The future grid

Engineering Dreams

NRECA
Do we need a new grid?
NO

• The grid is an amazing achievement and it works exceptionally well

• It is recognized as the greatest engineering achievement of the 20th century by the National Academy of Engineering

We could sustain reliable and cost effective delivery of electricity through basic maintenance and extension using conventional technology
But ... that’s not the way engineers do things

- From the first – engineers and utilities have asked – how can we do it better?
- Every component and every procedure has been relentlessly refined, relentlessly polished.

Engineers Dream
Past, Present, and Future

1883 first deployed transformer

Current distribution transformer

The future? solid state transformer, Dynamic voltage control at the edge.
The grid “evolves” in small steps

- “The mother of every chicken is a chicken, the daughter of every chicken is chicken”  Richard Dawkins
- --the grid looks the same, day to day, but over time it is essentially reinvented
- This is true because:
  - The grid is *immensely complex* – vastly beyond “simple” things like the Apollo program.
  - Different portions of the grid are *independently configured* and controlled – there is no “Deus ex machina”.

Will the future grid be smart?
YES, the grid will be smart

- **Smart is the alternative to big.**
  - When the grid was first built, it was all about expansion — more power, delivered ubiquitously

- When you reach a limit, you built MORE
- While we still focus on more, but the first thought now is getting more from what we have.
Engineering Dreams
(with respect to Henry Petroski)

Every new tool or materials allows and encourages an engineer to rethink every aspect of a problem – Solid state technology is the new tool that is allowing engineers to ‘dream’ the smart grid.
And Shockley said “let there be transistors”

The rate of the improvement in grid components was slowing in the 1980s. --
   Electricity prices were low and stable
   Reliability was very high
   “Everything had been invented”
Then – solid state electronics entered the power industry
   metering
   communications
   control
   power electronics
And it was time to reconsider / re everything

(731 million)
Living in the Interesting Time

1883 → 1990

Control Through Angular Momentum

- Reliability through overbuilding
- Lack of overall model
- Changing Technology
- Complicated Transition

Transition

2025? → ...

Analytically Driven Control

- Knowledge of state
- Precise control
- High performance analytics
The smart grid encompasses many ideas and many technologies.
“Gimme power, make it cheap”
“I don’t need you any more,  
I make my own power”
“Buy my power”
“Crap, the power’s out. Can you help?”
“Can you hang around just in case”
“Hey, lets work together”

(To be hoped)
Goal: An Agile Grid

Hint: It needs to be fractal
Control Area

- generation
- load
- storage
- Transmission and distribution
- Transport and delivery

Control and Communications
Autonomous Operation
Collaborative Operation
Central Control Area

Control Area

Control Area

Control Area

Control Area

Control Area

Control Area

Control Area
Control Area

Control Area

Control Area

Control Area

Control Area

Control Area

Control Area
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(To be hoped)
An office building or a grid?
A home or a grid?
The Key is Analytics

Shared, consistent data
Open development
Death to silos
Focus first on real problems
Distributed generation
CVR
Big Computing
Cloud
All grid applications have the same basic structure
Abstraction Model

Data → Information → Analysis → Decision → Action
Future Grid

Grid State

Analytics
Future Grid

Grid State

Analytics

Testing
Grid State

What is it –

• complete,
• immediate,
• accurate,
• precise
• high resolution

knowledge of the state of the grid.
Grid State – How to you get it

• Sensors
• SPAN Ports
• Smart components
• Systems extensions and modifications
• Databases and Data Warehouses
• Other
Human Intelligence and Machine Intelligence

- One Dimension
- Two Dimensions
- Three Dimensions

Requires a Computer

Voltage

Many Dimensions
Machine derived rule in natural language

pressure measurement <= 3.32352000543e+02
..AND setpoint <= 0.00499999988824
..AND 0.5 < address <= 3.5
OR pressure measurement <= 3.32352000543e+02
..AND setpoint <= 0.00499999988824
..AND 0.339700013399 < reset rate
..AND 3.5 < address <= 4.5
OR pressure measurement <= 3.32352000543e+02
..AND setpoint <= 0.00499999988824
..AND 4.5 < address
OR 3.32352000543e+02 < pressure measurement
..AND setpoint <= 0.00499999988824
OR 0.00499999988824 < setpoint
..AND gain <= 88.5
OR 0.00499999988824 < setpoint
..AND cycle time <= 0.25
..AND 88.5 < gain
OR 0.00499999988824 < setpoint
..AND 0.25 < cycle time <= 0.625
..AND 88.5 < gain
..AND system mode <= 0.5
OR 0.00499999988824 < setpoint
..AND 0.25 < cycle time <= 0.625
..AND 88.5 < gain
..AND 0.5 < system mode
OR 19.9500007629 < setpoint
..AND 0.625 < cycle time
..AND 88.5 < gain
..AND rate <= 0.167421996593
OR 0.167421996593 < rate <= 0.216356009245
..AND 0.625 < cycle time
..AND 88.5 < gain
..AND 0.00499999988824 < setpoint
..AND 0.625 < cycle time
..AND 88.5 < gain
..AND 0.216356009245 < rate
..AND 0.00499999988824 < setpoint
..AND 0.625 < cycle time
..AND 88.5 < gain
..AND 0.00499999988824 < setpoint
setpoint VS time (ground truth)
cycle time VS time (anomalies detected by classifier)
cycle time VS time (ground truth)
Small slide, huge idea

PQ vs VI
Overview

• Unify steady state, transient, distribution and transmission in a circuit-based simulation environment
• Utilize circuit simulation based methods to improve robustness and scalability and accommodate advanced models
• Enhance power flow to include identification of infeasibility
• Enable load models that are compatible with transient and steady state and characterized via machine learning
• Create new methods for state estimation, anomaly detection, optimal power flow, stability analysis, harmonics, …
• **Simulation with Unified Grid Analyses and Renewables**

• *Circuit simulation methods adapted for power systems*

• Decomposition into circuit elements enables **improved N-R convergence**

• Any component can be represented by an equivalent circuit for single-phase and 3-phase distribution and/or transmission
Robustness of Convergence

- Continuation methods, such as **Gmin stepping**, are used for simulation of large-scale circuits
- **Homotopy** methods have been shown to guarantee global convergence to the physical solution in circuit simulation*
- SUGAR uses a **Tx stepping** approach to ensure convergence to the correct voltage solution for power flow
  1. **“Virtually short”** the system initially to produce a trivial problem
  2. **Gradually** reduce the added conductances until original problem is solved

SUGAR: Scalability

- Can simulate systems of large scale and complexity with “Tx-stepping”
- Example: US Eastern Interconnection
  - SUGAR converges from any initial conditions, but standard tools generally rely on a good initial guess

### Case ID # Nodes

<table>
<thead>
<tr>
<th>Case ID</th>
<th># Nodes</th>
<th>SUGAR</th>
<th>Standard Commercial Tool</th>
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<td>Flat Start</td>
<td>From Solution</td>
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<tr>
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<td>75456</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td>3</td>
<td>80962</td>
<td>✔</td>
<td>✔</td>
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✔ converged
X diverged

Any choice of flat start works in SUGAR
Contingency Analyses

- Robust convergence is needed when system state is unknown
- *Example*: simulate removal of two (N-2) and three (N-3) large generators for Eastern Interconnection

<table>
<thead>
<tr>
<th>Case ID</th>
<th># Nodes</th>
<th>Contingency Type</th>
<th>SUGAR</th>
<th>Standard Commercial Tool</th>
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<td>Diverged</td>
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</table>

Simulated w/o automatic generator control
Making Analytics Accessible

- Multiple tools
- Shared common data
- Ubiquitous free access
- Sophisticated security model
- Shared non-proprietary data
- All runs stored until deleted
- Collaboration encouraged
Open Modeling Framework – https://www.omf.coop

- Free and open source electric utility modeling software
- Built by the co-ops and the US Department of Energy
- Offers models to determine:
  - Benefits of energy storage for arbitrage, peak demand reduction and asset upgrade deferral
  - Cost and financing options for utility-scale solar
  - Cashflow and engineering impacts of distributed generation
  - Full distribution dynamic powerflow simulation (for the ambitious)
- Users from 176 organizations (utilities, vendors, universities) as of June 2017.
Web interface for managing feeder configuration

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Sample Output
# Model / Run Library

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<th>Owner</th>
<th>Model Name</th>
<th>Type</th>
<th>Run Time (H:MM)</th>
<th>Created</th>
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<td>Demo CVR DEC Red</td>
<td>gridlabMulti</td>
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<td>2014-07-30 11:35:33</td>
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<td>Demo Batter Olin Barre GH Battery</td>
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<td>Demo gridlabMulti 13 Node Feeder</td>
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<td>Demo cvrStatic ABEC Columbia</td>
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<tr>
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<tr>
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<td>Demo PV Watts</td>
<td>pvWatts</td>
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<td>2014-07-25 18:00:13</td>
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<tr>
<td>public</td>
<td>Demand Response</td>
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<td>Demo solarEngineering Regulator and Capacitor Switching</td>
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