Optimization & Control Theory for Smart Grids

DR 2010 pre-proposal

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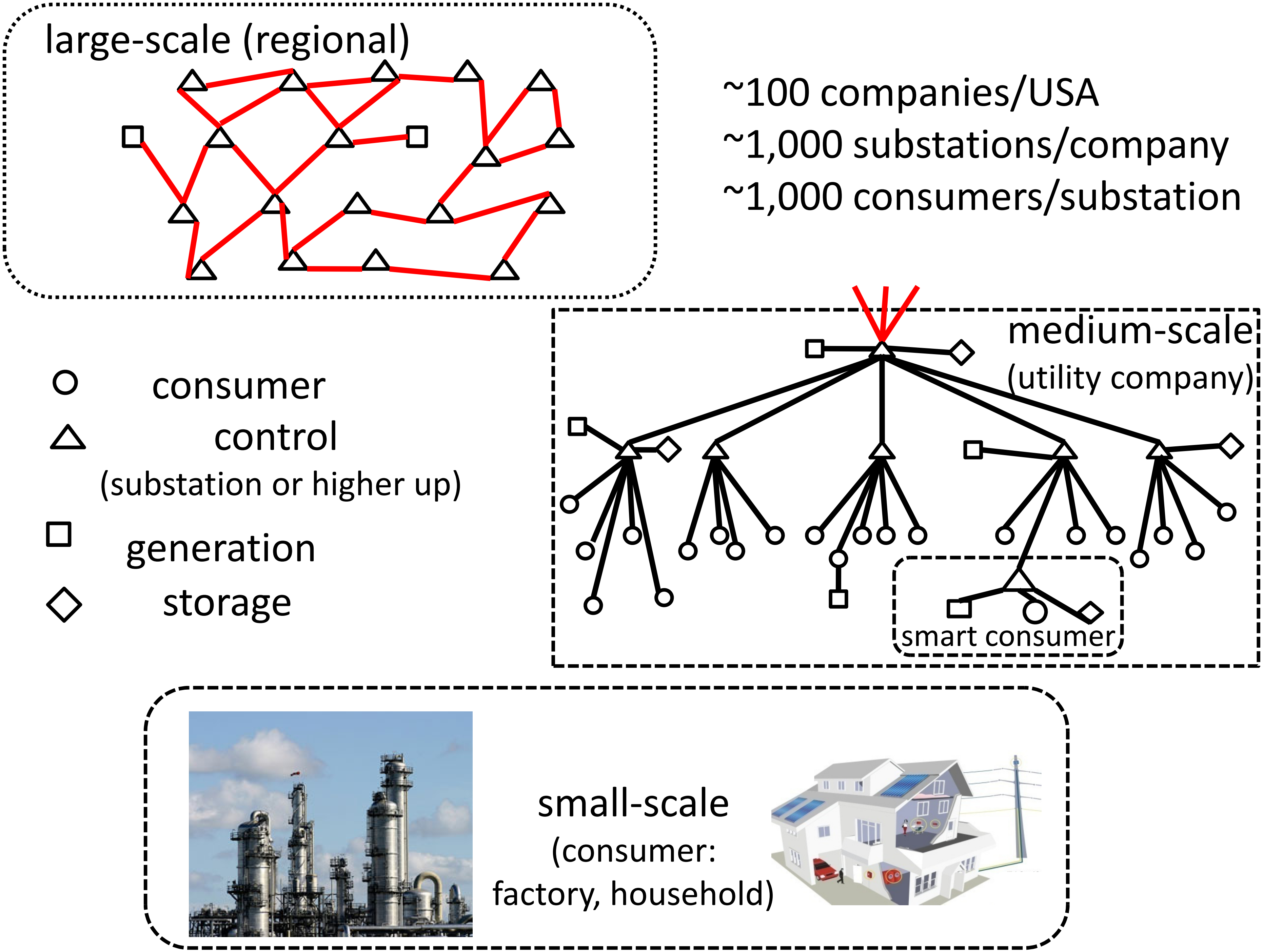
- What are smart(er) grids (scales, challenges)?
- What do we suggest?
- How do we do it (problems, capabilities)?
- Modus Operandi & Integration/Collaboration



large-scale (regional)
~100 companies/USA
~1,000 substations/company
~1,000 consumers/substation
consumer
control
(substation or higher up)
generation
storage
medium-scale
(utility company)
smart consumer
small-scale
(consumer:
factory, household)

DOE Modern Grid Initiative report.

The future smart grid must [Objectives]:

- Be able to heal itself
- Motivate consumers to actively participate in operations of the grid
- Be resilient to attacks
- Provide higher quality power that will save money wasted,
- Accommodate all generation and storage options (i.e. be flexible)
- Enable electricity (and generally energy) markets to flourish
- Run efficiently

A smart grid delivers electricity from suppliers to consumers using digital technology to save energy and cost. The term *"smart grid" represents a vision for a digital upgrade and design of distribution and multi-scale transmission grids.*

Control

Optimization

Our task is to develop CAPABILITIES at LANL

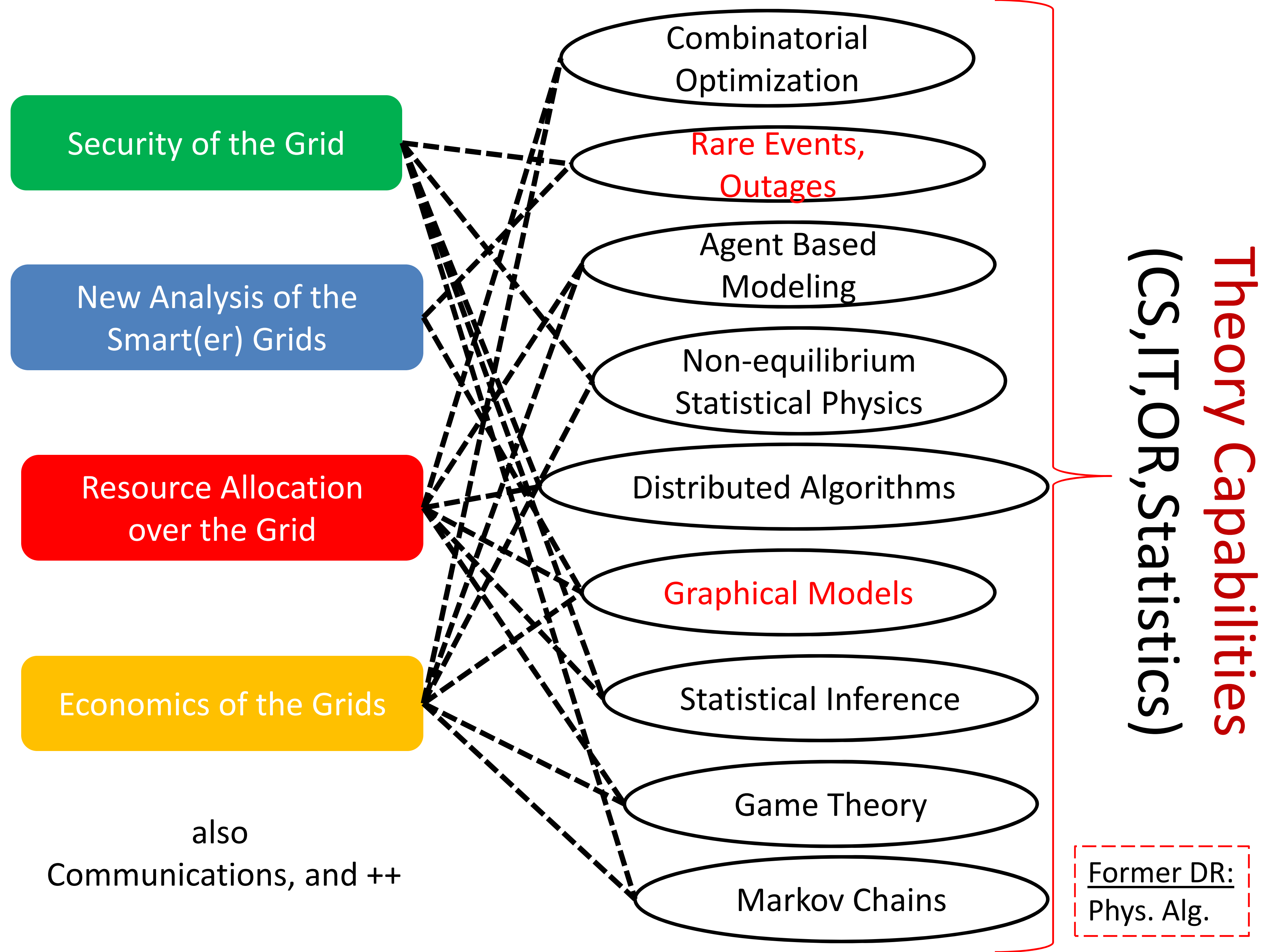
Control & Optimization Theory for Smart(er) Grids

We propose to develop:

new scientific framework and capability underpinning the design, optimization, and operation of the smart grid.

Framework will incorporate new realities of the smart grid, such as renewable resources, distributed generation and storage, smart controllers and appliances.

Main focus will be on detection and prevention of outages and developing efficient graphical algorithms for analysis and design of the smart grid and associated control network.


Security of the Grid
New Analysis of the Smart(er) Grids
Resource Allocation over the Grid
Economics of the Grids
also
Communications, and ++
Combinatorial Optimization
Rare Events, Outages
Agent Based Modeling
Non-equilibrium Statistical Physics
Distributed Algorithms
Graphical Models
Statistical Inference
Game Theory
Markov Chains
Theory Capabilities
(CS,IT,OR,Statistics)
Former DR:
Phys. Alg.

Grid Security -protecting against relatively rare but devastating outages. Using efficient power solvers and accurate grid model that includes intermittent generation and consumption, we will develop extreme events analysis for detection of rare but dangerous outages based on our new powerful instanton approach and importance-sampling method. The goal is to detect hard to identify failure modes of loads on power graphs and to predict the probability of coherent failure at medium-and large- scales (i.e. outages) on existing and smarter grids and to show how to heal or stabilize the damage. We will solve the combinatorial optimization problem: given an outage, distributed over the grid at a given instance, identify locations of cuts that preserve the maximum amount of total generated power possible. Using related Belief Propagation inference technique, we will look for optimal inter-utility regulations strategies to minimize outages.

New Analysis of the Smart Grids -defining the quality of renewable output predictions. As distributed renewable resources comprise a large fraction of generation, accurate predictions of their output are required to: a) maintain grid stability (according to an appropriate smart grid metrics); b) allow utilities to ramp up or down traditional fossil plants (i.e. supply-side management); c)redirect power into or out of available storage; d) adjust pricing to match supply and demand through demand-side management. It is unknown how far into the future these predictions must extend and how accurate they must be to meet these goals. By exploring the quality and time horizon of the predictions, we will identify important "break points" such as the minimum quality and quantity of information to maintain grid stability and the point of diminishing returns beyond which more information does not contribute to grid performance.

Resource Allocation over the Grid -intelligent placement and scheduling of generation, storage, and loads. The time-variable nature of renewable generation will be accommodated by physical storage (e.g. potentially batteries via vehicle-to-grid) or by virtual storage (i.e. information management and demand-side scheduling). We will evaluate the virtual storage capacity of different networks and determine optimal placement and sizing of renewable generation and new physical storage units. Identifying optimal placement of new equipment, influenced by geography and the proximity to existing grid resources, will require new scalable and distributed graphical algorithms. We study fundamental structural dilemma, e.g. economical but unstable tree vs robust but redundant lattice, guiding design of future smart grids at different scales.

Economics of the Grid: -optimal pricing and regulation to drive optimal grid performance. We adopt the OR approach which suggests that it is advantageous to introduce spatio-temporally evolving prices, demand-side management and develop optimal pricing theory to challenges of the smart grid. When it comes to priorities of government regulation, creation of a fair market is one criterion which should be considered on par with other, such as control of outages and admitting the largest fraction of renewable generation as possible.

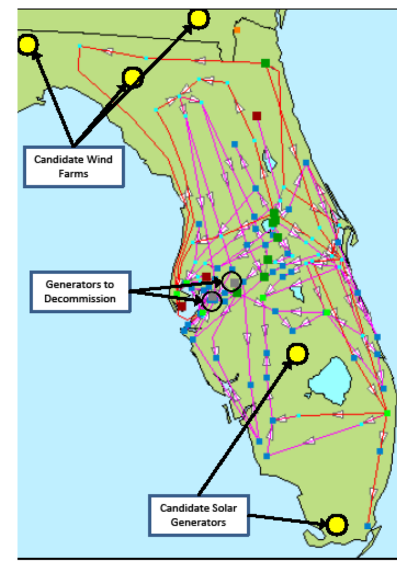
How do we do it? [strategy]

- *Identify* [~20%] the host of important Optimization and Control problems
- *Suggest* [~10%] new or adopt existing models
- *Analyze* [~50%] the models=> optimization, control suggestions => algorithms
- *Verify & Validate* [~20%]the models, data from PNM, NREL, IEISS/DHS.

Build it in *Interdependency Environment for Infrastructure Simulation Systems* (IEISS) of D-4

+ *Collaborations with*

- Academia: a) LIDS & MIT Energy Initiative
  b) NM Consortium
  c) EECS U of Wisconsin-Madison
  d) EECS U of Minnesota
- Operators/Industry (PNM – smart initiative)
- DOE (NREL- smart city Boulder)



Transition to Programmatic, e.g. with extensive collaboration & help of IS&T institute, Energy Institute and D-division