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
## 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

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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</table>
| **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

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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</table>
| **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

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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</table>
| **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

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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</table>
| **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

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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</table>
| **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**

March 1-2, 2011
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
3/4/2011 8:00 AM DOE/EPRI High Penetration Solar Forum
The DOE/EPRI 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 CUNI Emerging Phenomena in Changing Electric Energy Systems
http://www.cce.cmu.edu/~electronic/

3/8/2011 2:00 PM SUNGRIN Project Team Meeting

3/20/2011 12:00 PM 2011 IEEE PES Power Systems Conference & Exhibition (PSCC)
http://www.piscexpo.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....)

News and Announcements
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]

<table>
<thead>
<tr>
<th>Year</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>45,743</td>
<td>48,887</td>
</tr>
<tr>
<td>2019</td>
<td>51,226</td>
<td>56,363</td>
</tr>
</tbody>
</table>

System Capacity [MW] (2009)

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generating</td>
<td>61,156</td>
<td>56,793</td>
</tr>
<tr>
<td>Import</td>
<td>3,600</td>
<td>3,800</td>
</tr>
<tr>
<td>Export</td>
<td>1,000</td>
<td>1,900</td>
</tr>
</tbody>
</table>

Solar Energy [MW]

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~50</td>
<td>&gt;275</td>
</tr>
</tbody>
</table>

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

Florida

Typical FL Daily Load Profiles

Solar PV Variability
Timescales

Power system operation, protection, and control

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

Solar Input Variations Across Florida

- NOAA GOES satellite data
- One pixel = 5x5 mile grid
Short term (1/4 & 3 s)

3-sec. data showing higher rate of change in power factor at low power level (USF St. Pete. Campus)
Mid & Long-term (1-min)

Power Spectrum
Lakeland Center, July 2010, 1-min data

Lakeland Center
7/1/2010 PV output
Mid & Long-term Spectral Analysis

Northeastern Arizona

Lakeland, Florida

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.
PV Projects in SUNGRIN Partner Service Areas
## SUNGRIN Utility Partner - PV Project Info

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

• 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

Sandia Results

Voltage vs Feeder Length Comparison

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

Power Flow vs Feeder Length Comparison

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

PSCAD Results

Voltage (pu) vs Feeder Distance (mi)

Real Power (pu)

Reactive Power (pu)
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
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

![Diagram of RTDS Model – Jacksonville Solar, Distribution Feeder Circuit from Substation]

12.6 MW AC PV Plant
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

Substation

6.3 MVA Variable Voltage Source (VVS)

Real Time Simulator RTDS

PV Array Simulation

Real Time Simulator RTDS

Power Grid Simulation

466/4160V
3.93MVA
Z=5.6%

AC Bus1: 0-4.16 kV
I max = 0.433 kA

4.16kV AC Bus

4.16kV
S10

B1
B2
T1
B15

B13

T9.1
T9.2

T10.1
B14

B11

T5

4160/480V
1.5MVA
Z=5.86%

DC Bus: 0-1150VDC
I max = +/- 2.5 kA

AC Bus2: 0-0.48 kV
I max = 1.8 kA

up to 1.5 MW
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)

**PV + MPPT** Output power from the PV array
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?

Varying PV ramps

![Graphs showing power, frequency, voltage, and time for varying PV ramps.](image-url)
Grid-connected PV System
Integrating Energy Storage Elements
Research Background

High penetration PV system issues

The operation window for small PV systems is 106-132V on a 120V base according to IEEE STD 1547.

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

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

Proposed Cascaded PV System integrating Segmented Energy Storage
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

Standards and Industry Groups

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

Web Portal, Information Kiosks Workshops


Sunshine State Solar Grid Initiative (SUNGRIN)

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Q & A