Prosumer-Based Distributed Autonomous Cyber-Physical Architecture for Ultra-Reliable Green Electricity

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Project Objectives

- **Main Goal:**
  - Show that a decentralized approach can support reliable, efficient, and scalable operation of the electricity grid with high penetration of renewables.

- **Uniqueness of the Approach:**
  - Multi-disciplinary team. Formal control architecture.
  - Prosumers, Energy Internet, Electricity OS, Co-simulator.

- **Challenges:**
  - Not attempted before.
  - Required formal architecture, new distributed control, new optimization methods, HPC computation, and data management.

- **Metrics:**
  - Same objective function and reliability compared to BAU.

- **Outcomes of the Project:**
  - Foundations of a massively scalable and extendable operational paradigm for the future grid.
Project in a Nutshell

- Large-scale grid divided into subsystems.
- Use same abstraction (prosumer) to characterize subsystems at ALL scales.
- Design real-time cyber-infrastructure for prosumers to interact and exchange services.
  - Application Framework
- Designed distributed algorithms to operate the system.
  - Decentralized Unit Commitment
  - Distributed Frequency Control
  - Others (power agreement, malicious agent detection, etc.)
- Simulated integrated operation with realistic data at large-scale ISO level.
Decentralized Unit Commitment

Accomplishments:
- Improved performance of decentralized UC, currently running 2-3 times faster than traditional UC while including ALL line constraints

Challenges (Solved):
- Overcame constrained computational resources by implementing our own task assignment and scheduling

Challenges (Remaining):
- Simulation of more decentralized use cases showing of advantages of decentralized operations approaches.

Surprise:
- Possible to reach same objective function and duality gap.
- Some organizations are looking toward greater centralization of operations even though complexity grows exponentially and other industries move toward decentralization.
Distributed Frequency Control

- **Accomplishments:**
  - Demonstrated DFC on PJM Interconnection
  - Validated the scalability and efficacy of the DFC algorithm by developing a new framework for integrating DFC on large-scale ISO systems

- **Challenge (Solved):**
  - Integration of large-scale data
  - Implementing a cyber-layer for real-time communication between prosumers controlling frequency.

- **Challenges (Remaining):**
  - Algorithm integration in operational environment.

- **Surprise:**
  - Achieving system-wide performance for large-scale ISO systems in a distributed architecture with one-hop communication
Accomplishments:
- Service-Oriented Application Framework complete.
- Application Framework implemented as extension to ns-3 simulation.

Challenges (Solved):
- Real-time guarantees by extending the Giotto programming model.
- Integrated environment simulated the combined operation of individual algorithms under various cyber system requirements for PJM.

Challenges (Remaining):
- “Back up safety modes” for individual distributed algorithms is tough requiring fundamental research in fault tolerant distributed algorithms for power systems.

Surprising Result:
- Robustness of the Giotto programming paradigm to bring real-time and formal guarantees to level similar to automotive and avionics.
Remaining Tasks

- Projects ends as we speak.
- Most program elements at target TRL 6
- Remaining tasks are:
  - Q12 Review and final report
  - Develop presentations of final simulations
  - Continued commercialization activities beyond program funding.
Full Project Accomplishments

**Most Important Contributions**

- Established the need for new control architecture.
- Formal decentralized power protocols
- Scalable decentralized framework and key tools to tackle emerging grid operational complexity.

**Challenges (Solved):**

- Project complexity: Strong architecture and systems model.
- New Theory: Early realization of basic theory needs
- Risks: Multi-disciplinary team. Local team was beneficial.
- Data acquisition and integration: unified model, IAB support.

**Challenges (Remaining):**

- “Spatio-temporal diversity” of the industry pain. No consensus in industry since different organized see different things.
- Needs are not obvious until problems arise.
Full Project (Cont. …)

- **Surprising Result:**
  - Decentralized control can actually achieve same objective function, faster and with sparse information exchange.
  - Robustness and scalability of the prosumer concept.
  - Robustness and simplicity of the layered model.

- **Change in Approach:**
  - Need for decentralization is evident in smaller scale levels today.
  - It will be evident in transmission several years from now.
  - Strategy: provide decentralized solutions where they are most needed now.
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<thead>
<tr>
<th>Commercial Objectives, Successes &amp; Challenges</th>
<th>Technology-to-Market</th>
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<tbody>
<tr>
<td><strong>1. Commercial Objectives</strong></td>
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<tr>
<td>• Recently Incorporated <strong>ProsumerGrid, Inc.</strong></td>
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<td>• Raise capital for further Product Development</td>
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<td><strong>2. Target Market Segments</strong></td>
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<td>• Now: Distribution Utilities</td>
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<td>• Midterm: T and D Interactions</td>
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<td>• Future: ISOs</td>
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<td><strong>3. Key Commercial successes</strong></td>
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<td>• I-Corps: found product-market fit!</td>
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<td>• Won DOE ACC Clean Energy Challenge</td>
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<td>• 5 verbal commitments for pilot projects</td>
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<td><strong>4. Key Commercial Challenges</strong></td>
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<tr>
<td>• Many possible applications</td>
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<td>• Understanding complex customer’s decision process</td>
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## Important Upcoming Commercial Activities

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<tr>
<th>1. Contract</th>
<th>• being finalized to develop multi-scale decentralized demo of transmission and distribution coordination</th>
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<td>2. Working on two SBIR proposals</td>
<td>• focusing on porting algorithms to cloud computing with two supporting partners</td>
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<td>3. About 5 verbal commitments</td>
<td>• of support of a pilot of simulator/controller at the distribution level coupled with efforts towards responses to larger solicitations.</td>
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<td>4. Exploratory partnership with large Energy Provider</td>
<td>• Focus is scalable PV-Storage control decision making.</td>
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Post ARPA-E Goals

- **Immediate Plans**
  - Decentralized control and management of subsystems at the distribution level.

- **Resource Needs:**
  - Combination of Federal and State funding opportunities with initial revenue from customers, then VC.

- **Remaining Challenges:**
  - Future grid will consist of billion smart devices and millions on decision-makers. Decentralized control is the only scalable approach to support the future grid requirements.
  - But a larger investment is needed in order to realize broad transition.
Conclusions

- DARPA created the **Internet**
- This ARPA-E project provides foundations for an **Internet of Energy**.

**Team:**
- Has learned a lot, worked a lot, and had fun.
- Extremely appreciative of ARPA-E GENI’s support.
- Will continue to work on decentralized grid solutions.
- Excited to be part of grid modernization efforts.