The Sunshine State Solar Grid Initiative
SUNGRIN

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HIGH PENETRATION SOLAR PV TEST CASES IN THE FLORIDA GRID

Project Sponsors and Partners

U.S. DEPARTMENT OF ENERGY
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FLORIDA SOLAR ENERGY CENTER
Creating Energy Independence

FMPA Florida Municipal Power Agency

GRU More than Energy

LAKELAND ELECTRIC Your Essential Link to a Quality Life

amec

FPL

JEA

OUC The Reliable One

OSIsoft.

FRCC Florida Reliability Coordinating Council, Inc.

SMA

Team

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- **AMEC:** *Mike Allman*
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Focus Areas

- PV and load variability characterization and impact
- Power system circuit model development (distribution and transmission; Florida circuits)
- High-penetration PV impact analysis with FL utility circuit models and data
- Development and testing (including HIL) of Power electronics, storage, and control solutions and strategies
- Outreach and engagement

PV Variability at High-Pen Sites

Data:

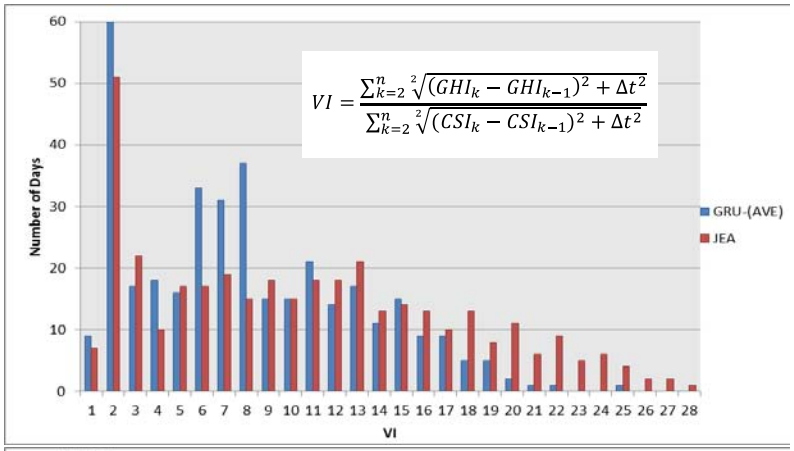
- ***Satellite:*** SolarAnywhere data at 1 km spatial and 1-min temporal resolution
- ***Ground Measurements:*** PV site measured data, typically 1 min., 15 min.

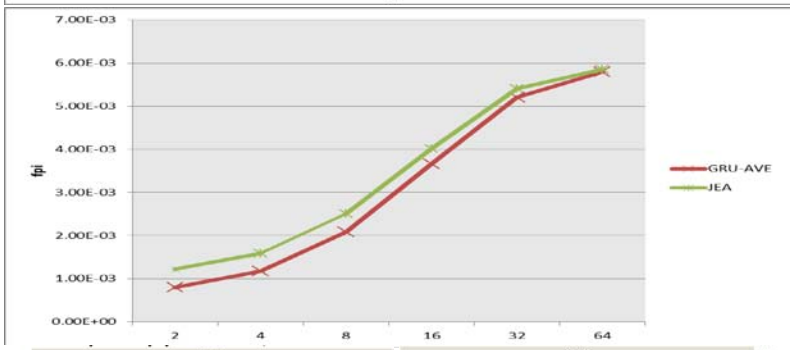
Approach:

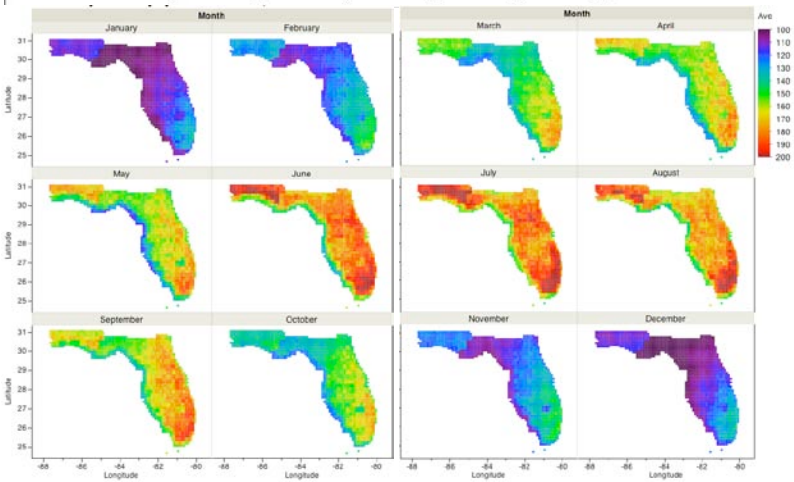
- ***Classify and compare variability,*** temporal and geographic, using Variability Index
- ***Distribution of ramps*** of irradiance and modeled power output
- ***Estimate the reduction in variability*** due to ***geographic smoothing***
- ***Quantify*** the amplitude and frequency of occurrence of ***fluctuations at each timescale using a stationary wavelet transform***

Conclusion:

- Geographic smoothing offers a strong benefit over short timescales
- This benefit decreases with longer timescales and increased spatial correlation







High-Penetration PV Studies of Florida Distribution Circuits

JEA Circuit 345 to Jacksonville Solar Plant (Ph. 1-2)

GRU Circuit 435
GRU Circuit 432
(Ph. 2-3)

OUC Stanton Solar (Ph. 3-4)

NASA KSC Circuit (w/FPL) (Ph. 1, 4-5)

Lakeland Electric
Lakeland Airport
2 circuits
(Ph. 2-4)

Modeling Tools

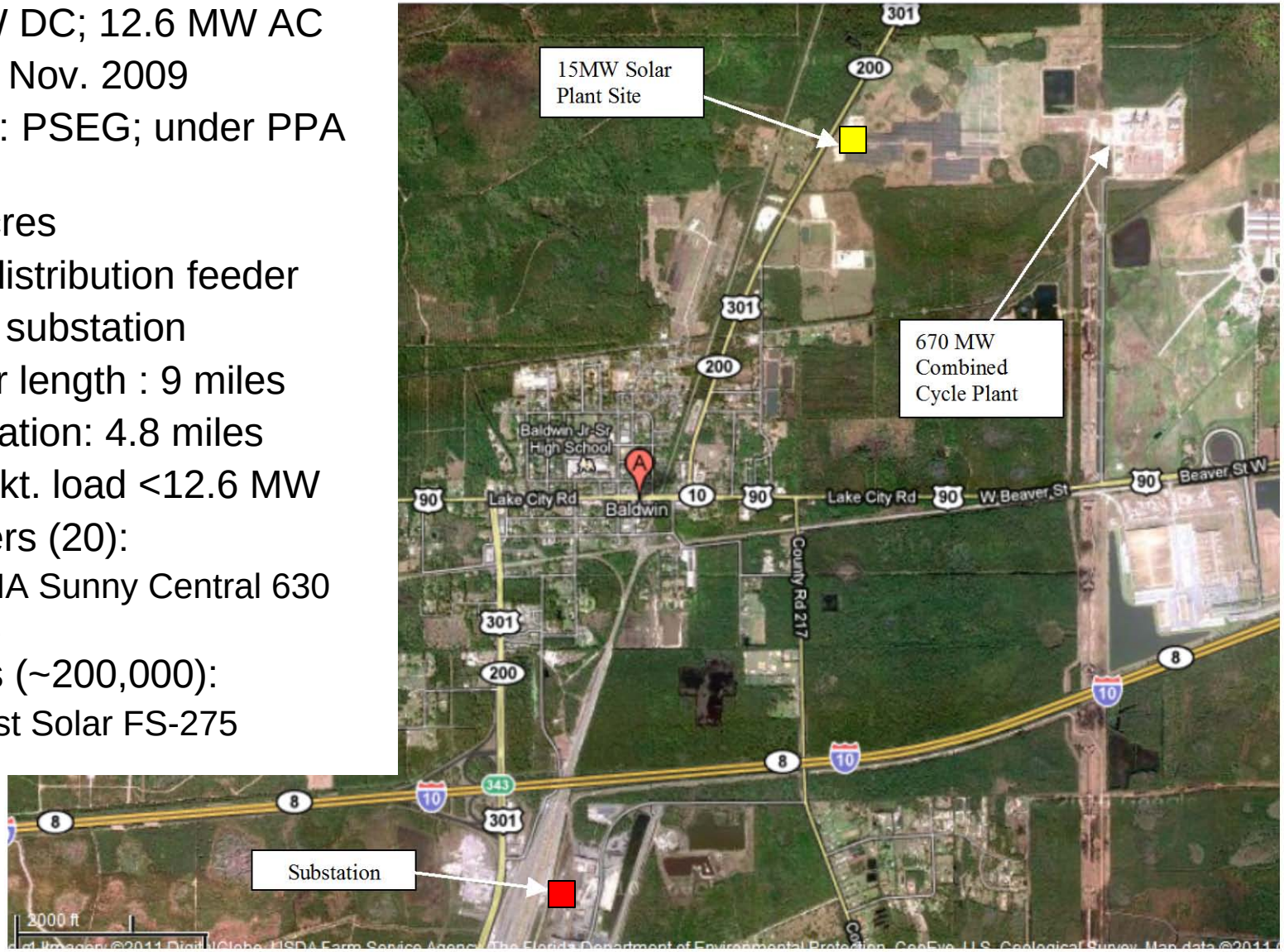
- Real Time Digital Simulator (RTDS)
  - Electromagnetic Transient Program (EMTP) solution
  - 3-phase time-domain solution
  - >110,000 MFLOPS; 14 “racks”, parallel processing
  - EMTP type simulation covers load-flow, harmonic, dynamic, and transient regime
  - 50 μs timestep simulation in real-time; <2 μs possible for portions of the simulation
  - 66 real-time electrical nodes per “rack” x 14 racks = 924 nodes
  - 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.
- OpenDSS (EPRI)
  - Frequency domain solution – power flow, dynamics, harmonics
  - Running from MATLAB (where other processing, analysis, and plotting occurs)
- PSSE (Siemens PTI)
  - Phasor-based load flow
  - Primarily used for transmission grid modeling

Model Validation Approaches and Challenges

- Software based validation
  - Cross-validation against other model results from *SynerGEE* and *OpenDSS*
  - Both steady-state and fault situations were compared (RTDS vs. OpenDSS and RTDS vs. Synergee)
  - Fault currents at different locations provided by the utility are compared against simulation results
- Field measurement based validation
  - Voltage, current, real and reactive power at substation and along circuit
  - Synchronized data from 3-5 locations are sought
  - Imperfect knowledge of load variation along circuit and across phases
    - Circuit load at substation and recloser (if present) known from field msmt.'s
    - Loads distributed based on the transformer's kVA ratings and utility estimates of typical transformer loading vs. load type (residential / commercial)

JEA – PSEG Jacksonville Solar

- 15 MW DC; 12.6 MW AC
- Online Nov. 2009
- Owner: PSEG; under PPA to JEA
- 100 acres
- 24kV distribution feeder
- 230kV substation
- Feeder length : 9 miles
- PV location: 4.8 miles
- Max. ckt. load <12.6 MW
- Inverters (20):
  - > SMA Sunny Central 630 HE
- Panels (~200,000):
  - > First Solar FS-275



JEA Circuit Model Validation

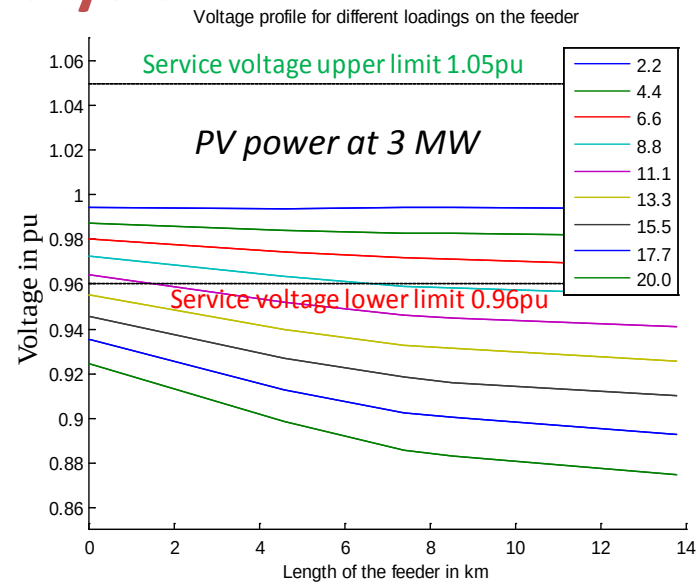
Power flow validation against field measurements

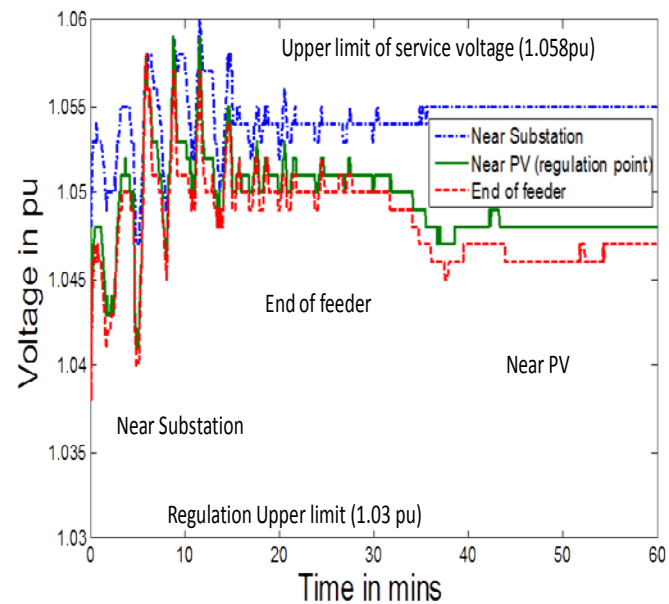
For simulation runs at four different time periods, various times of day:

- Voltage at substation breaker in agreement within 1.97% to 2.21%
- Voltage at PV plant in agreement within 1.25% to 1.56%
- Current at substation breaker in agreement within 3.24% to 4.92%

JEA Circuit Model – Voltage Profile Analysis

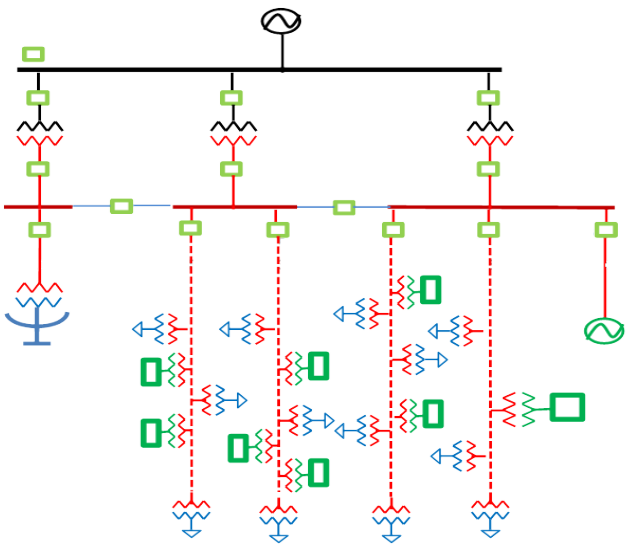
- **Examined voltage profile for varying X/R ratio**,
  - Circuit X/R is about 4.5
  - At higher X/R (>7), low voltages would occur beyond ~7 km out
- **Examined voltage for varying load, and PV production**,
  - With loading greater than 8 MVA, at low PV production, and 11 MVA, at high PV production, it is possible to see low voltages on the feeder
- **Examined voltage regulation**,
  - With no regulation (actual circuit), traditional regulation, and PV participation, single plant vs. multiple plants,
  - Without regulation, using severe load swing, slightly low voltage can occur at end of feeder, but overall voltage tends to be quite stable and in limits
  - Traditional regulation alleviates somewhat
  - PV regulation exhibits very good control (in simulation)
  - Multiple PV plants – concern with control interaction

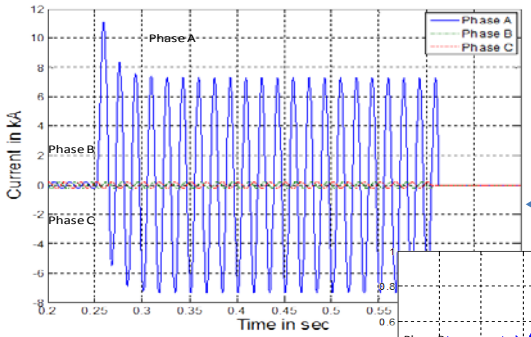




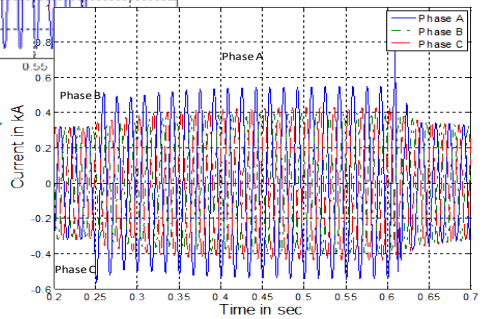
Protection Impact Analysis for JEA Feeder & Substation

- Relay settings provided by JEA
- Substation & protection modeled in RTDS
  - 2-Rack real time (60 µs) case
  - 5-Rack non-real time (1 µs) case with detailed feeder data
- PV inverters are current limited to 1.3 p.u.
- Substation, which has strong source (230kV).
- Various types of faults applied at different locations on substation for,
  - NO PV penetration.
  - PV penetration on 1 feeder.
  - PV penetration on many feeders.
- Impact of PV location with respect to the fault location also studied





Current through breaker 344 for fault on FDR 344, Phase A, with 0.1 ohm fault impedance



Fault current from 12.6 MW PV system on FDR 345, due to fault on FDR 344 Phase A

Conclusions:

- No sympathetic tripping on the PV feeder breaker from adjacent feeder fault
- Results specific to this site. Need to examine others

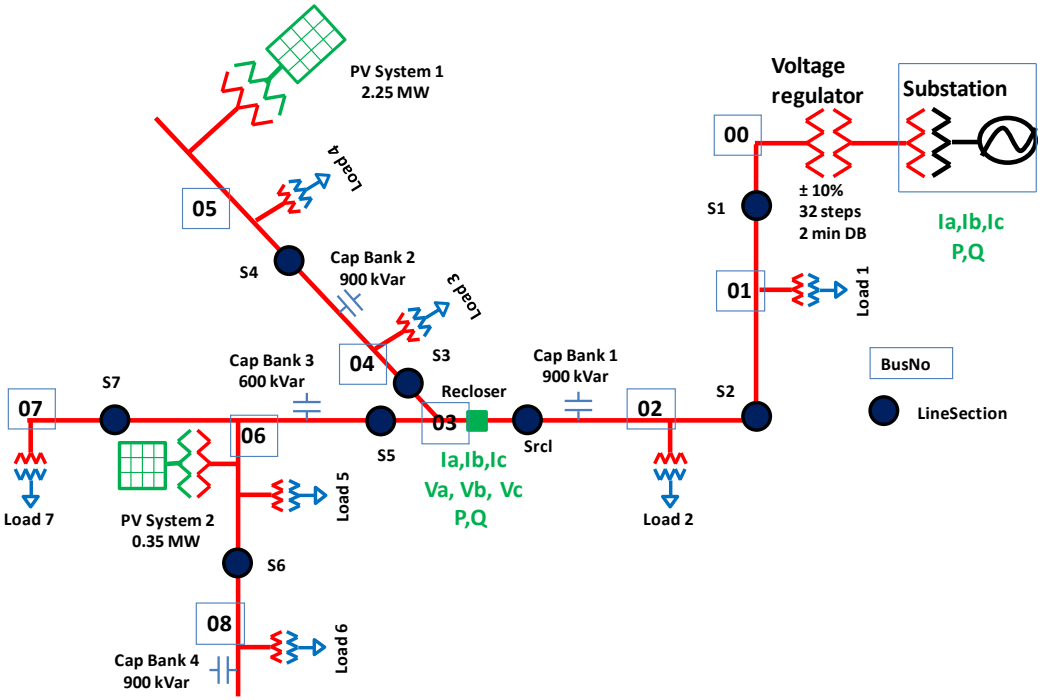
GRU Circuit 435 Feeder ("6th St. Solar)

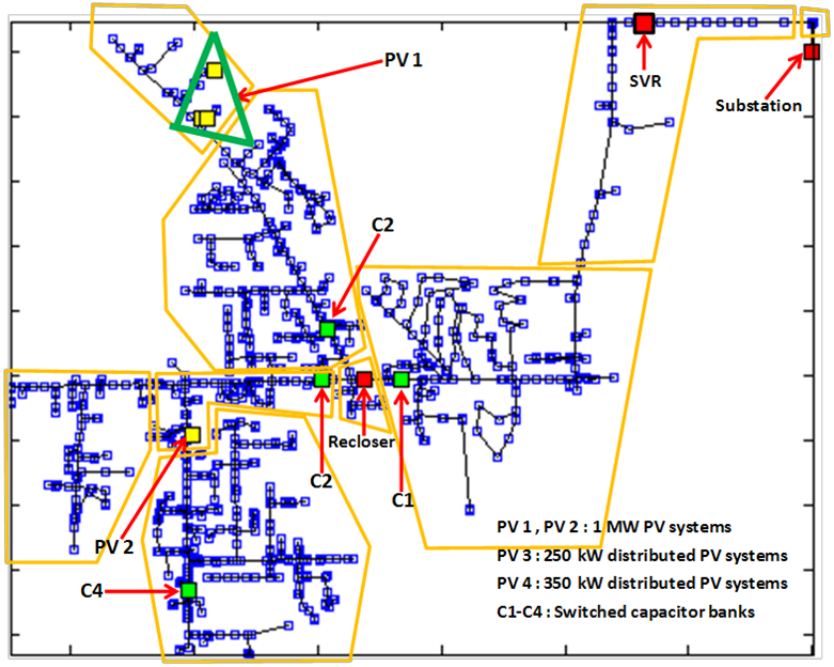
- 12.47 kV circuit with overhead primary about 4.5 miles.
- Peak loading on the feeder 9 MVA.
- Peak PV installed capacity 2.6MW distributed:
- Recloser at around 2.2 miles from substation.
- Four capacitor banks
- Voltage regulator installed near substation.
- A fairly typical mix of residential and commercial loads

Substation | Voltage Reg. | Recloser | Capacitors | PV (large)

RTDS One rack real time GRU Feeder Model

- Feeder data was provided by GRU.
- To be able to run model in real time, feeder model was reduced.
- Load distribution on feeder assumed based on aggregated transformer ratings.

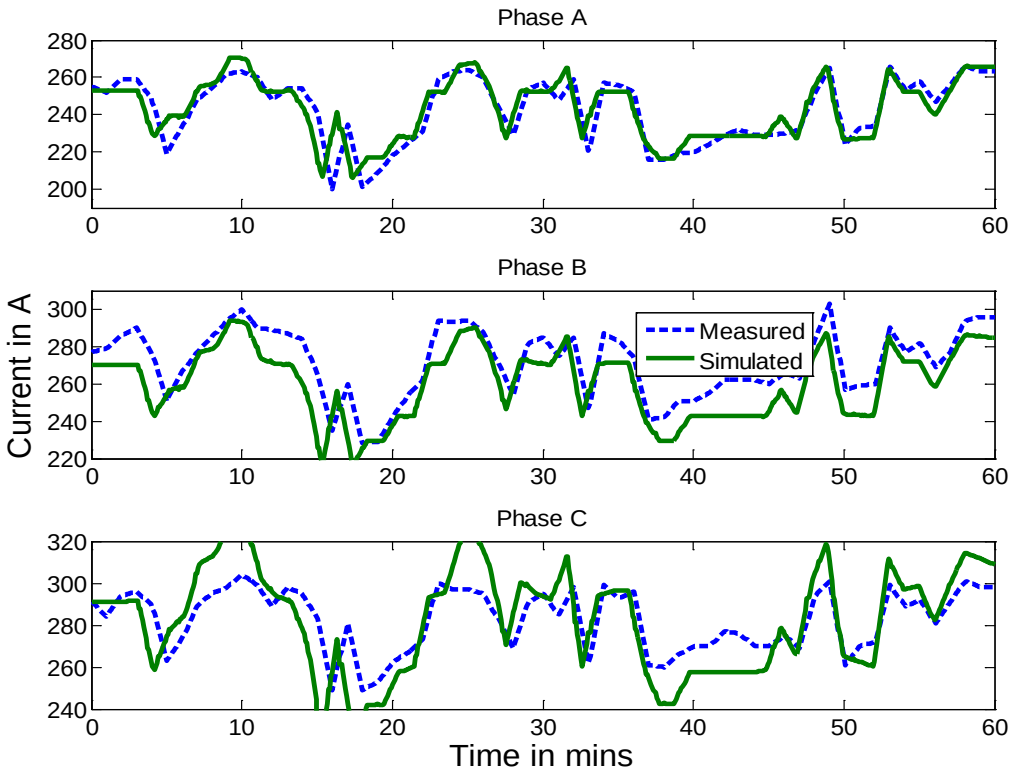




1 Rack Case, reduced feeder model

- Line, transformer, and phasing data
- 10 buses, 7 line sections, 7 PQ-loads,
  2 PV locations, 4 capacitors, 1 regulator

Field Measurement Based Validation of GRU Circuit 435

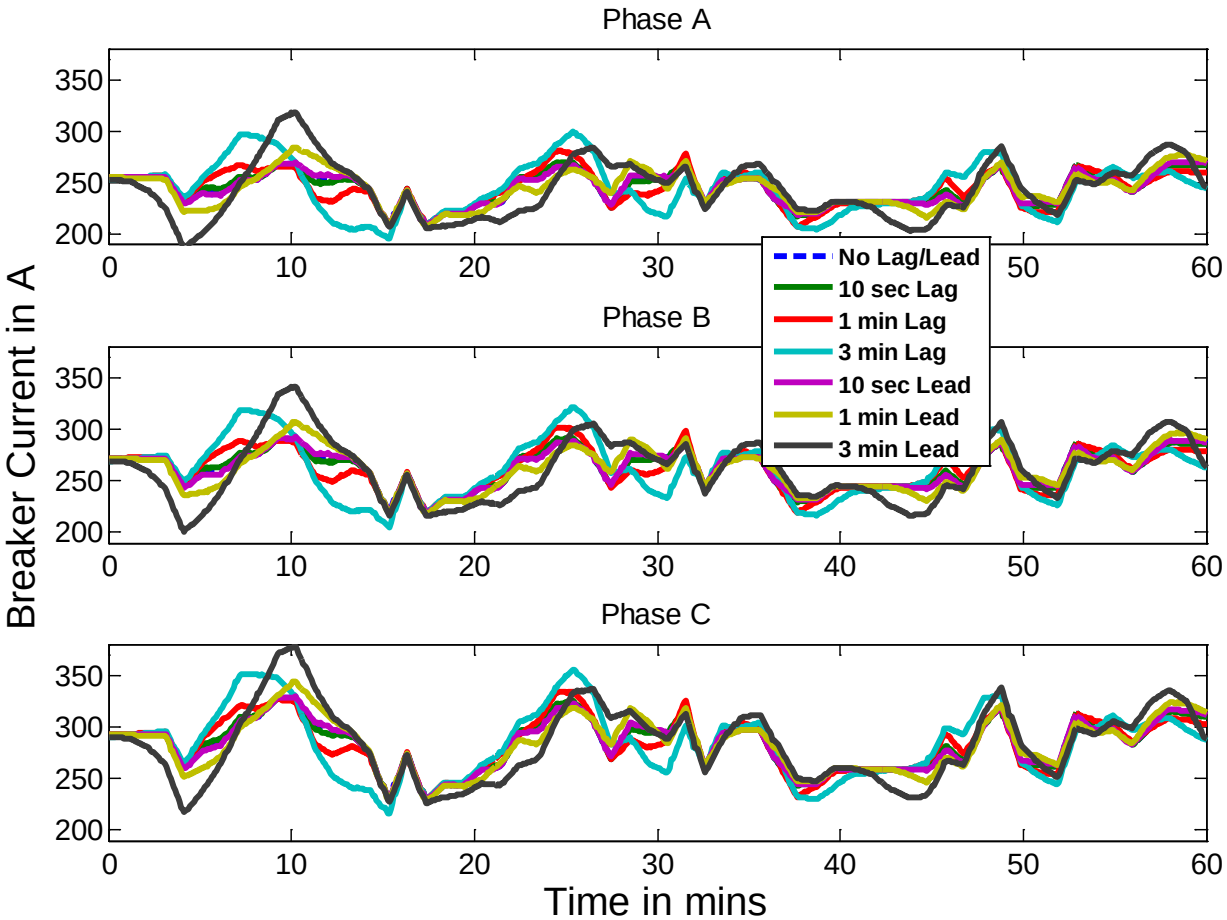


- Compared RTDS power flows against field data at breaker, recloser, and PV plant.
- Results of one hour simulation validation case for 5/14/2012 from 4.00 – 5.00 P.M.
- *Average loading 7 MW* for duration.
- Figure shows plot of *measured* vs. *simulated* breaker currents for 3 phases for one hour.

- Voltages at recloser location agree within less than 2.5% error
- Average error for currents varies between 1.97% and 8.46%, depending upon phase and location, with maximum error of 16.11%

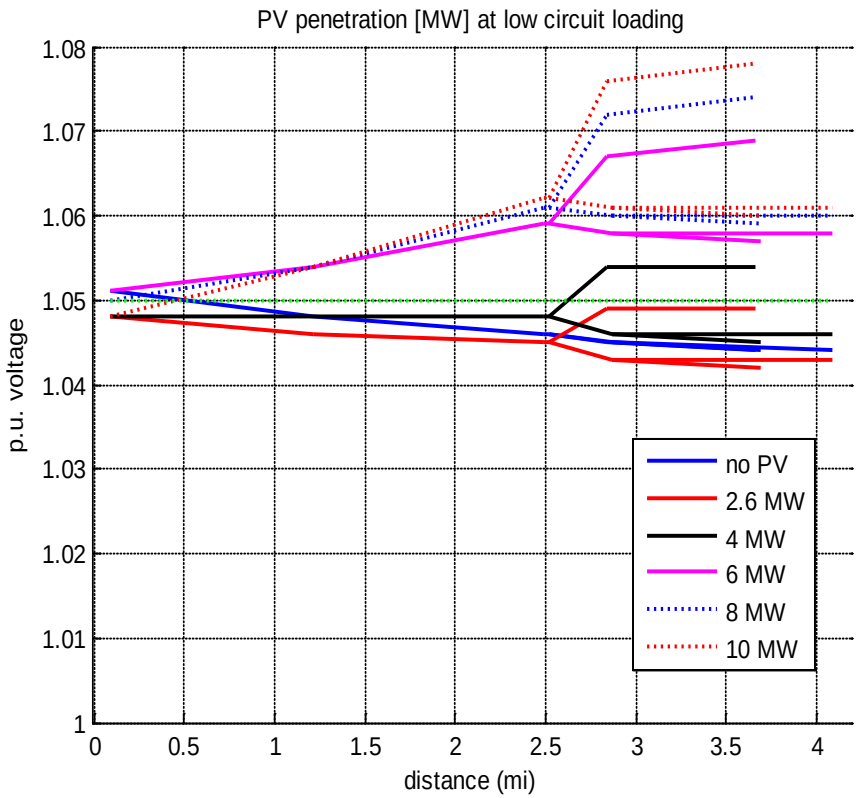
Examining Model Uncertainty Sensitivity to Different Error Sources

Example: Validation Data Time Synchronization Errors

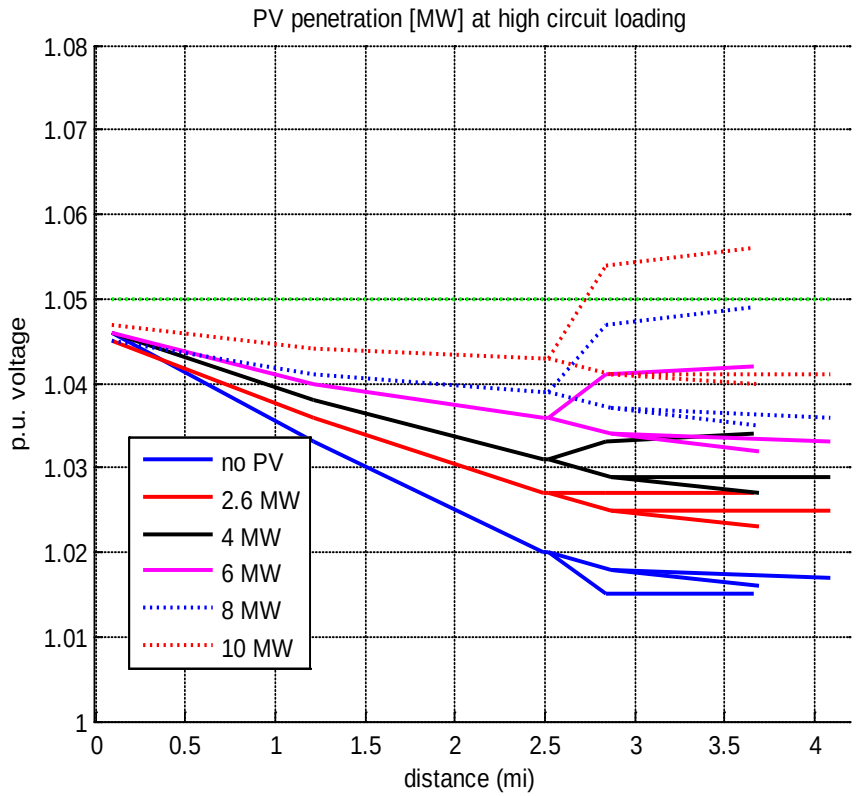


PV Penetration Analysis – GRU
(with RTDS Model)

Low loading scenario – 4 MVA

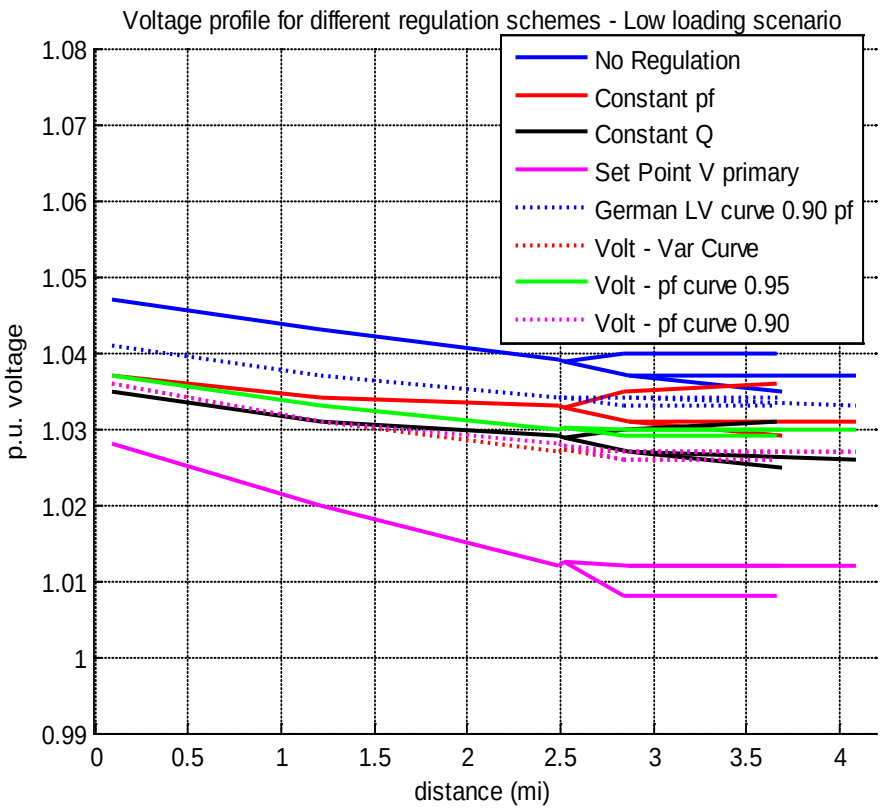


High loading scenario – 9 MVA

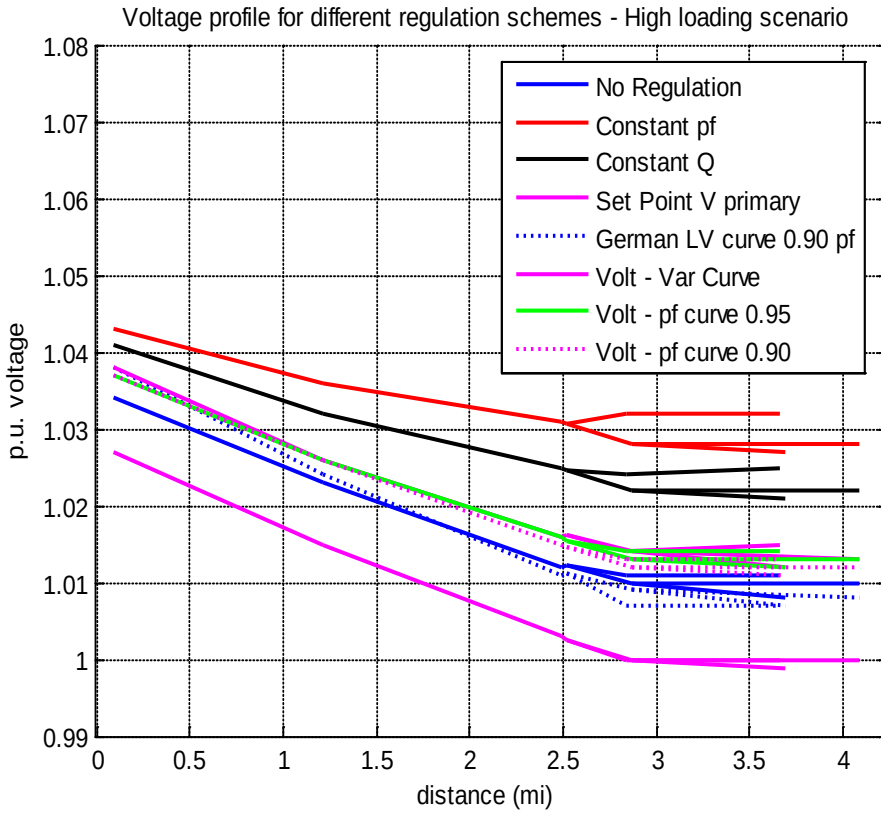


PV Participation in Voltage Regulation
GRU Circuit – High Loading

Low loading scenario – 4 MVA



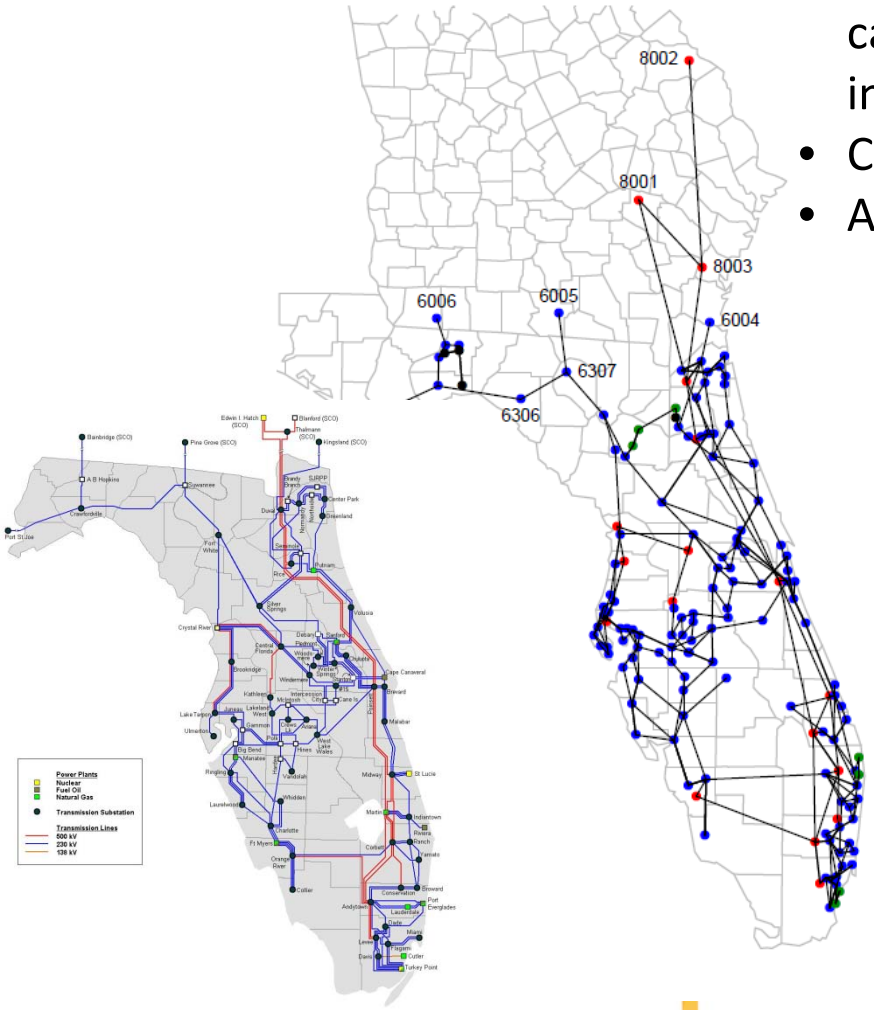
High loading scenario – 9 MVA

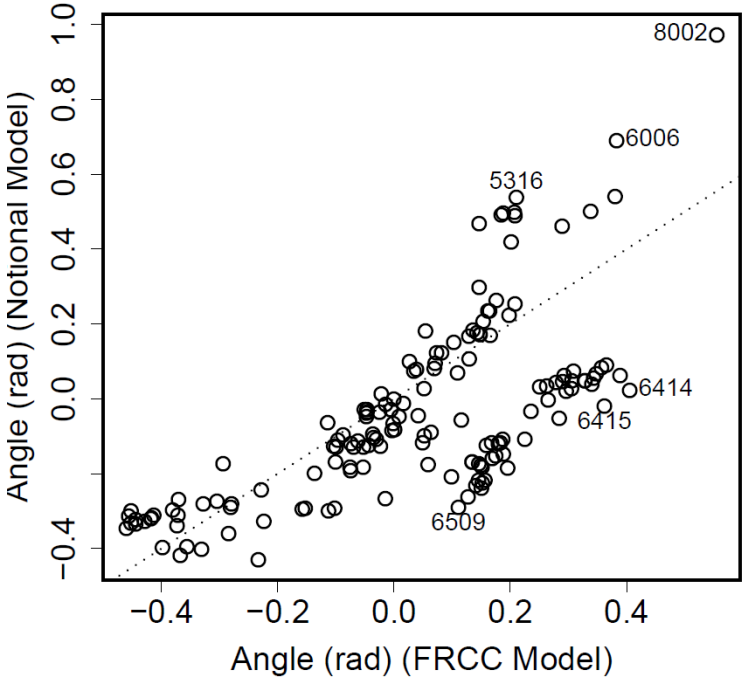


Dynamic Model of the Florida Transmission Grid

PSSE Validation of 154-bus Model Against Very Large Utility Planning and Event Analysis Model

- Developing reduced size FL grid model that captures important behavior, for investigation into grid changes like high-pen. PV effects
- Currently validating 154 bus PSSE model
- A model of <300 busses to be built in RTDS





Summary
Some Observations from Work-to-date - Modeling

- Models that capture dynamic behavior will be needed for investigation of control behavior and interactions
- Distribution circuits often exhibit significant phase imbalance; (individual) phase analysis will be needed in some cases
- Validation of current measurements (more sensitive) in addition to voltage provides increased confidence in model
- Common sources of modeling and simulation error:
  - Field measurement time synchronization
  - Load estimates (spatial, temporal, and per phase)
  - Operation and settings of regulation devices

Summary
Some Observations from Work-to-date - Analysis

- Percent penetration and 15% screen is a poor metric
- Seeking a classification of circuit types and more appropriate metrics than % penetration – must look at many circuits first
- PV can be very effective (usually exceeding performance using traditional means) in voltage regulation
- System dynamics and interaction of regulation equipment can cause issues
- Control and protection schemes, algorithms and settings – challenge and opportunity
- Hardware-in-the-loop simulation is useful for evaluation and testing of dynamic behavior in system context

Future Work

- Arrive at meaningful penetration metrics (screens) through analysis of a large no. of circuits
- Reduce, refine, and streamline modeling and analysis processes and tools
- Develop and demonstrate hardware-in-the-loop evaluation methods and rationale for improved anti-islanding and islanded operation inverter testing
- Examine transmission level benefits (e.g. “230 kV DG”) through integrating distribution and transmission simulation-assisted analysis
- Develop a basis for PV capacity credit
- PV as mitigation of FIDVR

Publications

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Q &A AND DISCUSSION