Power Systems Engineering Research Center

Transforming the Grid from the Distribution System Out

Tom Jahns Bob Lasseter
University of Wisconsin - Madison

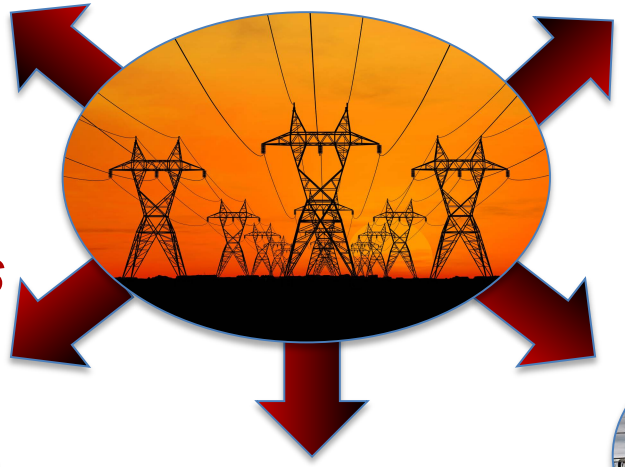
PSERC Webinar
Tuesday, November 4, 2014

Wisconsin Energy Institute
UNIVERSITY OF WISCONSIN-MADISON

Changing Grid Environment

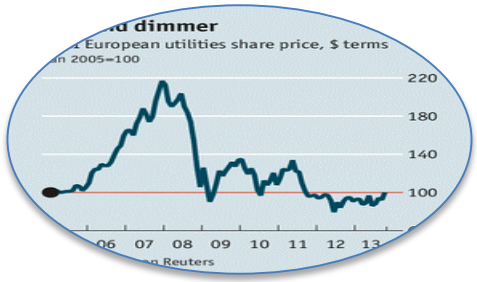
Renewable Energy

Greenhouse Gases



Distributed Energy Resources

Weather Events



Economics & Policy

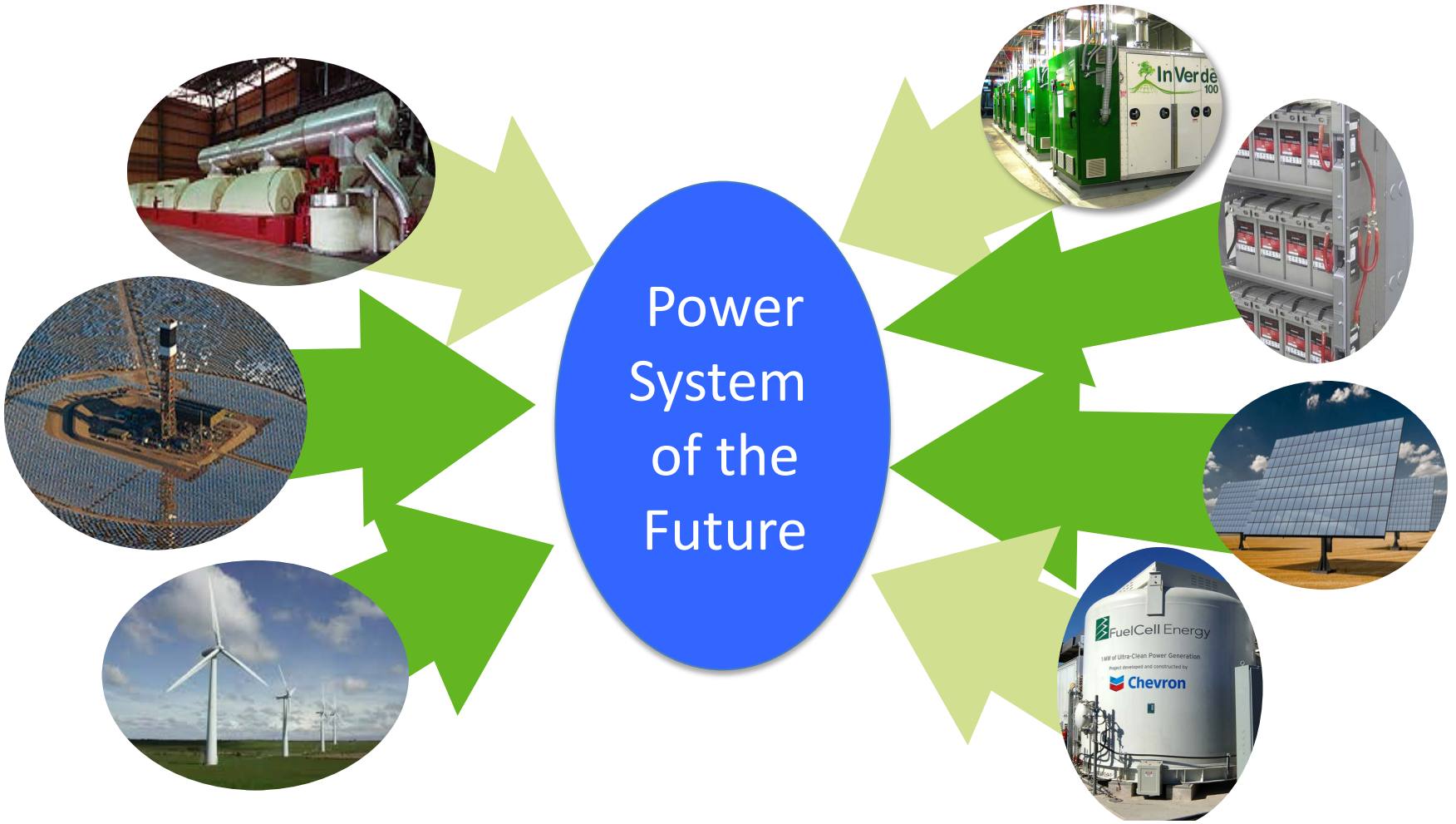
Question for Today

What would our electrical power system look like if we could redesign it to meet tomorrow's challenges and needs?

What Do We Want?

- Improve system resiliency
- Maintain high reliability
- Increase efficiency
- Reduce carbon emissions
- Maximize use of renewables
  - Both centralized and distributed
- Minimize volatility at the T-D interface
- Lower cost and rates

Key Generation Technologies



Central Generation with Low CO_2
Economy of Scale, 100s MW
Scalable, reliable

Distributed Energy Resources
Economy of numbers, 1000s units
Small, Efficient and Robust

Central Generation: Economy of Scale

Pros

- ✓ Equipped to design/build/finance/operate large-scale energy systems
- ✓ Very effective systems technically & financially: *Economy of Scale*

Cons

- ◆ Carbon-based plant losses and emissions too large
- ◆ High initial costs requires planning with time horizons of ~30 years
- ◆ Difficult to handle volatility

Distributed Energy Resources: Economy of Numbers

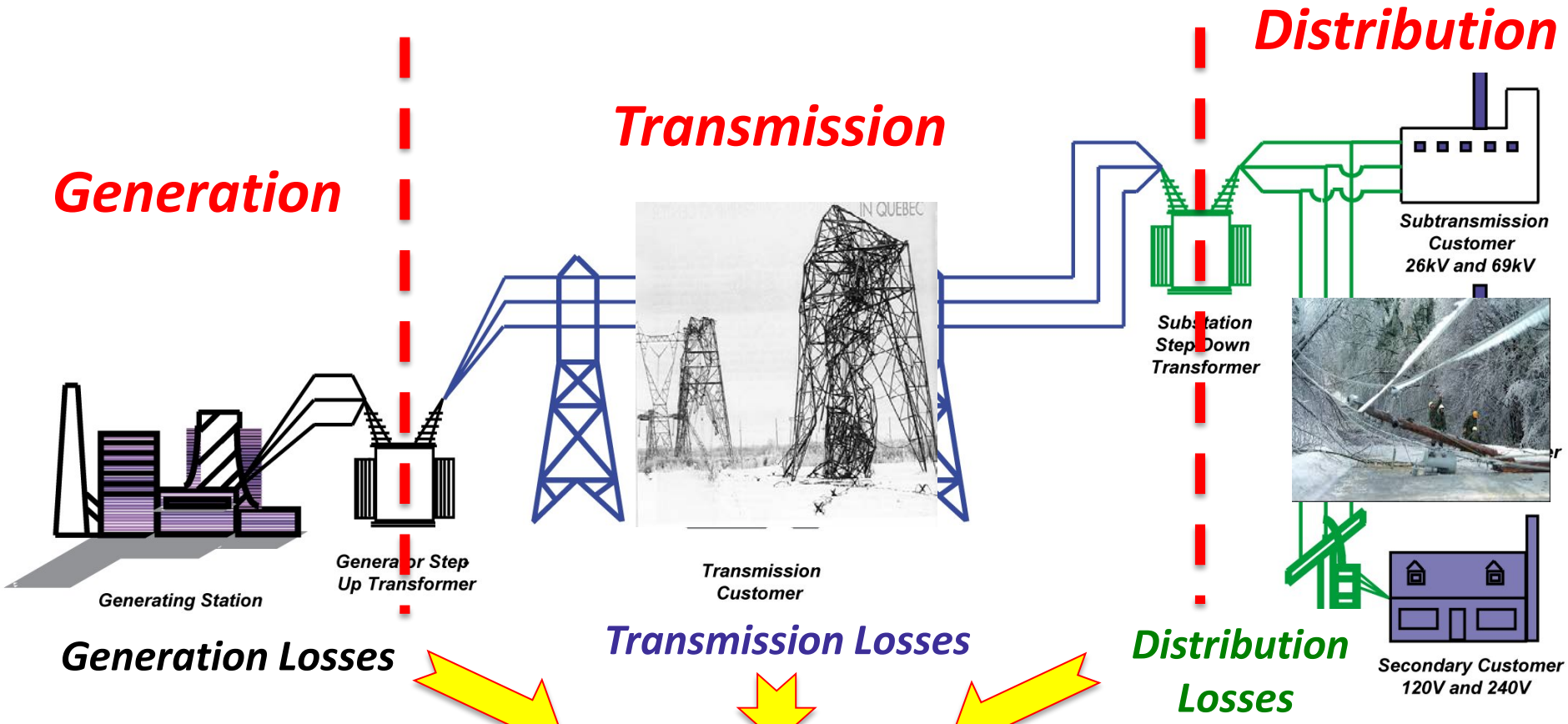
Pros

- ✓ Diverse range of technologies
- ✓ Much faster response
- ✓ Reduces line losses & enhance local reliability
- ✓ Double efficiency/ half emissions through use of waste heat
- ✓ Payback periods <5 years for some DERS installations

Cons

- ◆ Difficult to insure stability of large numbers of DER units
- ◆ Potential high cost of operation and management of the system

Electric Delivery System

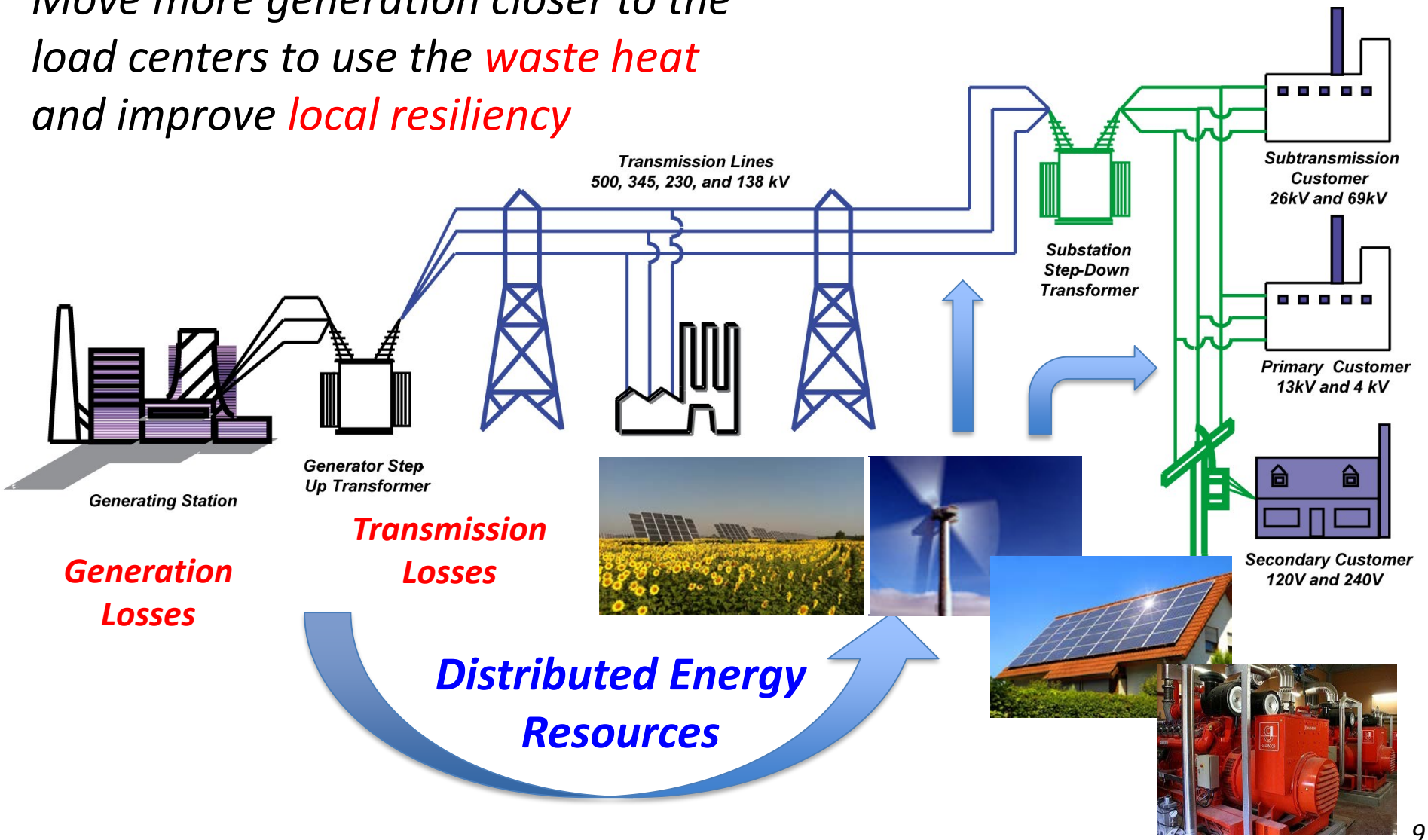


> 2/3rds of Input Energy is Lost

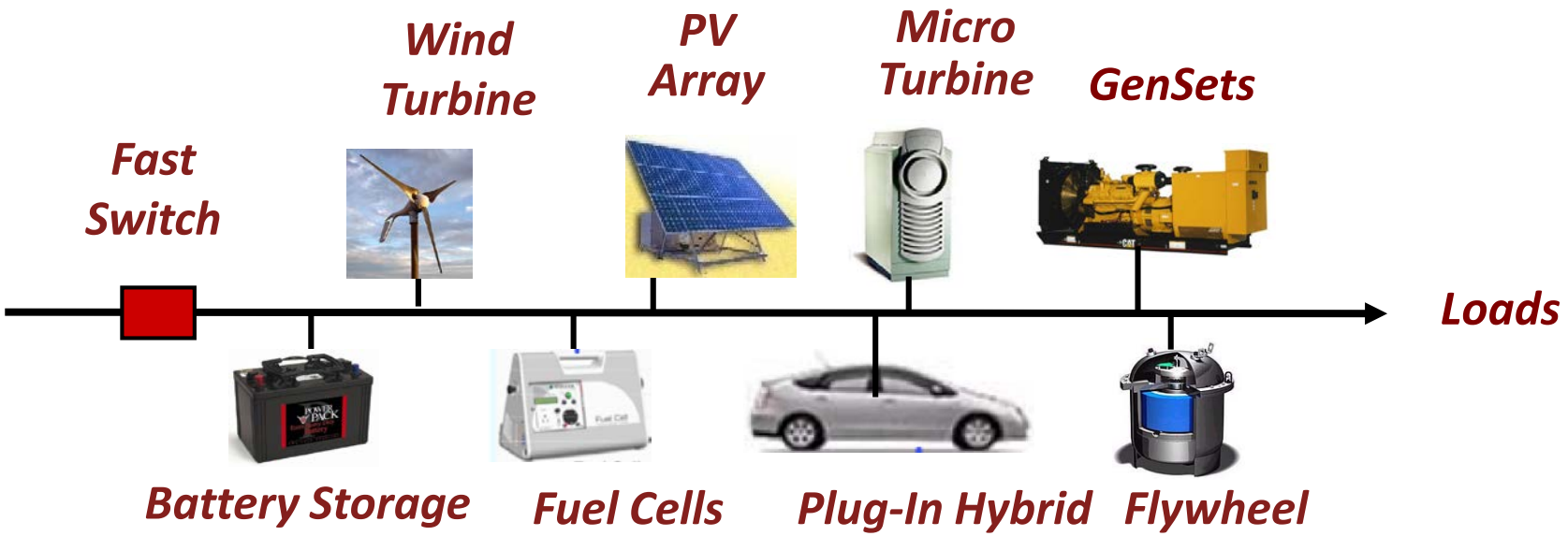
Losses and resiliency are problems

Electric Power System with Distributed Energy Resources

Move more generation closer to the load centers to use the waste heat and improve local resiliency

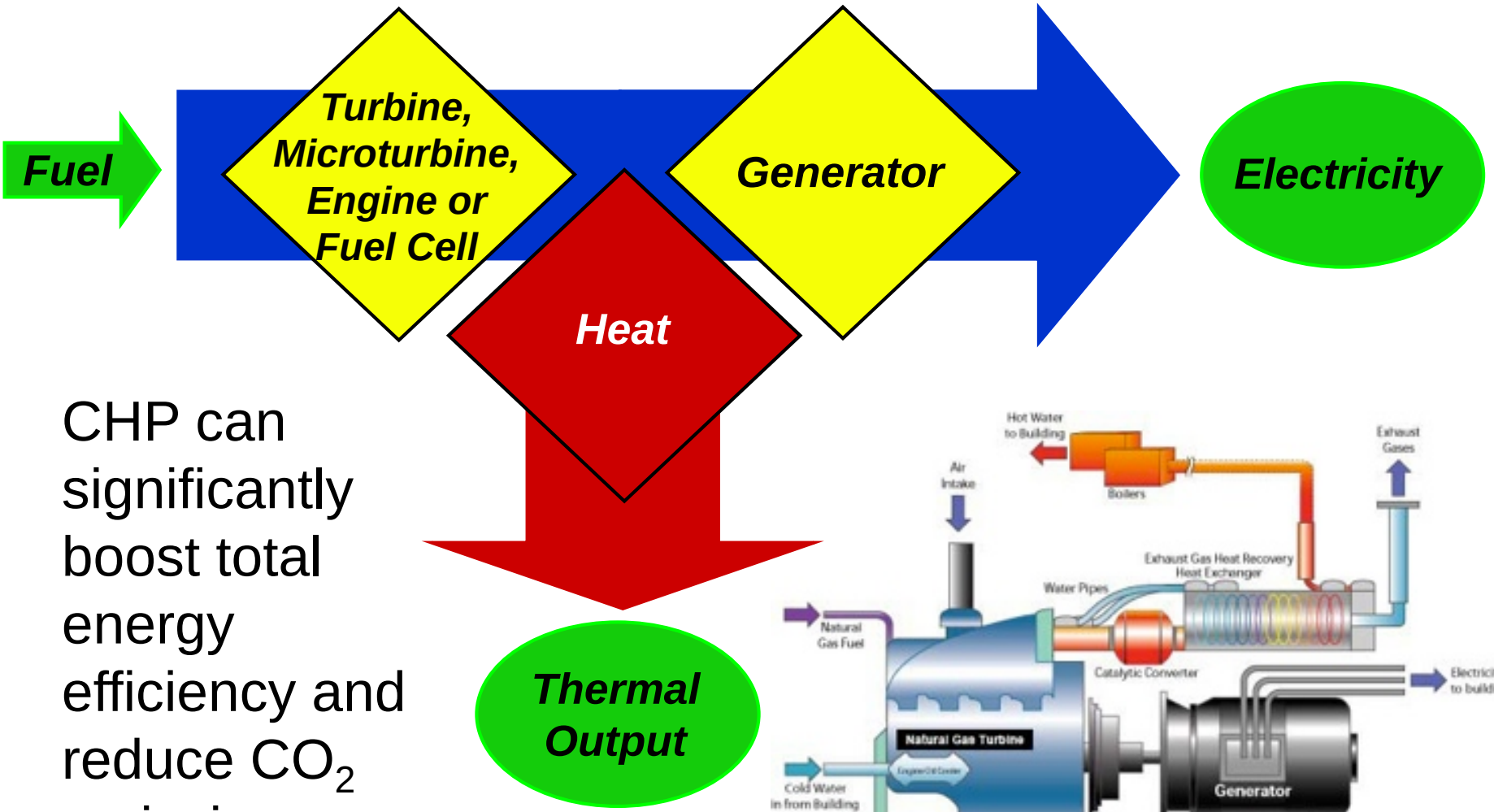


Microgrids



- Microgrids provide a promising means of integrating large amounts of distributed sources into the power grid
- Microgrids open the door to significant system efficiency reliability/resiliency improvements

Combined Heat and Power (CHP)



CHP can significantly boost total energy efficiency and reduce CO_2 emissions

Generation in buildings provides local resiliency

CERTS Microgrid demonstrated its value during outages caused by Superstorm Sandy

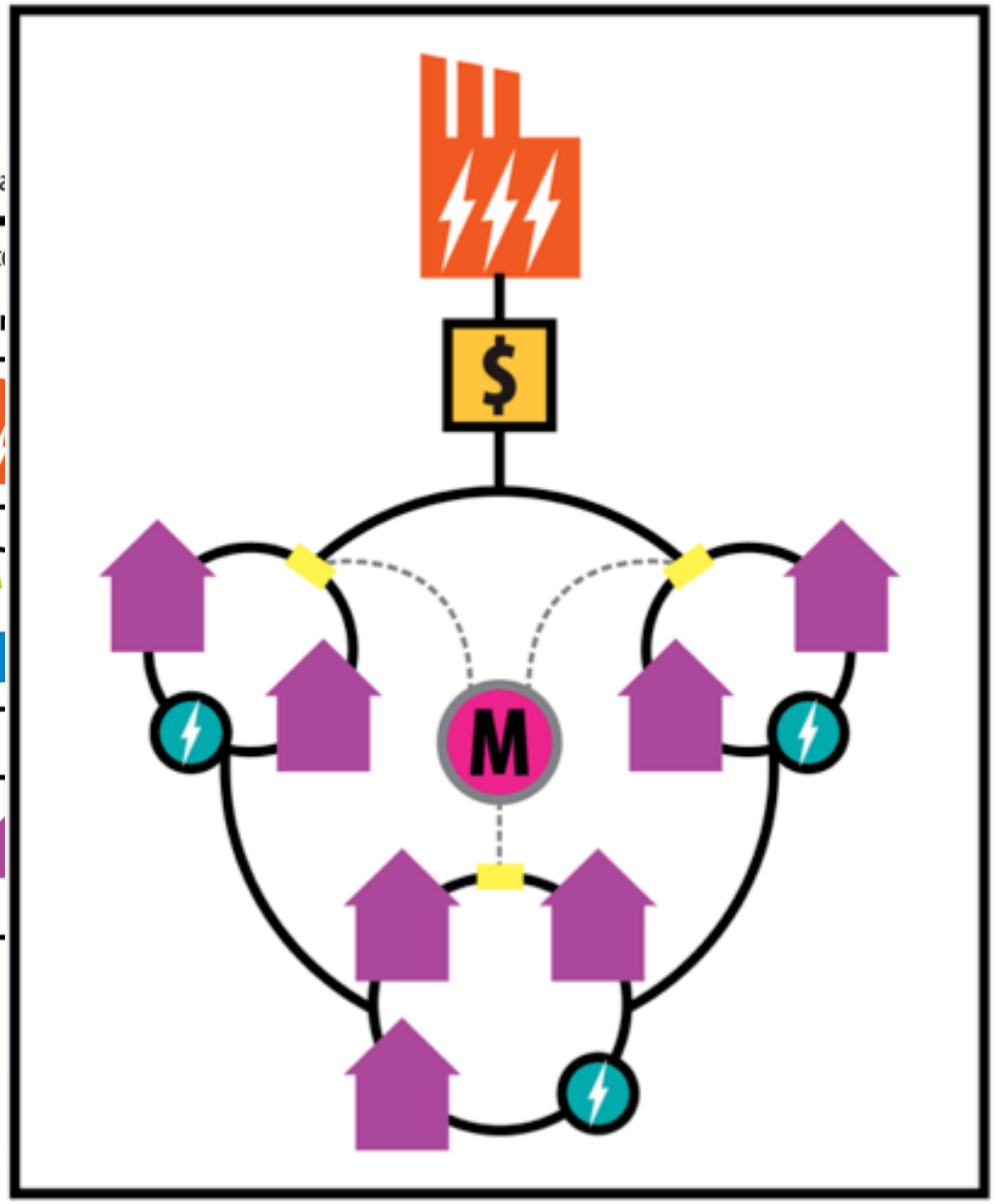
Need to Rethink T-D Interface

- Transmission-distribution interface serves as:
  - Traditional boundary of wholesale/retail markets
  - Boundary between operations and regulatory jurisdictions associated with transmission and distribution sectors
- Expansion of DER in distribution systems is causing T-D boundary to be blurred
  - DER participation in wholesale markets
  - DER contributions to grid ancillary services

What is the appropriate role of the T-D interface in the future as DER penetration increases?

Dynamic Distribution System

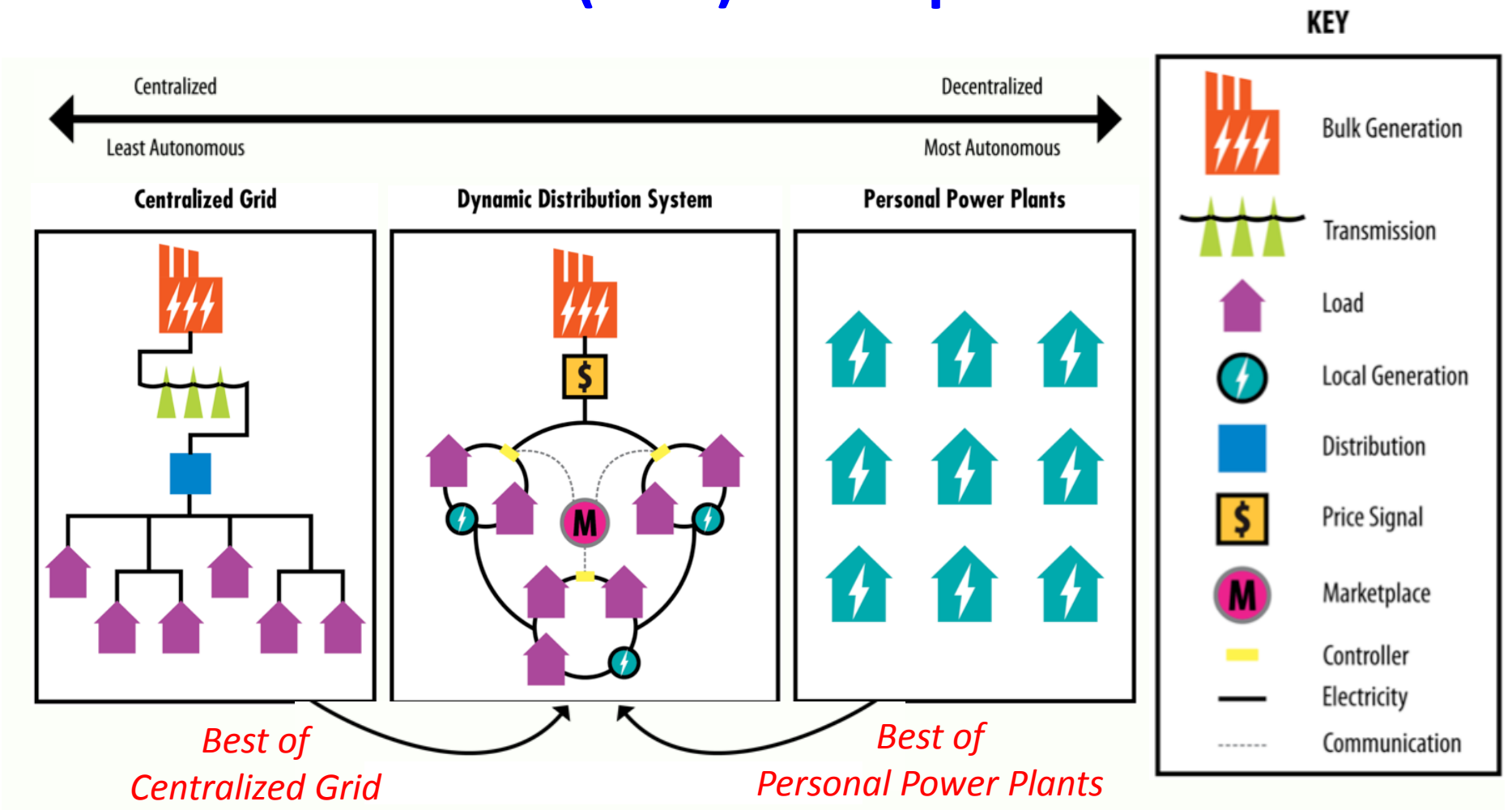
System



KEY

- Bulk Generation
- Transmission
- Load
- Local Generation
- Distribution
- Price Signal
- Marketplace
- Controller
- Electricity
- Communication

Dynamic Distribution System (DDS) Concept



Dynamic Distribution System (DDS) represents a serious attempt to define a path for DERs to flourish in grid

Key DDS Principles

More reliable/efficient systems using 1000's of DER near loads

- Increase efficiencies and reduced emissions through use of waste heat
- Reduced transmission losses
- More resilient system using local generation, microgrids & network reconfiguration

Economic efficiencies via distribution-based marketplace

- Independent Distribution System Operator
- Local balancing authority
- Local marketplace

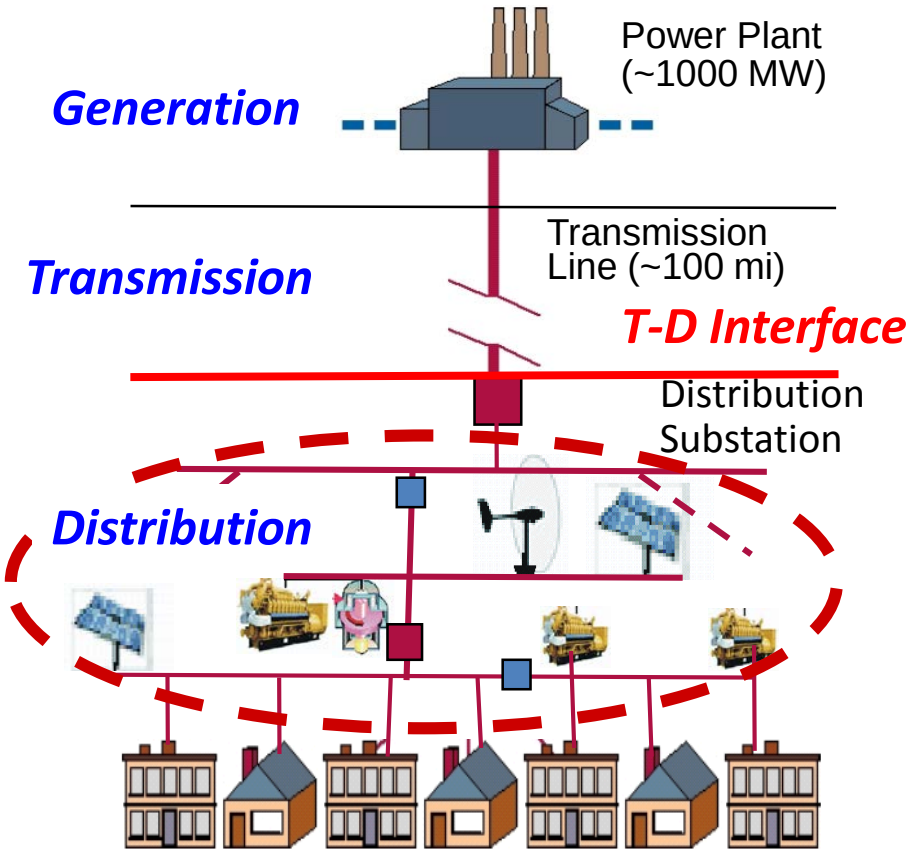
Simplify the central generation planning and operation

- Handle distribution system's dynamics locally (minimize volatility at the T-D interface)
- Improve efficiencies by increasing base load operation.
- Constant/contracted wholesale energy transactions.
- Minimize CO_2 content

Problem with 1000s of DERs

TSO

Transmission System Operator
ISO/RSO



The challenge is how to manage this wide, dynamic set of distributed energy resources and their control points.

Central Control by ISO/RSO

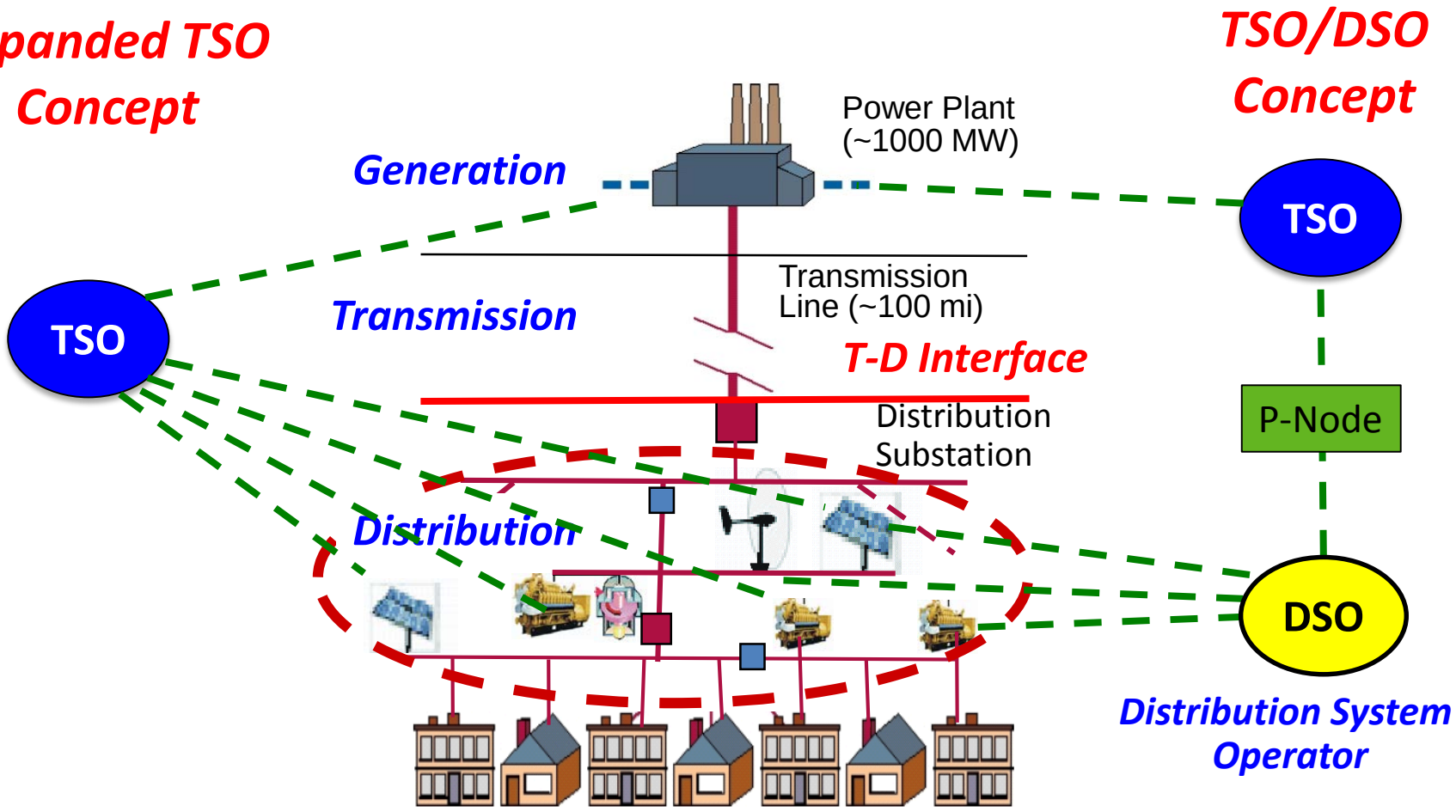
- Complex is huge
- It is structurally problematic*
- Extra cyber-security problems

Highly Decentralized

- Structurally sound*
- Scalable
- Easier to secure

*Lorenzo Kristov, Paul De Martini, "21 century electric distribution system operations," California ISO, www.academia

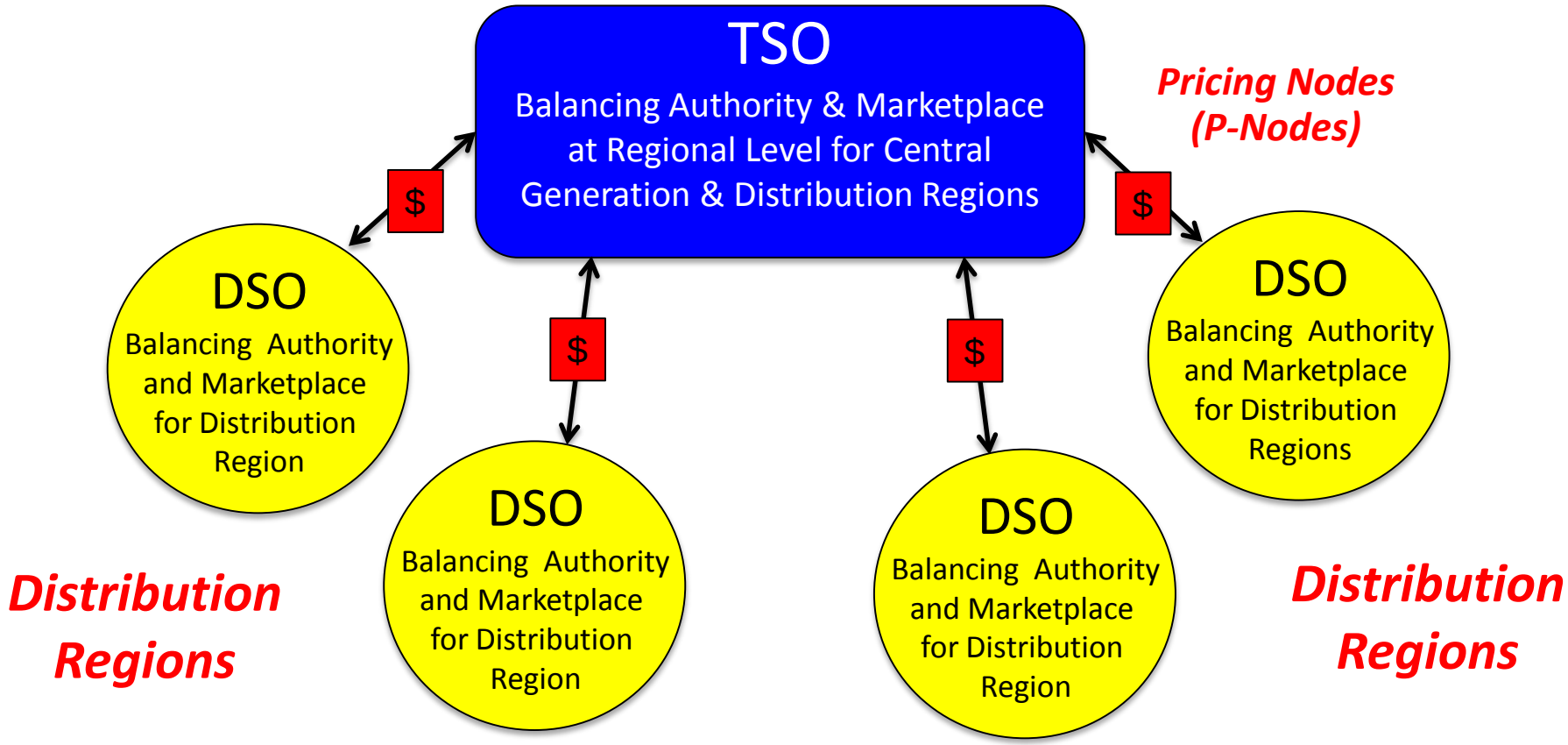
Alternative Grid Management Approaches



- *Expanded TSO Concept:* TSO role expands to incorporate DER at distrib. level
- *TSO/DSO Concept*: Each distribution region has its own DSO which serves as balancing authority and market provider for sources/storage inside region.

Dynamic Distribution System Operator Architecture

Central Generation and Transmission

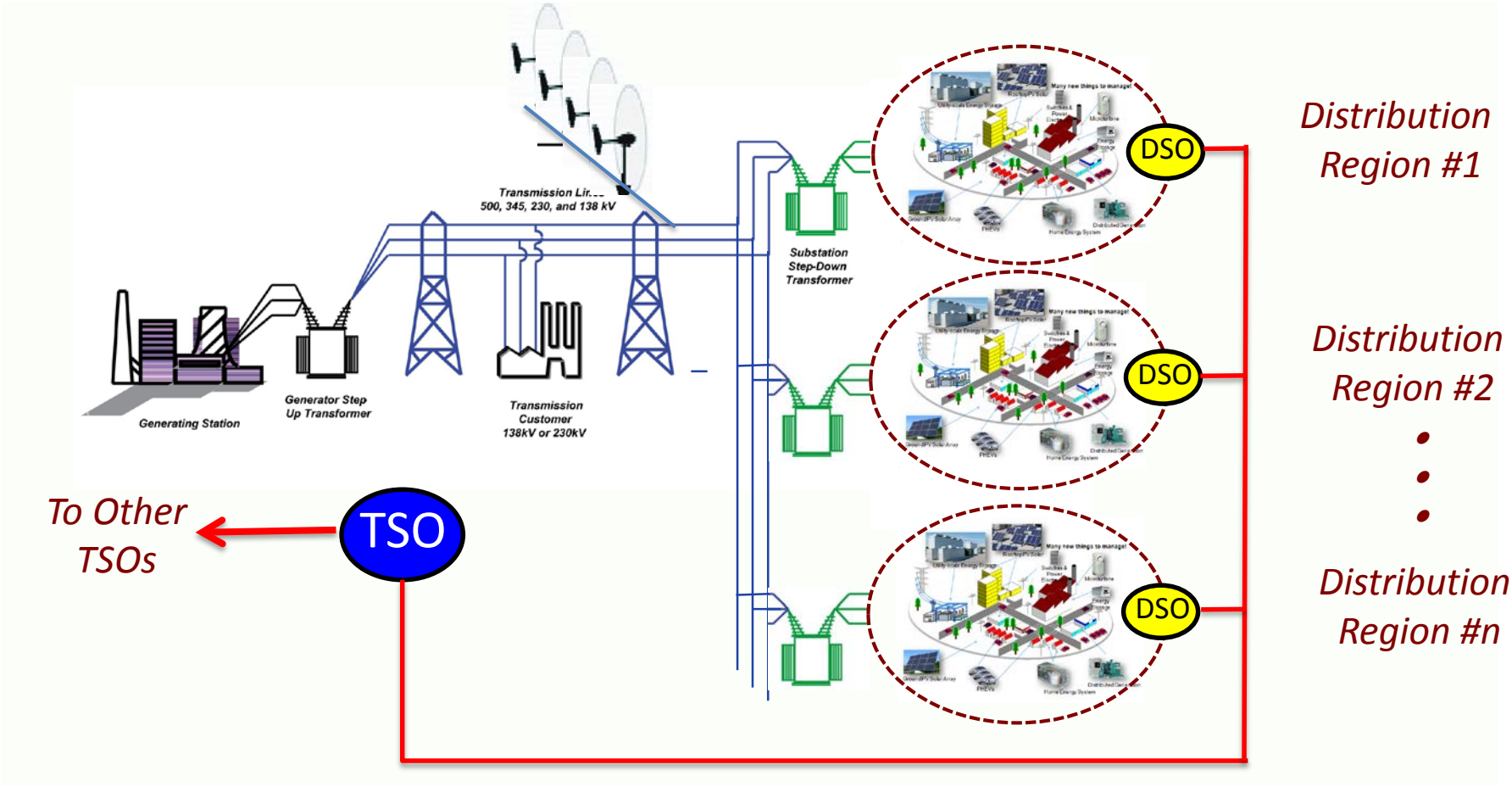


- One TSO may be linked to significant numbers of DSOs

Major DDS Operation and Control Principles

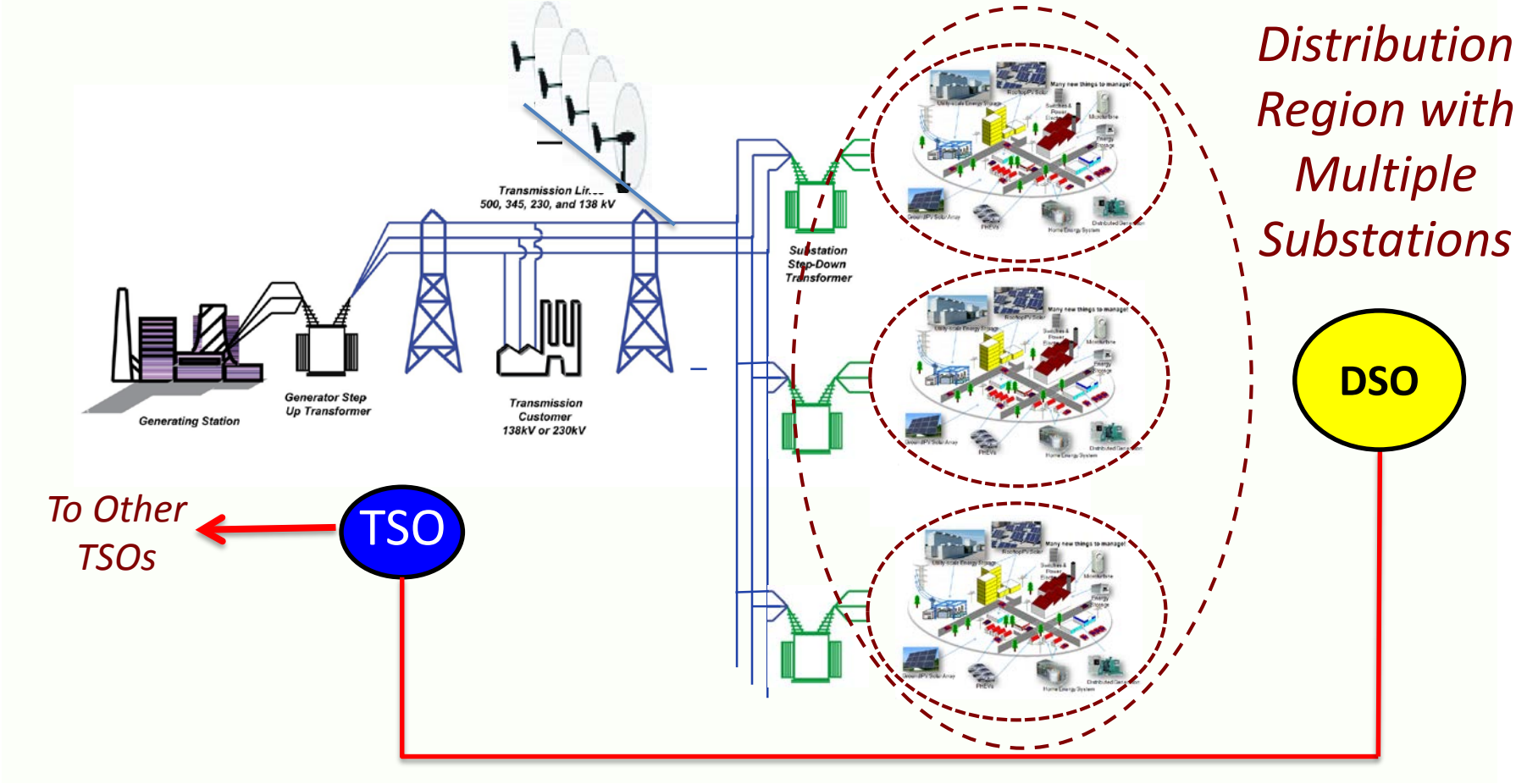
- TSOs continue to play their current role as balancing authorities (BA) and electricity market providers (MP) at transmission level
- Each distribution region has its own DSO that serves as BA and MP for its region
- Central power plants have responsibility for delivering bulk power to distribution regions
- DSO's act to reduce volatility of power flow from central power plants to their distribution regions
  - Use authority in region to adjust DER power sources, energy storage, and loads to achieve objective

Dynamic Distribution System Architecture



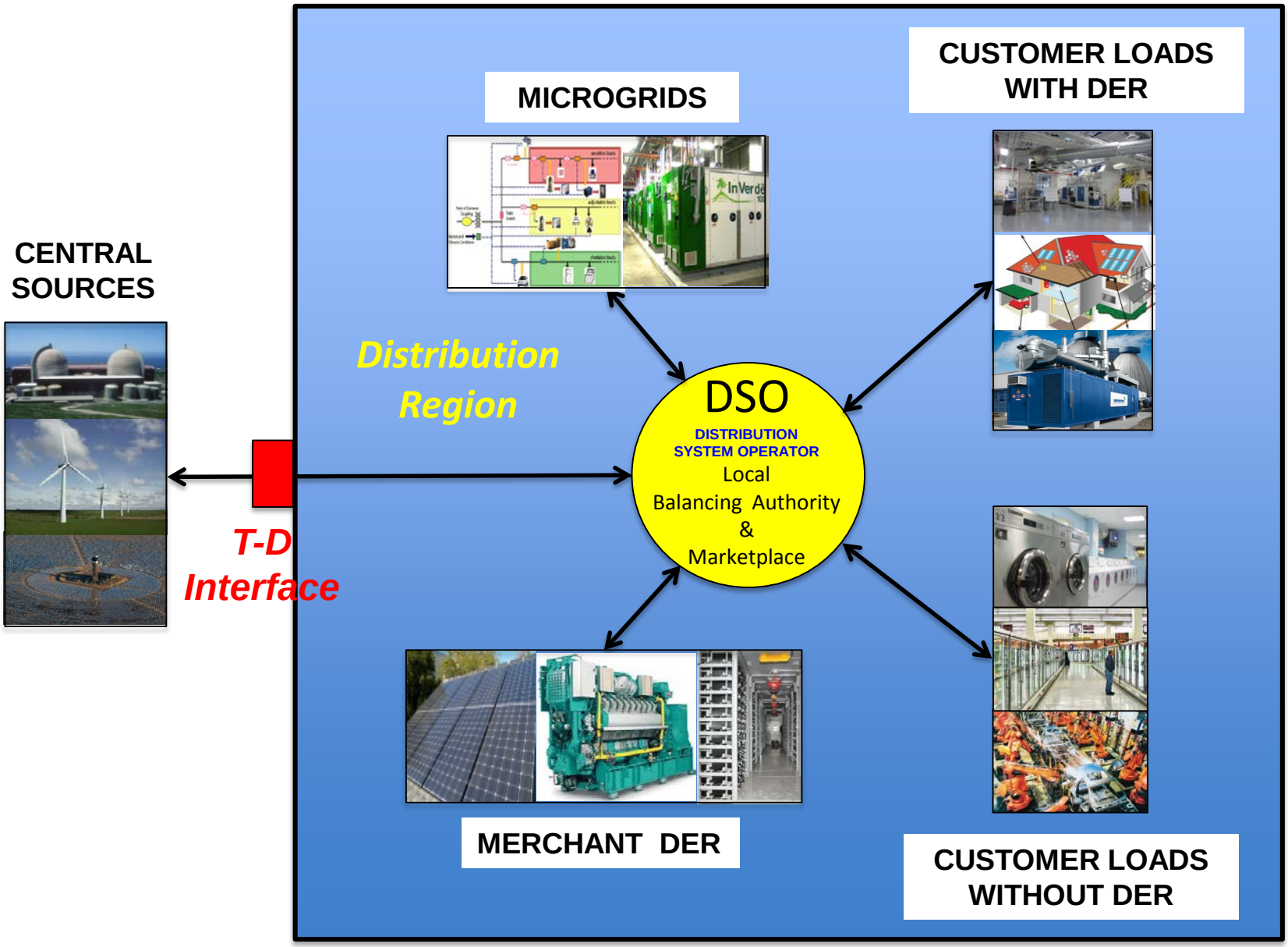
- Proposed DDS architecture is conveniently scalable over a wide range of grid sizes and configurations

Dynamic Distribution System Architecture



- Boundaries of distribution can be flexibly defined to encompass one or several substations

Distribution Region Resources



DDS Resources:
Central Sources

- Contracted wholesale energy
- Dispatchable with slow variations
- Minimum CO_2 and other GHG emissions
- Maximum efficiency

DDS Resources:
Merchant DER

- Opportunities for both power sources and energy storage
- Built by utilities or 3rd parties to deliver needed services to the distribution region
- Objective is to maximize revenue from services:
  - Load tracking to reduce volatility due to loads/renewables
  - Voltage and frequency control ancillary services

DDS Resources:
Microgrids

- Local resiliency via islanded operation
- Convenient opportunities to use waste heat (CHP)
- Compatible with wide range of energy sources & storage

DDS Resources

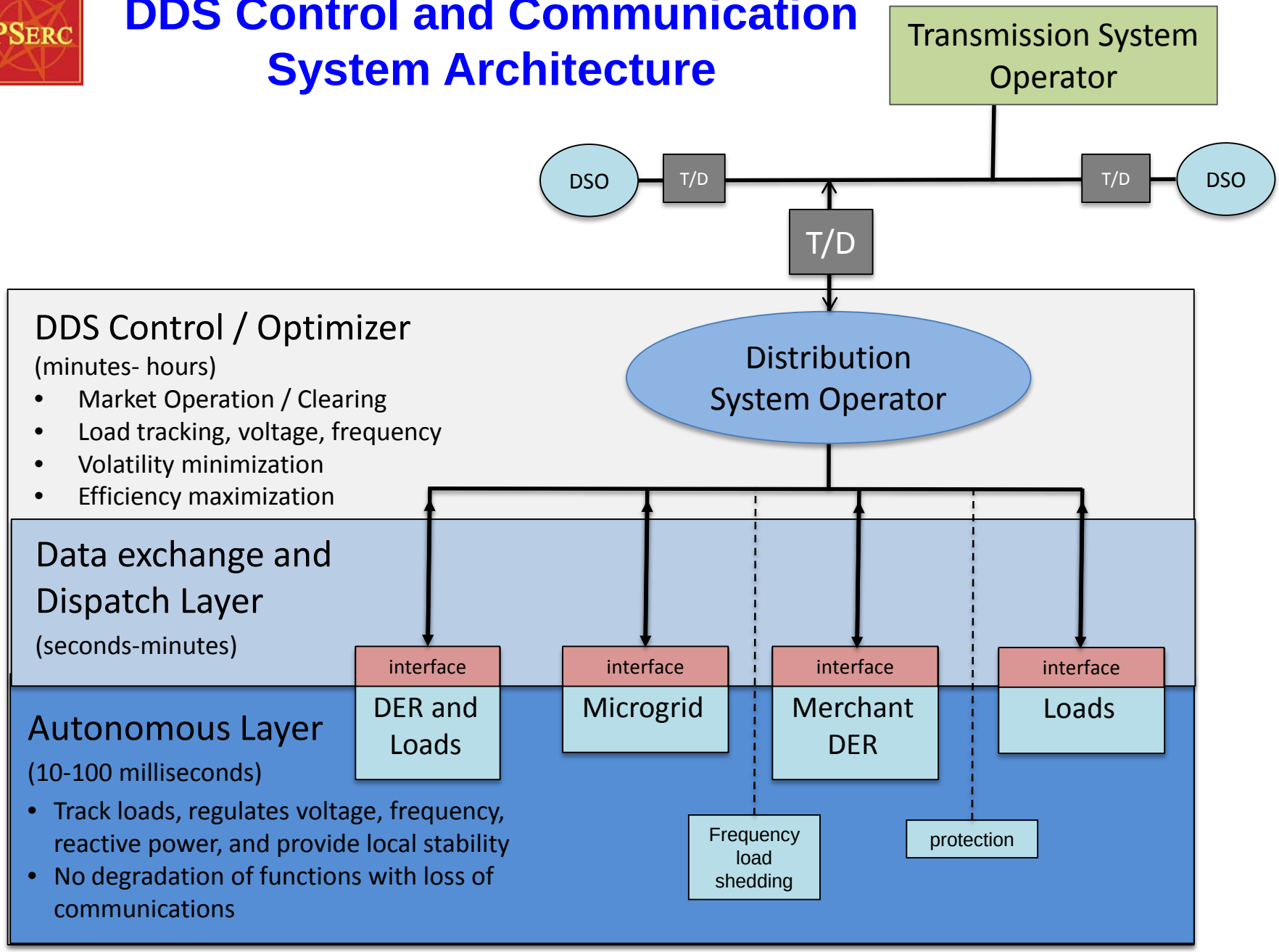
Customer Loads with DER

- DER used to reduce load demand
- Export excess energy when available
- No islanding capability; dependent on grid for reliability

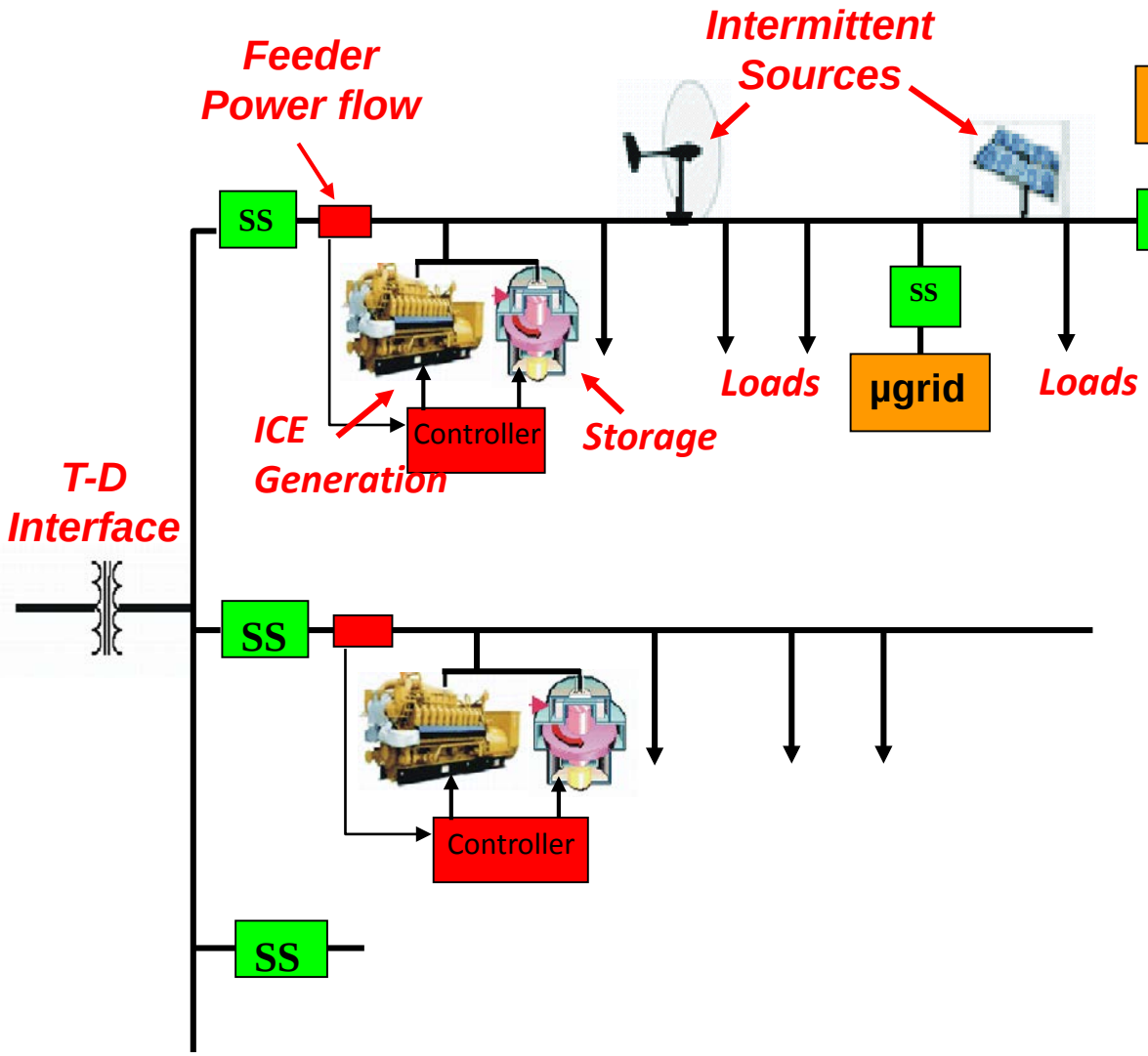
Customer Loads without DER

- “Traditional” utility customer
- Demand side management candidate
- Dependent on utility for reliability

DDS Control and Communication System Architecture

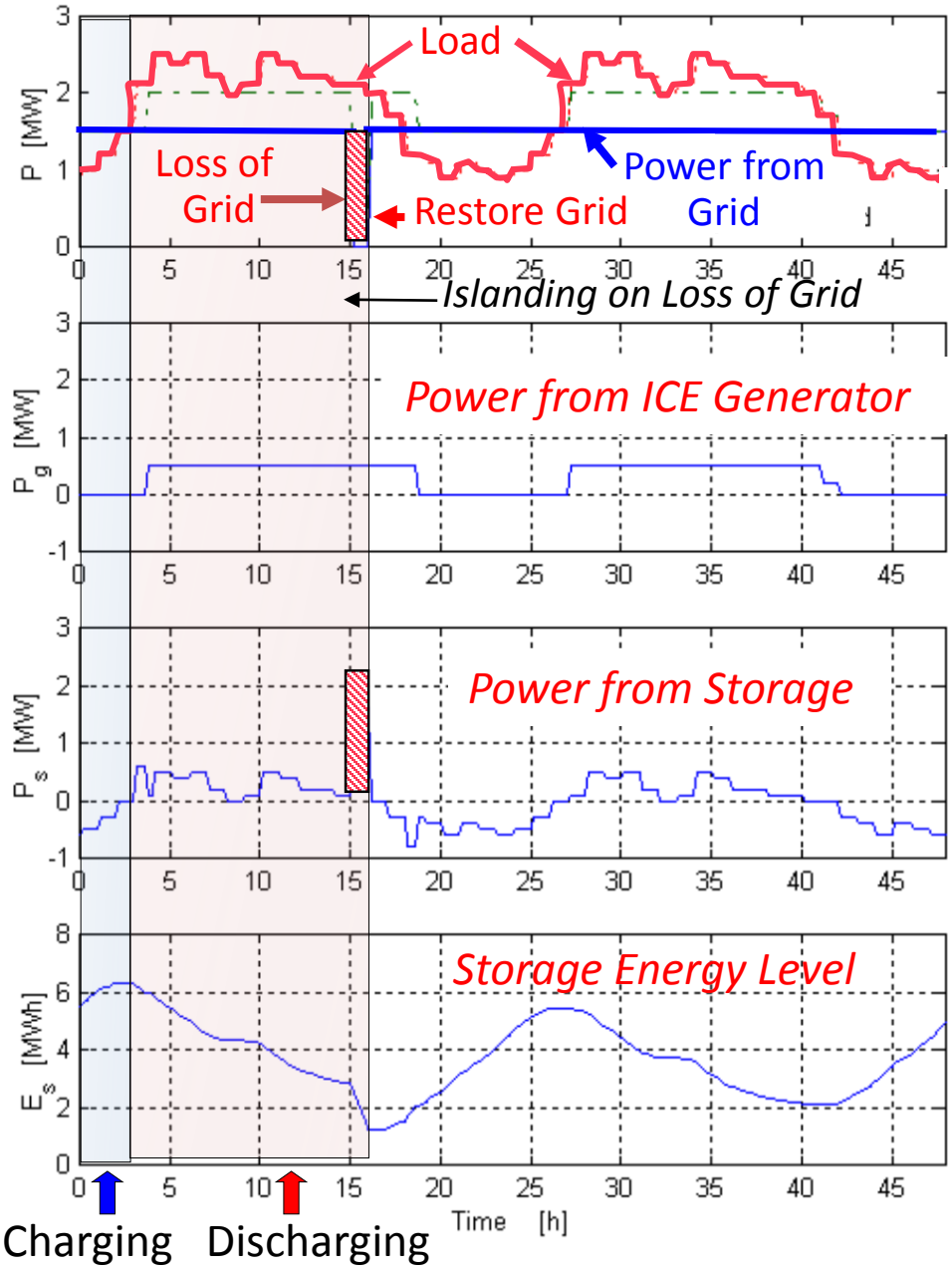


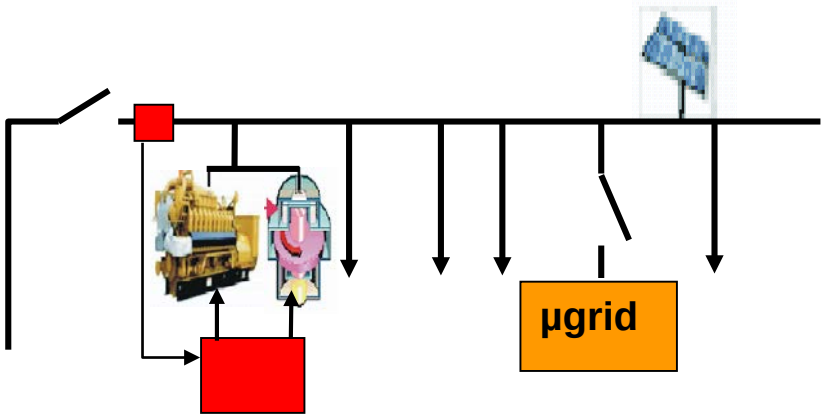
DDS Volatility Response Inside Distribution Region



- Important DDS objective is to minimize grid volatility
- Volatility is contributed both by varying loads and intermittent sources
- Resources for suppressing volatility include:
  - Energy Storage DER
  - Conventional DER sources (e.g., nat. gas gensets, etc)
  - Load demand-side management

Simulation of Constant Power Flow Control

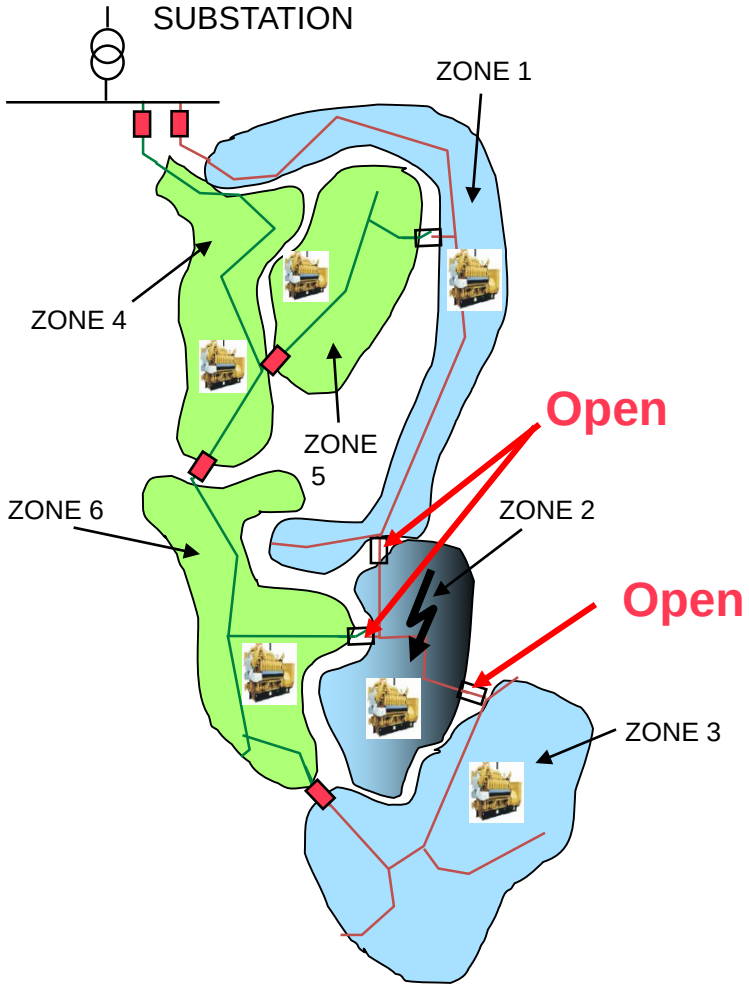




- Power from grid is constant 24/7 except during outage.
- Storage is charged during low load periods.
- Generation is run at optimum level to minimize losses & emissions.
- Storage and local DER follows load and provides fast power balance during islanding.

Distribution Region Protection and Restoration

- Initial fault in one of the region's zones may open multiple inter-zonal switches
- Protection scheme uses inter-zonal switches & sensors to reenergize zones that do not include fault
- Local DER sources and storage in zone with fault are coordinated to clear fault as quickly as possible.
- Inter-zonal switches reclose following fault-clearing to restore original pre-fault operating conditions



DDS architecture is well-suited for fast-acting intelligent protection & restoration schemes within distribution regions

DDS Implementation Challenges

- By encouraging distributed resources, well-known obstacles to wider DER penetration are encountered
  - Grid is not designed to handle multi-directional power flow
  - Business model of existing utilities experience growing financial pressure as DER power replaces central generation
- DDS architecture is new with many unknowns
  - Existing utility regulatory structure has no provisions for key DDS components or structure, including DSOs
  - Control algorithms for TSOs and DSOs are immature
  - Major questions about federal vs. state jurisdiction
  - Risks from unexpected consequences are unavoidable

Transition to DDS-based grid architecture raises many issues!

Conclusions

- DDS concept provides an appealing scalable approach for integrating large amount of DER into electric grid
- DDS architecture rests on foundation of independent DSOs that incorporate local balancing authority and marketplace
- If implemented, DDS offers combination of benefits:
  - Significant efficiency improvements via higher renewable penetration, lower XM losses, and wider CHP installation
  - Significant long-term improvement of grid resilience via microgrids, local storage, distributed control advantages
  - Significant reduction of grid volatility, increasing the efficiency of base power plants and improving XM line utilization
- Market principles play key role in DDS operation & growth

DDS provides path for DER to fulfill its potential

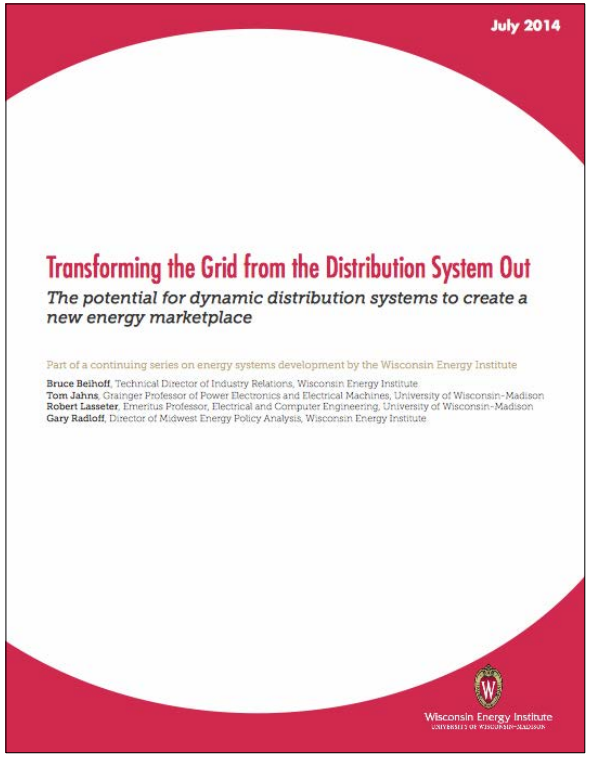
For More Information:
White Paper

Transforming the Grid from the Distribution System Out

by

Bruce Beihoff, Thomas Jahns,
Gary Radloff & Robert Lasseter

Wisconsin Energy Institute
UNIVERSITY OF WISCONSIN–MADISON



http://energy.wisc.edu/sites/default/files/Transforming-the-Grid-from-the-Distribution-System-Out.pdf

For more information, please contact:

Prof. Tom Jahns jahns@engr.wisc.edu

Prof. Bob Lasseter lasseter@engr.wisc.edu

University of Wisconsin – Madison