GridSpice - A Virtual Test Bed for Smart Grid

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The Modern Grid: Innovation & Complexity

**New Technologies**

**Renewable Energy**
- Solar
- Wind
- Hydro
- Fuel-Cells

**Energy Efficiency**
- Demand Response
- Smart Meters
- Smart Appliances

**Storage**
- Utility Scale Storage
- Distributed Storage
- End-user level storage (e.g. PHEV)

**Market Dynamics**

**Wholesale Market Deregulation**
- Day-ahead and hour-ahead markets
- IPPs and LSEs

**Retail Market Deregulation**
- Dynamic Pricing
  - Block Pricing
  - Time-Of-Use
  - CPP, CPR
  - Real-Time Pricing

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The Modern Grid: Innovation & Complexity

Requires new tools to model & optimize the system

Complex interactions of power flows, data flows and markets
Our Research Objectives

- Create a framework to model all interactions of a smart-grid
  - Power Flows, Communication and Market Operations
    - Distribution and Transmission Operations
    - Wholesale and Retail Operation
  - Provide all operating and business metrics of interest
- Allow researchers, system operators and planners to work together
  - Provide easy-to-use, cost-effective, and realistic models of the system
  - Serve as a catalyst for a faster adoption of innovative ideas in the Smart Grid Space
- Maximize ROI, reliability and system efficiency, reduce costs and risk for all constituents
- One-hundredth the cost of expensive “pilot city” projects and more comprehensive
The GridSpice Solution

Modeling the interactions between all agents of the smart grid

Power
- Transmission & Distribution Network
- Smart Meters & Smart Devices
- Demand Response Aggregators
- Residential, C&I Consumers

Markets
- Wholesale Markets
- Retail Markets

Generation Cos, IPPs & LSEs
GridSpice - Initial Applications

- Renewable Energy Integration
- Utility Scale Storage
- Demand Response & Distribution Operation
- Home Area Control / Smart Algorithms
- Electric Vehicle Infrastructure
- Distributed Energy Resources
- Micro-grid Systems

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Application: Modeling Demand Response Price Sensitivity and Load Management

Management of customer-owned assets
- Generation
- Storage
- Smart appliances

Design of retail pricing contracts
- Real-time
- Time-of-use
- Fixed-price

Demand-Response impact on wholesale electricity pricing

Demand-Response impact on peak-load management and supply adequacy

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Application: Electric Vehicle Adoption

- Wholesale Markets
- Impact on Wholesale Prices
- EV Pace of Adoption
- Charging / Discharging Locations
- Load Mobility
- Impact on Peak Demand
- Dynamic Pricing Models
- Role of Aggregator

Energy Sourcing / Load Management

- Weather
- Physical Network
- Demand Response
- Renewable Energy
- Oil & Natural Gas Prices

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Application: Trading, Risk Management

- Demand Response
- Physical network
- Power Markets
- Carbon Trading Markets
- Derivatives
- Renewable energy
- Coal, Oil & Natural Gas Prices
- Utility scale storage

MISO – Apr 25, 2006, 7:55pm
$156

~4X Lower!

MISO – Apr 25, 2006, 8:00pm
GridSpice - Modeling Approach

- **Complex adaptive system (non-linear)** to model interactions of power systems, wholesale and retail markets and consumer behavior

- **Agent based simulation** to model complex adaptive systems
  - Modeler constructs a virtual world populated by various agents (social, economic, structural, biological etc), the rules of interaction and initial conditions
  - Modeler steps back and observes how this world evolves without any further intervention
  - Stochastic, dynamic open-ended game between participants
GridSpice - Agent Based Modeling

- **Agents** are encapsulated software entities capable of
  - Adaptation to their environment
  - Communication with other agents
  - Goal directed learning
  - Autonomy – self activation and self-determinism based on internal private processes
- System shows **Emergent Behavior** that is difficult to predict apriori based on closed form solutions

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GridSpice: Open-Source Model

- Leveraging other open-source simulation modules when possible
  - Partner with other universities, research labs and industry
  - Reduces cost of development, lets us focus on new ideas and innovation
GridSpice – An Integrated View of the Smart Grid

- **Market Processes**
  - ISO
  - T/D Utilities
  - LSEs

- **Data Flows**
  - Offers & Settlement
  - Dispatch
  - Contracts / Pricing
  - Meter Data

- **Power Flows**
  - HV Transmission Grid
  - Substation
  - Consumers
  - Consumer DER

Commercial Distributed Energy Resources

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GridSpice Architecture

Transmission Network and Wholesale Markets

Controller

Distribution Network
Customer Owned Assets
Retail Contracts

Weather, Initial Conditions, Time-step (T_t)
Load Information

Weather, Initial Conditions, Time-step (T_d)
Real-time Prices

Locational Marginal Prices Based on Optimal DC flow

Aggregated Load Information

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Project Milestones and Timeline

Month-0
- Initiate the program

Month-6
- Prototype ready to validate key architectural ideas
- Demo for 1-2 applications

Month-12
- Start development of additional applications
- Add features to the engine
- Complete the initial applications
- Show Real Industrial Applications

Month-18

Month-24
- Study interaction with Carbon and other ancillary markets
- Show Real Industrial Applications

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Conclusion

GridSpice –
A new software simulation & optimization platform to enable the sustainable energy infrastructure of the future.