Computational Infrastructure for Renewable Energy

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Towards A Sustainable Environment
Cyber-Enabled Smart Distribution

- **Smart Grid**
  - Automated Meter Reading (AMR)
  - Demand Side Management
- **Centralized Supervisory Control And Data Acquisition (SCADA)**
- **Electric Utility Control**

Scalability, fault management, security and privacy

- **Smart Grid Version 1**
Cyber-Enabled Smart Distribution Systems and Micro Grids

- Move away from Centralized SCADA
  - Distributed Control
- Advanced Power Electronics
  - Finer-grained control over physical entities
  - Schedulable entities
- Design Issues
  - Complex and unpredictable interactions between the cyber and physical processes
  - Information flow across the cyber-physical boundaries
Future Renewable Electric Energy Delivery and Management (FREEDM) – NSF ERC

- An efficient and revolutionary power grid utilizing revolutionary **power electronics** technology and **information technology**
- Decentralized management integrating **distributed** and scalable alternative energy sources and storage with existing power systems
Pre-1980s
Centralized Mainframes

Paradigm Shift

Internet

Distributed Computing
- Shipping 250M pcs/yr.
- Ubiquitous ownership
- Ubiquitous use
- Ubiquitous sharing

Innovation & Industry Transformation

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FREEDM Systems Center
Today

Centralized Generation
100+ year old technology

New technologies for distributed renewable energy

New energy companies based on IT and power electronics technologies

Paradigm Shift

FREEDM System

Distributed Renewable Energy Resources (DRER)

- Ubiquitous sales
- Ubiquitous ownership
- Ubiquitous use
- Ubiquitous sharing

Innovation & Industry Transformation

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FREEDM Systems Center
The FREEDM Concept

• Distributed Intelligence
  – People share energy resources
  – Neighborhood or industrial level
  – Where is the centralized controller?
The FREEDM System Is Distributed

- Distributed Intelligence
  - Spread over components of a FREEDM node
  - Components work together to provide a solution
  - Failure of a single component does not cause system failure
  - Components are not bound to any specific device or location
  - Multiple Points of Vulnerability
• IEM and IFM nodes each run a portion of the DGI to manage their own resources
• Coordinate to control the whole as a Distributed Algorithm

**IEM**: Intelligent Energy Management
**IFM**: Intelligent Fault Management
**DRER**: Distributed Renewable Energy Resource
**DESD**: Distributed Energy Storage Device
Schedulable Entity

The Solid State Transformer
Inside an IEM Node

- Solid State Transformer (SST)
  - Power Electronics
  - Schedulable Entity
How to use it?
Distributed Grid Intelligence
Within the Context of FREEDM

- Each FREEDM IEM node runs a portion of the DGI to manage its own resources
- Power Management
  - Load Balance DESD, DRER, and LOAD
  - Control and react to the SST
  - Migrate power through the Gateway that connects an SST to the system shared bus.
Distributed Power Balancing

- Correctness: Keep all IEM nodes’ “balanced” in terms of Supply and Demand
- Pass messages negotiating load changes until the system has stabilized
- Global optimization decomposed into individual processes that cooperate to meet the global correctness.
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More Critical need

Lesser need

I CAN SUPPLY

Migrate 1 quantum of Power per successful request

After Load Balancing

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FREEDM Systems Center
1. Use local power first
2. Request power from neighbors
3. Neighbors respond with available power
   Repeat 2 and 3 as needed.
4. Buy/Sell power from grid when neighbors are exhausted.
5. Use local storage to offset utility cost.
   (min cost and max profit)
   Also needed for island operation as energy source.
Threats To Distributed Energy System

- **Hardware Degradation**
  - Maintenance required
  - Rollback and Recovery

- **Software Failure**
  - Residual Design Flaws
  - Rollback and Recover with Alternate Algorithms

- **Hackers**
  - Teenager in the basement hacking into an IEM
    - Denial of Service Attack

- **Information Warfare**
  - Buffer Overflow and Quality of Service (Denial of Service)
  - Confidentiality of decision making
    - Integrity attacks

- **Confidentiality**
  - Information flow - Multi-level security model
  - Less studied aspect in the cyber-physical world – key problems arise from observation of physical interactions
Security and Privacy

Would you sign up for a discount with your power company in exchange for surrendering control of your thermostat? What if it means that, one day, your auto insurance company will know that you regularly arrive home on weekends at 2:15 a.m., just after the bars close? (MSNBC Red Tape Chronicles 2009)
Information Flow Models

- FREEDM contains Power Electronics Devices that perform physical actions that are observable
- Cannot keep these secret – loss of confidentiality/privacy
- Some other models
  - Non-Interference
    - High-level events do not interfere with the low level outputs
  - Non-Inference
    - Removing high-level events leaves a valid system trace
  - Non-Deducibility
    - Low-level observation is compatible with any of the high-level inputs.
Microgrid Observability
Fred and Barney

• Share Resources and Make a Profit
• Fred Gets Greedy
  – Stores wind energy and sells on his own
• Barney Gets Suspicious
  – Observes Fred’s wind and power draw from utility
  – If the wind isn’t blowing and Fred is selling to the grid, Fred is dishonest
  – If the wind is blowing, Barney cannot deduce anything
Microgrid Observability

- “Dumb” System from an Observer is Nondeducibility Secure
- Dumb System from an External Observer is NOT Nondeducibility Secure (if we can see everything)
Does Distributed Intelligence Help?

- Observer node without DGI cannot ascertain anything
- Observer node with DGI is NOT Nondeducibility

  Secure

  – I can hack into the DGI and observer Send or Receive of Loads for most of the system
Wrap up

• Smart Distribution Systems
  – Very new – power electronics and distributed computing
  – Many difficult issues for Electrical Engineering, Computer Science, and Materials Engineering

• Consumer Acceptance and Usage
  – Social Science

• All a type of “Smart Grid”