Energy and MicroGrids Workshop
2 June 2015

University Research and Technology Transfer
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UCF’s FSEC Leads in Energy
UCF is a Leader in Commercialization & Tech Transfer


Building America
U.S. Department of Energy

PVMC
U.S. Photovoltaic Manufacturing Consortium

Clean Cities
Coalition

Regional Test Centers
Differentiating PV Quality

FEEDER
Foundations for Engineering Education for Distributed Energy Resources
Florida Energy Supply: The Big Three

- Efficiency
- Efficiency
- Efficiency
Energy Reductions - 
California (not) Dreamin'
Heat Pump Water Heaters

- Dependable savings vs. replaced electric resistance Water Heaters
- 80 gal. models: 4+ person households
- 65% overall savings (3.6 kWh/day)
- 60 gal: 61% savings (2.1 kWh/day)
- 80 gal: 69% savings (5.2 kWh/day)
Other Component Solutions

High Efficiency Water Heating

Variable Capacity Space Conditioning

Fixed Capacity SEER 13

Variable Capacity SEER 21

Variable Capacity Considerations
• Extended runtime (65-70% vs. 30-35%).
• 46% improvement in efficiency at minimum capacity.
• Interior ducts even more important.
New Tech: Variable Speed Pool Pump

- Site #7: 18.7 kWh/day pre
- 1.9 kWh/day after replacement: **90% savings**
- Huge demand reduction
- 1.8 kW @ 5 PM!

![Variable Speed Pool Pump Image](image)
23% Energy Drop in Heaviest Use Site (good load shape reduction potential)

Average 6 month savings in eight sites: 18% (0.6 kWh/Day)

Impact of EnergyStar Clothes Dryer
Site 19: Heaviest Dryer User in Study

Pre-retrofit: 6.6 kWh/Day
Post: 5.1 kWh/Day

Julian Date: August 1st - December 31st, 2013
PDR: Why Evaluate cooling influence?

- Installers already know cooler under standoff arrays
- Variation of a double roof
Florida Energy Supply: The Big Three

- Efficiency
- Efficiency
- Efficiency

William of Ockham
b. 1285  Surrey, England
Florida Energy Supply: The Other Three-

- Sunlight $\rightarrow$ Electricity (aka PV)
  - Optimization/Efficiency of the Grid
  - Utility Fossil Fuel $\rightarrow$ Steam $\rightarrow$ Electricity
My View-The Four Great Challenges of PV Research:

- Manage the Light
- Manage the Heat
- Provide Storage
- Minimize Metal & Glass

(what’s next---)

Breakthrough Advances will Happen!

William of Ockham
b. 1285  Surrey, England
Manage the Light

- Conventional Material
- Left-handed metamaterial
Manage the Heat
Provide Storage

Transmission electron micrograph of A123 stable Nanoscale materials

**Charge Profile**

![Graph showing charge profile of A123 batteries](image)

*At 123 batteries can safely charge to very high capacity in less than 5 minutes with low temperature rise and no cell damage. This chart shows the temperature (orange curve) of a cell as it charges at different rates between 2°C (30 minutes) and 20°C (3 minutes) and discharges at 10°C (6 minutes) after each charge.*
Minimize Glass & Aluminum

- 30-50% of module cost
- >50% of weight
- Glazing can aggravate Light Management
- Non-conducting Frame saves Grounding, more reliable, safe
U.S. Photovoltaic Manufacturing Consortium (PVMC)

• FSEC/UCF leads the c-Si branch of the PVMC, a DoE funded SunShot Program ($10M)
• Industry-led consortium driving collaborative projects in c-Si PV
• Currently 14 active collaborative projects in metrology and feedstock/wafering

http://uspvmc.org/technology_csi_PVMC.html

Diamond Wire Failure Mode Analysis

Prototype Diamond Wire Metrology System

Multi-functional Oxide Passivating Films

Predictive Metrology

Casting/Wafering Impact on Cell Performance
Novel Metrology for Diamond Wire Monitoring

Generation 1.0
(Static)

Generation 2.0
(Dynamic)

Diamond wire wear monitoring (Sawing)

Quality control (DW manufacturing)

Impact:
1. A provisional **patent** has been filed
2. In-line metrology provide up to a **$1M/year** in savings for 200MW wafer line (2% breakage)
3. In-line metrology **does not depend on the velocity** of the diamond wire
New DW Failure Modes and Wear Mechanisms Identified

**Impact:**
1. Quadrupled the wire resistance to failures due to twisting
2. Multiple paths to increasing the longevity of diamond wire identified
Variability in Cz Ingots Significantly Affect DW Wear

Impact:
1. Opportunity for using in-line metrology for active control of fresh wire feed to lower wire consumption usage by 50% at $200/km (manufacturing line spools are > 250km)
2. Discovered that there is a significant difference between sawing CZ and MCZ ingots
Impact:
1. Reduce silicon usage *by a factor of 4* while remaining cost competitive
Imaging Cell-Level Defects – at all process points

IR thermography

(a) Good edge iso.

(b) Poor edge iso.

Photoluminescence imaging

As-Cut

Doped/Passivated

Electroluminescence imaging

Gridline defects

High recombination

Belt marks from firing

Cell fracture

Shunt paths
QE Mapping for Advanced Cell Loss Analysis

$J_{sc}$ mapping

$J_{sc} = \int SR(\lambda) \cdot I_{AM1.5}(\lambda) d\lambda$

Wavelength dependent EQE mapping

Frontside defects

385nm, 420nm, 505nm, 1050nm, 1090nm, 1112nm

Belt marks and non-uniformities in backside metallization
Imaging Module-Level Defects

- Infrared thermography
  - Forward bias (indoor)
  - Under load (outdoor)
- Electroluminescence
  - Variable bias conditions

PID Study: EL and Outdoor Thermography (at FSEC, in collaboration with NREL)

Standard Module with Cell Mismatch: Outdoor Thermography, Low Current EL and Standard EL

Interconnect Failure: Indoor Thermography and EL
Module Level Parameter Mapping via EL

- Example below: Module after PID testing (at FSEC, in collaboration with NREL)
- Working on ways to extract the operating voltage of individual cells from EL images
- Doing this at multiple currents allows one to construct a dark $I-V$ curves of individual cells – then, $R_s$, $R_{sh}$, $J_0$, ideality factor can be extracted for each cell.
Multi-Functional Oxides

- Results: SiO$_2$ passivated stacks vs. SiN$_x$

- SIMS depth profiles for four groups with equivalent sheet resistances ($R_{\text{sheet}} \approx 60 \, \Omega/\square$)
Regional Test Centers

Supporting the DOE SunShot Initiative by helping accelerate technological evolution in the energy sector and increasing PV deployment

Crystalline Silicon Technologies

Thin Film Technologies
Performance Degradation Analysis

Sandia, FSEC/UCF, and NMSU
New Collaborations

Brookhaven National Lab
Developing new techniques incorporating the National Synchrotron Light Source (NSLS)
Florida Energy Supply:
The Other Three-

- Sunlight $\rightarrow$ Electricity (aka PV)

- Optimization/Efficiency of the Grid
  
  - Utility Fossil Fuel $\rightarrow$ Steam $\rightarrow$ Electricity
My View-The Four Great Challenges of Integrated Grid Research:

- **Distribute the Resource**
  - Make it where we use it
  - PV turns load flow on its head (reverse power)
- **Manage Variability-Storage & Control**
  - PV turns gen mix on its head (Baseload gen at noon)
  - EVs turn load profile on its head (Peak Loads at night)
  - EVs have great dual function (transport & grid storage)
- **Secure the Grid from External threat**
  - Cybersecurity
  - Resiliency in Storms and Physical attack
- **Secure the Grid from Inherent threat**
  - Stability against Cascading Outages
  - Improved Inter-regional Transfer Capabilities

*MicroGrids play a BIG role in all these areas*
MicroGrids – a key part of the Integrated Grid*

*Graphic credit to DOE
Electric Vehicles – a key part of the Integrated Grid*

*Graphic credit to DOE
<table>
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<th></th>
<th>Fuel Efficiency</th>
<th>Fuel Price</th>
<th>Cost per Mile</th>
<th>Cost per 12,000 Miles</th>
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<td><strong>Gasoline Car</strong></td>
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<tr>
<td>25 mpg</td>
<td>$3.60 per gal</td>
<td>14.4¢ per mile</td>
<td>$1,728</td>
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<tr>
<td>25 mpg</td>
<td>$3.00 per gal</td>
<td>12.0¢ per mile</td>
<td>$1,440</td>
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<td><strong>Electric Car</strong></td>
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<tr>
<td>3 miles per kWh</td>
<td>11.88 ¢/kWh ($0.99 per gal equiv.)</td>
<td>3.96¢ per mile</td>
<td>$475</td>
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<td><strong>Retrofit of House</strong></td>
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<tr>
<td>3 miles per kWh</td>
<td>5.0 ¢/kWh ($0.42 per gal equiv.)</td>
<td>1.67¢ per mile</td>
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EVTC Data Collection, Reduction, and Analysis

1. Analysis of Publix EV Charger Data
2. Verification of Measured EMS Data
3. FPL Utility Meter Data Comparison
4. Historic Literature Review of FCV Data
Grid Changes – One Slide:

**In the Beginning....**

- Evolution as a radial distribution, networked transmission
- Urban networks are only grid-like structure today
- The Quiet Century
  - DG for reliability, few parallel operations
  - Reliability through “brute force”- (Reserves & Redundancy)
- DG Economics arrive
  - Massive DG Penetration coming
  - Still trying/planning (creatively, to be sure) to mash it into the old architecture
- Still not really a “grid” – yet.
- Then rise of Reliability through DG
- Leads to difference in Kind, not just Degree
  - Reliability through Diversity and Flexibility

And there you go.....
Down come the DG Costs,
While for Central Station, Big Cost/Big Risk Remains:

- Stability (real & reactive)
- Unit Commitment
- Long Restoration and Repair times
- (un)Reliability of a Gazillion Parts
- Fuel/Diversity Risk
- Environmental Risk
- Large Reserve Requirements
- Remote from Load → Transmission needs
Inverter Based DG Can Do:

- Utility control of gen status (switching, overloads, etc)
- PV generation ride-through of grid disturbances
- VAR Generation & Voltage Support
- Shared Inverter Designs for Utility-Owned Complex Sites
- All Under Utility Control !! (highly automated)
And Can Do things CS Cannot:

- Stabilization of Mini/Micro Grids (Island Mode)
- Harmonic Cancellation
- Deliberate Phase Unbalance/Rebalance
- Prognostics and Diagnostics
- Real-time phase balance of feeder circuits
- Enhanced transient response (H Constant)
- Oscillation Damping
- Spinning & Ready Reserve
And some things are (almost) Free:

Reactive power control through **PCU**

- Q can be controlled independently from S
- Q + P <= max. connection output of the unit/PCU
Said Visually:

Low Cost ➔ Big Scale ➔ Utility Accept/Want ➔ DG in Aggregate, Behaving Like Conventional Utility Generation -- & Then Some

"Fast and Furious" Power Electronics

Advanced Communications & Control of Smart Inverters to Enable DG to Surpass Conventional Generation
We must remember:
The Eye of the Beholder…

Not all Central Station is Fossil or Nuke…
But Things are going to happen:

- Roof top PV – 12-15% economic adder over Central Station
- EVs will be big, sometimes dominant
- Storage/Commercial “demand shaving” grows
- Storage/Residential technology responds to net metering limits
- Wind keeps ITC and grows
- New transmission tougher and tougher
- All generation provides ancillary service
- Loads provide (inverse) droop and voltage regulation
- EVs as “electric fuel tankers”

*All Driven by Economics – but Difficult to Mash Into Today’s System Architecture*
Still not a True “Grid”

- Flexible and Smart, but still radial
- From DG towards IG
Transforming to an Integrated Distribution System

Distribution Management System Integrating Distributed Resources with Distribution Technologies

From: Arshad Mansoor, EPRI
Finally, “True Grid” – though Virtually at the Edge
And then over the Edge...

• 1φ and 3φ Secondary ties through Power Electronics – the new “spot network”
• Future MV ties through Power Electronics – Feeder-Feeder, Sub-Sub, Utility-Utility
So Much Work Needs Doing,

**Big**
- DC services
- HV SS switching – More/Better wide-bandgap devices
- Hierarchical controls (only really needed for safety)
- Impact on Transmission Planning
- Optimal Operating Strategies

**And Small,**
- Substation DC reliability via DG (PV)
- Real time Changing protection settings – dynamic within range to handle infeed
- Directed Trip
- Impact on Feeder reclosing and restoration strategies
- Interconnection reqmts for smart inverter...
- Interactions between inverters
Integrated Grid: Opportunities for Ancillary Services

- At their full potential, PV systems are more than just a negative load. They can support grid operation by providing a wide variety of ancillary services.

- Ancillary services from PV inverters do-able now
  - Control Area Energy Balance - now (need mid-range storage)
  - Reactive Power Supply for feeder & system – now 24/7/365 with utility control or pre-set options (no storage needed)
  - Voltage control for customer & feeder - now 24/7/365 with utility control or pre-set options (no storage needed)
  - Frequency Regulation – now with mid-range storage
  - System Inertia – now with transient storage
  - Spinning Reserve – now with mid-range storage
  - Supplemental Reserve – (need mid-to-deep storage)
  - Black Start – now (need mid-to-deep storage)

- Great benefits of Inverter Plant with little incremental cost
Opportunities for Utilities, which become Opportunities for University Tech Transfer

- Develop, update and adapt performance and interconnection standards
- Develop generic and standard PV system models for power flows and stability studies
- Determine how PV can fulfill NERC requirements to gain capacity credit
- Investigate the impact of securing ancillary services through larger balancing area
A HUGE Argument for Doing It!

Note: Frequency of the Oscillation is about 1/3 Hz. This is the “Frequency of the Frequency”
Behold, the “Asynchronizition of the Grid”
Florida Energy Supply: The Other Three-

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• Optimization/Efficiency of the Grid

• Utility Fossil Fuel $\rightarrow$ Steam $\rightarrow$ Electricity

  *Can we transition away eventually? --Ask Hawaii (ie: Fahgetaboutit?)*
Solar PV Now Beats Natural Gas in Some Markets
**Solar Data Cheat Sheet**

**Amount of Solar Currently Installed in the U.S.:** 17.5 GW

**Number of People Employed by the Solar Industry:** nearly 143,000

**In 2014, the U.S. is expected to install:** 7.2 GW of solar capacity, an increase of 40% over 2013

**State Ranking by Cumulative Solar Capacity:**
1. California - 8,544 MW
2. Arizona - 1,929 MW
3. New Jersey - 1,369 MW
4. North Carolina - 722 MW
5. Massachusetts - 678 MW
6. Nevada - 656 MW
7. Hawaii - 417 MW
8. Colorado - 376 MW
9. New York - 338 MW
10. New Mexico - 319 MW

**Largest Solar Power Plants in Operation:**
- Topaz Solar Farm, CA - 550 MW
- Ivanpah, CA - 392 MW
- Agua Caliente, AZ - 290 MW
- Solana, AZ - 280 MW
- Desert Sunlight, CA - 278 MW

**Number of Solar Energy Systems Installed in the U.S.:** 578,000

**Carbon emissions reduced:**
- 19.8 million metric tons annually, equivalent to:
  - taking 4.3 million vehicles off the road
  - 2.2 billion gallons of gas not used
  - planting 507,000,000 trees
  - shutting down roughly 5 coal-fired power plants

**Since 2006, the solar market has grown an average of 72% every year.**

**Number of Solar Businesses in the U.S.:** 6,100

**Number of Solar Projects in the U.S.:**
In the first half of 2014, a new solar project was installed in the U.S. every 3 minutes

The average price of a residential PV installation in Q3 2014 was $3.60/watt (46% lower than 2010)

Value of the U.S. Solar Market in 2013: $13.7 BILLION

Solar has accounted for 36% of all new electric generation capacity installed through Q3 of 2014

There is enough solar energy installed in the U.S. to power 3.5 million households

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Most of Florida has ~88% of the Best Solar Resource in the World!
FLORIDA SOLAR ENERGY CENTER®
Creating Energy Independence

A Research Institute of the University of Central Florida