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Energy Storage as Core Grid Infrastructure

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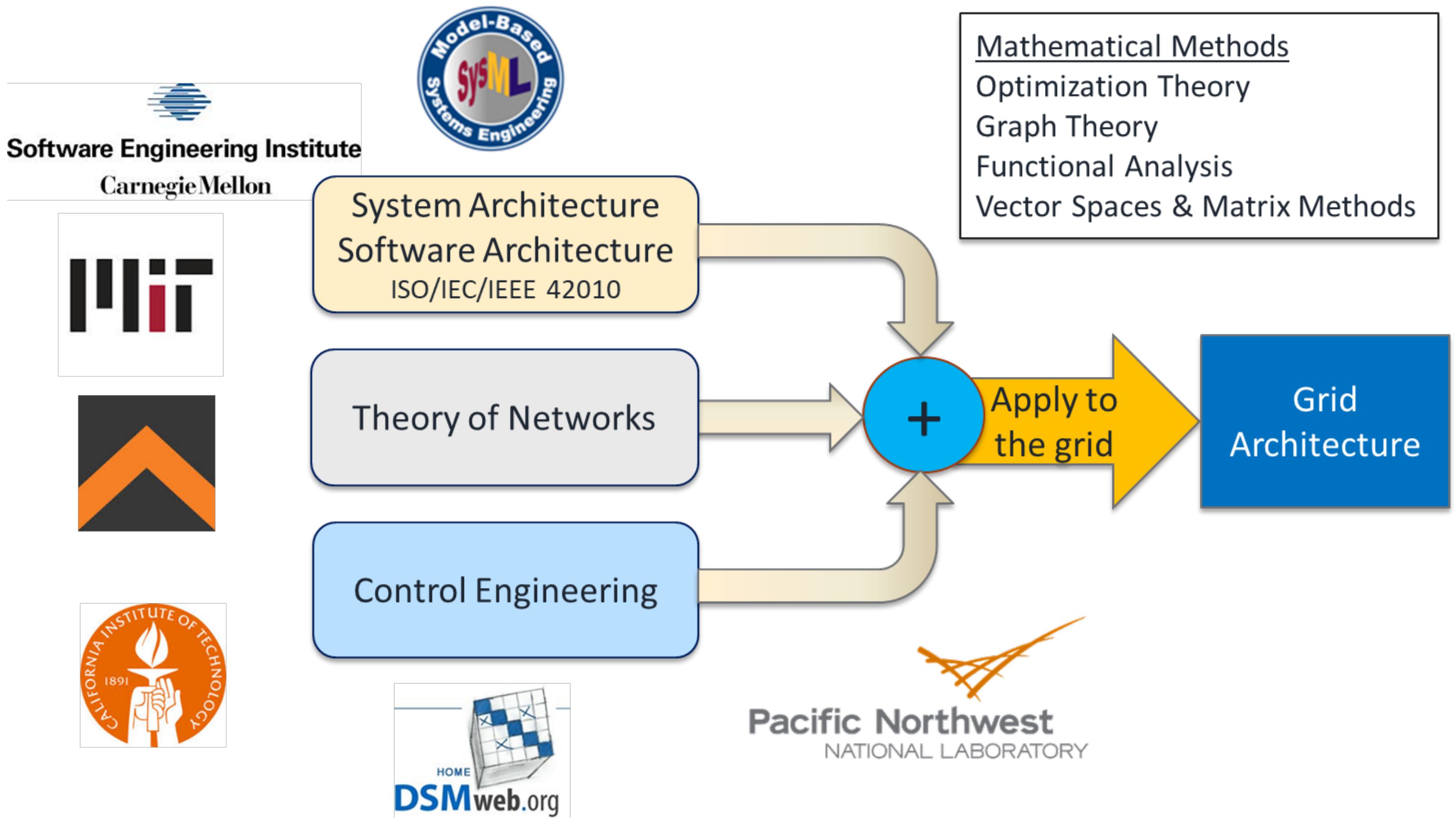
Understanding the Whole Grid: Grid Architecture

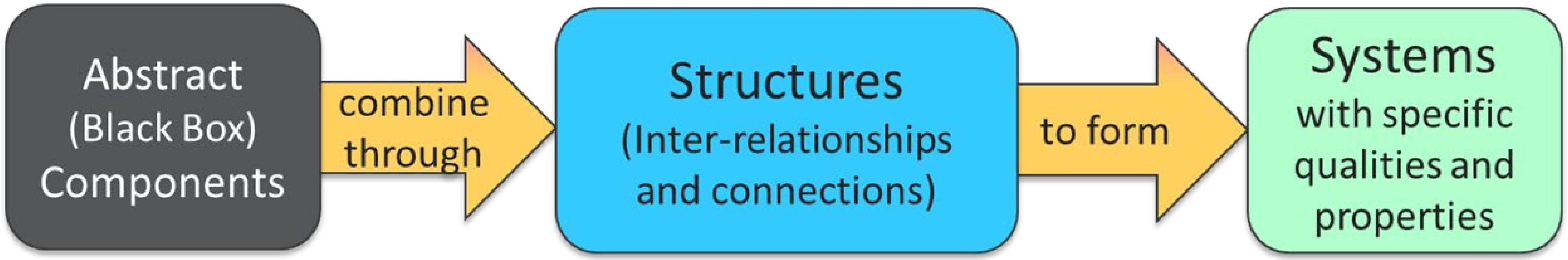
Grid Architecture is the top level view of the whole grid; it enables reasoning about the grid's properties, behavior, and performance.

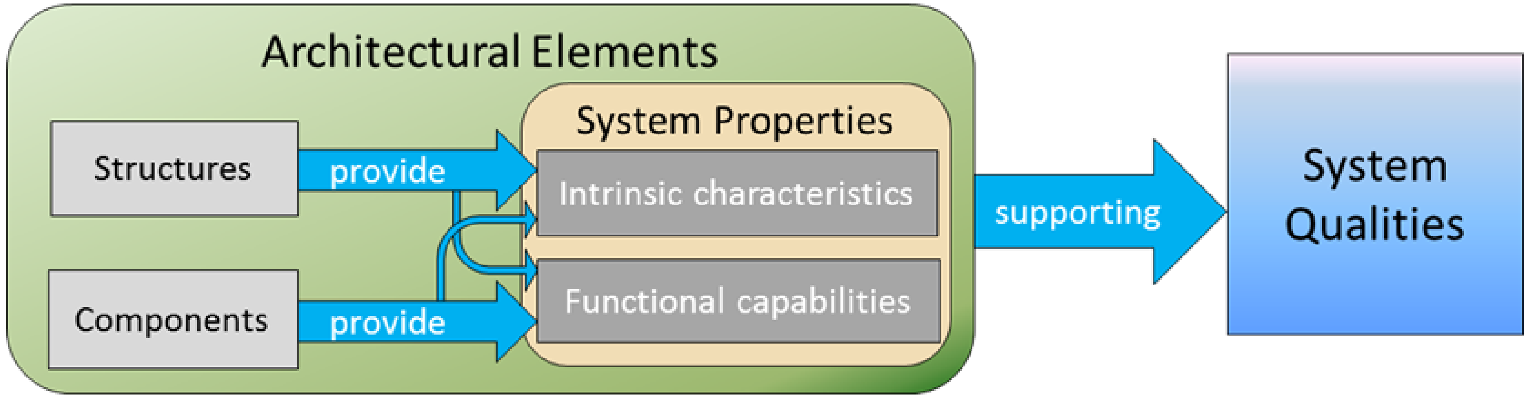
Grid Architecture is about ***structure*** - structure sets the essential limits on what complex systems like the grid can and cannot do. Components are black boxes: we are agnostic to technologies.

- Identify legacy constraints
- Remove barriers and refine essential limits
- Help manage complexity (and therefore risk)
- Improve structural grid characteristics
- Identify technology gaps
- Assist communication among stakeholders
- Define platforms
- Inform interfaces and interoperability



The Grid Architecture Perspective





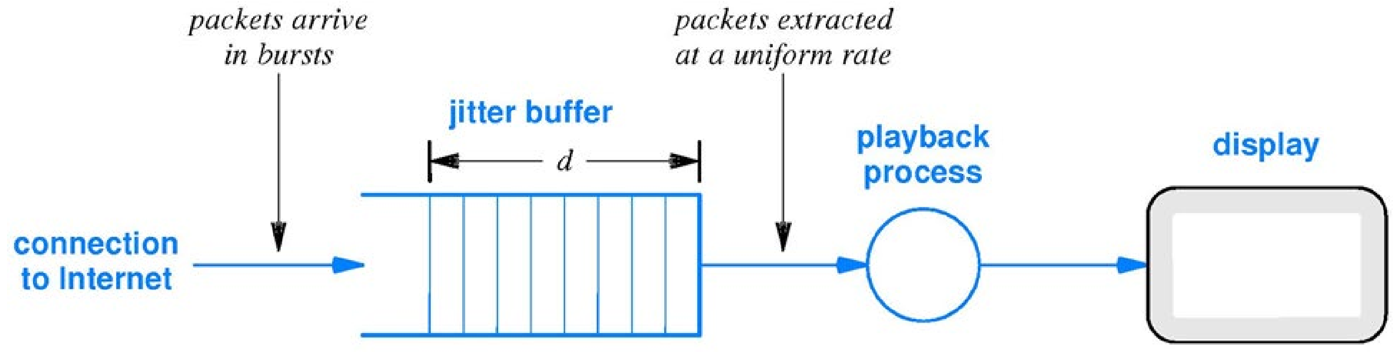
The grid is deficient in two key characteristics:

- Resilience
- Operational Flexibility

These are largely traceable to a single structural factor: lack of internal system-wide buffering.

The Role of Buffering in Complex Systems

- Most complex systems have buffers
  - communications (jitter buffers)
  - logistics (warehouses)
  - water and gas (tanks)



- Buffers decouple flow variations (volatility)
- This gives a system “springiness” that makes it resilient to a variety of perturbations
  - Lack of “springiness” (buffering) is a vulnerability
- Power grids lack such springiness

The grid needs shock absorbers.

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What is Unique About Bulk Energy Storage?

Conventional view: storage is a swiss army knife

- Lots of functions – just pull out a blade
- Leads to value stacking and the “but it can be done more cheaply” syndrome
- Used as a marginal point solution or an ancillary services device, not as a system component, mostly for reliability reasons
- Fundamentally anti-resilient

Systemic view: storage is a shock absorber

- One function: to decouple power flow volatilities
- Directly improves system-wide grid characteristics: resilience and operational flexibility
- Becomes a core grid component, as fundamental as a power transformer or a circuit breaker
- Can be implemented in highly resilient distributed form

Storage Characteristics from a Systemic Perspective

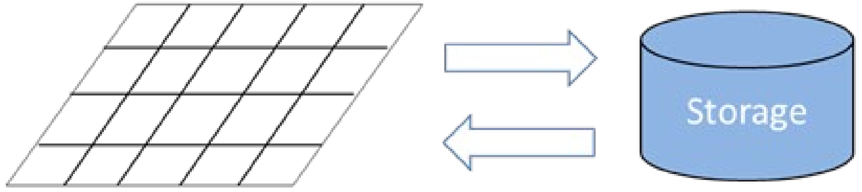
Many storage technologies and uses

(see the technology taxonomy diagram in the paper)

For our purposes we need:

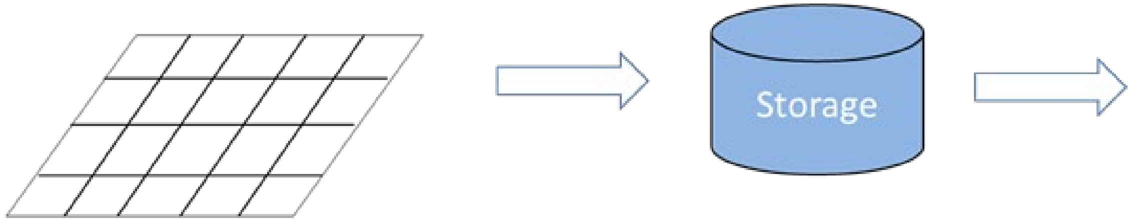
- Reflexive operation
- Fast symmetrical power flow in and out
- Very fast switching from input to output flow
- Flexible control and grid interface

Reflexive:



storage outputs electric energy to the grid in the same form as was received (example: chemical battery with a bi-directional power electronic connection to a grid)

Transitive:



storage outputs energy in some form not directly grid compatible (example: conversion of electricity into heat in thermal storage for later use in a building)

Storage Technology

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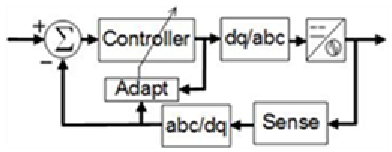
Advanced Control



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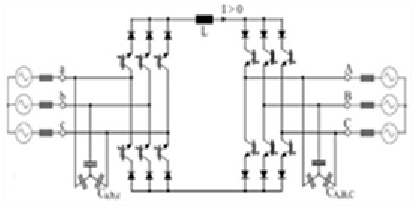
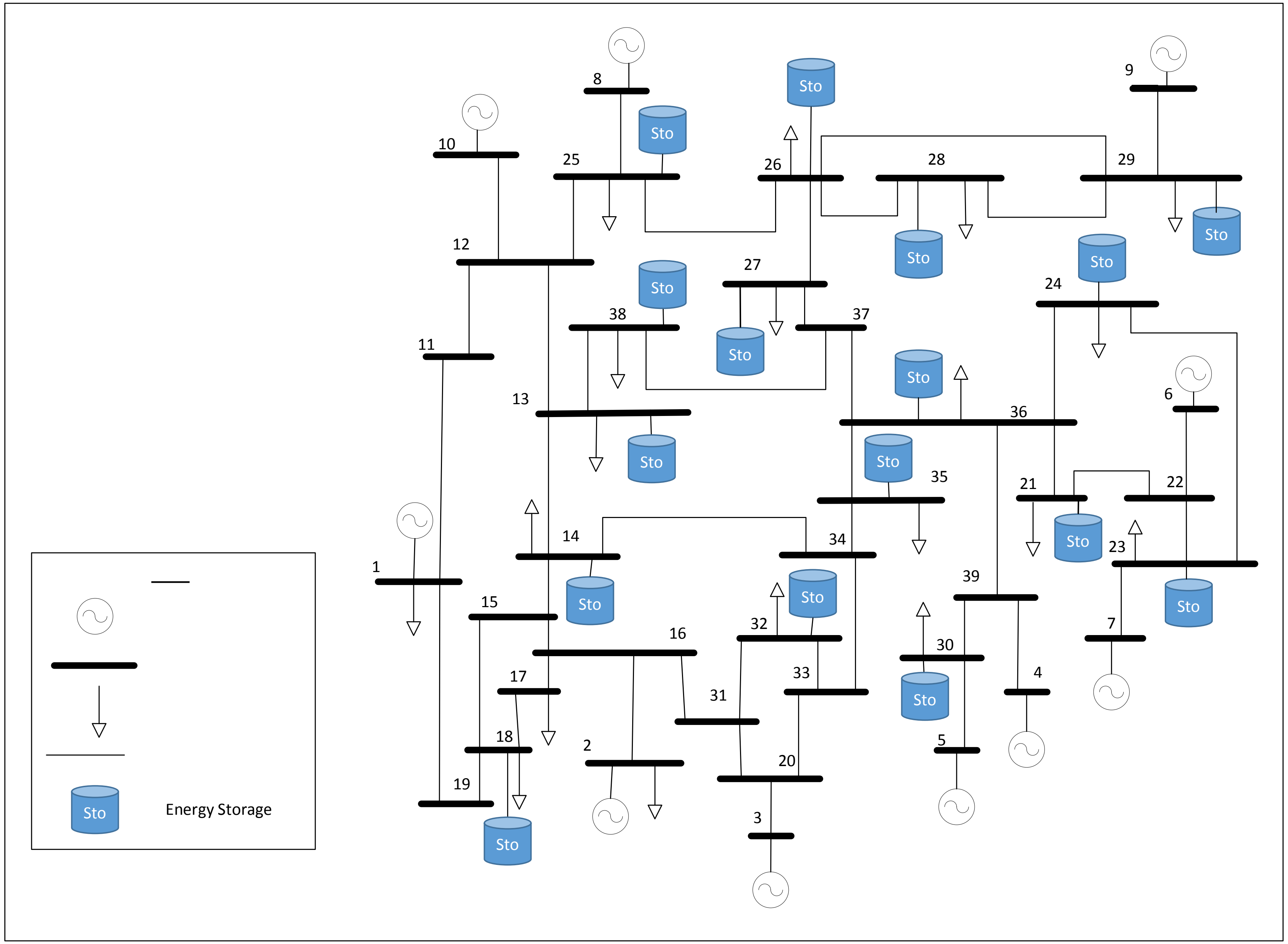
Power Electronics



Storage as Core Grid Infrastructure

- Embed storage in the grid
- Locate at T/D interface substations
- Connect on the low voltage side
- Do not place on generator buses
- Operate collectively, as a *Coordinated Storage Network*



Some Uses of Embedded Storage

- Flatten demand curves – use of storage in a cyclic manner to shift apparent demand so as to make the aggregated demand seen by the bulk power system as flat (over daily time cycles) as possible

- Avoid/mitigate outages – local supply during outages, including ”line packing” in advance of resilience events such as severe storms; outage ride-through support for critical facilities and services

- Reduce exchange of volatilities between bulk system and distribution systems

- Facilitate source/load matching and source/load decoupling; loosen balance and area frequency control constraints

- Support generation black start – provide initial station power to selected generators and also act as interim load while generation is stabilizing

- Manage volatility exchange between bulk natural gas and electric generation systems – to even out the mismatch between desired constant gas flow and peaking gas turbine generator operation

The paper contains a more complete list.

Operational Requirements for Embedded Storage

- Firm designable – it must be possible for the utility to specify where the storage units are placed and how much capacity/capability to put there

- Firm dispatchable – the utility must have direct control of the storage units so as to be able instantly to select operating modes and meet dynamic operating objectives as well as special objectives during resilience events

- Securable – storage operational and control must meet utility standards for cyber and physical security

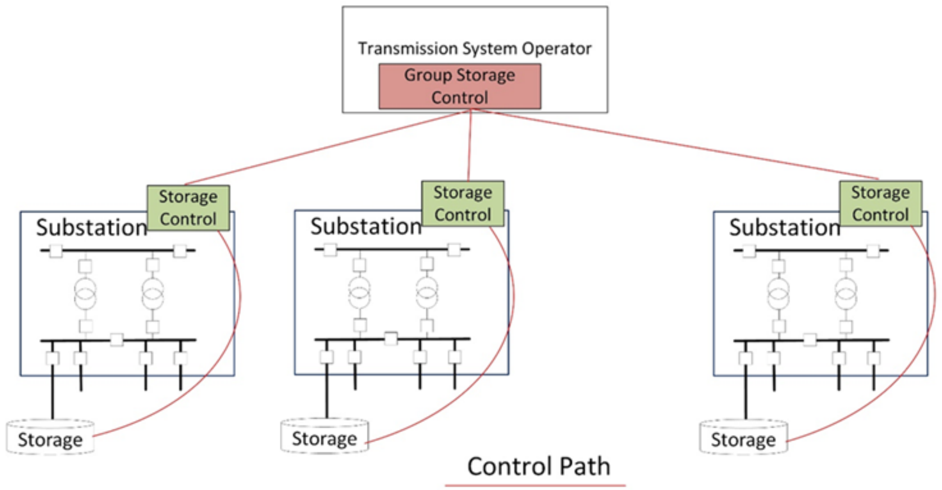
- Service-assured – presence of the storage must not be optional. Its availability must be assured in the same manner as other utility assets and cannot become unavailable if third party ownership changes hands or a third party exits a business or an owner wants to opt out.

Control of Embedded Storage Infrastructure

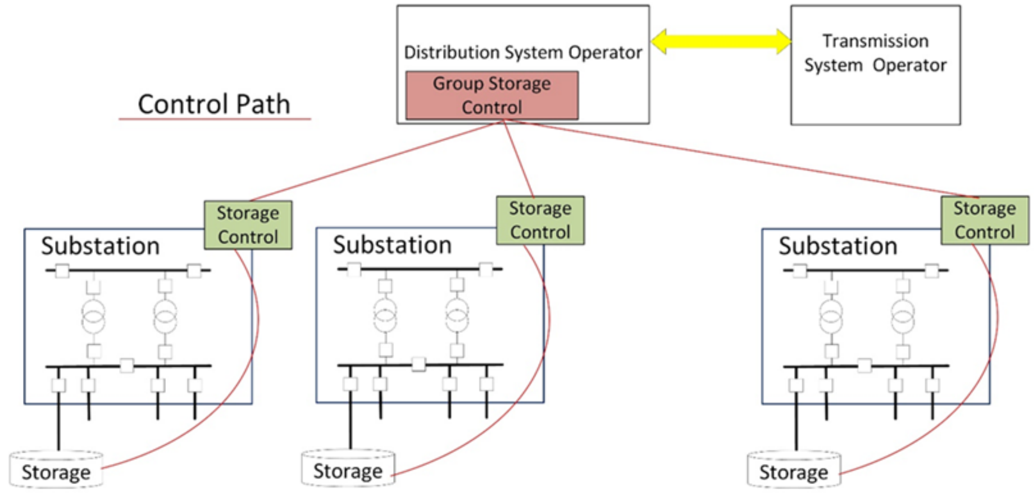
Three general control structures:

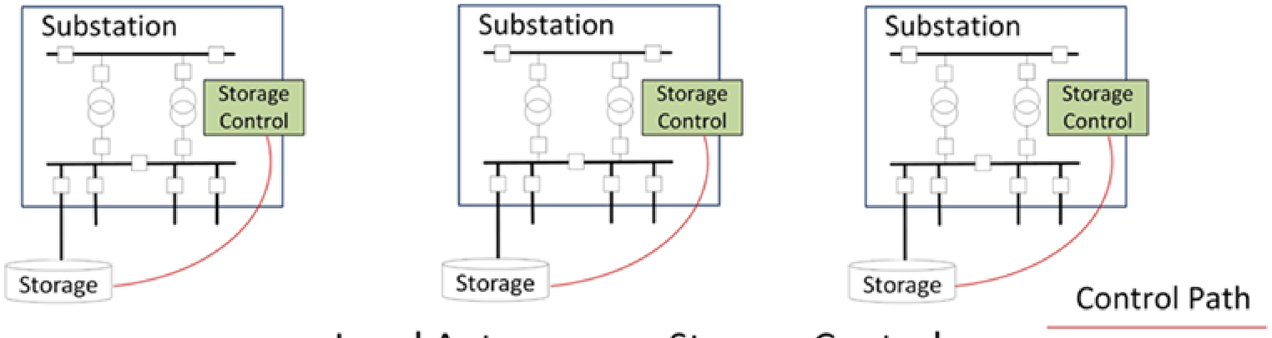
- Central TSO
- Distributed via DSO
- Decentralized (autonomous)

Centralized Control Model



Layered Storage Control
DSO Model





Local Autonomous Storage Control

The Use of Energy Storage as Core Infrastructure

1. Deploy grid energy storage as a systemic upgrade, not as edge-attached services devices

2. Deploy storage as a large number of smaller distributed units rather than as a few giant central devices

3. Locate storage units at T/D interface substations

4. Control groups of storage units as Coordinated Storage Networks

5. Let control of the storage units reside with grid operations

Open Questions and Challenges

- How do we move the industry past its reliance upon fragmented and inappropriate criteria for justification of modernization efforts based in incrementalism when the industry needs large scale systemic changes that fall across multiple regulatory jurisdictions to facilitate significant improvement in grid resilience and flexibility?
- What is the most effective way to establish a base of deployments of Coordinated Storage Networks on a regional grid scale?