The Grid of The Future: From Vertical to Flat

Decentralized Control: Benefits, Technologies and Challenges

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The Emerging Grid

- Smart Grid functionality restores the balance
- Hydro power plants
- Nuclear Power Plants
- Natural Gas Generators
- Transmission System
- Distributed storage
- Distributed wind
- Rooftop Solar
- Home Energy Storage
- Energy Efficiency
- Commercial Customers
- Rooftop Solar
- Distributed generation
- PHEV
- Wind Farms
- Solar Farms
- Solar power plants
- Distributed control
- GIS
- Frequency control
- Carbon Sequestration
- Distributed Generation
- WiMAX
- Smart Meters
- Dynamic Pricing
- AMI
- Fault Restoration
- Outage Management
- Volt/Var Control
- Smart Appliances
- Data Management
- Home Area Network
- Active Loads
- Power Flow Control
- Time of Use
- PMU
- Power Electronics
- Efficient Lighting
- Asset Management
- Network Management
- Fault Location
- Smart Grids
- Energy Efficiency
- Smart Grids
- Energy Efficiency
Unprecedented Changes

<table>
<thead>
<tr>
<th>Domain</th>
<th>Change</th>
<th>Future System</th>
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<tbody>
<tr>
<td>Objectives</td>
<td>• Reliability+, Economy+, and Sustainability</td>
<td>Sustainable</td>
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</table>
| Sources | • Fossil fuel to renewable  
• Bulk centralized to massively distributed  
• Highly Variable | Renewable Distributed, Two way Stochastic |
| ICCT | • Can control entire system through SW  
• Interdependency of physical and cyber  
• Privacy and cyber-security issues | Cyber-Controlled Cyber-Physical Secure, Private |
| Actors | • Consumers can also produce and store  
• Consumers seek their own objectives  
• Massive number of actors and devices | Prosumers Smart Massive |

- How should these systems be controlled and operated?  
- Need new control architecture -> Decentralized
Concept 1: Prosumer Abstraction

- A generic model that captures basic functions (produce, consume, store) can be applied to power systems at any scale.
- The fundamental task is power balancing:
  \[ P_{INT} = P_G - P_D - P_{Loss} - P_{STO+} + P_{STO-} \]
- Energy services can be virtualized.
Concept 2: Flat Electricity Industry

- Interactions occur among entities of the same type (prosumers)
- Can achieve “flatness”


Concept 3: Prosumer Services

- Prosumer exposes standardized services
  - Energy balancing
  - Frequency regulation
  - Reserve
  - Sensing and Information
  - Forecasting
  - Security
  - Self-identification
  - Voltage control
  - Black Start
  - Etc.
Decentralized Control

- 20 Self-Optimizing Regions in a Large-Scale RTO System.
- Tie-Line Bus LMP convergence using Decentralized Optimization.

Potential Benefits

- Scalable to large number of control points.
- Reduces need for massive communication
- Leverages sensing investment
- Enables solving otherwise intractable optimization problems
- Enables integration of distributed renewables
- Eliminates single point of failure
- Leverages distributed intelligence
- Empowers customers
- Increases information privacy
- Enhances cyber-security
- Incrementally deployable
- Backward compatible
## Technology Needs and Challenges

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<th>Technologies</th>
<th>Challenges</th>
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<td><strong>Modeling and Simulation</strong></td>
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<tr>
<td>• Prosumer models</td>
<td>Device function to prosumer service</td>
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<tr>
<td>• Multi-scale models</td>
<td>What temporal scales</td>
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<tr>
<td>• Co-Simulation</td>
<td>Supporting theory</td>
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<tr>
<td>• ICCT and physical</td>
<td>Market/business models</td>
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<tr>
<td>• System control and market</td>
<td>Information footprint, computation</td>
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<td>• System planning</td>
<td></td>
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<tr>
<td><strong>Control and Operation</strong></td>
<td></td>
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<tr>
<td>• Control theory</td>
<td>Decentralized resilient control of large, open, uncertain networked network systems. Layered control theory</td>
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<tr>
<td>• E-CPS theory</td>
<td></td>
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<tr>
<td><strong>Architecture</strong></td>
<td>Control Architecture drives ICC Architecture, Security Architecture</td>
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Summary

- Future electricity systems will consist of billions of smart devices and millions of interconnected decision makers.

- A decentralized control and management architecture may be able to support the objectives and requirements of the future electricity industry.

THANKS!