Laminar Control for Distributed Generation and Microgrid Integration

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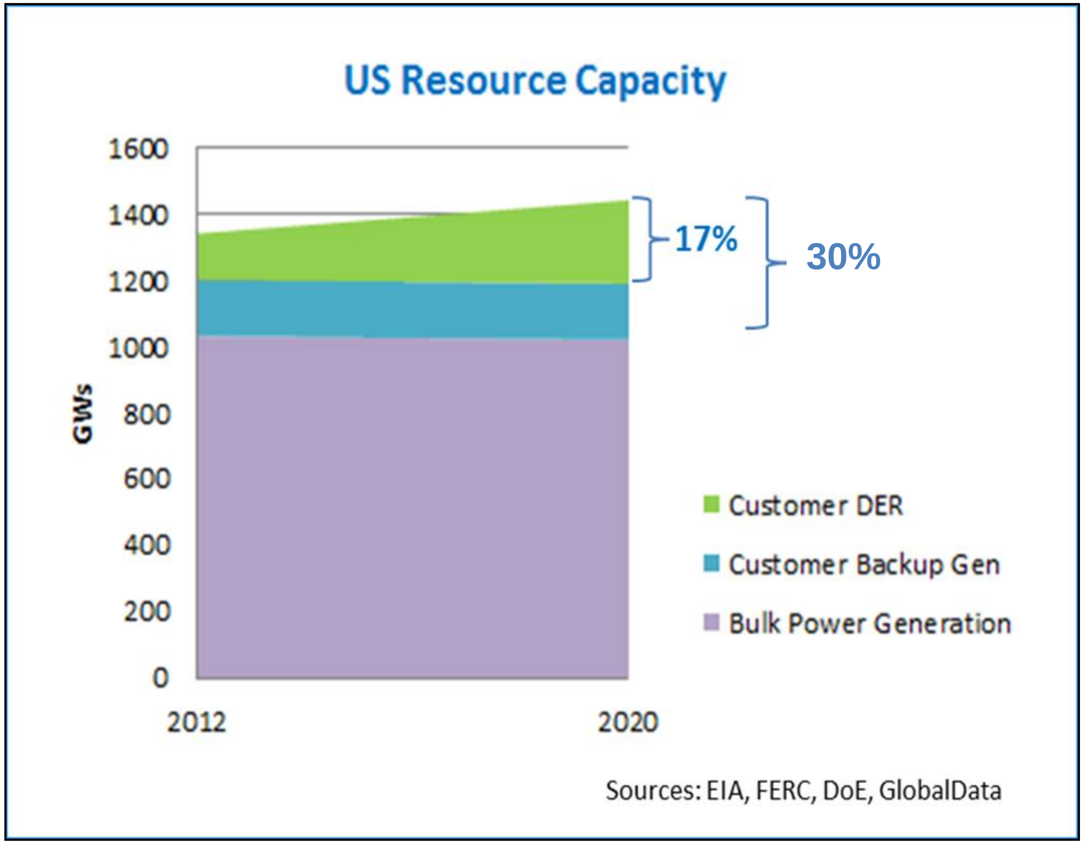
Emerging Issues

- Changes to power grids are in the process of violating most previous grid operating assumptions
- Existing controls are becoming inadequate
- Faster operations, significant interactions growing, even across tiers
- Multi-controller, multi-objective control emerging
- Hidden coupling via the grid becoming significant
- Resulting in destabilization

DER will reach 30% of Installed US Capacity by 2020

Effectively all incremental growth in capacity will come from customers



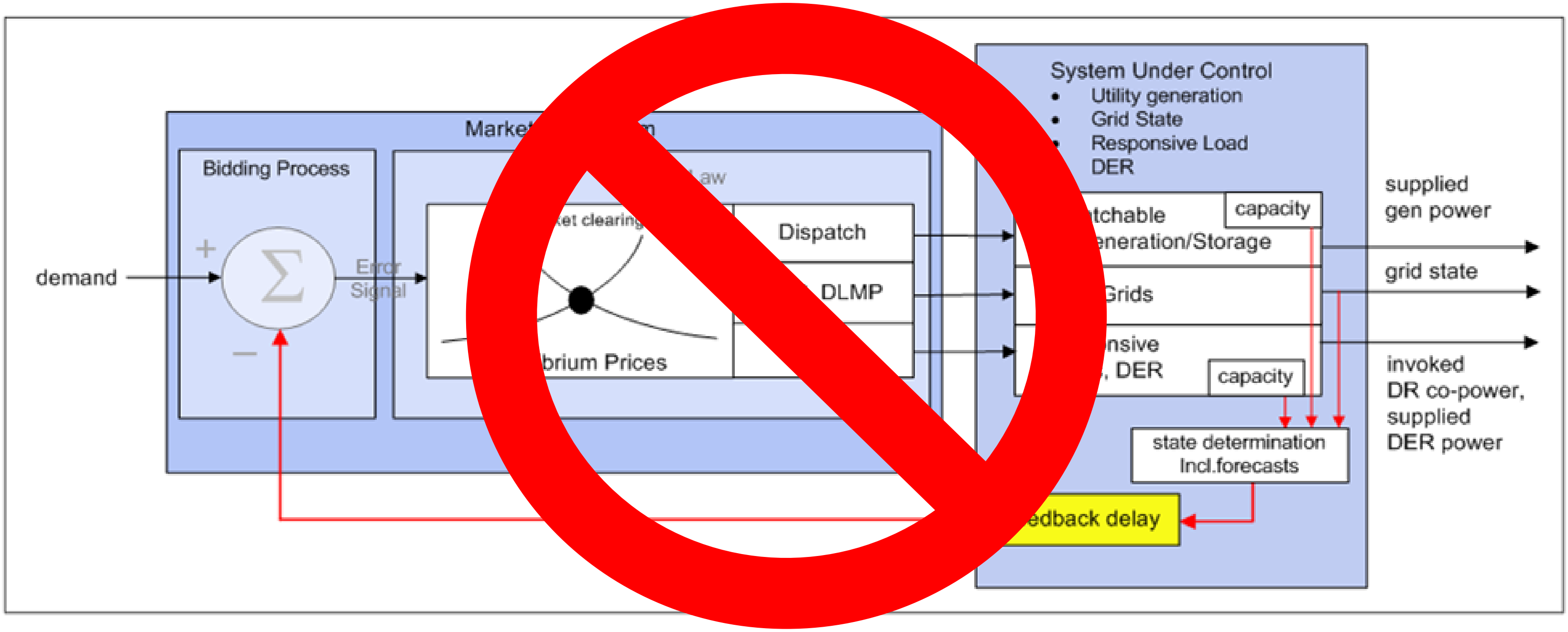
Backup Generation:	**225 GW**
CHP:	**122 GW**
Demand Response:	**90 GW**
Solar PV:	**50 GW**
Other DG:	**25 GW**
Dist. Storage:	**3 GW**

Potential DER Total: 515 GW

Problematic Approaches: Embedding Markets

Current market designs may act as a control element in a feedback control loop, whether intended or not.

- Hidden feedback
- Flash crashes with programmed trading
- Lack of tools to ensure stability in prices and grid operations



Origins of Laminar Control

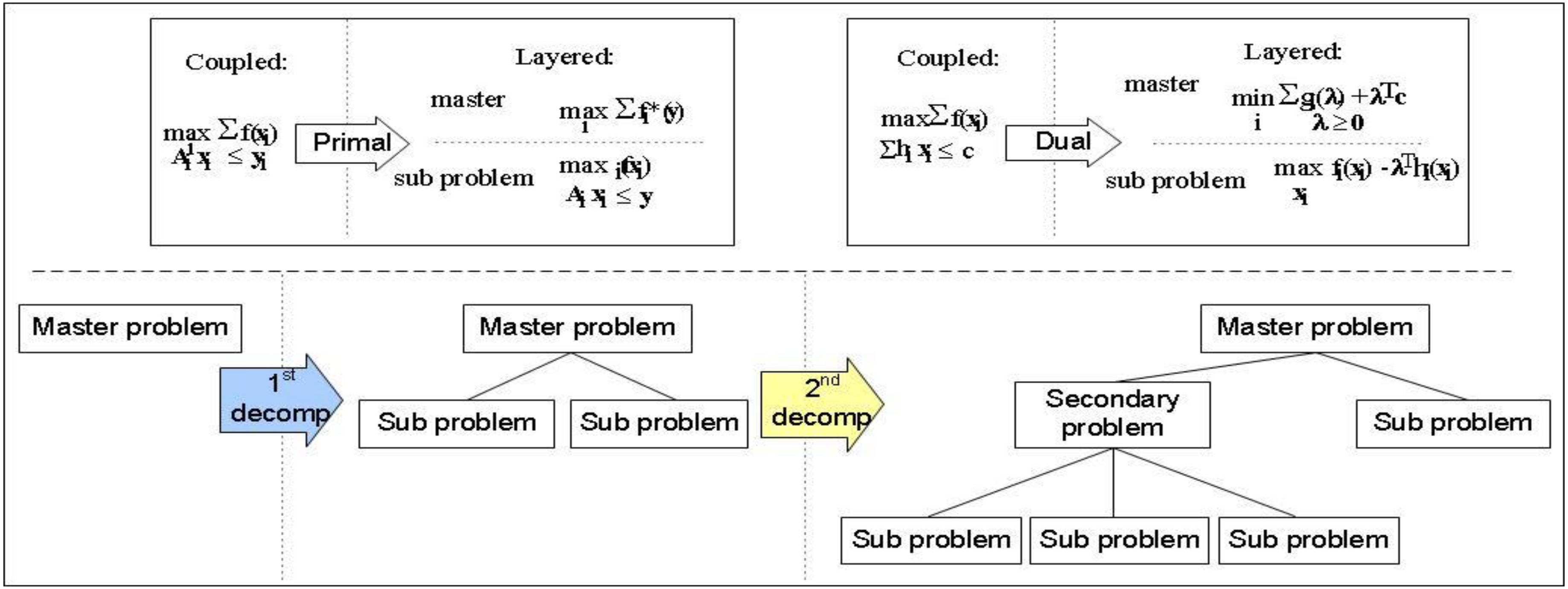
- Layering for Optimization Decomposition (control engineering)
  - Widely used to solve coupled optimization problems
- Network Utility Maximization (networking)
  - Used for power allocation and congestion control in networks
- Receding Horizon Control (control engineering)
  - Widely used in process control
  - Model Predictive control

The combination of these three methods to hierarchical infrastructure leads to what we have named

Laminar Control

Layering for Optimization Decomposition

- Based on layering for optimization decomposition
  - Use network utility maximization as template for optimization
  - Apply convex relaxation as needed
- Leads to a distributed control architecture



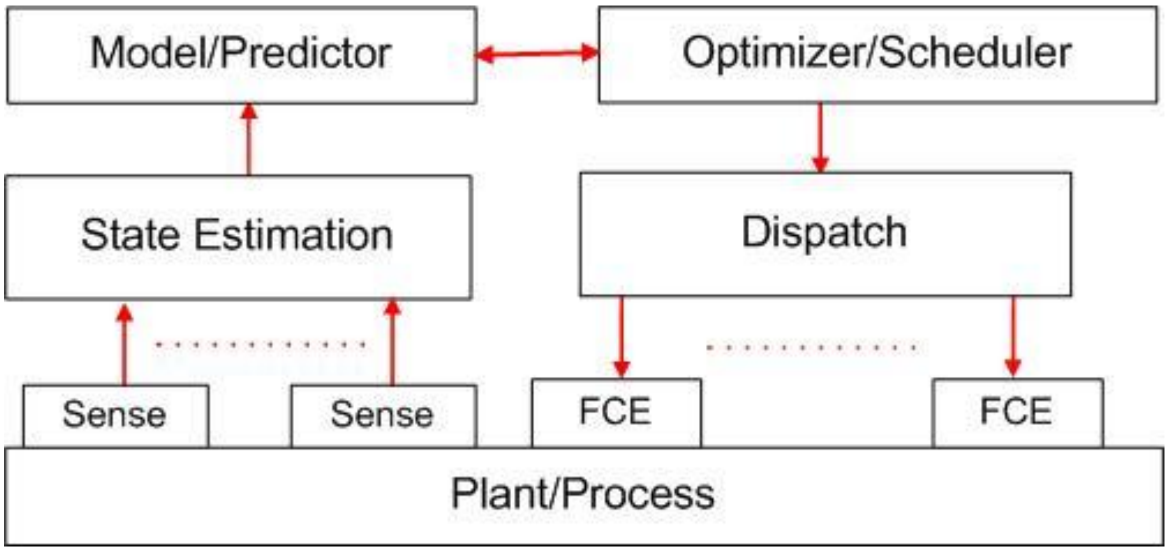
Daniel Palomar and Mung Chiang, "Alternative Distributed Algorithms for Network Utility Maximization: Framework and Applications," **IEEE Transactions on Automatic Control,** Vol. 52, No 12., December 2007

Network Utility Maximization

- Utility functions have strong connection to economics
- Utility has been applied to layered network architectures as a means to capture:
  - End user objectives
  - Constraints and dynamics
  - Design degrees of freedom
- Network Utility Maximization provides formulations that can be vertically decomposed, thus matching system layers
- Has been applied to communication network control issues
  - TCP/IP congestion management
  - Wireless network channel power allocation
- Now being applied to other forms of control

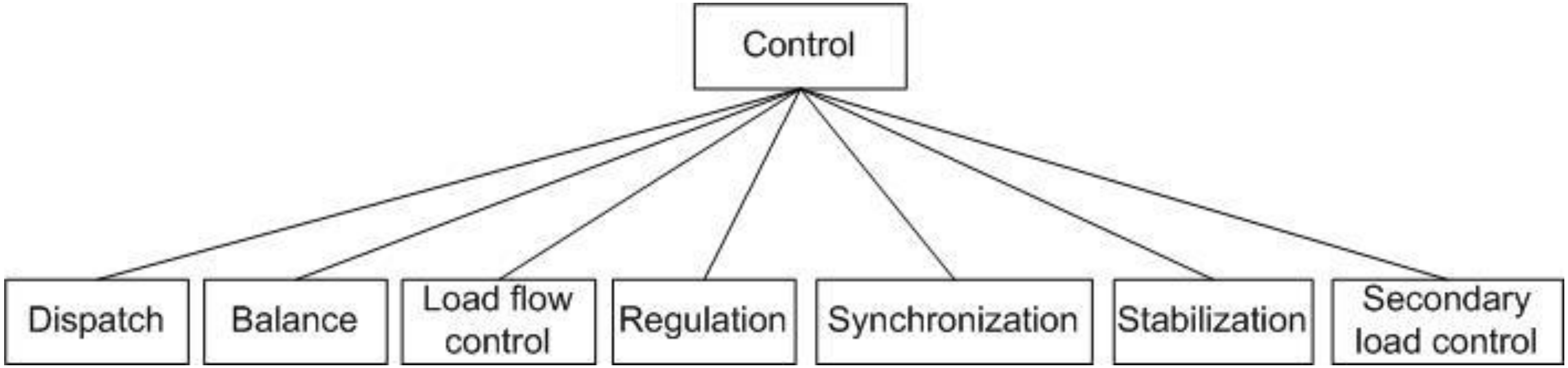
Receding Horizon/Model Predictive Control

- Measure/estimate system state
- Solve an optimization problem over a time horizon (N time steps) using a system model
- Execute the control for one time step, then repeat the process
- Widely used in process control
- Note the similarity to OPF



Applying Laminar Control to Power Grids

- Top level problem is "grid control"
- Too complex to formulate and solve directly
  - Too many constraints
  - Too many objectives
  - System and organizational boundaries
- Decompose by layers
  - local selfish optimization
  - boundary deference
- Eventually reach end point devices



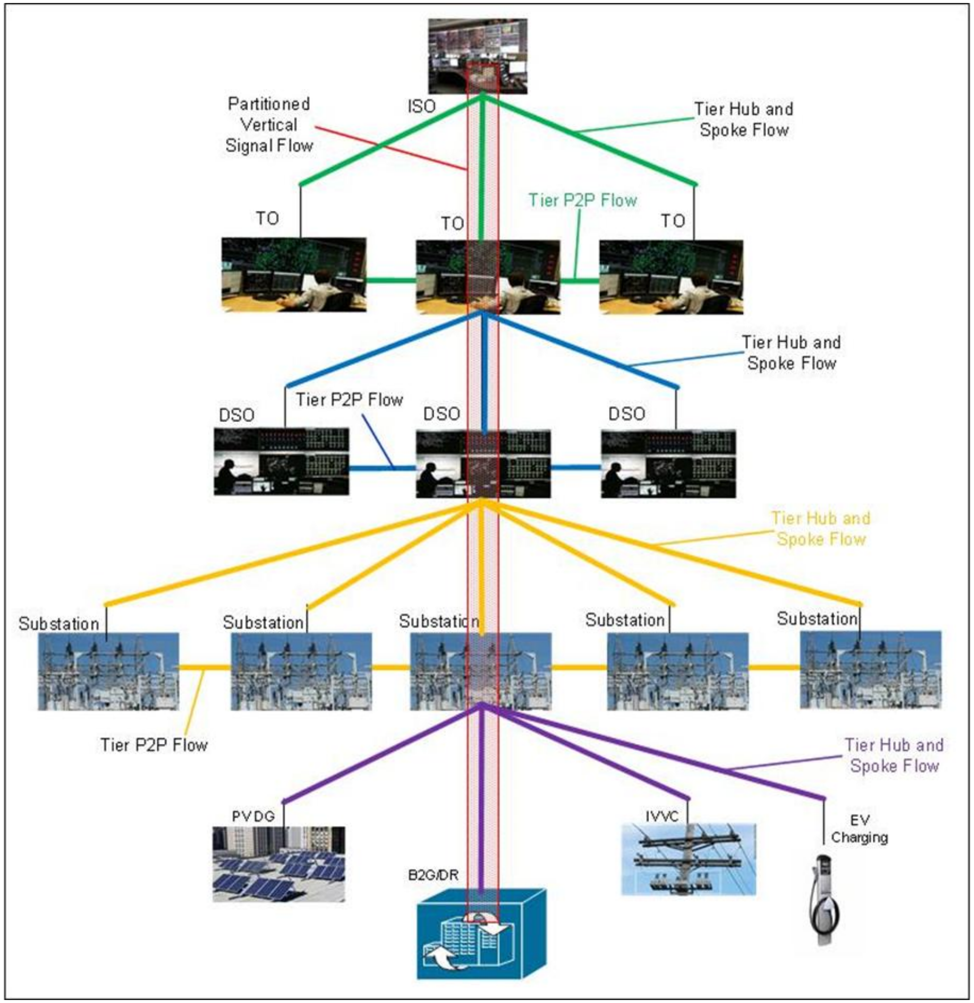
Mapping Laminar Control to Power Systems

Structured network of optimization nodes communicates hierarchically via scalar signals to cooperate in solving a joint optimal control problem.

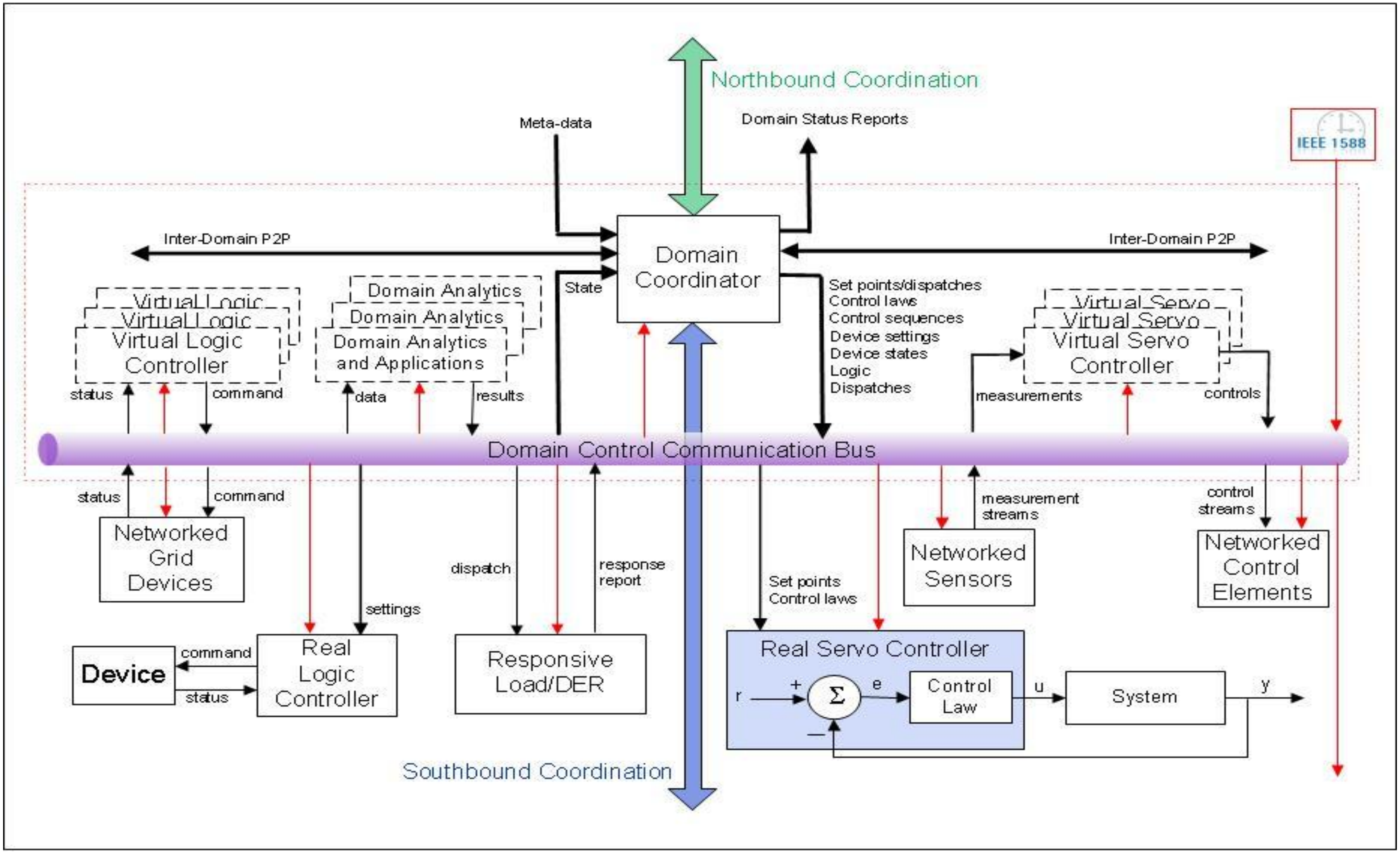
Node tree starts at the balancing authority and spans transmission, distribution, and even prosumer elements if needed.

Layered decomposition can be mapped onto the structure of the power grid to solve the control issues of federation, disaggregation, and constraint fusion while allowing for local "selfish" optimization.

Scalability



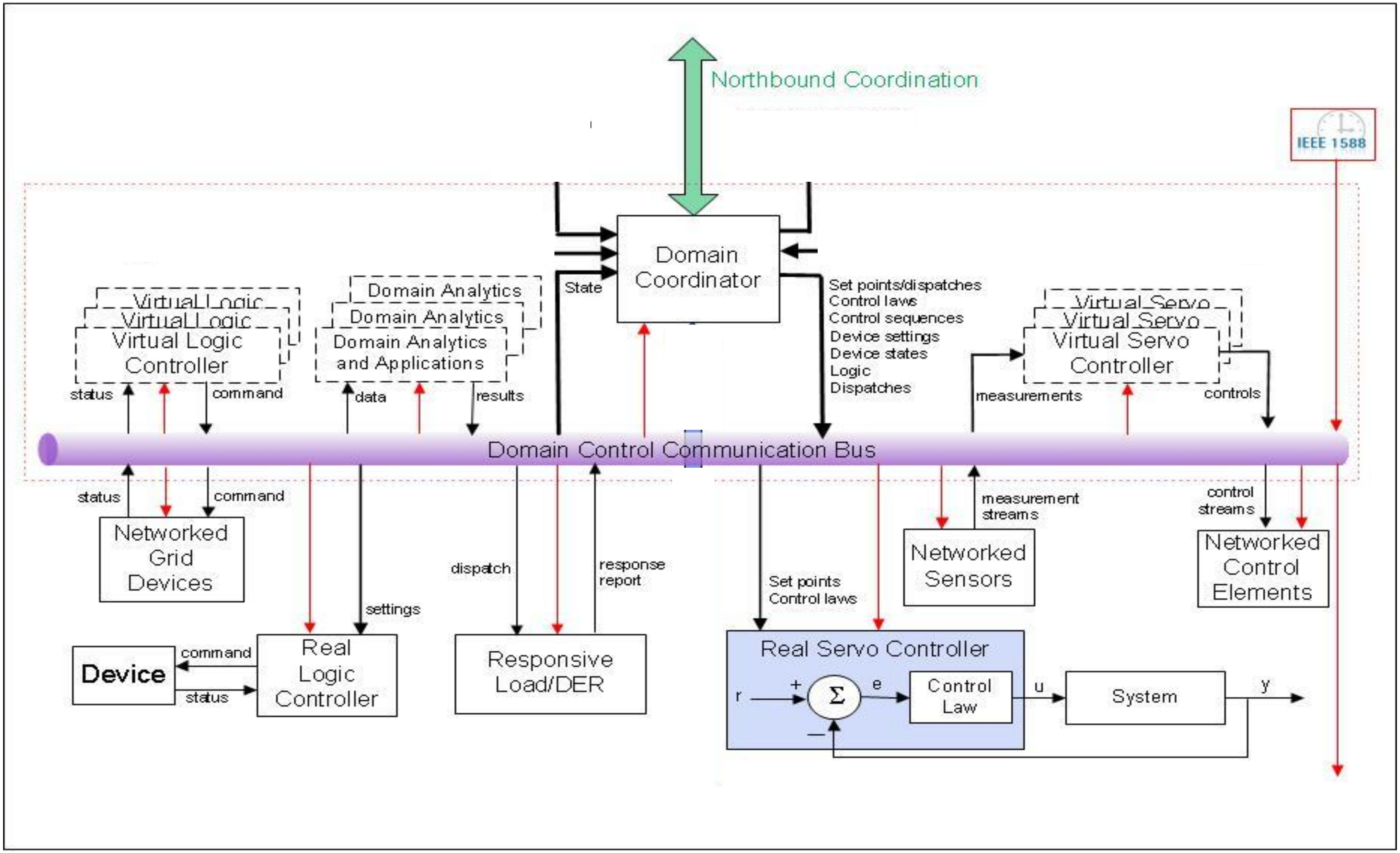
Familiar Data Flows Inside Domains



Implications for DG and Microgrids

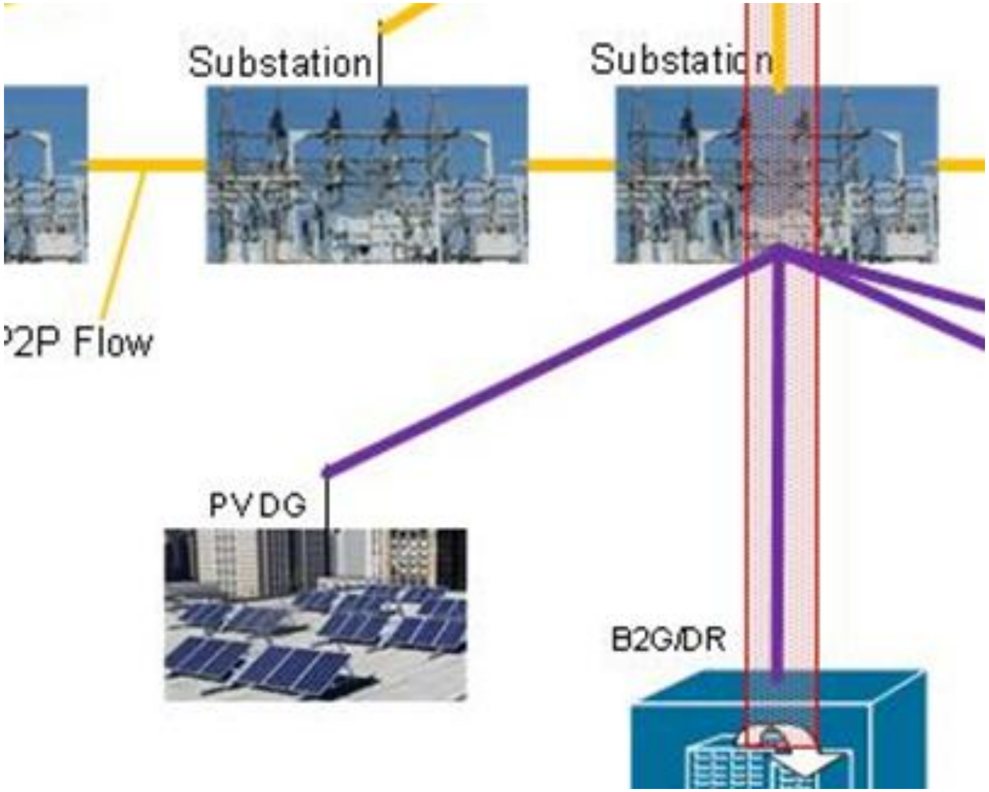
- Laminar Control can provide the standard way to integrate with utility grid control systems
  - DG and whole microgrids can be endpoints in the Laminar chain
  - Simple interfaces and optimization computation
- Can participate in joint market/operations optimization via the coordination mechanism inherent in Laminar Control
  - Coordinate with utility distribution ops
  - Also with DR/responsive loads
- The Laminar Control model can be applied recursively inside the microgrid as well

A Microgrid Domain Example



Distributed Generation Integration

- DG may be a simple endpoint or may be complex
- If it is simple (i.e. a legacy device) then optimization node can be at substation or on feeder section
- If it is complex, then it may contain its own optimization node



Conclusions

- Laminar Control combines several known methods of control
- Applied to grid structure it can provide:
  - Deep area coordination
  - Objective federation
  - Control disaggregation
  - Constraint fusion, including stability constraints
  - Boundary deference
- Facilitates traditional control as well as transactive approaches by allowing joint economic and operational optimization

thank you