Operation and Markets in Changing Electric Power Systems-Challenges and Opportunities

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Outline

- Very brief description of our EESG@MIT research group
- Need for new SCADA and enhanced control in systems with renewable resources
  - During normal operation. During extreme conditions (equipment failures)
- Potential benefits from such SCADA-enabled control
- Our Dynamic Monitoring and Decision Systems (DyMonDS) unified approach; Both technical and market signals included
- The need for scalable electric power system simulator of the grid and the effects of new control on its performance
- Possible ways for collaborating

Electric Energy Systems Group at MIT

https://lids.mit.edu/labs-and-groups/electric-energy-systems-group-eesgmit

Research Goals

- **Formulate, model and simulate electric energy systems as complex dynamical systems**
- **Design cyber systems for enabling their performance (SCADA, markets, control, optimization)**

Systems Tools

- Modeling of complex systems
- Network Systems
- Control methods
- Numerical and simulation methods
- Distributed interactive systems

Current research areas

- Microgrids
- Electricity markets
- Scalable power system simulators
- Cyber-Secure Energy Systems
- Social-ecological energy systems

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Electric power system is changing

- **Evolution of electrical power system architectures**
- Electrical power systems architectures started as small low voltage DC distributed grids (Pearl Street, NYC);
- Grew into AC interconnected systems supporting economies of scale supply and power delivery to aggregate loads via EHV/HV/MV power networks and further distributed via local LV distribution grids (no resources close to small end users).

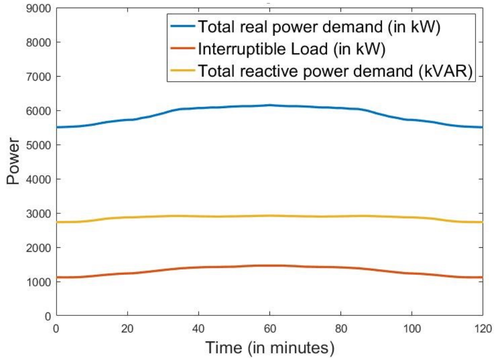
Architecture changes..

- This hierarchical architecture has served society well, electricity services have been relatively low cost and fairly reliable (the most frequent interruptions at the LV levels, very little observability and control).

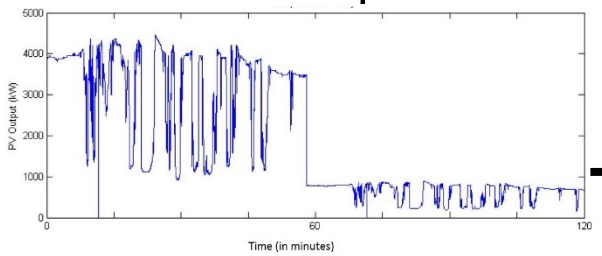
- Most recently, fundamental architecture is changing—"open systems"; distributed technologies, much more observability and controllability; much more intermittency; end users potentially active participants.

Emerging microgrid— potential of smarter control

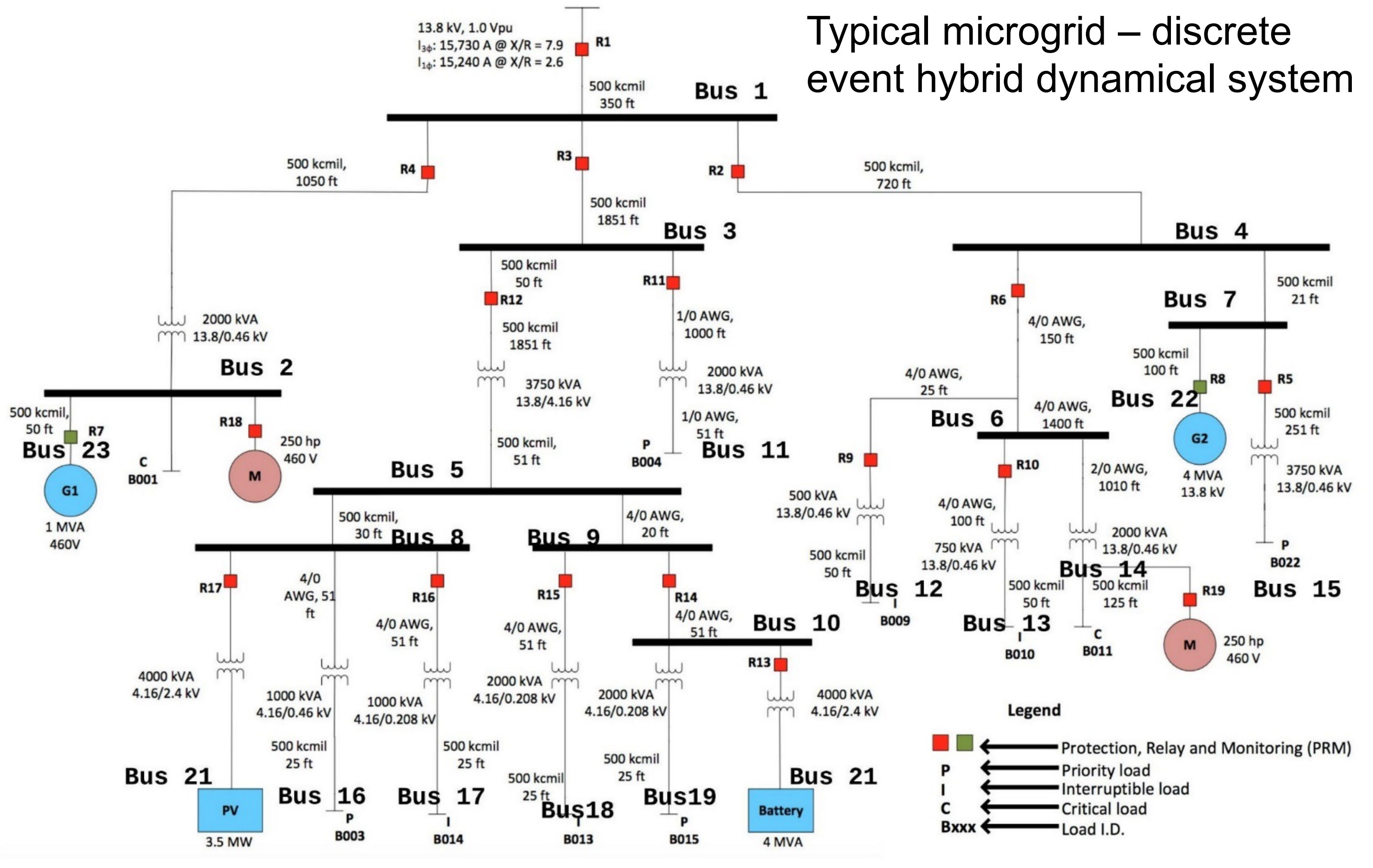
Load Profile



Solar PV output



Typical microgrid – discrete event hybrid dynamical system



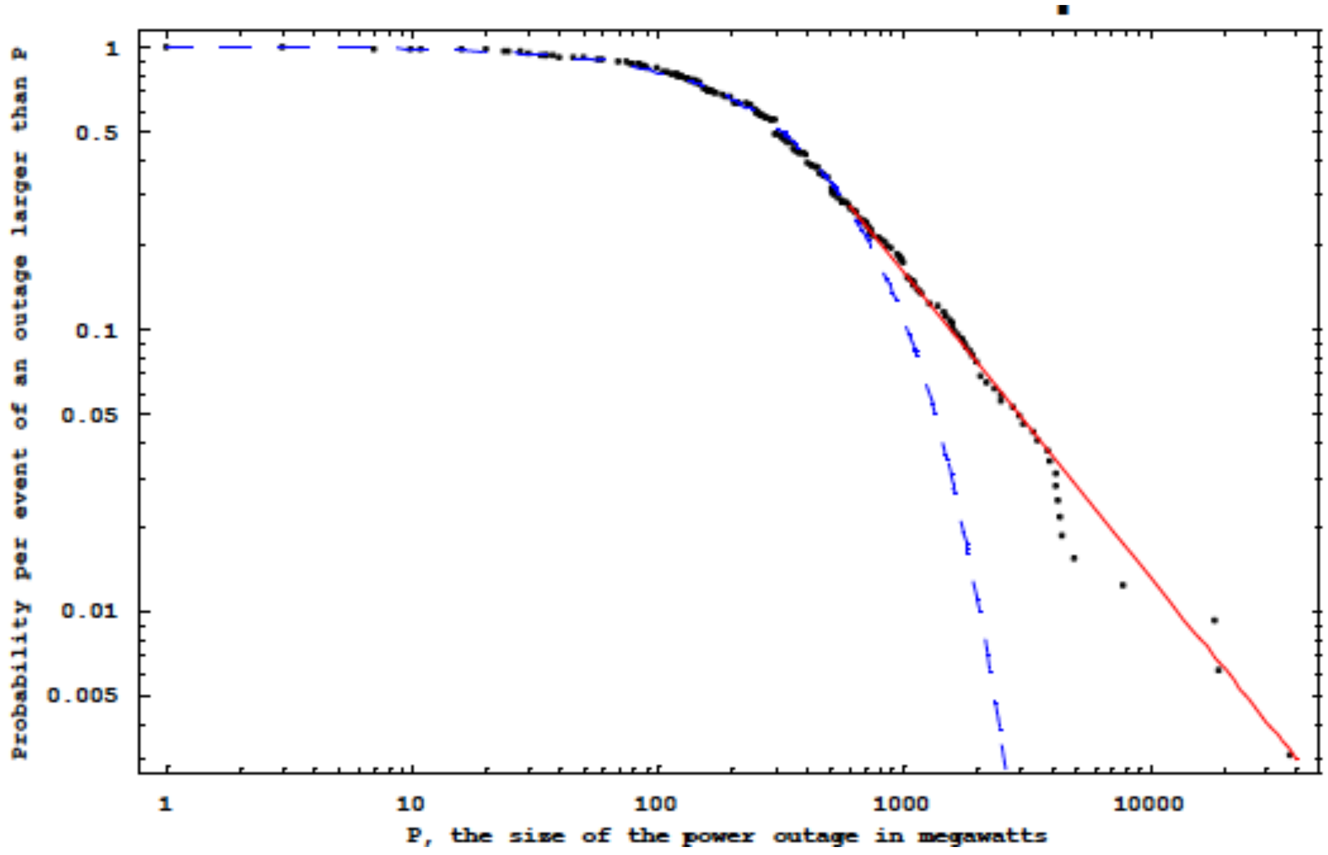
HUGE DEVELOPMENT COST!

Today's operating paradigm in large grids—
need for smarter control

- Typical of any hierarchical top down approach. Lots of feed-forward, very little feedback in normal operations.
- The off-line worst case approach is mainly taken to have sufficient spinning reserve for extreme conditions.
- Distributed frequency regulation (AGC)-utility level feedback
- The only continuous feedback PID controllers embedded in large power plants (governors and automatic voltage regulators.)
- IT IS NOT CHANGING TO ACCOMMODATE NEW ARCHITECTURES.
- GREAT DIFFICULTIES BY UTULITIES INTEGRATING END GRID ACTORS.

Potential benefits--in both normal and extreme conditions

- Cumulative inefficiency; high impact low probability events.
- Statistics on blackouts



Key role of control and protection in preventing blackouts

- The root cause of major historic blackouts have been hidden failures in control and protection systems.
- So, during blackouts protection gives false alarms (acts too soon) in response to a nearby equipment failures, disconnects their equipment and this makes the situation worse, cascading follows.
- Control is generally not designed to ensure stable and feasible response to large equipment failures.
- Academic research has been done to re-think control and protection principles, but technology development has been slow.

Fundamental modeling and control design

Issues

Specific to temporal and spatial scales of interest

Difficult to compose interconnected/ multi-layered models

Fundamental problems

Stiffness of the system to simulate as a flat monolithic entity
Non-scalability (temporal and spatial)

Interfaces and functional characteristics inconsistent

Dynamic Monitoring and Decision Systems (DyMonDS)-- ALIGNING ARCHITECTURE AND OPERATING PARADIGM

- **Multi-layered modular interactive modeling, simulation and cyber design framework – next generation SCADA**
- **In terrestrial power systems this means having smarts embedded in very complex loads, wires, storage, power plants, and having minimal coordination of energy/power/rate of change of power dynamics monitored/control at the interfaces of layers.**
- **Azores Islands project** (long-term cost effective, near-zero emission systems) –Springer book
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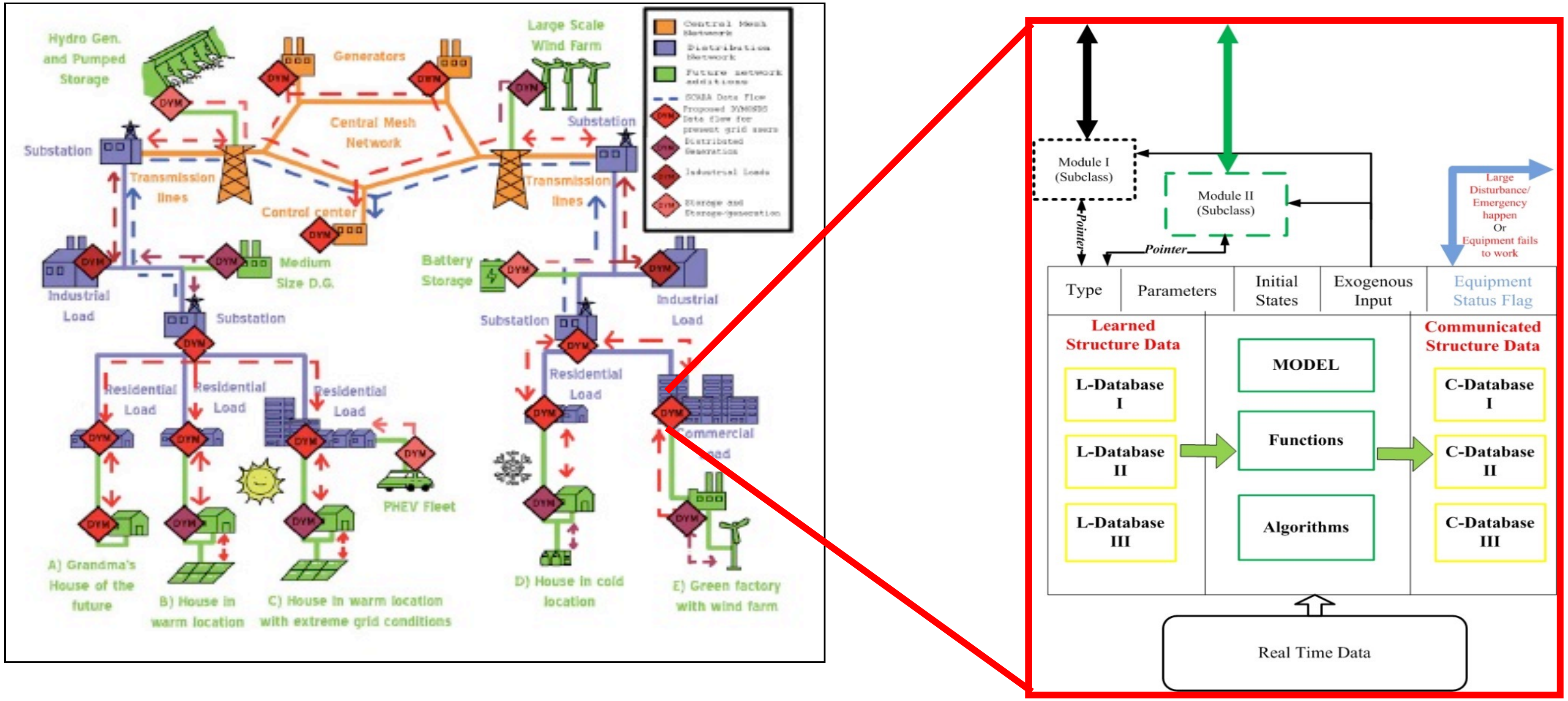
Multi-layer modular modeling for DyMonDS



Local DyMonDS module

The key R&D challenge (1)

- Unified modeling in transformed state space (modules use technology specific models; interface dynamics in terms of common variables based on general conservation laws in complex systems; scalable modeling, simulations and lower development (plug and play) cost ; autonomous industrial systems.
- Demonstrate on reconfigurable microgrids.
- Demonstrate on very large-scale electric power grids with lots of renewable resources (China grids, US continental grid)

The key R&D challenge (2)

- **SCALABLE ELECTRIC POWER SYSTEM SIMULATOR (BASED ON MULTI-LAYERED MODULAR MODELING);**
- COLLABORATING WITH NATIONAL INSTITUTE OF STANDARDS (NIST); JAPANESE RESEARCHERS –HARPS (Harmonized Power Systems) and GERMAN RESEARCHERS (IWR, Heidelberg). STILL TRYING TO RAISE MAJOR SUPPORT TO MAKE SEPSS AN OPEN ACCESS FACILITY TO RESEARCHERS TO DEMONSTRATE THE EFFECTS OF THEIR PROPOSED SOLUTIONS PRIOR TO BUILDING

Summary of our unified approach to control design for the changing electric power systems

- As in DyMonDS, for designing technology-specific best solutions details are needed so that specifications in terms of common variables are given so that interactive multi-layered integration becomes possible.
- Much on-going work on designing such control for integration of renewable resources.
- EESG@MIT group is pursuing these efforts.
- It would be tremendous to explore these opportunities with industry.

Possible ways for collaborating

- Perhaps most progress/tech transfer can be done short term working on “microgrids” with good understanding of their “loads” (interfaces with vehicle; proactive inclusion of large controllable clean electricity users).
- Close collaboration with industry can also help design next generation SCADA which would support clean and reliable services in very complex bulk power systems (like China, and continental US).
- Consider working on SEPSS for Chinese grid or for its regions to assess potential benefits from new SCADA and our control designs. This would open major doors to integrating all types of technologies into the legacy system at value.

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THANK YOU

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