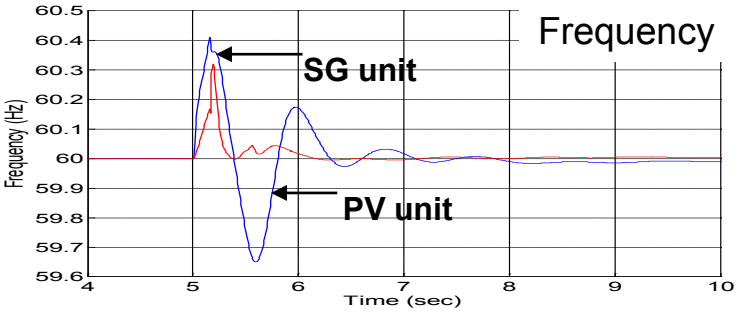
- A bus fault was applied at Bus 6504 with a fault impedance of 0.01 Ohm for 9 cycles.
- The Synchronous Generator unit at BUS 6504 (with P=1030MW) was replaced with a PV unit.
- The Solar Irradiance is assumed to remain constant at 1000Wm-2.

Behavior at Bus 6504:



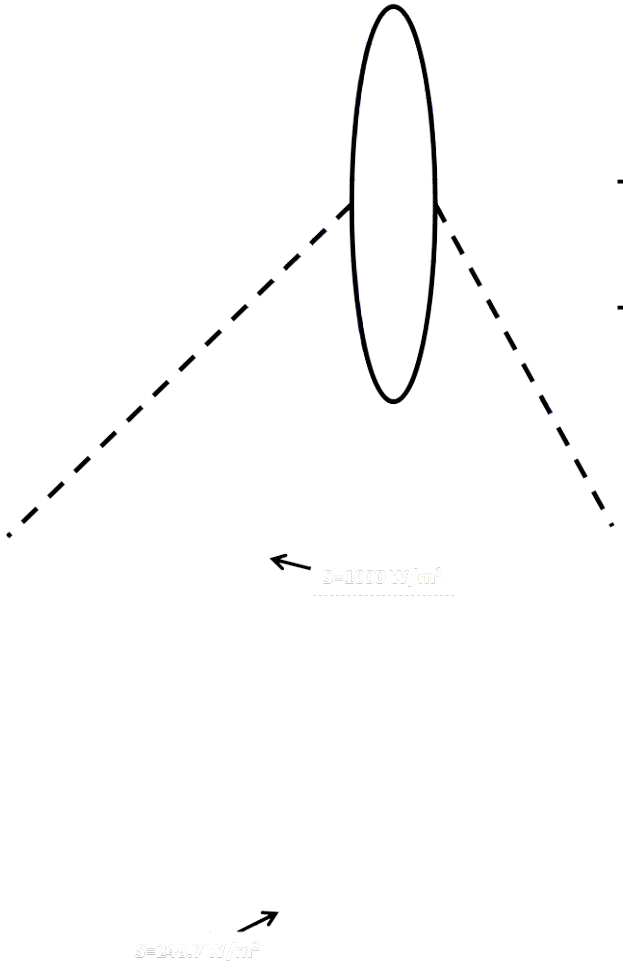




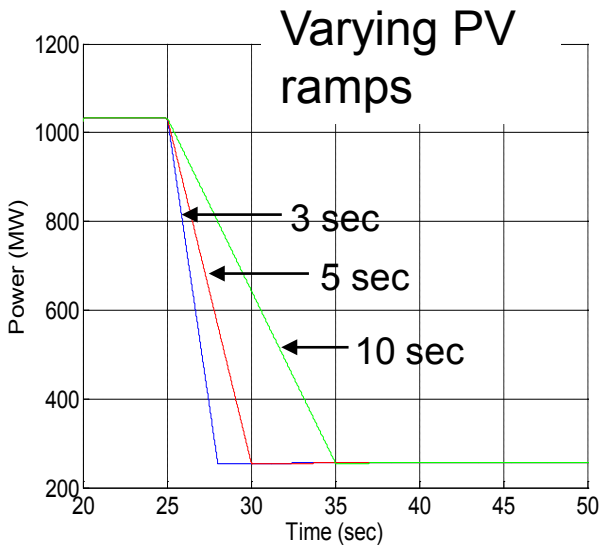


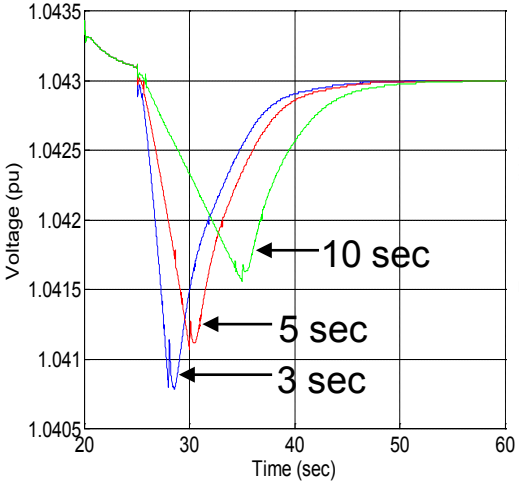
- After the fault is cleared, Synchronous Generator (SG) unit showed oscillation in power whereas PV unit does not show any significant oscillations.
- The frequency deviation for the SG is higher than that of PV unit.

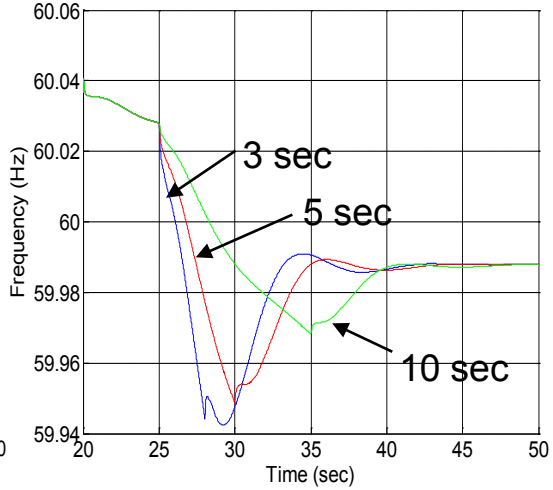
Evaluating Impact of Cloud Cover with 154-bus FL Grid Model



- A 75% drop in irradiance observed in 6 sec.
- Is the system stable to that rapid fall?
- What is the critical rate of change?



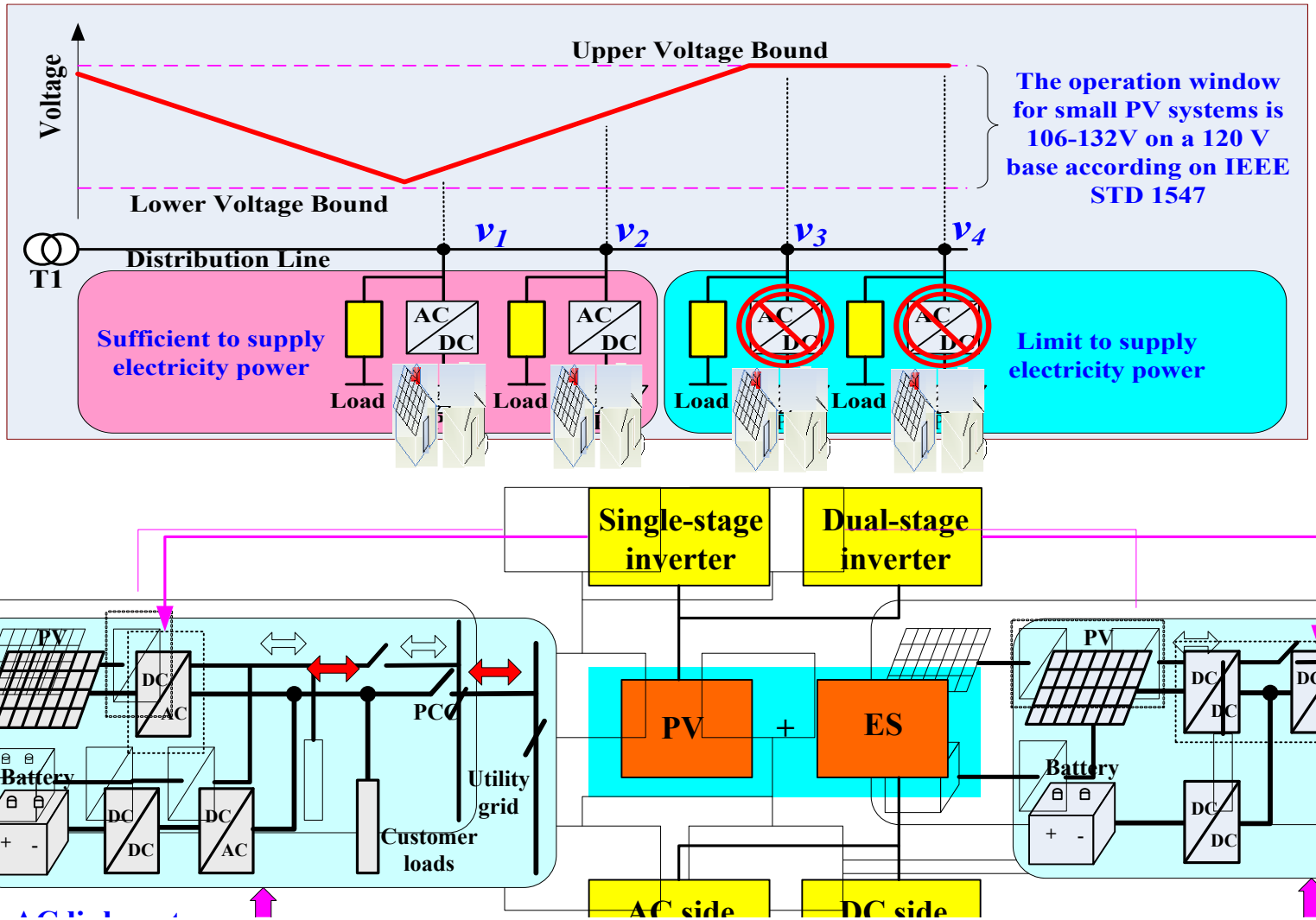




Grid-connected PV System Integrating Energy Storage Elements

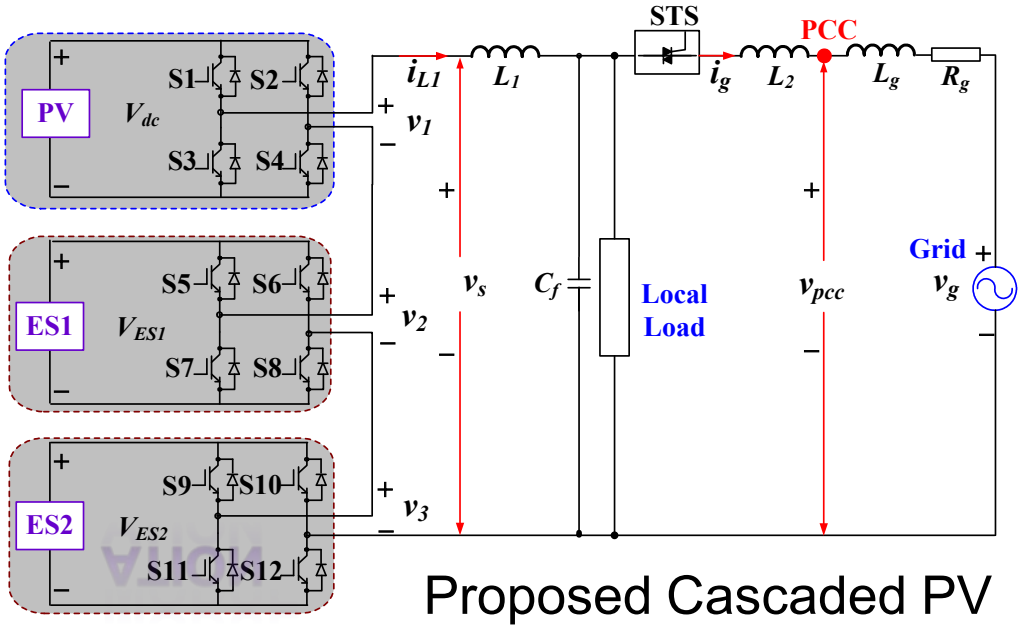
Research Background

High penetration PV system issues

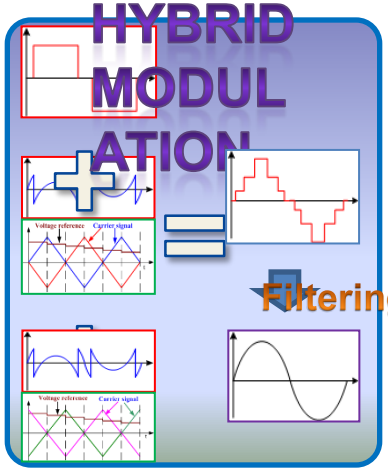


Current grid-connected inverter with ESS (a) AC link topology; (b) DC link topology

Proposed PV System Description



Proposed Cascaded PV System integrating Segmented Energy Storage



Developed Controls (in MATLAB/Simulink) for Grid-Connected System

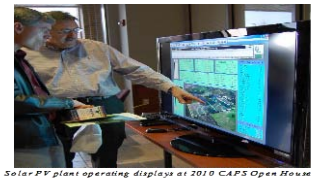
- AC-side control system
- DC-side PV control system
- DC-side batteries control system
- Grid-connected mode control, AC and DC sides

Outreach, Education, and Stakeholder Community Engagement

Smart Grid Technologies Professional Development Course

- 2/4/2011 at the Florida Public Service Commission
- Topics:
  - Smart grid history and overview, Power electronics, Energy conversion, Renewables integration and distributed energy, High temperature superconductivity, Fault current limiters, Protection and Communications, Wide area monitoring, Phasor Measurement Units, Meters and AMI, Advances in simulation and testing
- Organizers / sponsors: ASME, IEEE, FSU CAPS, USF PCUE, DOE

FSU CAPS Open House – 2/26/2011



Solar PV plant operating displays at 2010 CAPS Open House

Standards and Industry Groups

- IEEE 1547, IEEE P2030, Gridwise Alliance, NASPI, NERC SGTF, FMEA, etc.

Web Portal, Information Kiosks

Workshops

Publications

1. Xiaohu Liu, Liming Liu, Hui Li “Coordinated Control between OLTC Transformer and Local Energy Storage System for Voltage Rise Mitigation under High Photovoltaic Penetration,” *submitted* to the 2011 IEEE Power & Energy Society General Meeting, July 24-30, 2011 in Detroit.
2. Meeker, R., Islam, M., Omole, A., Click, D., et al, “Characterizing Solar PV Output Variability and Effects on the Electric System in Florida, Initial Results”, *submitted* to the ASME 2011 Energy Sustainability Conference, Aug. 7-10, 2011, Washington, DC.
3. O. Vodyakho, M. Steurer, T. Chiocchio, K. Schoder, "Establishment of a Unified Design, Test, and Research Platform for Solar Energy System Integration Utilizing the Power Hardware-in-the-Loop Concept", digest *submitted* for review to the 2010 IEEE Energy Conversion Congress and Exposition (ECCE 2010) to be held in Phoenix, AZ, 17-22 Sep. 2011.

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Q & A