BUILDING EFFICIENT, SUSTAINABLE AND RESILIENT GRID BY CONTROLLING THE EDGE

DR. SONJA GLAVASKI | EXECUTIVE VICE-PRESIDENT INNOVATION
OUTLINE

• Technology Megatrends & Future of Electricity
• Consumer Centric Power Grid
• Role of the Grid Edge
• Grid Edge Control Technology
### TECHNOLOGY MEGATRENDS SHAPING THE FUTURE

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>People &amp; Internet</td>
<td>Association and interaction with the web</td>
</tr>
<tr>
<td>Computing, Communications &amp; Storage Everywhere</td>
<td>Ability to easily interface with digital technology</td>
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<tr>
<td>Internet of Things</td>
<td>Instrumentation of the physical world</td>
</tr>
<tr>
<td>Artificial Intelligence &amp; Big Data</td>
<td>Ability to access &amp; analyze vast data, and to make decisions based on it</td>
</tr>
<tr>
<td>Sharing Economy</td>
<td>Direct exchange of services, goods and money</td>
</tr>
<tr>
<td>Digitizing The Matter</td>
<td>3D printing, &amp; creating materials on the spot</td>
</tr>
</tbody>
</table>

De-carbonization
Decentralization
Digitalization
Democratization
NEW TECHNOLOGIES

- ENERGY EFFICIENCY
- POWER SYSTEMS
- SYSTEMS & CONTROL
- POWER ELECTRONICS
- COMputation AL SCIENCES
- EARTh & ENVIRONMENTAL SCIENCES
- RESILIENCY
- SUSTAINABILITY

FARADAY GRID LIMITED | APRIL 2019 | COMMERCIAL IN CONFIDENCE
THE POWER GRID IS CHANGING

Current Grid Structure

Emerging Technologies

Points of Entry

- Responsive loads
- Distributed Generation
- Smart infrastructure
- Microgrids
- Energy Storage
- EVs

Current Grid Structure:
- Generation
- Transmission 300kV & 230kV
- Sub Transmission 115kV & 66kV
- Distribution 30kV, 16kV, 12kV & 4kV
- Customers

Emerging Technologies:
- Responsive loads
- Distributed Generation
- Smart infrastructure
- Microgrids
- Energy Storage
- EVs

Points of Entry:
- Generation
- Transmission
- Sub Transmission
- Distribution
- Customers
GRID OPERATION | TIMESCALES

- **Unit Commitment** - deciding which units will be operational at a given time (hours to days)
- **Economic Dispatch** - distributing loads among already-operating units (minutes to hours)
- **Frequency regulation and ancillary services** - only on certain participating generators (sub-seconds to seconds)
DERS GRID INTEGRATION CHALLENGES

- Dispatched generation
- Intermittent generation
- Predictable load
- Variable Net-Load
- Capacity available
- Capacity constrained
EMERGING GRID OPERATION PARADIGMS

**ISO & DER aggregators**
- ISO manages transmission & wholesale
- Aggregated DERs bid into bulk market

**ISO & DSO**
- ISO manages transmission & wholesale
- DSO manages distribution & retail

**Network of micro-grids**
- Locally supply power
- Grid supplies backup

**Super Grid**
- Global, interconnected, renewable energy grid
- Energy backbone
BUSINESS MODEL TRANSITION

• DER providers starting to participate in wholesale markets
• Utilities shifting from ROI toward performance-based & network-driven incentive business models
• Utilities becoming a platform delivering services
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THE ROLE GRID EDGE
DISTRIBUTED ENERGY RESOURCES (DERs) AND THE RISE OF THE GRID EDGE

Benefits of DERs

- Increased Customer Satisfaction & Retention: 53%
- Improved Energy Efficiency: 46%
- Improved Grid Reliability: 41%
- Improved Grid Resiliency: 34%

DER Deployment Status

- Energy Efficiency: Deployed 74%, Next 3-5 years 20%
- Solar: Deployed 60%, Next 3-5 years 29%
- Demand Response: Deployed 50%, Next 3-5 years 34%
- Energy Management Systems: Deployed 44%, Next 3-5 years 40%
- Wind: Deployed 19%, Next 3-5 years 19%
- Electric Vehicles: Deployed 38%, Next 3-5 years 36%
- Energy Storage: Deployed 25%, Next 3-5 years 51%
- Combined Heat & Power: Deployed 19%, Next 3-5 years 31%
- Microgrids: Deployed 17%, Next 3-5 years 50%

Resiliency - System improvements that prevent or reduce the impact on reliability and ability of the system to recover quickly after adverse events

**Resiliency is more than reliability**

- Prevent and minimize damage
- Enable continued operation
- Rapidly return to normal

![Graph showing the increase in service disruptions with at least 50,000 customers affected from 1984 to 2012.](http://www.climatecentral.org/news/weather-related-blackouts-doubled-since-2003-report-17281)

**$18B to $33B annual cost**

INCREASED GRID COMPLEXITY CHALLENGES

• Enabling millions of end-use devices to cooperate for real-time supply/demand balance without jeopardizing grid reliability

• Effectively integrating Transmission & Distribution to better utilize demand side technology to improve grid resiliency

• Bridging the spatio-temporal gap between real-time feedback control and system-wide energy management
ACTIVE CONTROL OF GRID-EDGE
ENABLES EFFICIENT, SUSTAINABLE AND RESILIENT GRID
WHAT DO WE WANT TO CONTROL?

Bulk Generation
Dispatch, Set-points & Inertia

Industrial Load
Bulk DR (hour-day)

High-voltage transmission lines

Substation step-down transformer

Low-voltage transmission lines

Industrial Customers

Residential Customers

Bulk Renewables
Curtailment

Grid-Edge
Utilize Grid-Edge control to provide low-cost ancillary services at different time-scales
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GRID EDGE CONTROL TECHNOLOGY
WHAT DOES CONTROLLING THE GRID-EDGE MEAN?

• Dispatching distributed generation in coordination with bulk generation
• Shaping net load over different time scales
• Coordinating large numbers of heterogeneous types of demand side technologies
• Self-Balancing
• Adapting to real-time variability
GRID RELIABILITY - FREQUENCY STABILITY

Directly affected by generation-demand balance
GRID-EDGE CONTROL IMPACT STUDY

- **Use DERs for Regulation**
  - Use controllable load to induce inertia-like response
  - Use controllable load to induce governor response
  - Engage in response to frequency measured at resource POC
- **Response times:**
  - Inertia = Seconds
  - Governor = Tens of Seconds

- **Actively Reshape Net-Load**
  - Load magnitude flexibility factor > 30%

- Objective: use renewables as much as possible
- Constraint: keep average daily load the same

LEVERAGE GRID-EDGE FOR HIGH SCALE RENEWABLES INTEGRATION

GRID EDGE CONTROL STUDY OUTCOME
LEVERAGE GRID-EDGE FOR HIGH SCALE RENEWABLES INTEGRATION
NODES: NETWORK OPTIMIZED DISTRIBUTED ENERGY SYSTEMS

Mission
Reliably manage dynamic changes in the grid by leveraging flexible load and Distributed Energy Resources (DERs) capability to provide ancillary services to the electric grid at different time scales.

Goals
• Improve overall grid efficiency and reliability
• Enable renewables penetration at >50%
• Reduce CO₂ emissions
• Guarantee Level-of-Service to the grid
• Guarantee customers’ QoS

<table>
<thead>
<tr>
<th>Project Categories</th>
<th>Response Time</th>
<th>Ramp Time</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1: Synthetic Frequency Reserves</td>
<td>&lt; 2 sec</td>
<td>&lt; 8 sec</td>
<td>&gt; 30 sec</td>
</tr>
<tr>
<td>C2: Synthetic Regulating Reserves</td>
<td>&lt; 5 sec</td>
<td>&lt; 5 min</td>
<td>&gt; 30 min</td>
</tr>
<tr>
<td>C3: Synthetic Ramping Reserves</td>
<td>&lt; 10 min</td>
<td>&lt; 30 min</td>
<td>&gt; 3 hr</td>
</tr>
</tbody>
</table>

DE-FOA-0001289: Network optimized distributed energy systems (NODES)
Faraday Grid: Platform Architecture
Provides primary frequency response to maintain network stability. It autonomously and continuously adapts to variations throughout the network, and maintains an optimal equilibrium, functioning as an emergent order.
- Is a network of Faraday Exchangers across electricity distribution.
- Solves short term volatility, provides synthetic inertia.
- Lifts the tolerance of the grid for renewables and variable, distributed energy sources.

Emergent Transactional Platform: Transactional Distributed Ledger
A system of control that balances supply and demand across the entire energy system, using price as the key operational mechanism. It is built on an integration of software with patented Faraday Grid technology. This unique combination of hardware and software creates a system allowing any device or person, with the right technical support, to trade energy with other parties.
- Allows any supported device or agent to participate in the trading of energy.
- Runs as a software protocol over the top of the Faraday Grid.

Faraday Exchanger: Underpinning Device – the router for an energy “internet”
A hardware device which operates in isolation and independent of any central network management. The primary function of the Exchanger is bi-directional power flow, with each device managing its immediate network area to maintain grid stability.
- Acts as an autonomous system node, like a router in the internet.
- Is the underpinning technology for the Faraday Grid and Emergent Transactional Platform.
- Is located in the network at any point of connection.
TECHNOLOGY OVERVIEW | THE FARADAY GRID PLATFORM ARCHITECTURE

- Poles, wires and FARADAY EXCHANGERS
- Platform with DISTRIBUTED CONTROL
- ENERGY anywhere to anyone
- CO₂ emissions directly and indirectly

Provides bi-directional power flow and contributes inertia

Significantly increases capacity of grid to integrate renewable energy

Reduces the need for and cost of network governance

Autonomously and continuously adapts to variations throughout the network to maintain optimum equilibrium

Integration of non-synchronous renewable energy generation

34% reactive power generation requirement

25% network carrying capacity of the grid

7% network losses
Stage 1: Distribution to Low Voltage
- 3-phase LV pad-mount
- 3-phase LV pole-mount
- 1-phase LV pole-mount
- EaaS Platform Software
- Emergent Platform Software

Stage 2: Renewable Generation Integration
- 3-phase LV pad-mount, to 20 MVA
- EaaS Platform Software

Stage 3: High Voltage Distribution & Transmission
- 3-phase pad-mount to >200MVA
- EaaS Platform Software

Stage 4: Large Scale Generation Integration
- 3-phase pad-mount to >200MVA
WHAT IS NEEDED FOR SUCCESS?

- Domain Knowledge
- Scientific Rigor
- Talent Pool
- Energy Eco-System
THANK YOU!

Dr. Sonja Glavaski
Executive Vice President Innovation The Faraday Grid
Former ARPA-E Program Director
sonja.glavaski@faradaygrid.com