

Wisconsin Energy Institute
UNIVERSITY OF WISCONSIN-MADISON

Transforming the Grid from the Distribution System Out

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Changing Grid Environment

Renewable Energy



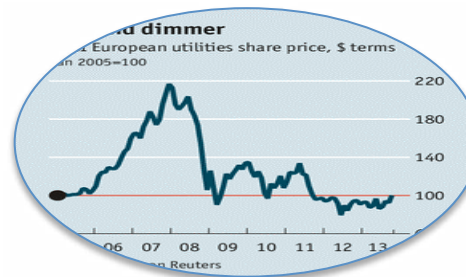
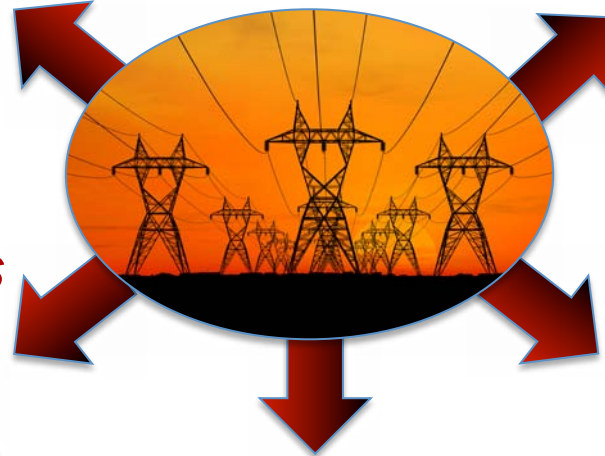
Greenhouse Gases



Distributed Energy Resources



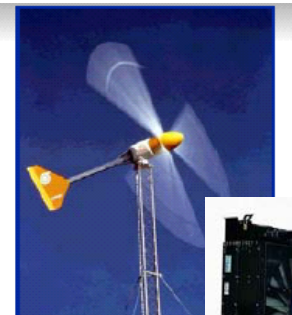
Weather Events



Economics & Policy

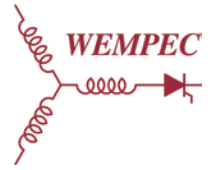
Question for Today

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



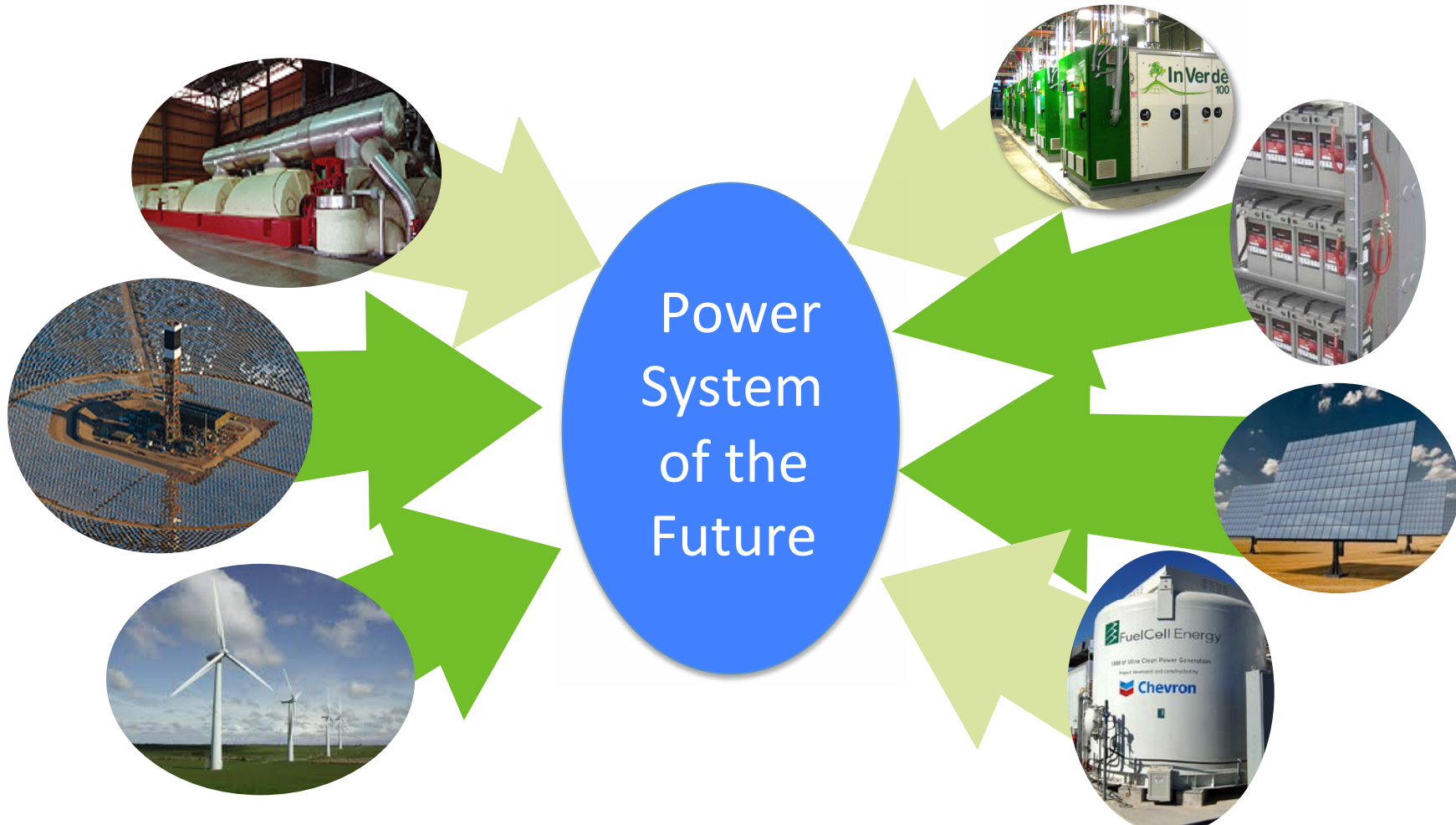


What Do We Want?



- 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

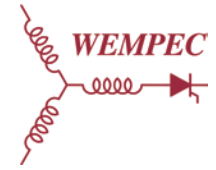
Key Generation Technologies



Central Generation with Low CO₂
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

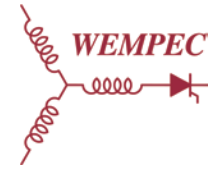
- ✓ Equipped to design/build/finance/operate large-scale energy systems
- ✓ Very effective systems technically & financially: *Economy of Scale*

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

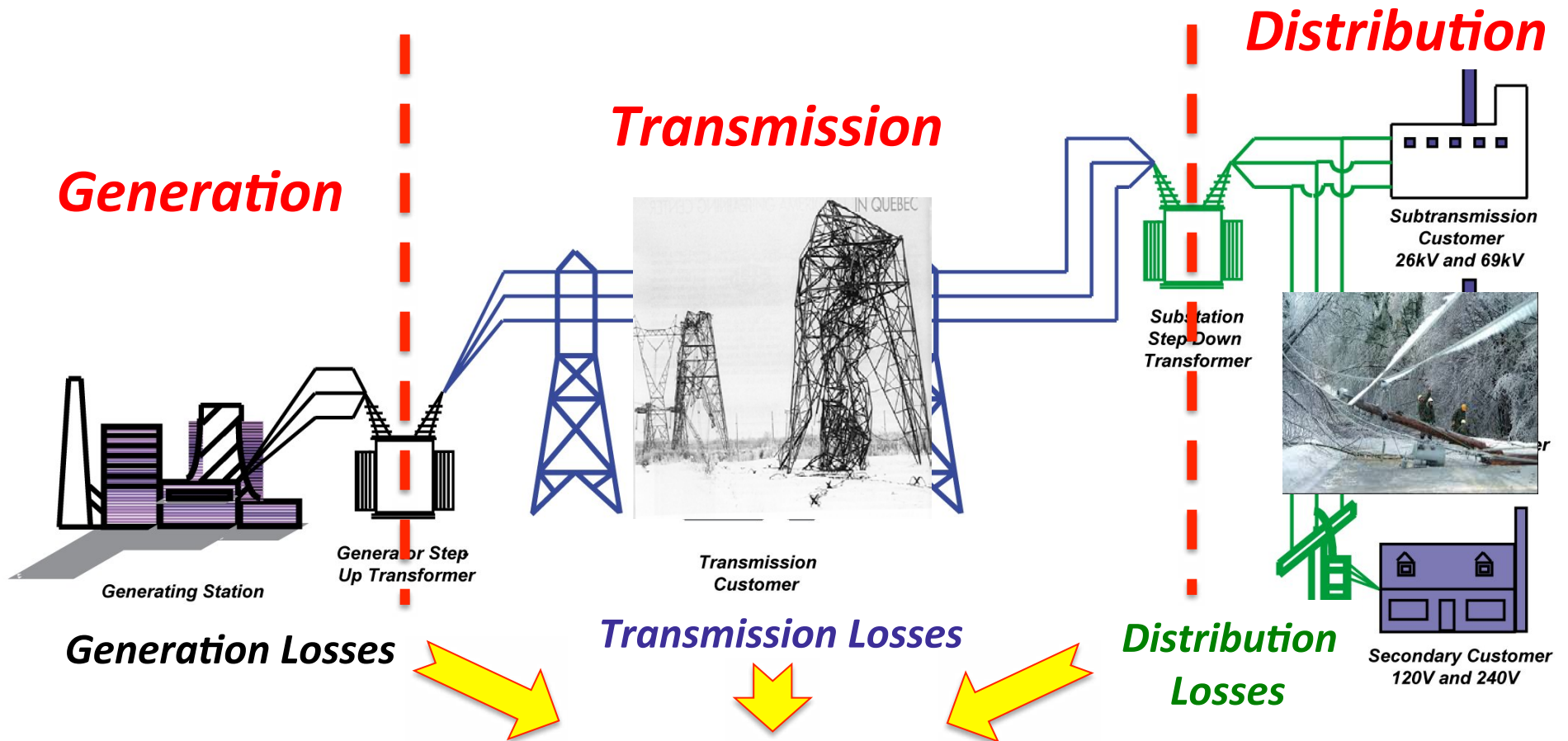
- ✓ Diverse range of technologies
- ✓ Much faster response
- ✓ Reduces line losses & enhance local reliability
- ✓ Double efficiency/ half emissions through use of waste heat
- ✓ Payback periods <5 years for some DERS installations

Cons

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



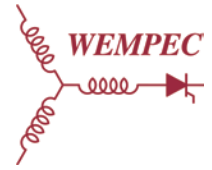
Electric Delivery System



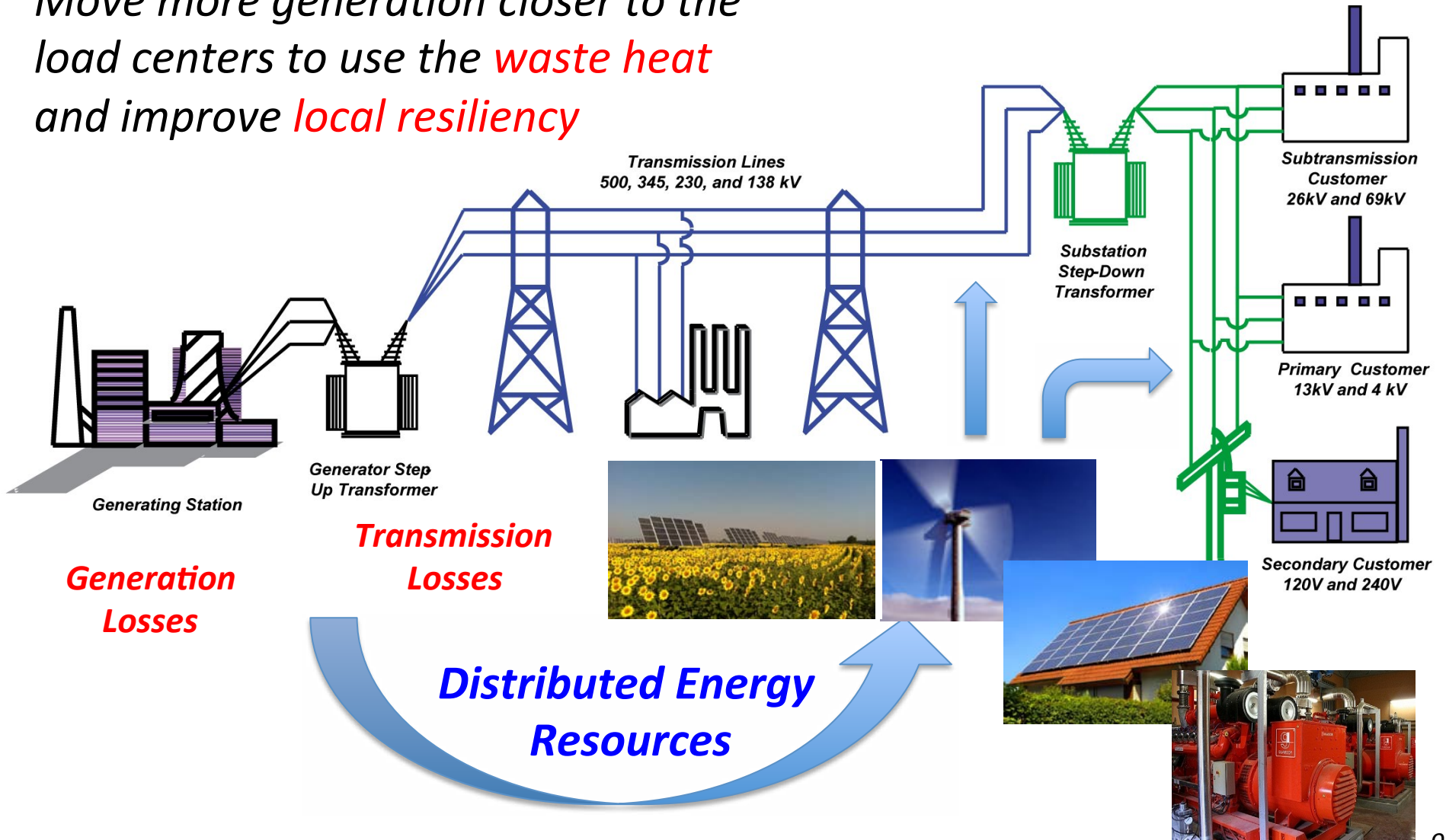
> 2/3rds of Input Energy is Lost

Losses and resiliency are problems

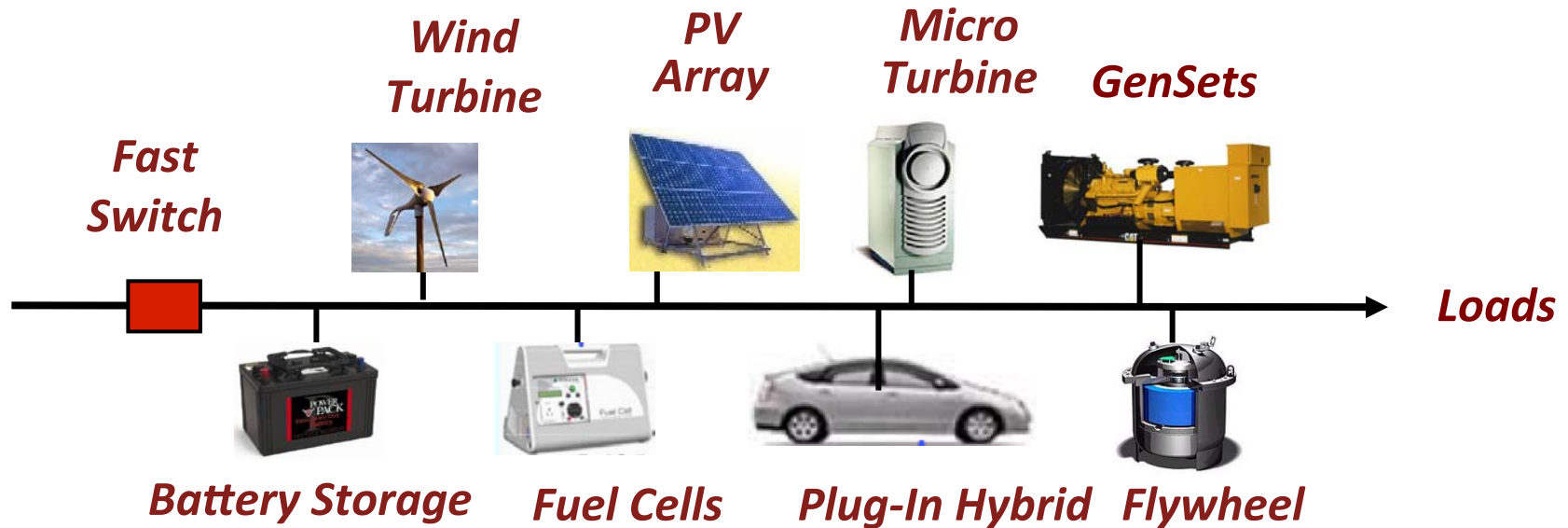
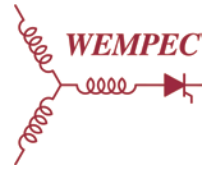
Electric Power System with Distributed Energy Resources



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

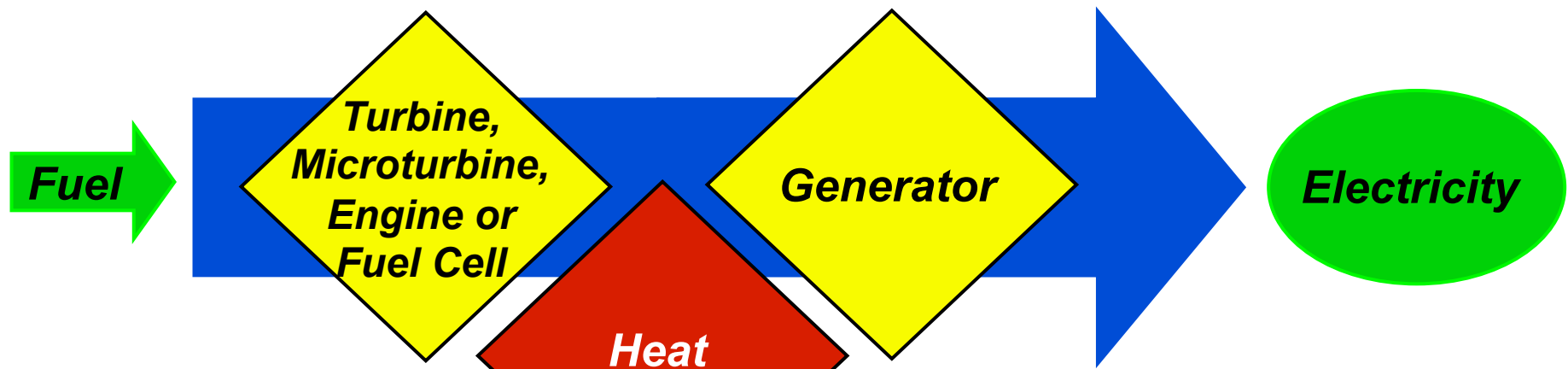


Microgrids

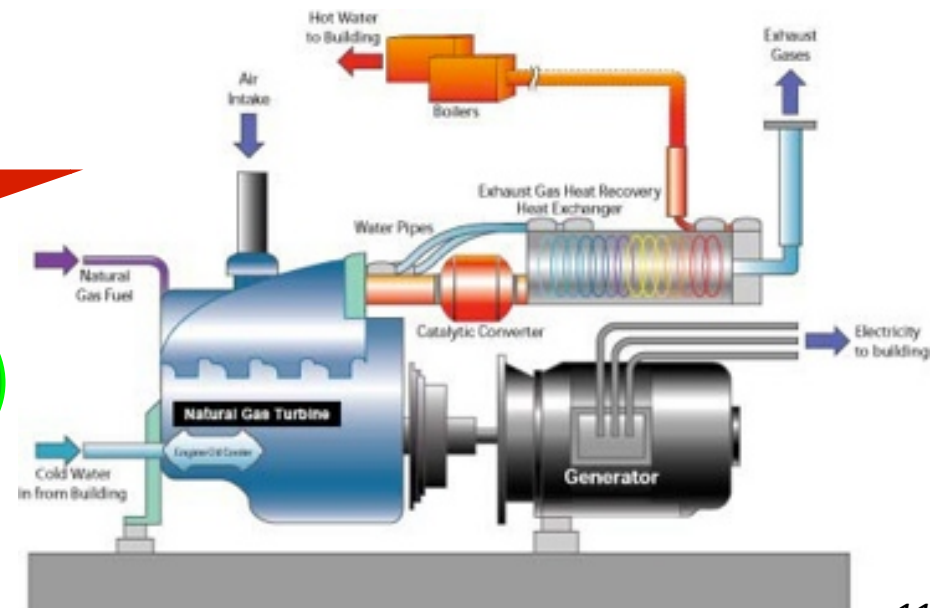


- Microgrids provide a promising means of integrating large amounts of distributed sources into the power grid
- Microgrids open the door to significant system efficiency reliability/resiliency improvements

Combined Heat and Power (CHP)



CHP can significantly boost total energy efficiency and reduce CO₂ emissions

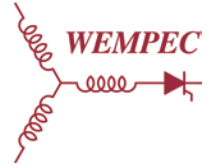




Generation in buildings provides local resiliency

*CERTS Microgrid demonstrated its value during outages
caused by Superstorm Sandy*

Need to Rethink T-D Interface

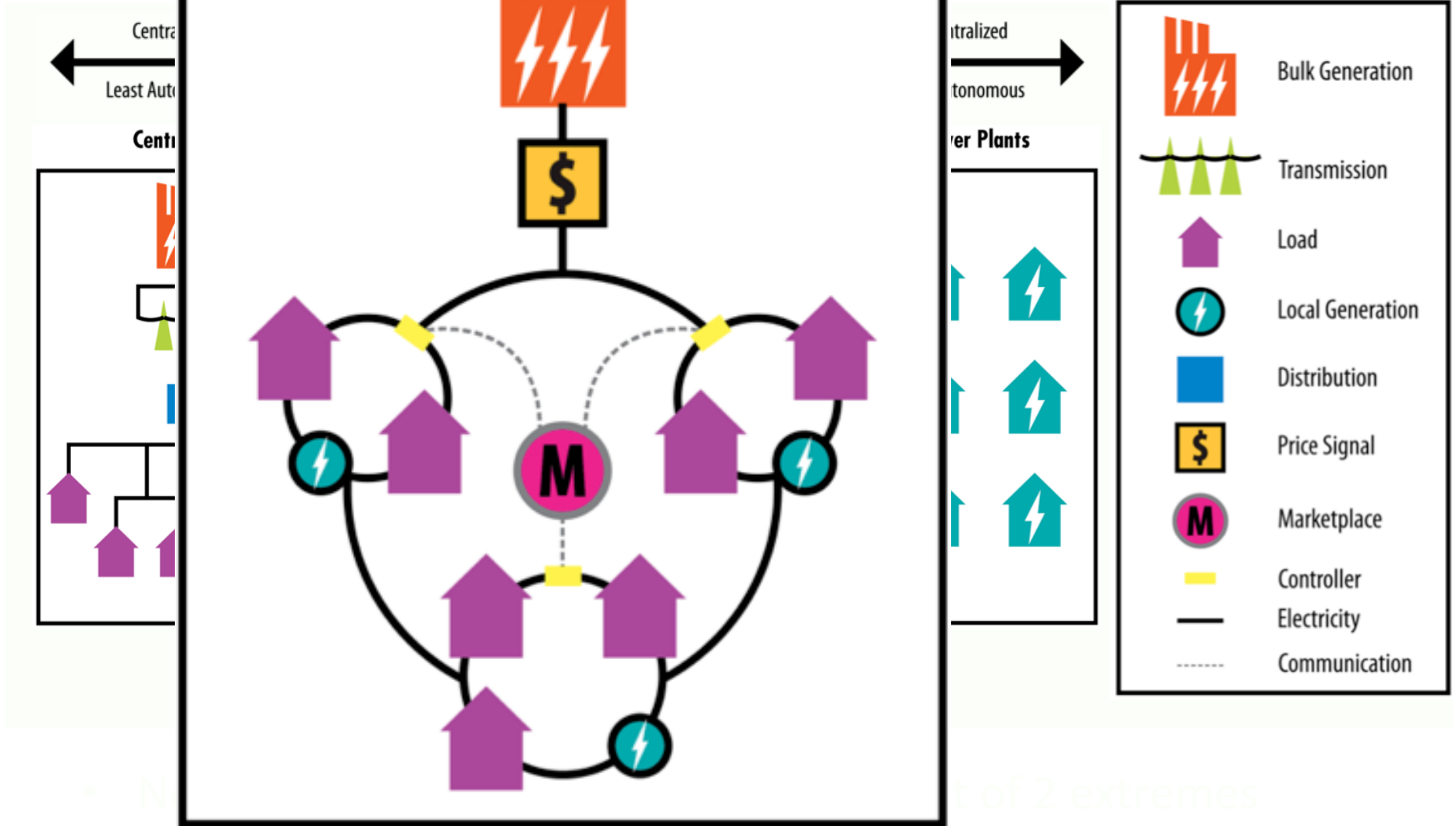
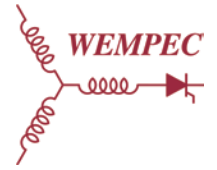


- Transmission-distribution interface serves as:
 - Traditional boundary of wholesale/retail markets
 - Boundary between operations and regulatory jurisdictions associated with transmission and distribution sectors
- Expansion of DER in distribution systems is causing T-D boundary to be blurred
 - DER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

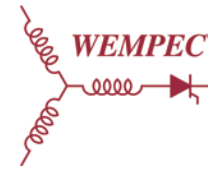
What is the appropriate role of the T-D interface in the future as DER penetration increases?

Dynamic Distribution System

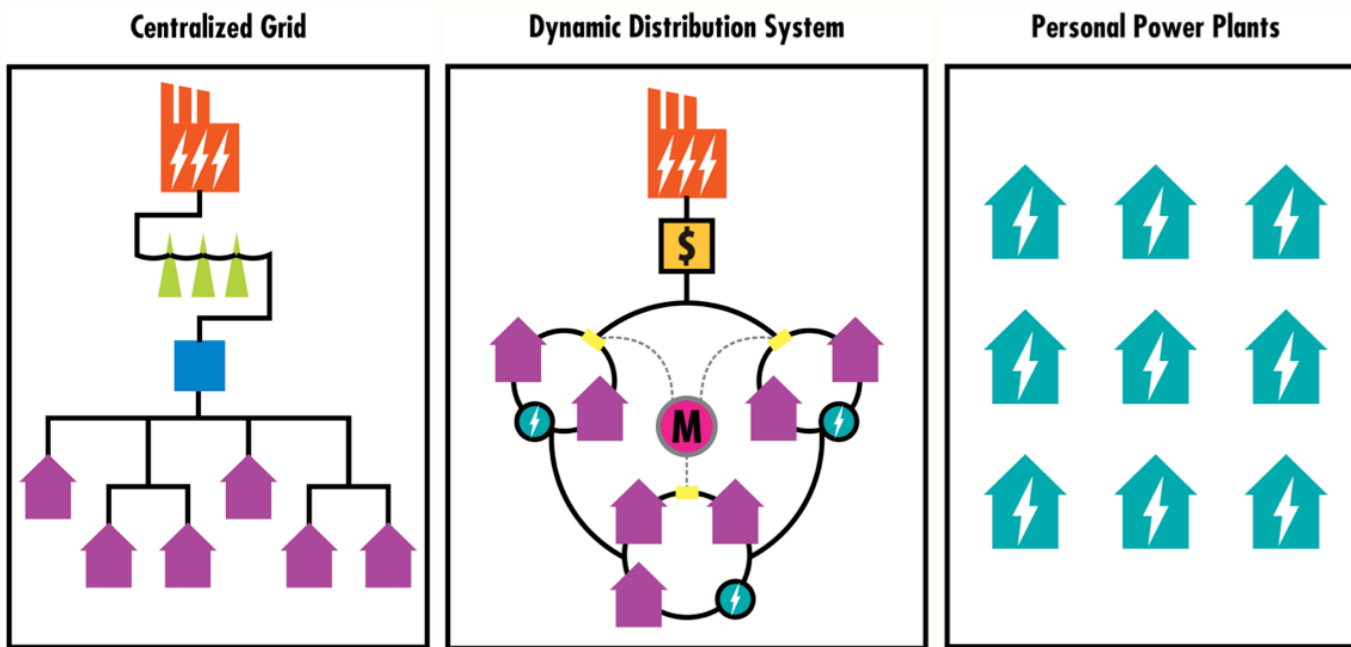
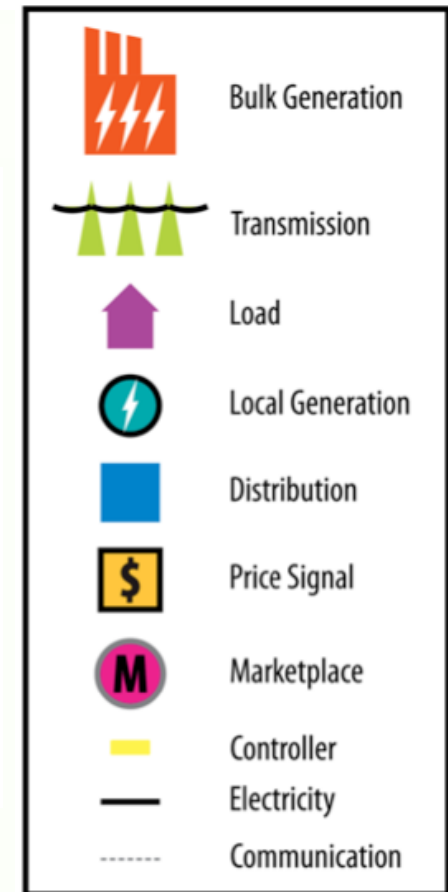
System



Dynamic Distribution System (DDS) Concept



KEY



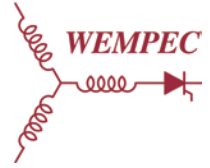
*Best of
Centralized Grid*

*Best of
Personal Power Plants*

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

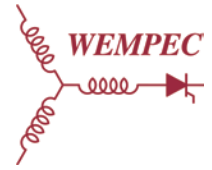
Economic efficiencies via distribution-based marketplace

- 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 CO₂ content

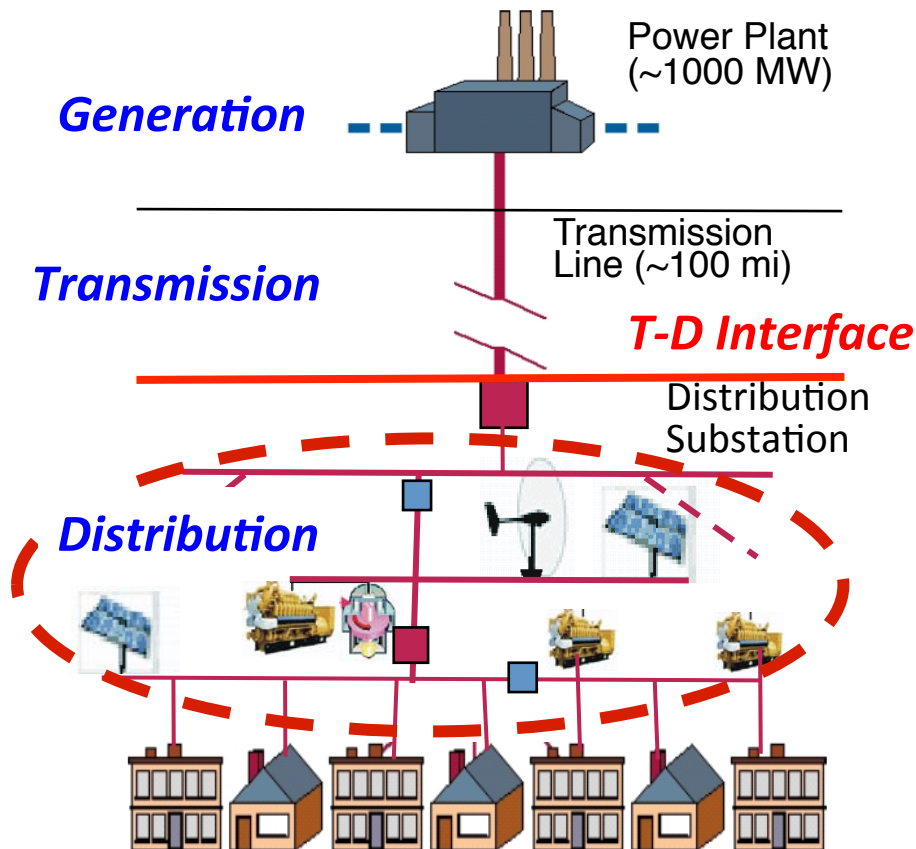
Problem with 1000s of DERs



TSO

*Transmission System Operator
ISO/RTO*

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



Central Control by ISO/RSO

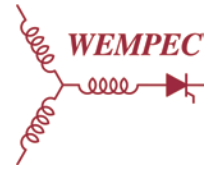
- Complex is huge
- It is structurally problematic*
- Extra cyber-security problems

Highly Decentralized

- Structurally sound*
- Scalable
- Easier to secure

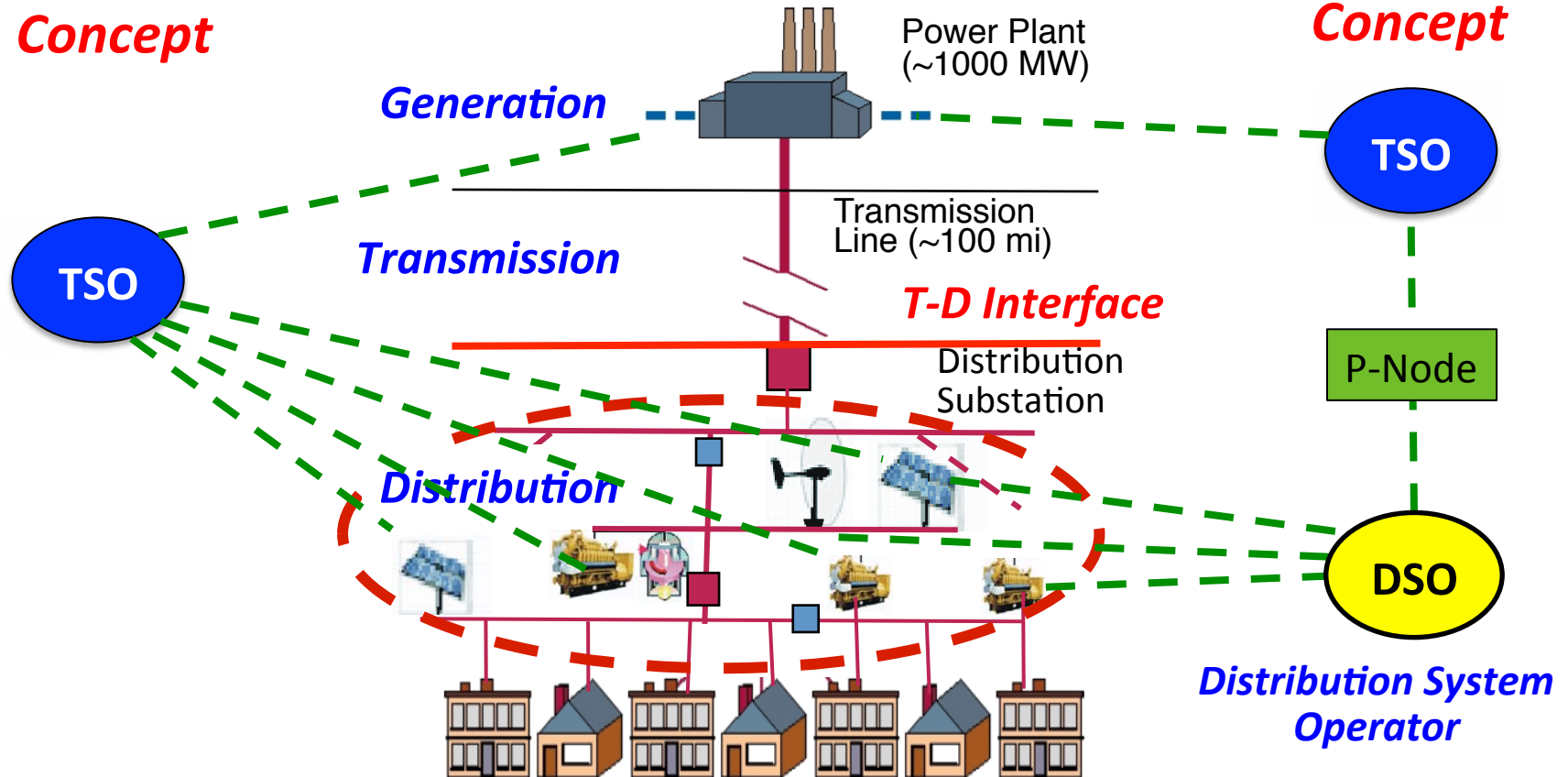
*Lorenzo Kristov, Paul De Martini, "21 century electric distribution system operations," California ISO, www.academia

Alternative Grid Management Approaches



Expanded TSO Concept

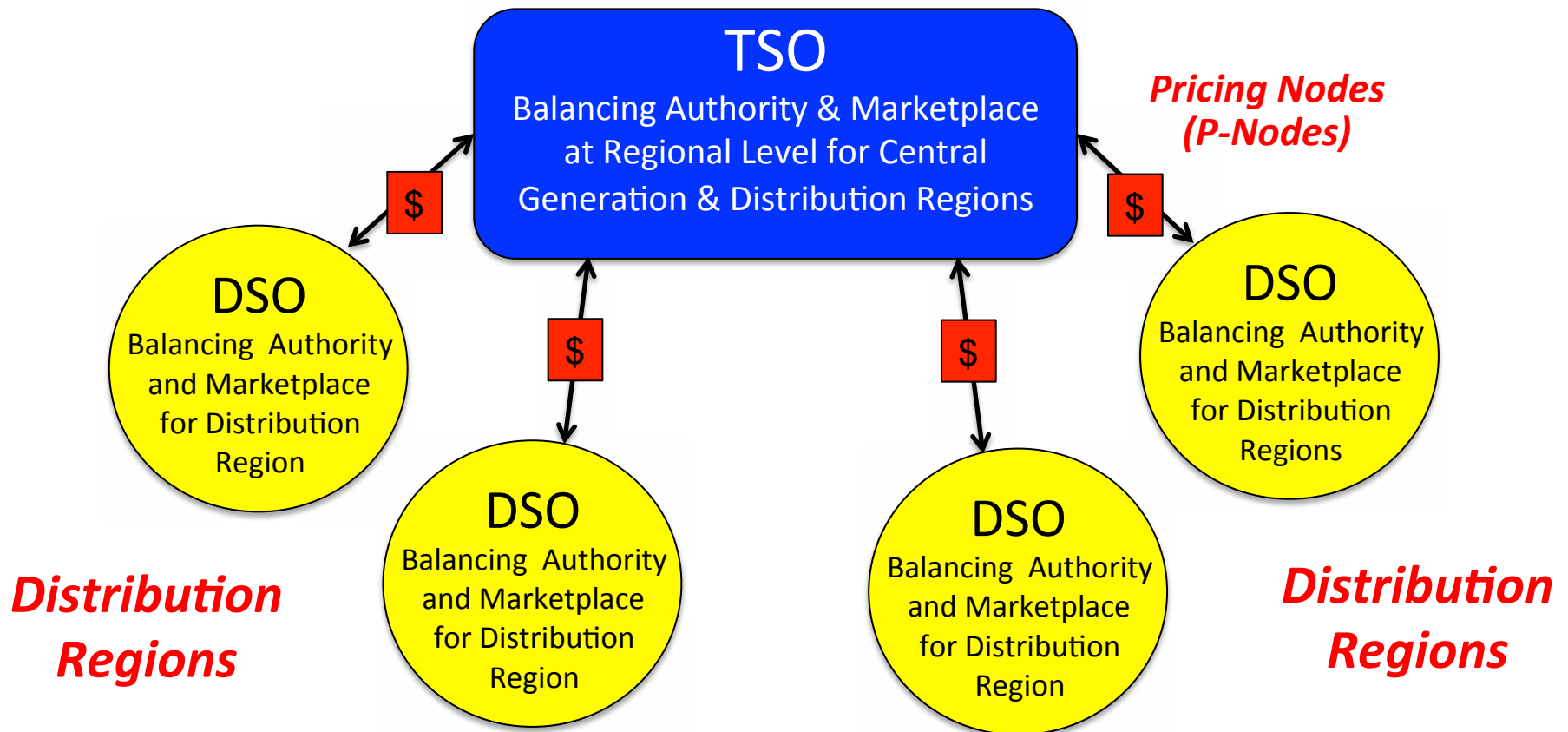
TSO/DSO Concept



- **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

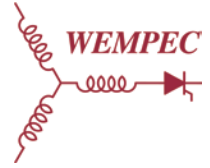
Central Generation and Transmission



- One TSO may be linked to significant numbers of DSOs

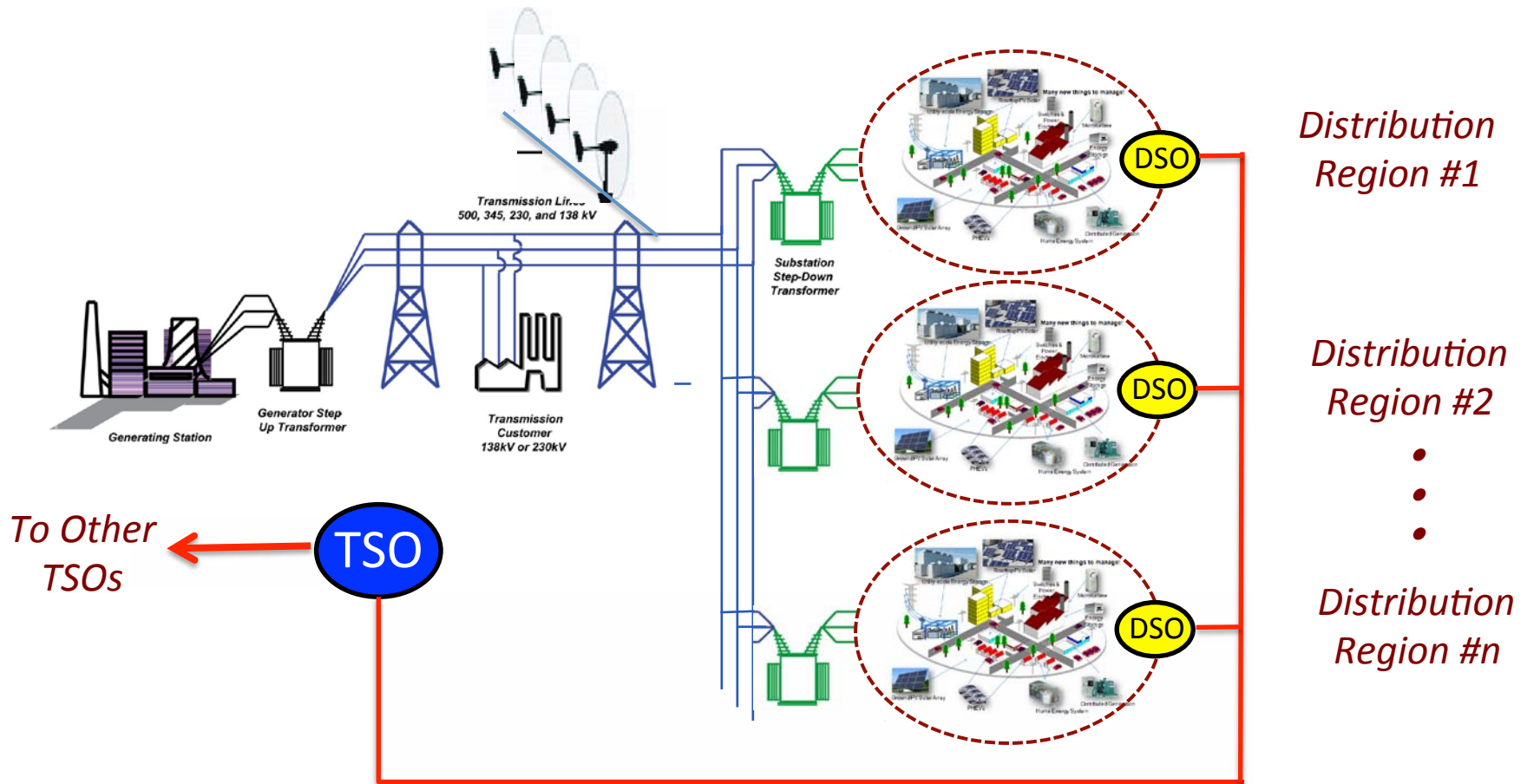
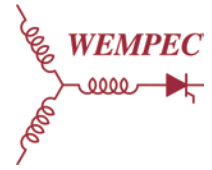


Major DDS Operation and Control Principles



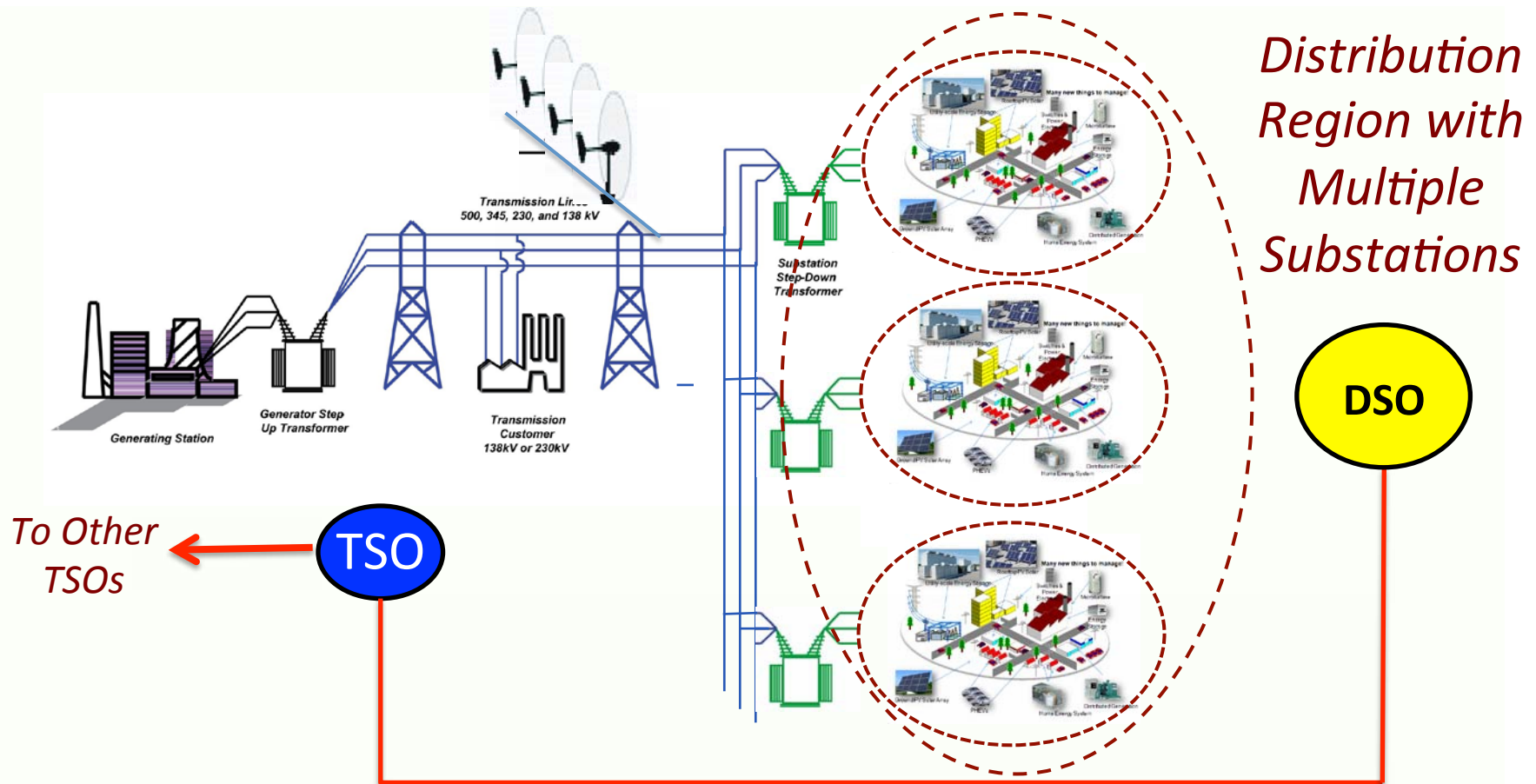
- TSOs continue to play their current role as balancing authorities (BA) and electricity market providers (MP) at transmission level
- Each distribution region has its own DSO that serves as BA and MP for its region
- Central power plants have responsibility for delivering bulk power to distribution 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



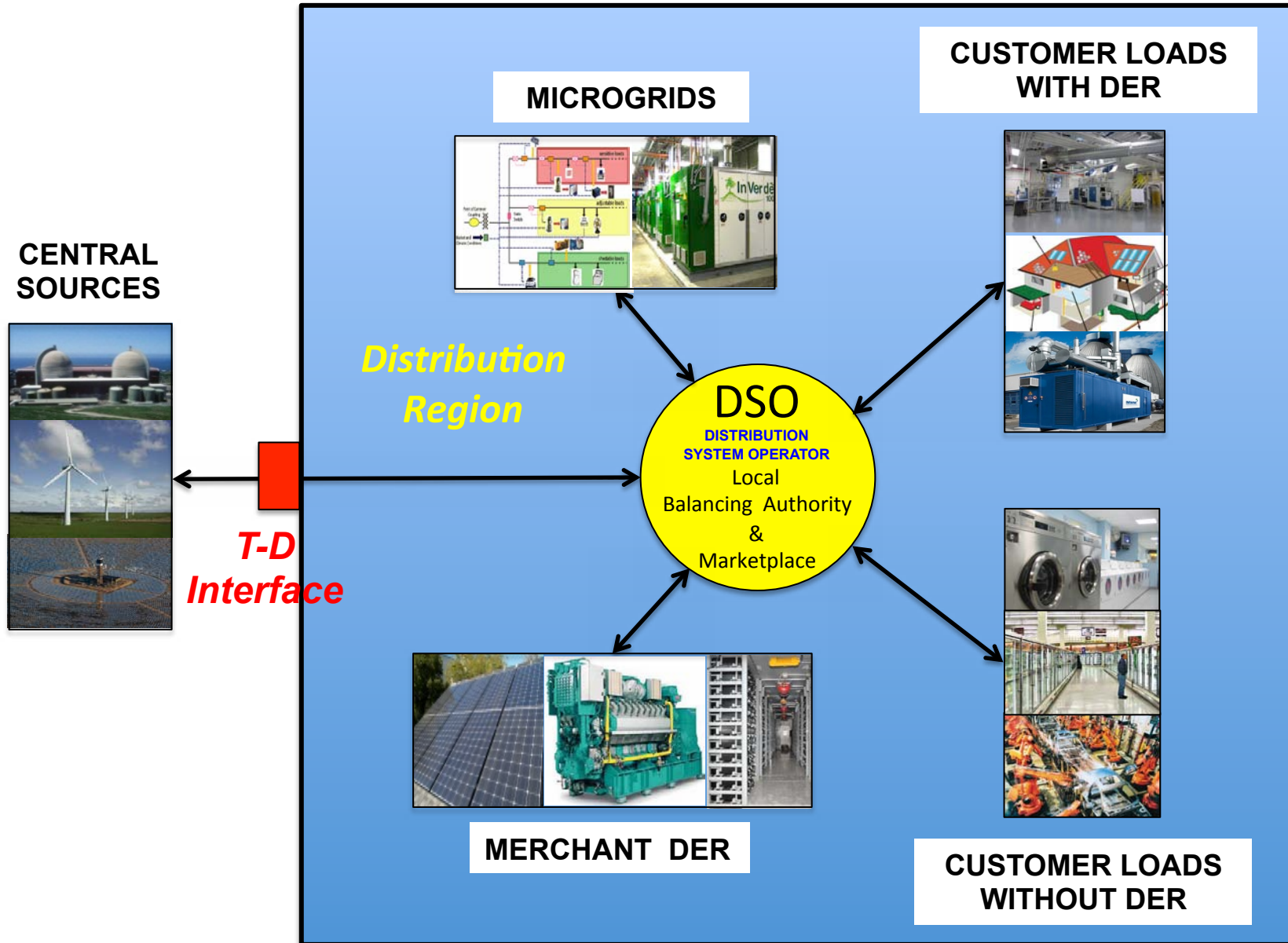
- Proposed DDS architecture is conveniently scalable over a wide range of grid sizes and configurations

Dynamic Distribution System Architecture



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

Distribution Region Resources



DDS Resources: *Central Sources*



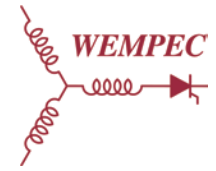
- Contracted wholesale energy
- Dispatchable with slow variations
- Minimum CO₂ and other GHG emissions
- Maximum efficiency

DDS Resources: *Merchant DER*



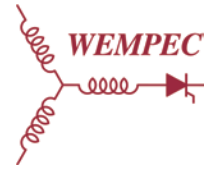
- Opportunities for both power sources and energy storage
- Built by utilities or 3rd parties to deliver needed services to the distribution region
- Objective is to maximize revenue from services:
 - Load tracking to reduce volatility due to loads/renewables
 - Voltage and frequency control ancillary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



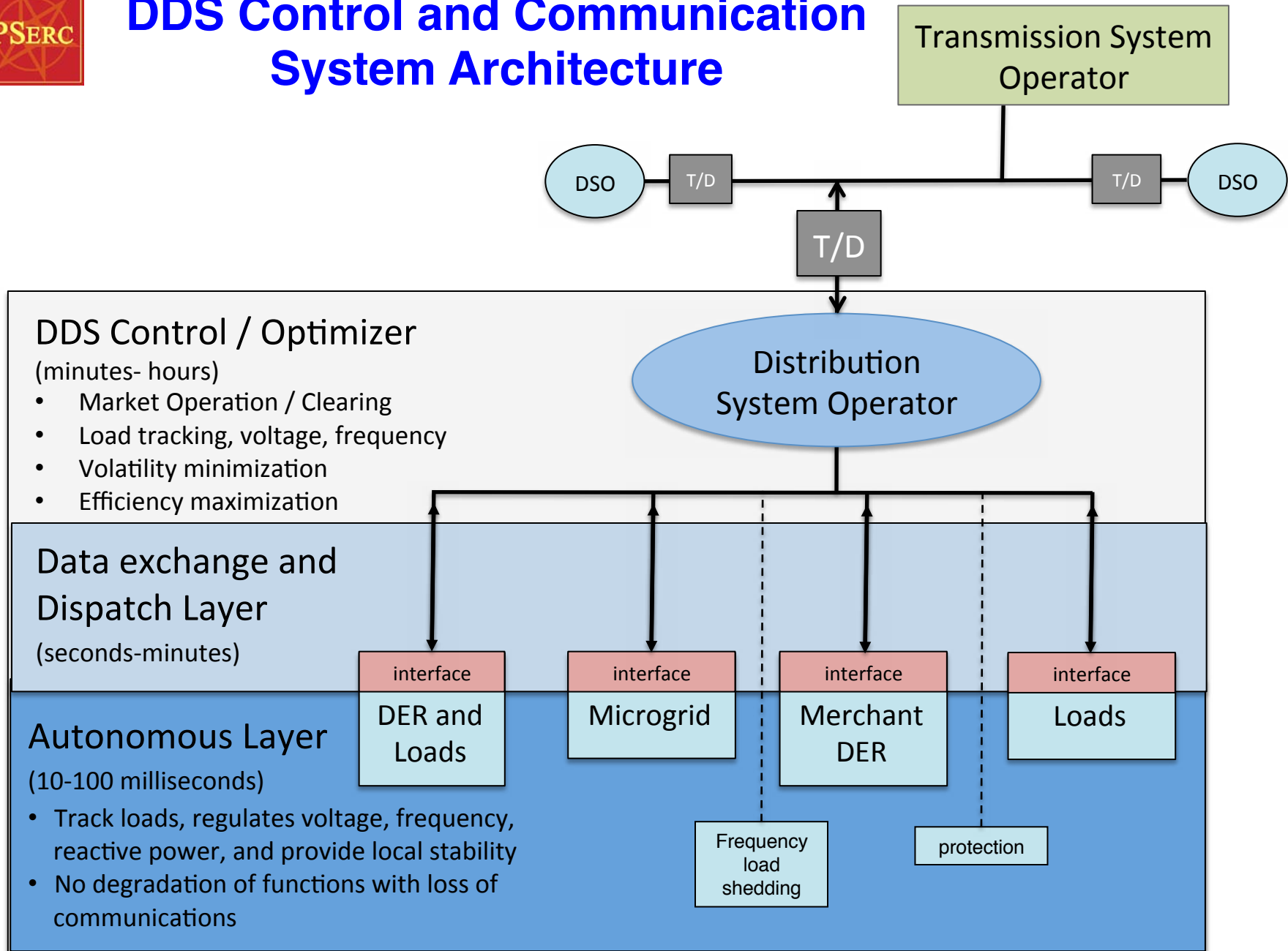
Customer Loads without DER

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

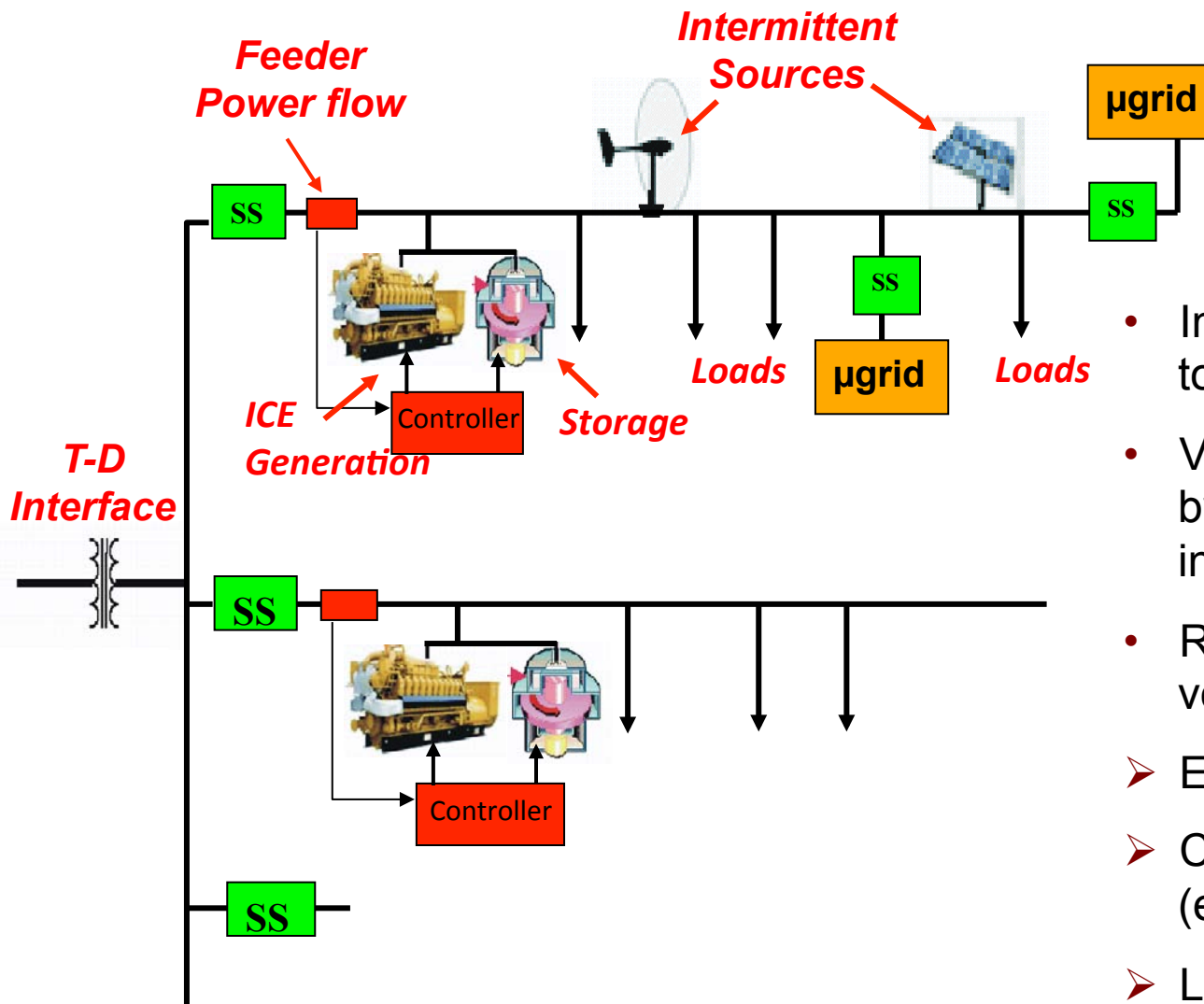




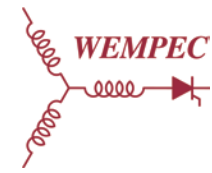
DDS Control and Communication System Architecture



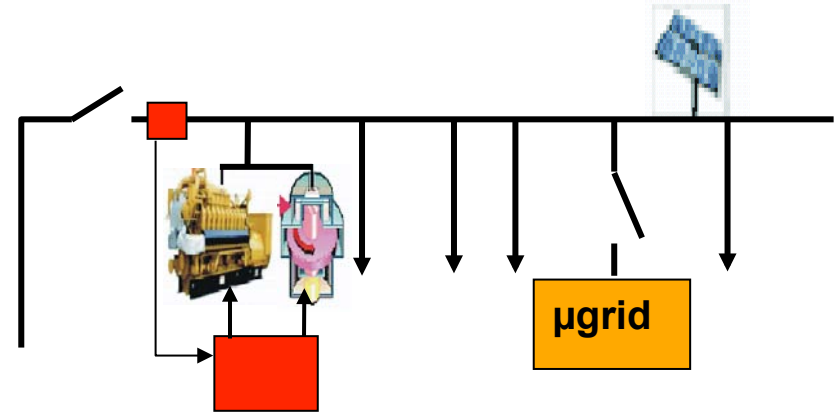
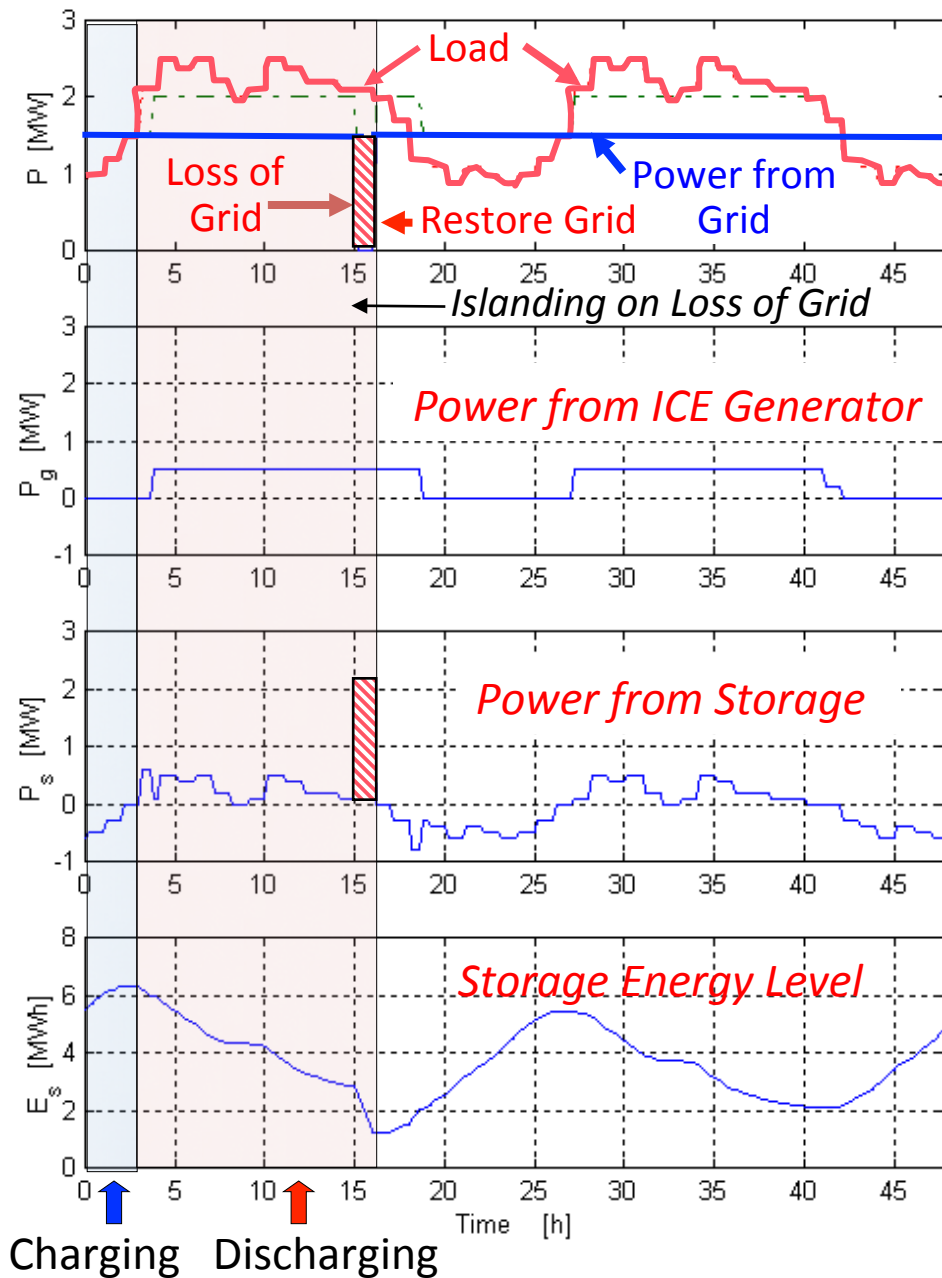
DDS Volatility Response Inside Distribution Region



- 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

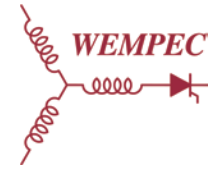


Simulation of Constant Power Flow Control

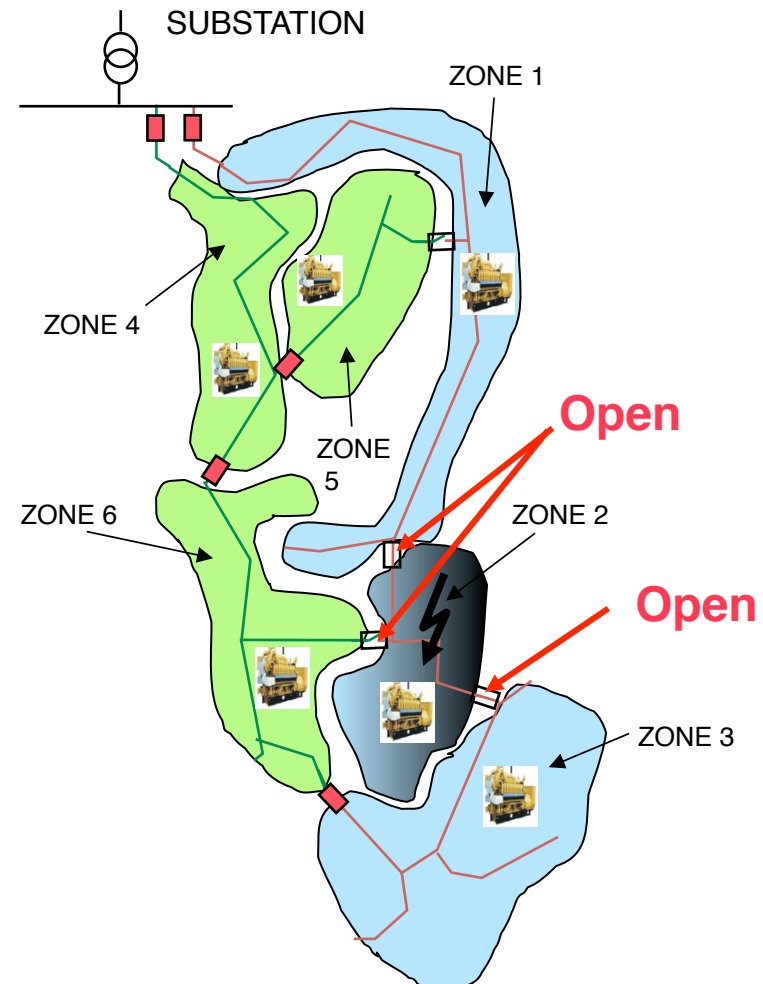


- Power from grid is constant 24/7 except during outage.
- Storage is charged during low load periods.
- Generation is run at optimum level to minimize losses & emissions.
- Storage and local DER follows load and provides fast power balance during islanding.

Distribution Region Protection and Restoration

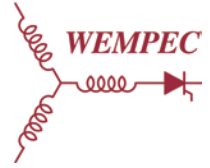


- Initial fault in one of the region's zones may open multiple inter-zonal switches
- Protection scheme uses inter-zonal switches & sensors to reenergize zones that do not include fault
- Local DER sources and storage in zone with fault are coordinated to clear fault as quickly as possible.
- Inter-zonal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

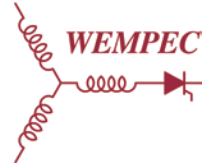
DDS Implementation Challenges



- 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

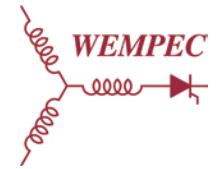


- DDS concept provides an appealing scalable approach for integrating large amount of DER into electric grid
- DDS architecture rests on foundation of independent DSOs that incorporate local balancing authority and marketplace
- If implemented, DDS offers combination of benefits:
 - Significant efficiency 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

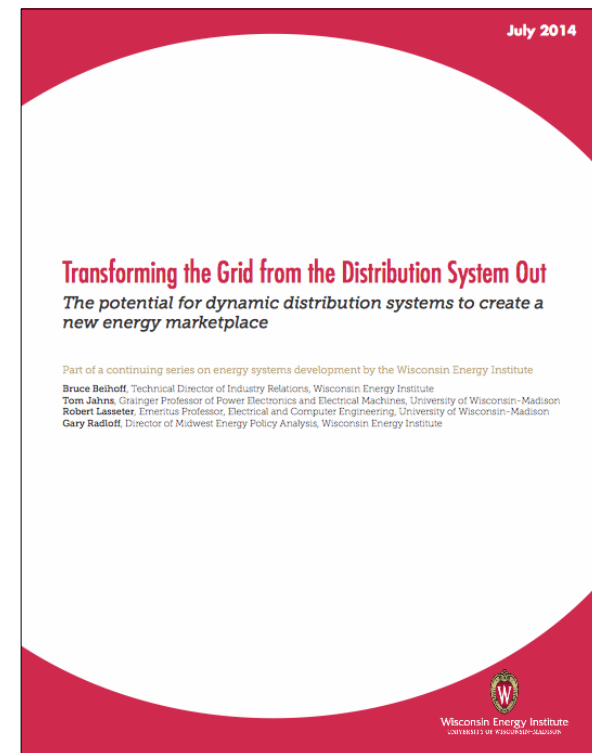


Transforming the Grid from the Distribution System Out by

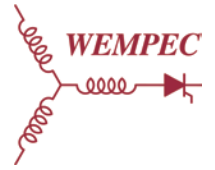
Bruce Beihoff, Thomas Jahns,
Gary Radloff & Robert Lasseter



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



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Dynamic Distribution System

