FESC
Florida Energy Systems Consortium

Florida State University

The Future Florida Grid: Ensuring a Reliable and Resilient Electrical Energy Transmission and Delivery System in a Changing Environment

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Students (2): Thamer Alquthami, Harsha Ravindra (MS Electrical Engineering)

Description: The project research goal is to address the challenges of the reliable movement of electrical energy throughout the state as the power system is transformed to include far more renewable and alternative sources, increased use of distributed energy resources (including storage and electric vehicles), emergence of microgrids, possible expansion of new very-large centralized baseload (nuclear), and incorporation of new power conversion, transmission, measurement, communication and control technologies (smart grid).

This project also is supporting broader FESC goals to attract new funding and build a strong collaborative Florida-based energy research and development, education, outreach, innovation, and technology transfer eco-system in Florida. To that end, the project team has submitted eight (8) proposals for federal and industry funding totaling approximately $41.6 M. Proposal efforts have resulted in one successful federal award, the Sunshine State Solar Grid Initiative (SUNGRIN), a $4.5M project, with $3.6M in funding from the Dept. of Energy, and, one utility industry-funded project at $100k, with other proposals still awaiting notification, and, new proposals in development.

This project has also supported ongoing participation and contributions in national, state, and local power and energy stakeholder groups, including the Gridwise Alliance, the North American Synchrophasor Initiative (NASPI), the American Society of Mechanical Engineers' (ASME) National Energy Committee, the Institute of Electrical and Electronics Engineers (IEEE) Power Engineering Society (PES), Florida's Great Northwest Alternative Energy Advisory Council, and the Tallahassee-Leon Economic Development Council (EDC) Energy and Environment Roundtable.

Budget: $359,642
Universities: FSU
External Collaborators:

- Florida Reliability Coordinating Council (FRCC)
    - Florida Grid Modeling and Simulation, Utility-University Engagement, including Collaborative Proposals
- FRCC member utilities (most FL utilities, through FRCC committees)
    - Florida Grid Modeling and Simulation, Utility-University Engagement, including Collaborative Proposals
- City of Tallahassee Electric Utility
    - System Restoration Simulation and Analysis

Progress Summary

Research Objectives and Progress made for the Current Reporting Period: There has been substantial progress this period in the development of research-oriented models of the Florida electric power grid, the ultimate aim being models with sufficiently representative in behavior for investigation of wide-ranging scenarios and options in future development of the grid. The analysis of the Florida Power Grid Disturbance of February 2008 has been used as a means for comparing and validating behavior against real grid response. This approach has been demonstrated using an aggregated 14-Bus dynamic model with refinements in the data and protection related switching events, with results matching the recorded data observed in the incident report with minor discrepancies. Results suggest that the reduced, 14-bus model version may be useful, with reasonable assumptions, for some simplistic studies. Work is underway to construct parametric studies to determine the parameters sensitivity in the simulation using factor screening and other statistical techniques.

Though the 14-bus Florida grid model may be sufficient for some simple studies, the project's objective requires a more detailed benchmark system of the Florida grid. Therefore, a 154-bus notional electrical grid of Florida was built with detail representation using data available in the public domain. Reasonable model power flow results have been produced, and, efforts have proceeded to develop a dynamic model for the 154-bus system. The dynamic model requires data for each unit of generators, exciters, turbine governors, power system stabilizers, automatic generation controls and all the required protective devices with accurate settings. Development of a notional dynamic model of the Florida gird in PSS/E is underway, with most of the dynamic data obtained from a variety of public resources. Where lacking complete details on each power plant's generation units, models for generators, exciters, and governors were chosen for the large plant or known plant at that bus. If information is available, models for the exact type of generation units are chosen. Typical data were assigned for the specified dynamic model parameters.

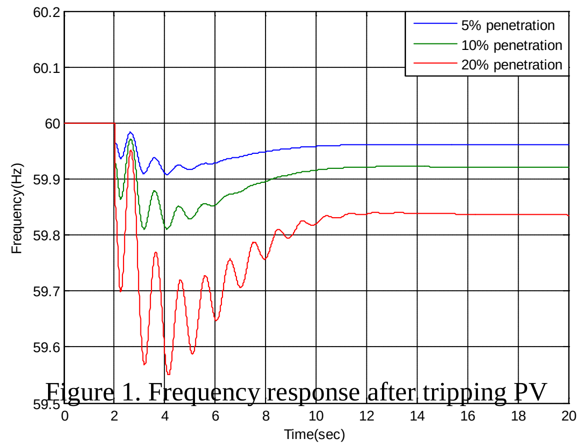

Figure 1. Frequency response after tripping PV

The development of a dynamic solar PV model with Maximum Power Point Tracking (MPPT) has been initiated and completed in this period. The model will contribute to the general power system modeling and simulation community as we intend to make it publically available and to the envisioned Florida Grid studies of future load and generation growth specifically. Initial studies of the impact of solar PV-based resources have been undertaken, and significant implications for power system operation and stability have been observed, see Figure 1. The depicted bus frequency traces after tripping of a solar PV-power plant at different penetration levels reveal unacceptable frequency deviations.

A simulation effort was completed for a major municipal electric utility in the state to examine power system restoration from a complete system outage. This is expected to continue with further examination of system dynamics under different scenarios and possible development of simulation-assisted training.

Research activities for the next reporting period: The next steps will focus on completing the dynamic model of the Florida grid, refining load and generation forecasting, and developing relevant case scenarios, with continued engagement with the FRCC and FL utilities toward validated notional research models and development of study scenarios most of interest to utility stakeholders. Probabilistic analysis will be performed and uncertainty and sensitivity analyses will subsequently provide insight into the expected resiliency of the grid in the context of future developments in load and generation patterns.

2010 Annual Report

BACKGROUND

In order to support efforts toward ensuring the reliability and resiliency of Florida's electric power grid as it expands to accommodate future loads, sources of generation, storage technologies, and new operating and control approaches and technologies, a principal thrust of this project has been the development of flexible, parameterized dynamic models of the Florida electric power system, for use in analysis of system reliability impacts and dynamic response and stability in the presence of extraordinary changes in the grid. In laying the groundwork for this effort, load forecasts provided by Florida's utilities, in conjunction with geographical population projections, have been used to provide geographically distributed load projections. Similarly, information regarding planned changes in generation has been collected. This information, along with projected potential for various renewable energy resources will be used to provide probability distributions for loads and generation that will be used in parametric studies involving the dynamic model of the power system. Through the study of a number of scenarios, the intent is to better understand the implications of plausible changes to the grid including a large penetration of renewable sources and to identify key improvements to the transmission architecture leading to a more resilient grid in the future.

PERSONNEL

Table 1 lists the personnel who are actively participating in research associated with this grant.

TABLE 1 PERSONNEL

Classification	*Personnel*
9 month Teaching Faculty	Tom Baldwin (FAMU-FSU College of Engineering, ECE Dept.)
12 month Researchers	Steinar Dale, Mischa Steurer, Omar Faruque, Karl Schoder, James Langston, Rick Meeker
Visiting Scholar/Scientist	Peter McLaren
Students (Graduate)	Thamer Alquthami, Harsha Ravindra (MS Electrical Engineering)

SYNERGISTIC ACTIVITIES

Below is a cumulative list of synergistic activities and outreach / stakeholder community engagement that have been associated with this research project.

- Engaging with the **Florida Reliability Coordinating Council (FRCC),** on Florida Grid Modeling, Simulation, and Analysis, including participating periodically, on invitation, in **Operating Committee and Planning Committee meetings, Systems Protection and Control Committee meetings,** and with the Stability Working Group (SWG) and Transmission Working Group (TWG).
- The **Capital Energy Forum and 6th Annual Engineers Week Town Hall Meeting**, on "Energy Technology and Economic Development – Making the Connection", was held on Wed., 3/4/09, at the Doubletree Hotel in Tallahassee, with over 120 in attendance. Speakers and panelists included Tallahassee Mayor John Marks, John Adams, president and CEO of Enterprise Florida, Rep. Paige Kreegel, chairman of the House Energy and Utilities Policy Committee, Commissioner Nathan Skop of the Florida Public Service Commission, Tim Anderson, director of the Florida Energy Systems Consortium, Don Markley, VP and COO of Southeast Renewable Fuels, and Jack Sullivan, President of the Florida Research Consortium, with Lynda Keever, Group Publisher of the Florida Trend as moderator. The event was organized by the Tallahassee Sections of ASME and IEEE, the Tallahassee-Leon County Economic Development Council, the Governor's Energy Office, and FSU CAPS. The event was taped by WFSU and aired on channel 4-FSU.
- A **Florida Smart Grid Workshop** was held Monday, 9/28/09, preceding the Florida Energy and Climate Commission meeting on 9/29 and the Florida Energy Systems Consortium 1st Annual Summit on 9/29-30. The workshop, attended by around 100 people representing electric utilities,

universities and other stakeholder groups, was organized by FSU CAPS and USF's Power Center for Utility Explorations. It was sponsored by the Gridwise Alliance, Areva T&D and FESC. Katherine Hamilton, President of the Gridwise Alliance, provided the keynote talk. The workshop was to start a dialogue, process, and stakeholder community engagement towards producing a Smart Grid Roadmap for Florida.

- In conjunction with the Florida Smart Grid Workshop, a memorandum of understanding, initially between FSU CAPS and USF PCUE, was executed and announced, establishing the **Intelligent Energy Grid Alliance**, as a basis for collaboration in electric power systems and smart grid.
- Attended the **1st Annual Florida Energy Systems Consortium Summit** at the USF campus, in Tampa, FL, and, on 9/30/09, at the Energy Storage and Delivery Session of the FESC Summit, a presentation and update was provided on this project.
- Exhibited at the **High Tech Expo and Gee Whiz Technologies session at the Florida Chamber's Future of Florida Forum** in Orlando on 10/13/09.
- Participating in **North American Synchrophasor Initiative (NASPI)** work group, including the Data and Network Management and Research Interest Task Teams (DNMTT, RITT).
- Membership and participation in the **Gridwise Alliance**, including member meetings, national conferences, and active in the Implementation Work Group (IWG).
- Participation in the **North American Electric Reliability Corp. (NERC) Smart Grid Task Force (SGTF)**, in production of a report on the impact of smart grid on bulk power system reliability, entitled "Reliability Considerations from Integration of Smart Grid".
- Membership and participation in the **American Society of Mechanical Engineers' (ASME) National Energy Committee;** Chairing new **"Energy Plan for America"** initiative.

PUBLICATIONS and Presentations

Below are listed journal, conference and other publications and presentations arising from efforts of the research team in fulfilling the research objectives of this project.

- Alquthami, T., Baldwin, T., Faruque, O., Langston, J., Dale, S., McLaren, P., Meeker, R., Steurer, M., Schoder, K., "Load and Generation Forecasts for Reliable and Resilient Electrical Energy Transmission and Delivery System", in Proceedings of the IEEE PES General Meeting, Minneapolis, MN, July 25-29, 2010.
- Allman, M., Meeker, R., Reedy, B., Senkowicz, E., "Integrating Solar PV into the Grid", FMEA Relay Magazine, Fall 2010.
- Alquthami, T., Baldwin, T., Faruque, O., Langston, J., Dale, S., McLaren, P., Meeker, R., Steurer, M., Schoder, K., "The Future Florida Grid: Reliable and Resilient Electrical Energy Systems in a Changing Environment", presentation at the Florida Energy Systems Consortium 1st Annual Summit, 30 September 2009, Tampa, FL.
- Alquthami, T., Ravindra, H., Faruque, M. O., Steurer, M., Baldwin, T., "Study Of Photovoltaic Integration Impact On System Stability Using Custom Model of PV Arrays Integrated With PSS/E", in Proceedings of the 2010 North American Power Symposium, Arlington, TX, USA, September 26-28, 2010.
- Alquthami, T., Baldwin, T., Faruque, O., Langston, J., Dale, S., McLaren, P., Meeker, R., Steurer, M., Schoder, K, "Reliable and Resilient Electrical Energy Systems in a Changing Environment" poster presented at the Future of Florida Forum in Orlando, FL.
- Alquthami, T., Baldwin, T., Faruque, O., Langston, J., Dale, S., McLaren, P., Meeker, R., Steurer, M., Schoder, K., "The Future Florida Grid: Reliable and Resilient Electrical Energy Systems in a

Changing Environment", presentation at the Florida Energy Systems Consortium 2nd Annual Summit, 28 September 2010, Orlando, FL.

PROPOSALS

Below is a list of some of the proposals, either submitted or in the pre-proposal stage, associated with the efforts of PI's and co-PI's on this project, leveraging resources this grant has provided to seek and obtain further research funds to sustain and expand the work (*successful, **in development or pending notification).

TITLE: "ADVANCING SYNCHROPHASOR NETWORKS AND APPLICATIONS IN THE FRCC REGION"
FUNDING OPPORTUNITY: DOE, ADVANCED SYNCHROPHASOR RESEARCH, DE-FOA-0000035
BUDGET: $1.75 M total, $1.15 M Federal
TEAM: FSU CAPS (lead), City of Tallahassee Electric, Keys Energy, TVA, Areva T&D, OSISoft, RTDS

TITLE: "THE SUNSHINE STATE SOLAR GRID INITIATIVE, SUN-GRIN"*
FUNDING OPPORTUNITY: DOE, HIGH PENETRATION SOLAR DEPLOYMENT, DE-FOA-0000085
Field Verification of High-Penetration Levels of PV into the Distribution Grid
BUDGET: $4.5 M total, $3.6 M Federal
TEAM: FSU CAPS (lead), University of Central Florida, Florida Solar Energy Center (FSEC), University of South Florida, Power Center for Utility Explorations (PCUE), SunPower Corporation, Satcon Technologies, AMEC, Florida Reliability Coordinating Council (FRCC), Florida Power and Light (FP&L), Gainesville Regional Utilities (GRU), Jacksonville Electric Authority (JEA), Orlando Utilities Commission (OUC), Lakeland Electric, Florida Municipal Power Authority (FMPA), Tampa Electric Company

TITLE: "INNOVATION NETWORK TO ACHIEVE WIND ENERGY TECHNOLOGY FOR A LOW CARBON ECONOMY"
FUNDING OPPORTUNITY: DOE, WIND ENERGY CONSORTIA BETWEEN INSTITUTIONS OF HIGHER LEARNING AND INDUSTRY, DE-FOA-0000090
BUDGET: $16.9 M total, $12 M Federal ($650 k to FL)
TEAM: Texas Tech University (lead), The Wind Alliance, University of California-Davis, University of Iowa, University of Northern Iowa, University of Wisconsin-Madison, University of Wisconsin-Milwaukee, FSU CAPS, New Mexico State University, University of Texas at Austin, Texas A&M University, Rice University, University of Houston, Texas State Technical College, Vestas Technology R&D Americas, Knight & Carver, Shell Wind, DuPont, AWS-Truewind, 3Tier, Michigan Aerospace, Garrad-Hassan, GEC-DNV, ABB, Rockwell Collins, TECO Westinghouse, Skyron Systems, CD-adapco

TITLE: "RELIABLE, RESILIENT, AND RAPIDLY RECOVERABLE CRITICAL INFRASTRUCTURES, RAPID"**
FUNDING OPPORTUNITY: DHS S&T DIRECTORATE, BAA#09-05 (unsuccessful)
CURRENTLY CONSIDERING RESPONSE TO BAA#10-11
BUDGET: $30 M
TEAM: FSU, UCF, USF, Datamaxx Corp.

TITLE: "SMART GRID OPPORTUNITY PLANNING AND ANALYSIS FOR LEE COUNTY ELECTRIC CO-OP"
FUNDING OPPORTUNITY: INDUSTRY: LEE COUNTY ELECTRIC CO-OP
BUDGET: $540 k
TEAM: FSU, UF, Lee County Electric Co-op

TITLE: "COORDINATED DISTRIBUTION FEEDER PROTECTION AND CONTROL TECHNOLOGY DEVELOPMENT AND DEMONSTRATION"**
FUNDING OPPORTUNITY: DOE, SMART GRID R, D, & D, DE-FOA-0000313
BUDGET: $3.98 M total, $3 M Federal
TEAM: FSU, FAMU-FSU College of Engineering, Arizona State University (ASU), City of Tallahassee Electric Utility, Green Energy Corp., Siemens Corporate Research, Basler Electric
TITLE: "AGGREGATION OF ANTELOPE-BAILEY WIND GENERATION SYSTEM MODELS FOR RTDS STUDIES "*
FUNDING OPPORTUNITY: INDUSTRY: SOUTHERN CALIFORNIA EDISON
BUDGET: $100 k
TEAM: FSU CAPS, SCE

TITLE: "DEPLOYED BASE SMART GRID DEVELOPMENT"**
FUNDING OPPORTUNITY: TYNDALL AFB**,** DEPLOYED ENERGY SYSTEMS, BAA1001TYN-LGCB
(PROPOSAL CURRENTLY BEING DEVELOPED)
BUDGET: $50 k
TEAM: FSU, Tyndall Air Force Base, Applied Research Associates (ARA)

Establishing a Dynamic Florida Grid Model

The expected increasing of renewable generation will certainly change the nature of the system from the dynamics of only rotary machine based generation to the dynamics of a mixed system with growing contributions from inverter interconnected resources. Publicly available electric power system libraries provide a limited number of systems which all date from the 1950s to the 1970s. Though the system examples are a good teaching tool, they are not sufficient for investigating the 21st century electric grid. To the best of our knowledge, currently there is no benchmark system that is suitable for parameterized dynamic and transient studies that considers load and generation growth based on any scientific projection, and is easily adaptable to increased renewable generation portfolios. Therefore, one aspect of this project is to develop such a benchmark system that can be used for studying future growth scenarios by the research engineering community, economists, and policy advisors.

Among different stakeholders in the power industry (utility operators, renewable developers, and Independent System Operators) including Federal Electric Reliability Council (FERC) and North American Electric Reliability Corporation (NERC), there is a question as to how sharp increases in renewable generation, or other distributed resources such as electric vehicles or co-generation, may impact system reliability. Therefore, study of dynamic interactions of such a mixed and complex power grid is very important, especially to understand the role and contribution of respective generation from both conventional and renewable sources in the case of disturbances. The study will also help determine whether the existing power grid can handle the addition of substantial amounts of new renewable resources in the next few decades, some intermittent, some dispatchable, depending on the resource. The Florida power grid provides for a good case study. It has potential for substantial expansion of a great variety of new generation sources (solar, biomass, ocean energy, wind, combined heat and power or cogeneration, nuclear, etc.) has a unique network architecture which resembles almost an islanded grid, with limited interconnection to the national grid (the Eastern Interconnect) along the state's northern border, and has a large number of different electric utility entities, including investor owned utilities (IOU's), municipals, and rural electric cooperatives.

Current Efforts and Assumption Made for the Florida Dynamic Grid Model

An effort is underway to develop notional, yet representative, dynamic models of the FRCC power grid for educational and academic research purposes, with the following aims:

(i) Reduced size models of the transmission grid, which can be solved quickly (<500 buses).

(ii) Models generally behave correctly at the transmission level, with credible topology and power flows.

(iii) System dynamic behavior should mimic the actual system at the large scale.

A 14-bus and a 154-bus models of the Florida electric system have now been constructed using publicly available data and educated assumptions. Based on the types of generators in the system (identified in the FRCC ten year site plans), notional generator dynamics are incorporated into the model using typical data for governors, synchronous machines, and exciters. Over-frequency generation shedding and under-frequency load shedding controls have been added to reasonably resemble Florida's current transmission grid and operation. Efforts have been made to verify that the dynamic response of this model resembles the overall dynamic behavior of Florida system disturbance of February 2008. The 14-bus model is a much more aggregated version, developed as a first step to capture the major characteristics of the grid at the 500 kV level. The models have been implemented in PSS/E and the derived systems are illustrated in Figure and Figure . The plan going forward is to work closely with the FRCC and the Florida utilities to significantly refine the model, including the dynamics and the protection settings, and carry out validation exercises to ensure behavior is sufficiently representative of the real system.

Methodology

The notional system was derived in several steps using data from several sources. The transmission network model was developed using transmission line data provided by the 2007 FERC 715 report submitted by the FRCC. Major transmission circuits were identified and included in the model. The primary transmission lines, which were considered for the model, operate at the 230 kV or 500 kV level.

Radial spur transmission circuits, operating at these voltage levels and serving bulk load substations, were reduced to equivalent loads at the switching substation associated with the starting terminus of the line circuit.

Generally, circuits with voltage level below 230 kV were considered part of the sub-transmission networks feeding load centers and were modeled as loads of the primary transmission grid. A few exceptions were made at the 115/138 kV level in the Miami, Gainesville, and Tallahassee areas where major generation plants are located at a significant electrical distance from the 230 kV network. The local transmission systems in Gainesville and Tallahassee areas were modeled in greater detail because of the availability of phasor measurement data provided by the Virginia Tech FNET metering system in which the University of Florida and Florida State University participate. The two universities host FNET meters on campus and have access to the national database of FNET phasor measurements.

System loads were modeled using the 2008 winter base case of the planning power flow for the FRCC. A mix of constant power and constant impedance loads was assumed at each large bulk power substation. The values of real and reactive power and resistance and inductance were based on the power flows across each step-down transformer from 230 kV or 500 kV to 138 kV or lower voltage. This assumption neglected any local generation in an area that was not directly connected to the 230 kV or 500 kV systems. Smaller bulk power substations, generally with loads less than 20 MW, were eliminated in the model. The loading at these smaller substations was partitioned and transferred to neighboring larger substations. Many of these smaller substations are located along a transmission circuit connecting two major switching stations. In these cases, the small loads were aggregated and then split between the two switching substations.

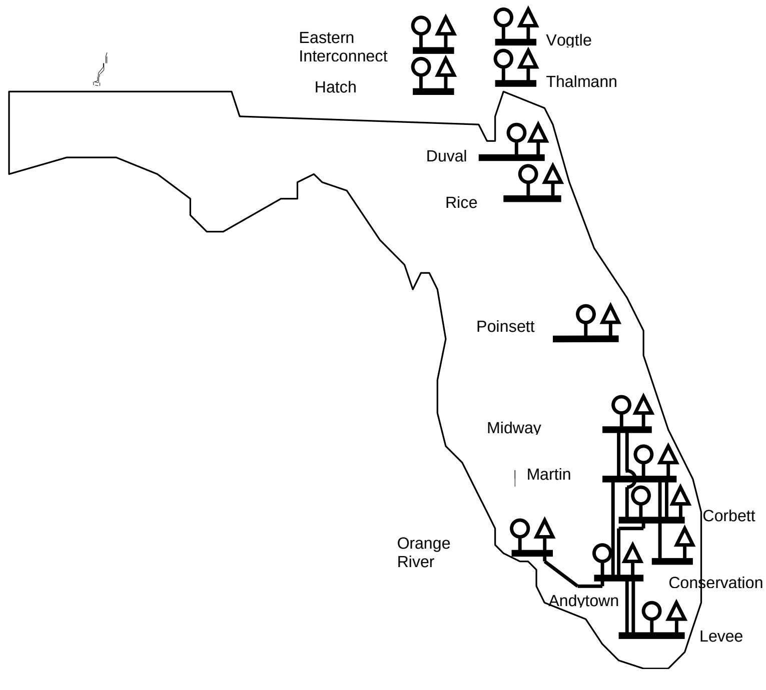

FIGURE 1. FLORIDA GRID 14-BUS MODEL

Generation was modeled using data primarily from EIA reports. The EIA reports provide general information of each generator at a power plant, including the MVA rating of the generator, the MW rating of the prime mover, summer MW maximum power, winter MW maximum power, the type of prime mover, the primary and secondary fuel supplies, and age of the unit. The data was supplemented with secondary details provided by the utilities to the general public. The prime movers were classified into four basic categories: traditional steam-turbine cycle, gas-turbine cycle, hydro, and combined cycle. The fuels were classified as nuclear, coal, #2 fuel oil, #6 fuel oil, and natural gas. From the generator data, typical generator parameters were selected using data tables found in the Westinghouse Transmission and Distribution Handbook. Generic governor, exciter, and power system stabilizer models were added to the generator model.

Validation

The notional FRCC system was validated for the power flows and the dynamic response. A comparison of the power flow results was made between the notional system and the FERC base case. Power flows on the major transmission lines, especially at the 500 kV level, agreed between the results.

For those lines where small substations were eliminated and the load centers transferred to neighboring substations, the power flows often were much smaller on the notional system than the flows on the original lines. The smaller flows represented just the power flowing across the area. The local load power was taken at the upstream equivalent substation.

14-bus Florida Grid Model

An aggregated Florida Dynamic 14-bus Grid Model, which comprises Florida Power and Light system only (500 kV backbone network), has initially been created to investigate grid dynamics.

This model focuses on the most crucial aspects affecting the behavior of the transmission system. In Figure , the bus labeled 'Eastern_Interconnect' represents the connection to the national grid. All the generation is locally aggregated at the respective buses. Similarly, all the power flows from the bus to the lower voltage transmission lines are represented as total load at the respective buses. It accounts for conventional generators including dynamic and transient stability behaviors in the time domain using round rotor machine models, steam turbine-governor models, and simplified excitation system models. The loads are represented by a mix of constant power, current, and impedance components. Typical parameters have been used for the parameters of the models, i.e., the model has not been "tuned" to match the recorded data for the event.

154-bus Florida Grid Model

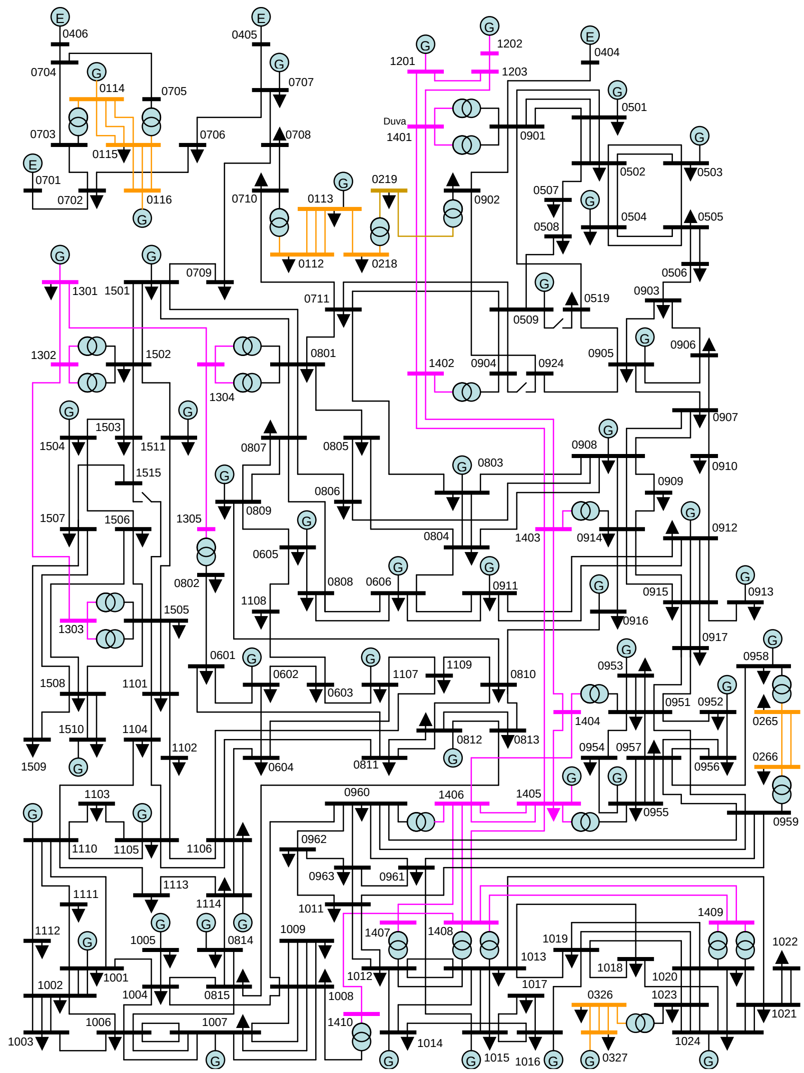

FIGURE 2. FLORIDA GRID 154-BUS MODEL

Efforts comparable to the 14-bus model have been undertaken to establish a more comprehensive Florida grid model. This model is based on a 154-bus representation with a more varied representation of the generation portfolio and aggregates the transmission system at the 500 kV, 230 kV, and 138 kV levels. Line parameters have been estimated based on typical values and line lengths approximate distances between buses. It includes 76 conventional generation units and 116 load centers. The generation local to a respective bus is represented by multiple individual units to allow for modeling of a mix of local power plants, e.g., a combination of steam, gas and combined cycle units. The power generation schedule is based on the estimated power demand, unit size, and unit type.

As little direct information for implementation of the dynamic models of the system was available, an initial "Base" case was developed using simple exciter and turbine-governor models with typical default parameters. A framework was implemented whereby the dynamic model to be used for a simulation is specified through a set of comma delimited input files. Python scripts have been implemented to generate the PSS/E dynamic data file based on a master file specifying the models to be used for each generation unit, along with a set of input files specifying the types' parameters. In this way, alternative dynamic models and parameter settings can be quickly constructed and tested. Furthermore, the individual model files, in addition to specifying the values of model parameters, specify intervals for these parameters, reflecting the uncertainty in the parameters. This approach facilitates the gradual refinement of the model through updating of default parameter values and tightening of parameter ranges as more information is obtained. The inclusion of parameter ranges also serves to provide information needed for parametric studies such as sensitivity and uncertainty analyses.

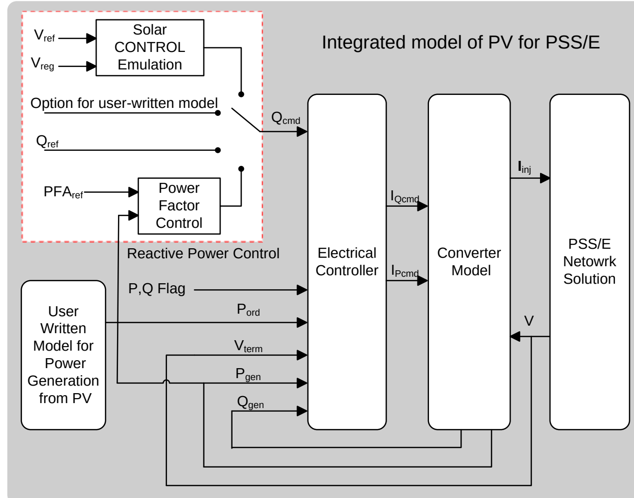

FIGURE 3. BLOCK DIAGRAM OF SOLAR PV MODEL IN PSS/E

The base model was constructed to test the framework and gain initial insight into the behavior of the model. Using information about the types of units, as identified in the FRCC ten year site plans, the work has begun to refine the base model. A more detailed model has also been constructed which incorporates more appropriate prime mover models for each unit, based on the type of unit. Additionally, based on the year in which the units were placed in service, specific exciter models have been specified for the units in the model. At this time, most of the parameters for the models are based on typical data, and the ranges for the parameters are quite large. Future work will focus on refinement of the parameter values and ranges to more appropriately represent the behavior of the Florida system. The loads are represented by a mix of constant power, current, and impedance components. Other future work will focus on appropriate dynamic modeling of loads, incorporation of appropriate protection, and power system stabilizers. The relevant details and parameters of the base and detailed model, as currently implemented, are given in the appendices.

Converter Interfaced Dynamic Solar PV Model

Since the Florida Grid study is intended to be used for investigating system behavior with proper consideration of future system growth, the integration of potential generation from renewable resources with power electronics based interface are considered. While, for example, wind turbine models (i.e., Types 3 and 4) are readily available in PSS/E, solar PV model is yet not available. A user defined component was added to the PSS/E that combines conversion of primary energy using a Maximum Power Point Tracking algorithm written in FLEX/FORTAN and power electronics interface to the grid using the Type 4 Generic Wind Plant model. **Error! Reference source not found.** shows the resulting model structure.

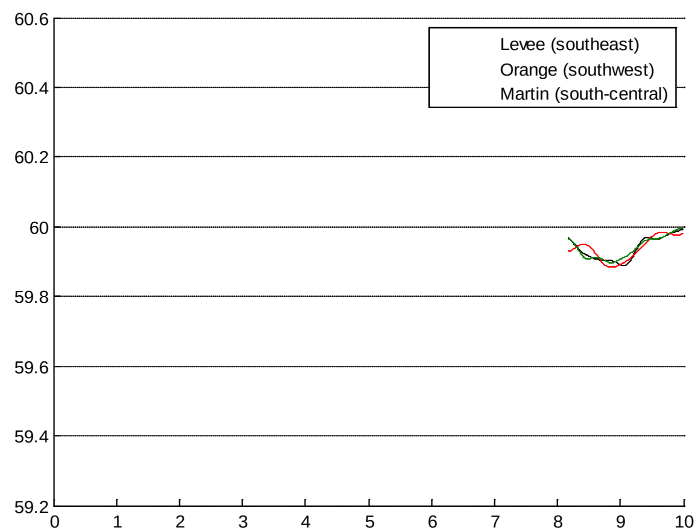

FIGURE 4. FREQUENCY TRACES OF THE 14-BUS NOTIONAL MODEL FOR AN EVENT SIMILAR TO THE

Preliminary Results

The developed systems have been used to obtain preliminary results as several modeling aspects and parameter choices require further consideration. A few results are included in this section to show the basic response to system disturbances.

Results for selected frequency traces of the 14-bus notional model response to sequence of event comparable to the February 26, 2008 system disturbance appear in Figure 4.

Figure 5 shows results for the 154-bus model using simplified turbine-governor and exciter models and smaller units have been replaced with type 4 wind turbine models (WT4G1 and WT4E1) to represent converter coupled renewable energy sources.

Future work

Future work includes addition of generator dynamics and controls, converter controls, and protection into the detailed model, continued work with the FRCC on model validation including dynamic instability outage assessment, refining load and generation forecasting to include types of loads (e.g. expected number of eclectic cars, types of renewable resource integration interconnects, etc.), developing relevant case scenarios, in collaboration with the FRCC and utilities, guided by refined load and generation forecasting, and, performing probabilistic analysis with the comprehensive models.

It is anticipated that a wide range of techniques for probing the system may be needed, ranging from direct application of Monte Carlo techniques, to the use of classical experimental design techniques, to the use of Gaussian process models and associated adaptive sampling techniques. Using the most appropriate methods (or combinations thereof), the functional relationships between the identified metrics of resiliency and the simulation parameters will be explored. Uncertainty and sensitivity analyses will subsequently be performed in order to provide insight into the expected resiliency of the grid in the context of the uncertainty in future developments in load and generation and the primary parameters affecting these metrics.

CONCLUSIONS

County-level load and generation growth investigation was completed in year 1. Substantial progress has been made in gathering necessary information for and development of dynamic models of the Florida grid, and initial demonstration of how these models will be used for analysis of scenarios for future development of the grid. Consistent with the goal of this project, to address the challenges of reliable integration of new large-scale intermittent and alternative generation resources throughout Florida, the developed grid and component models will enable studies of possible expansion and incorporation of new power conversion, transmission, and control technologies by the research community. We successfully have:

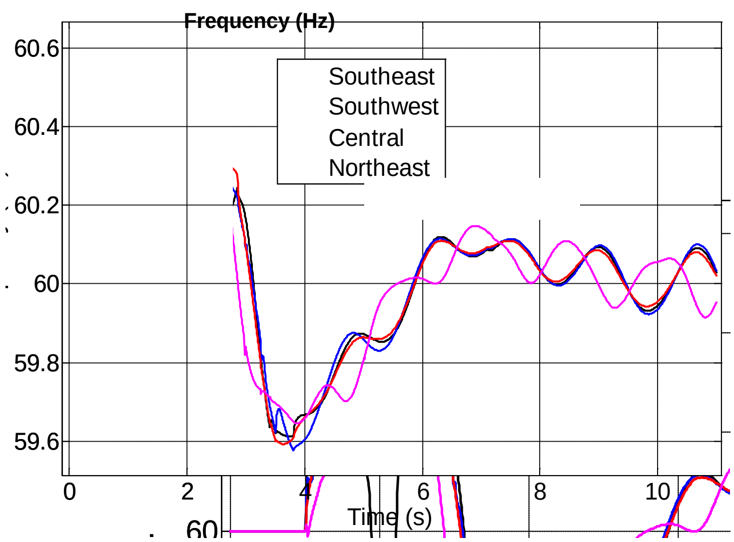

FIGURE 5. FREQUENCY TRACES OF THE 154-BUS NOTIONAL MODEL ASSUMING CONTROLLABLE POWER INJECTION SOURCES REPLACES A FRACTION OF THE SMALLER GENERATION UNITS.

- engaged with Florida's governing and advisory entities, such as the FRCC, Governor’s Energy Office, Tallahassee EDC Energy and Environment Roundtable, in strategic power and energy matters for a sustainable energy economy;
- developed a simulation-assisted approach to understanding of the unique geographical-spatial generation, load, and resource integration challenges which a Florida-specific sustainable energy economy must address in a successful energy strategy;

- collected and organized information related to load and generation projections for the state over the next 10-20 years. This information will form the basis for probabilistic models of loads in future years;
- developed notional 14 and 154 bus models of the Florida grid, and are moving towards further development and validation in collaboration with FRCC and utilities;
- have leveraged synergies with work from other funding sources such as DOE;
- are engaging with and contributing back to the stakeholder community
- are in the process of disseminating results through publications and presentations

The project will continue to engage graduate students in this rigorous, relevant, and impactful research. Project results will be further disseminated through publications, including articles, conference proceedings and presentations, and journal quality papers based on the research results.