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

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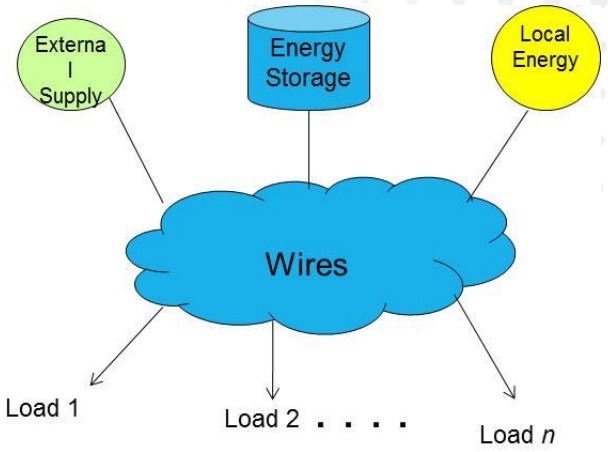
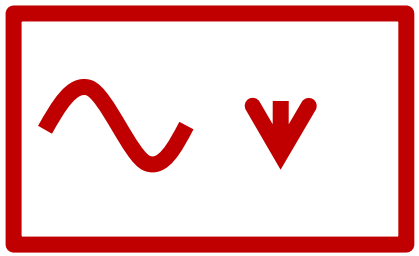
Project Objectives

- **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.
  - Massive scalability. Less communication. Less data. Higher privacy.
- **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

Application Framework/Simulation

Final Year Accomplishments

- **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.

Commercial Objectives, Successes & Challenges

1. Commercial Objectives	• Recently Incorporated ProsumerGrid, Inc. • Raise capital for further Product Development
2. Target Market Segments	• Now: Distribution Utilities • Midterm: T and D Interactions • Future: ISOs
3. Key Commercial successes	• I-Corps: found product-market fit! • Won DOE ACC Clean Energy Challenge • 5 verbal commitments for pilot projects
4. Key Commercial Challenges	• Many possible applications • Understanding complex customer's decision process

Important Upcoming Commercial Activities

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

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.