# Router Based Distributed Computing for Monitoring and controlling the Electric Grid

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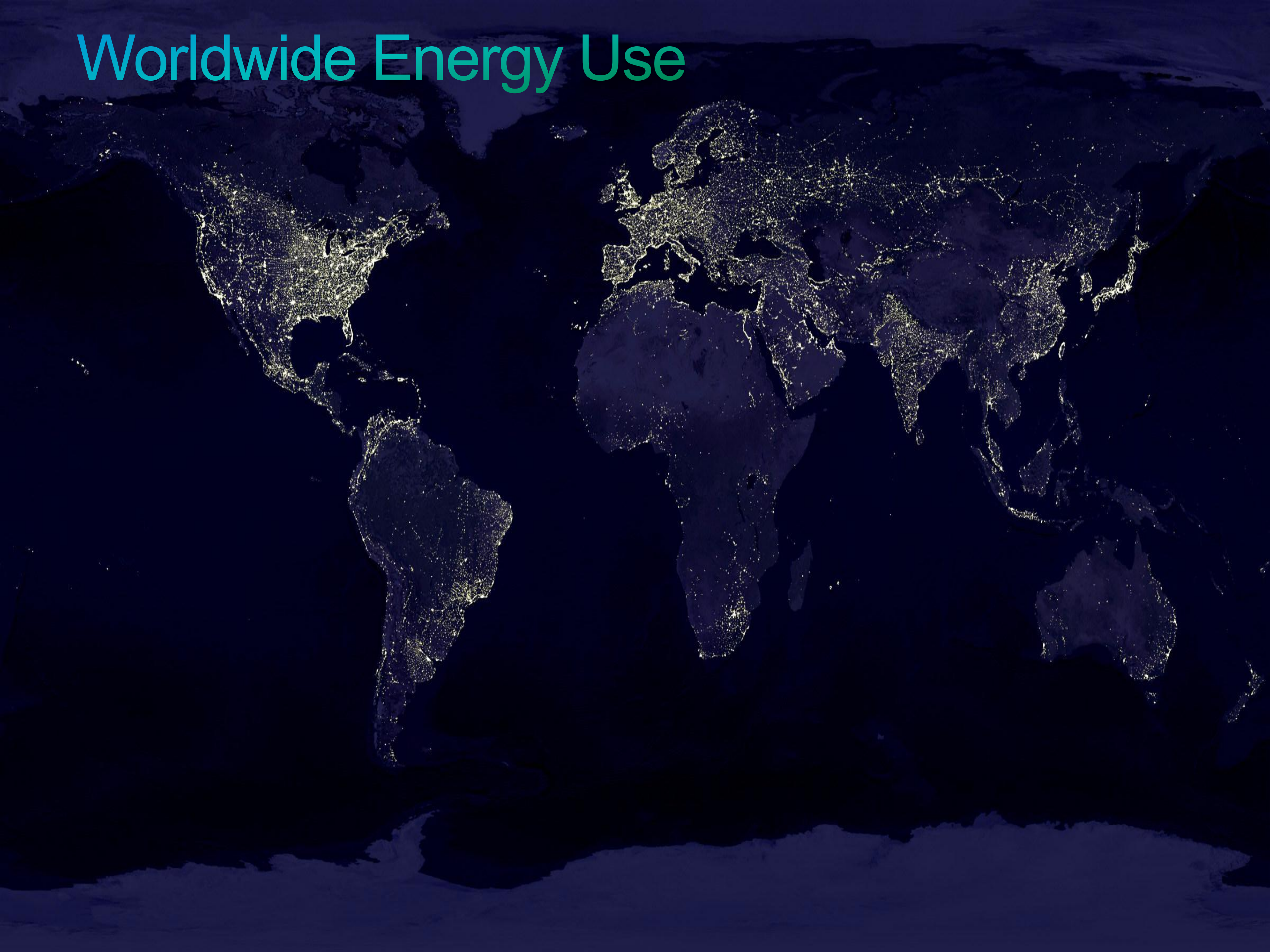
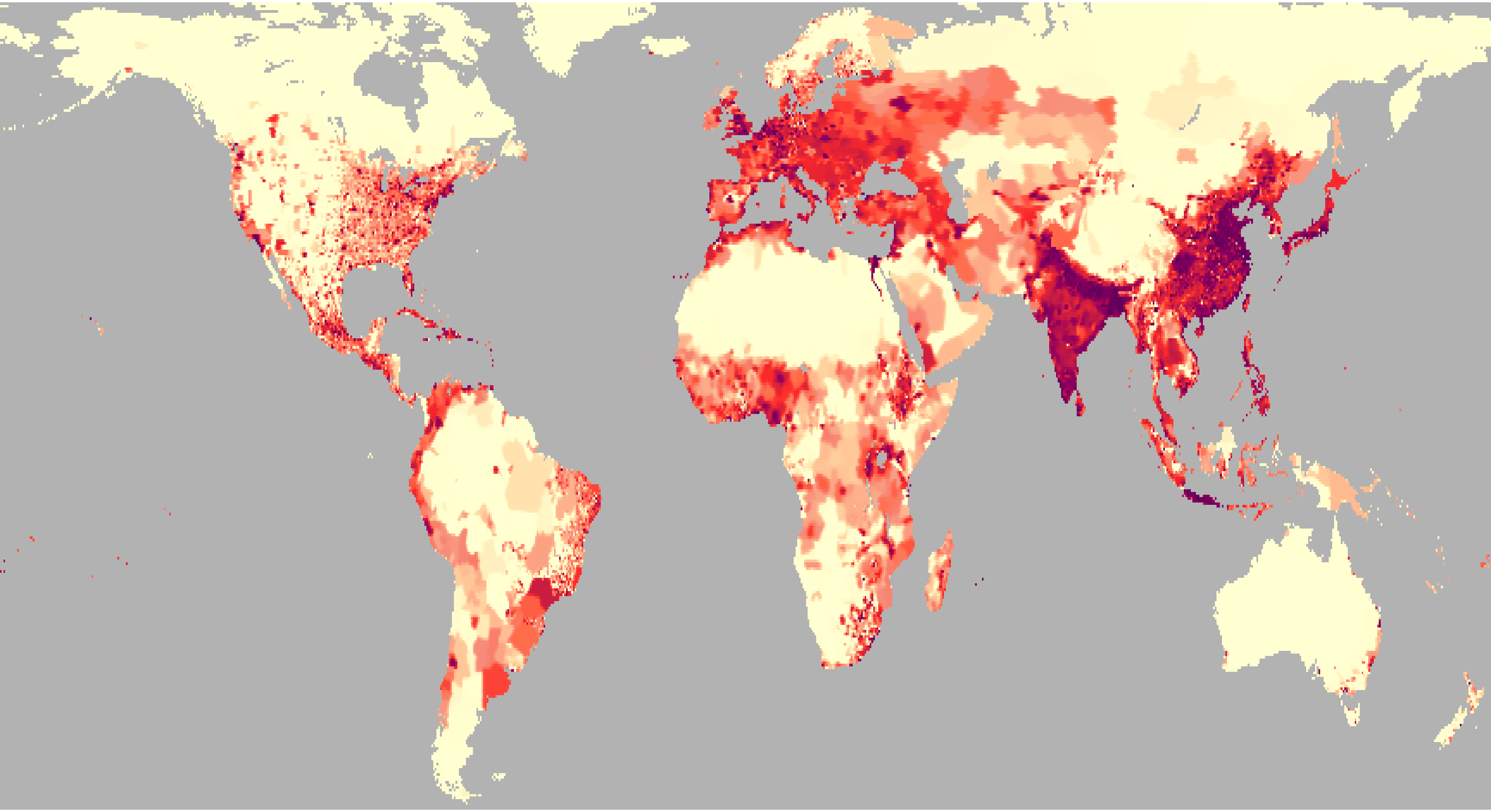
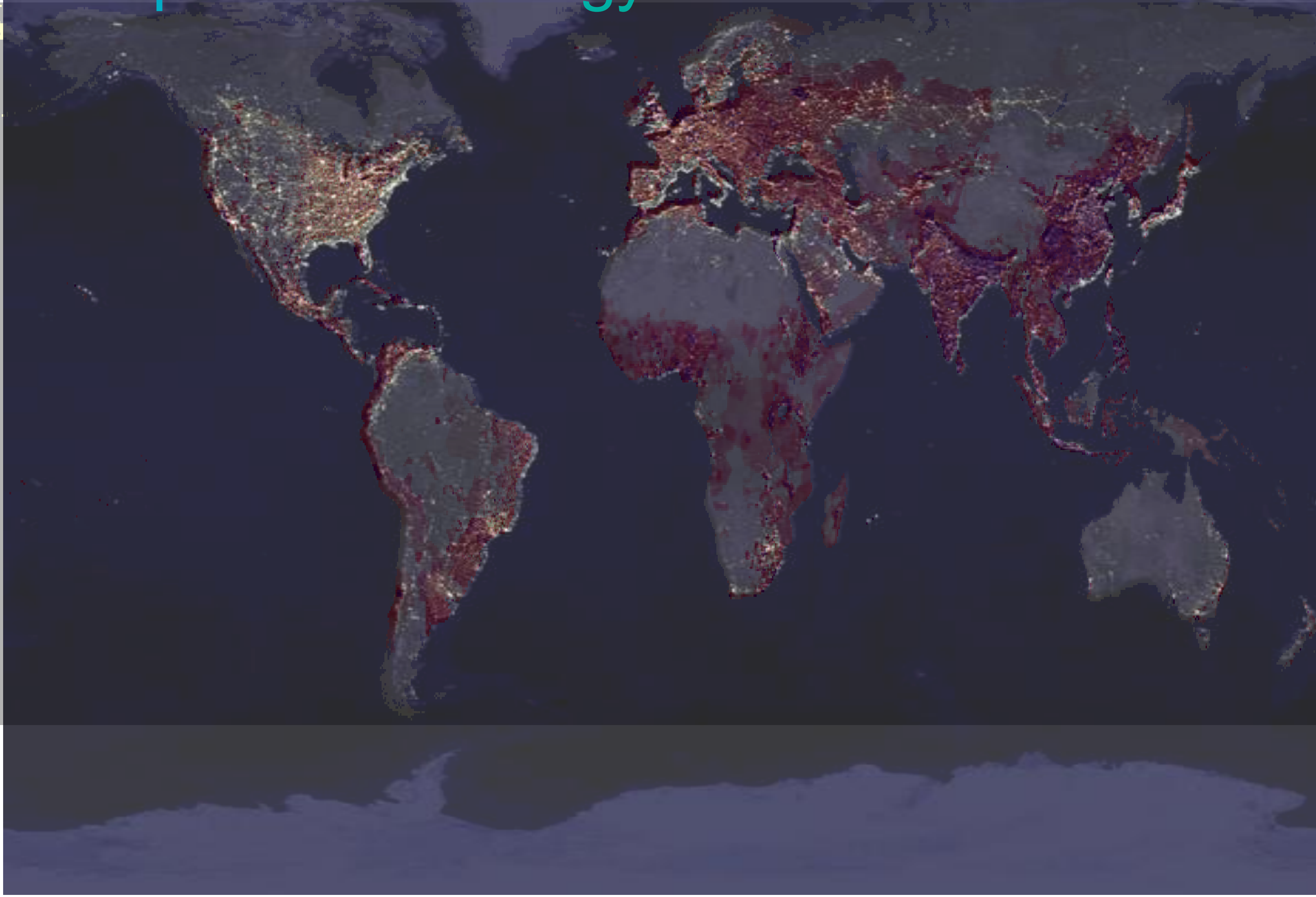
# Worldwide Energy Use



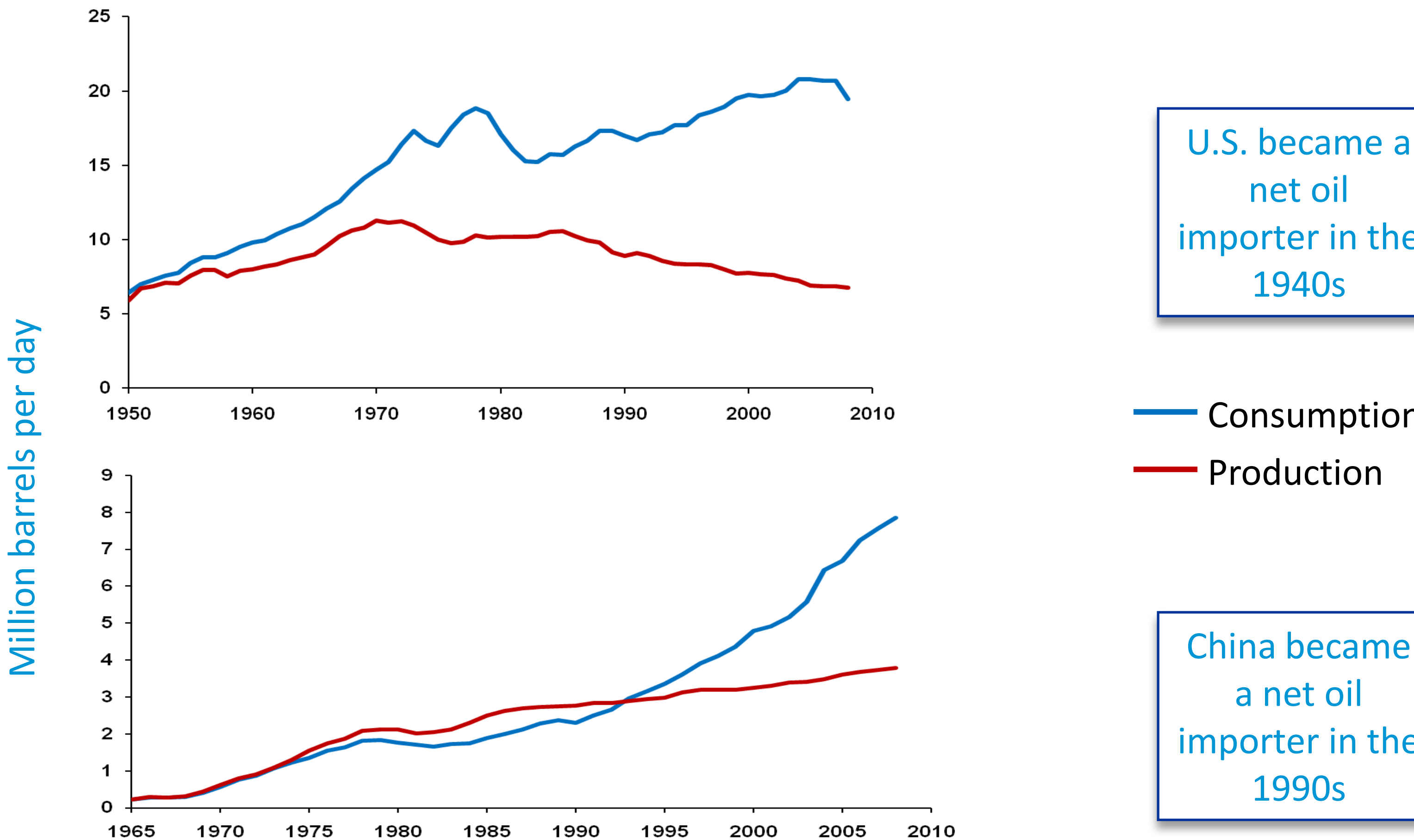
# Worldwide Population Density



# Population & Energy Use Do Not Correlate



# Geographical & Resource Constraints



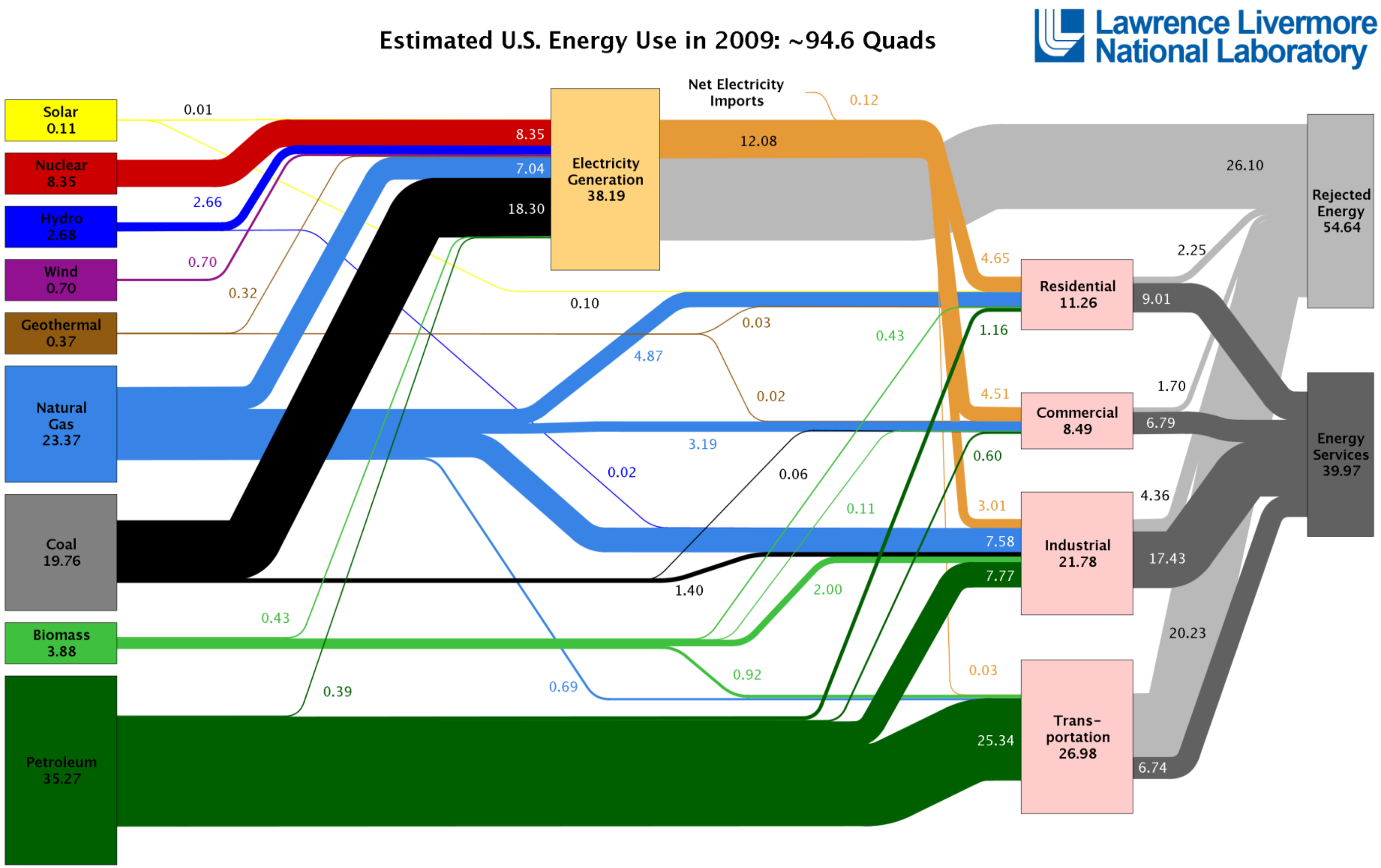

U.S. became a net oil importer in the 1940s

China became a net oil importer in the 1990s

Electrifying the Auto Sector - Is this the solution?

*Source:* Energy Information Administration

# Estimated U.S. Energy Use in 2009



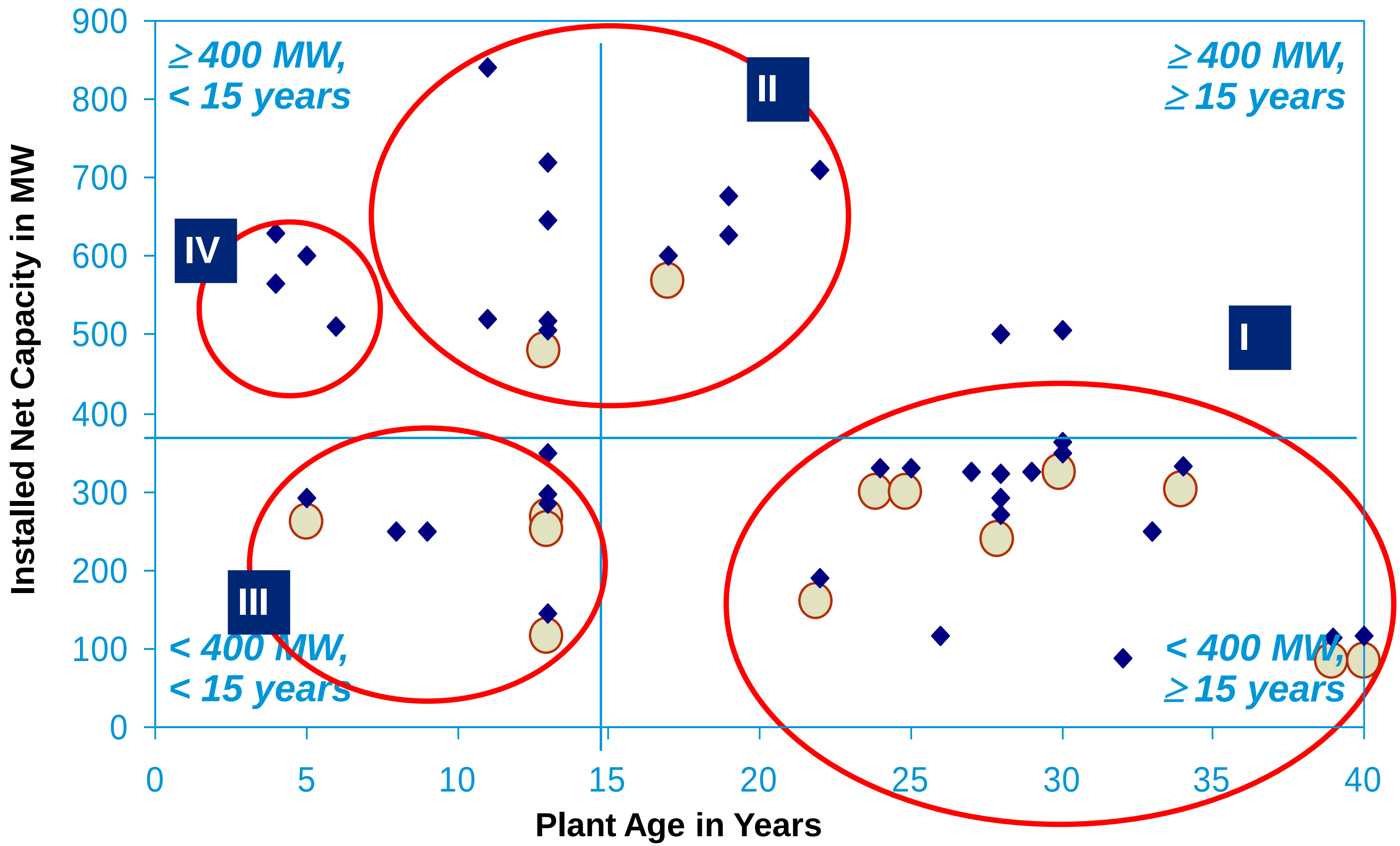

- Electrification of transportation will impose huge challenge to our aging generation, transmission, and distribution
- **A quad** is a unit of energy equal to $10^{15}$ (a short-scale quadrillion) BTU,[1] or 1.055 × $10^{18}$ joules

# U.S. Electric Power

- There are over 3000 utilities whose assets are valued at over $800 billion
- 10,000 power plants in the U.S.
- The Nation's "electric bill" is about $247 billion
- 40% of energy consumption in America is used to produce electricity
- Most of the nation's system is 30-50 years old

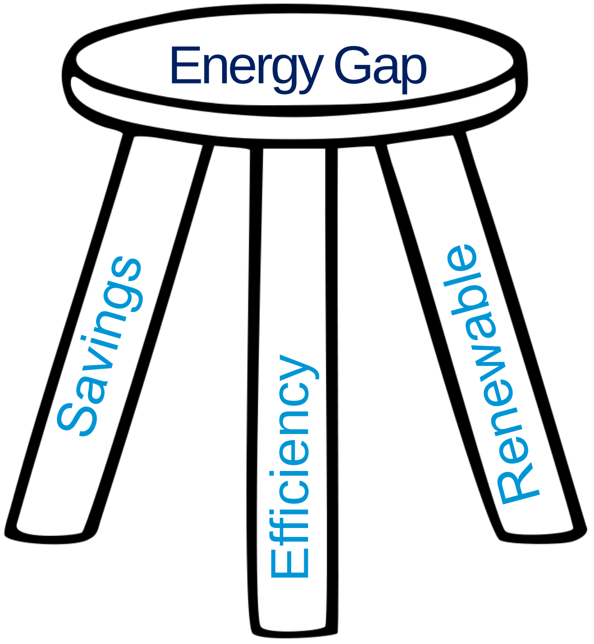
Power outages cost the economy from $25 to $180 billion annually

# Generation is Aging




Units without FGD: *≥15 years – Cluster V; < 15 years – Cluster VI*

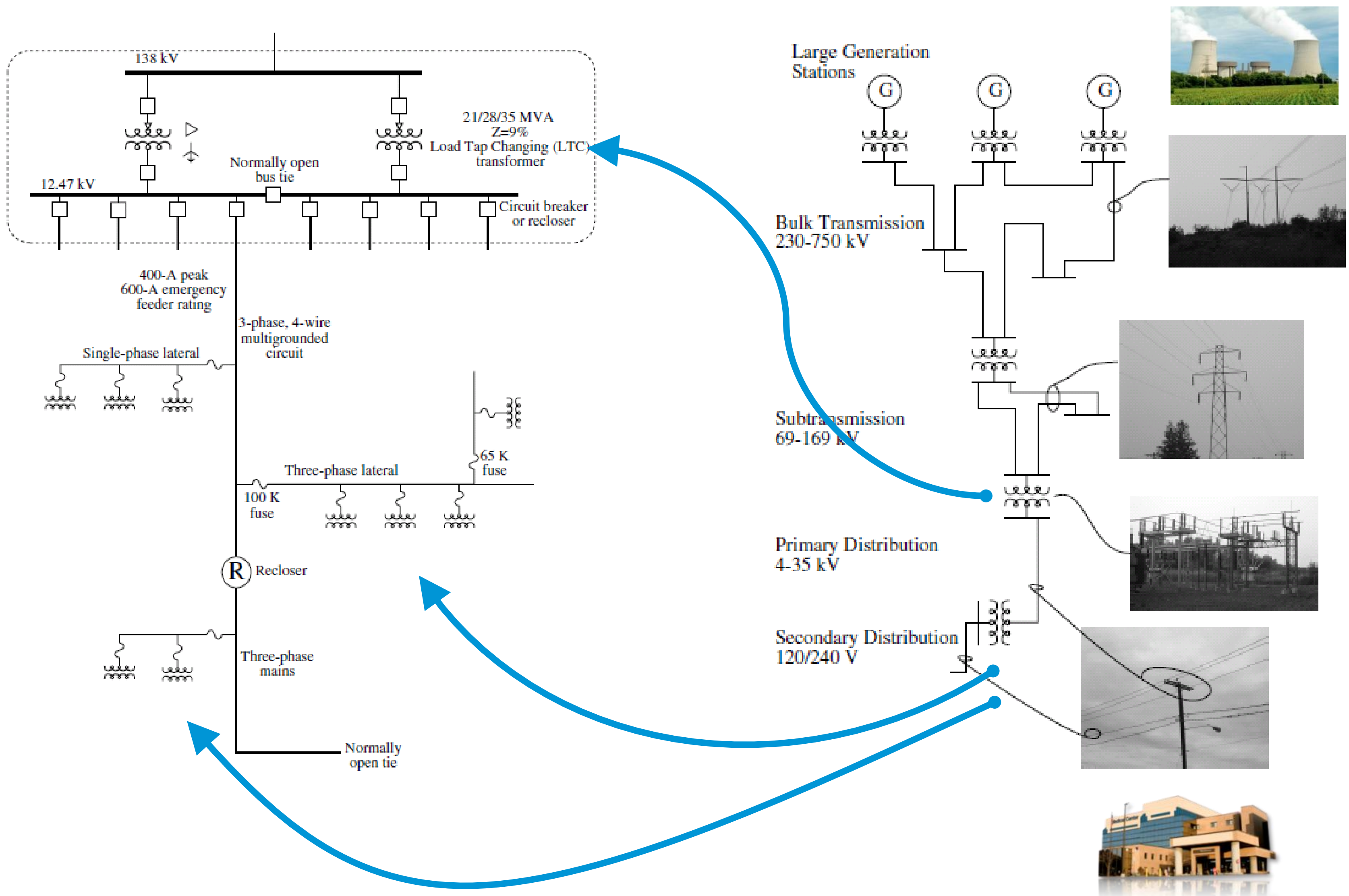
# Closing the Electric Energy Gap



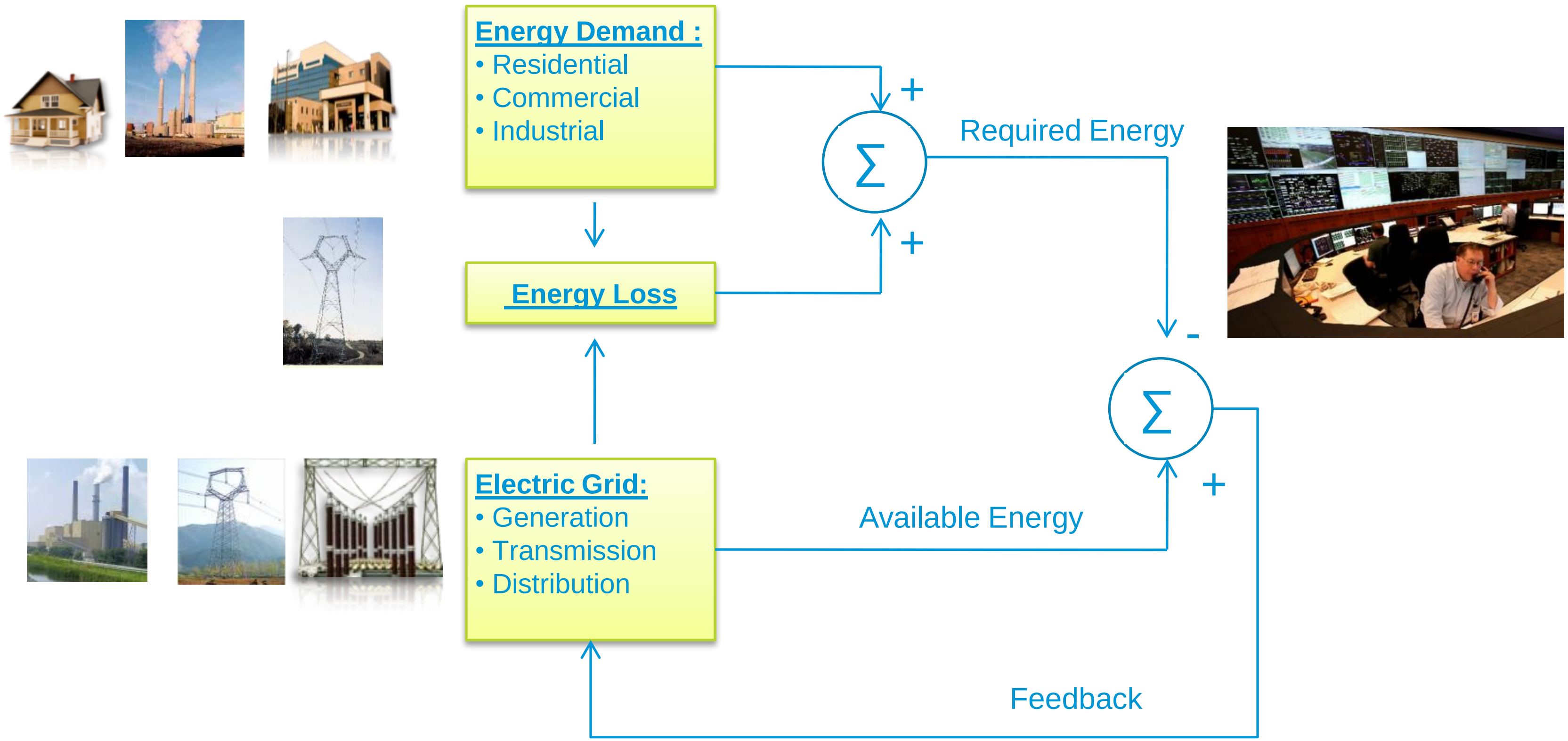

**The Smart Grid:**

- Key component of the End to End Solution

# North American Electric Grid

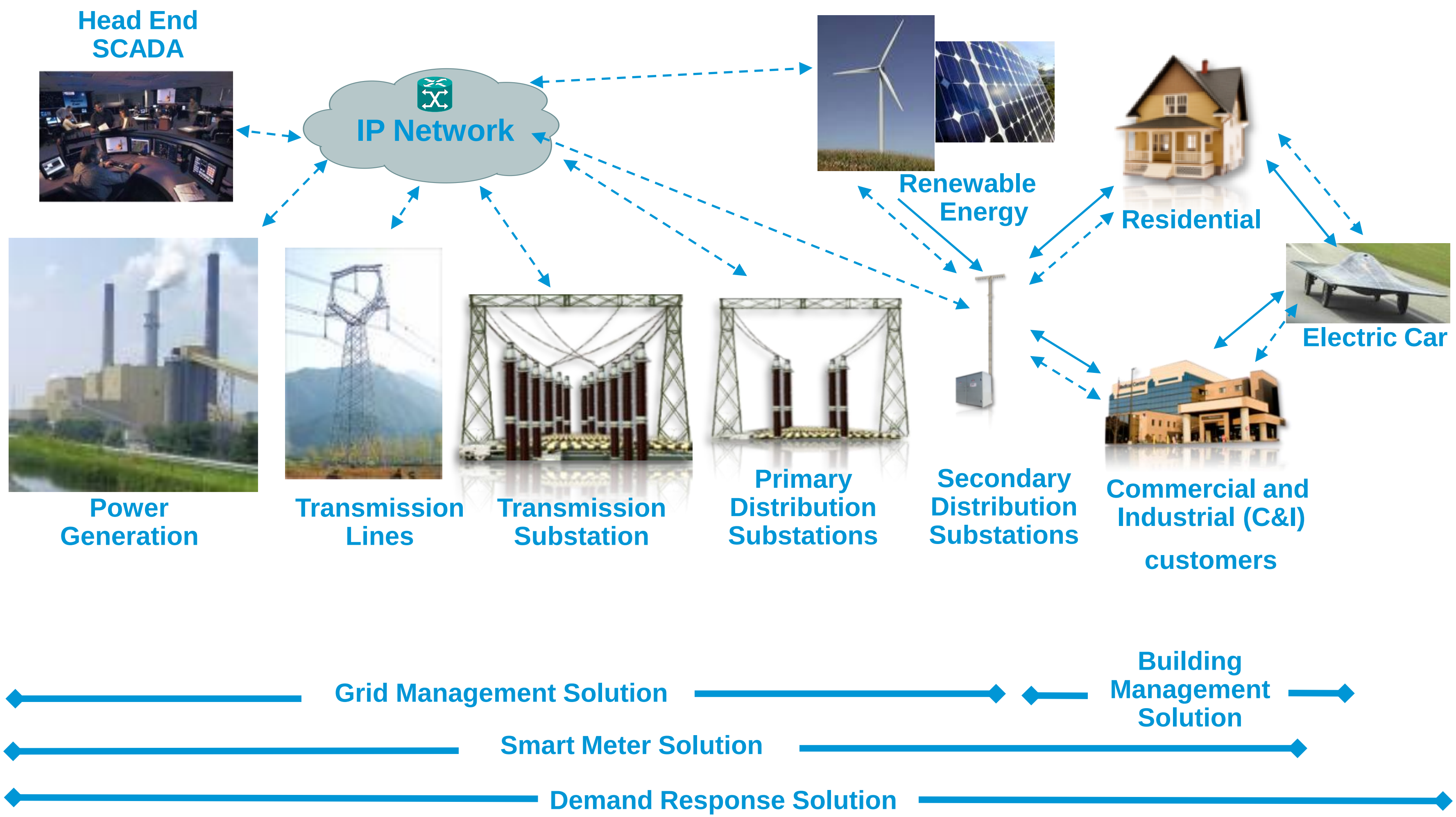


# Controlling the Electric Grid




**Grid Operations**: Meeting Energy demand while dynamically optimizing grid operations and resources

# The Smart Grid




**SCADA:** *supervisory control and data acquisition*

# Communication Network: Why IP

- Standards based
  - Ensure interoperability and facilitate innovation
- Scalable
- Secure (IPsec, TLS, etc.)
- Simplicity Over Perfection
- Evolutionary Flexibility
  - Layered architecture
- Bandwidth

**But what about reliability, delay, and jitter…..**

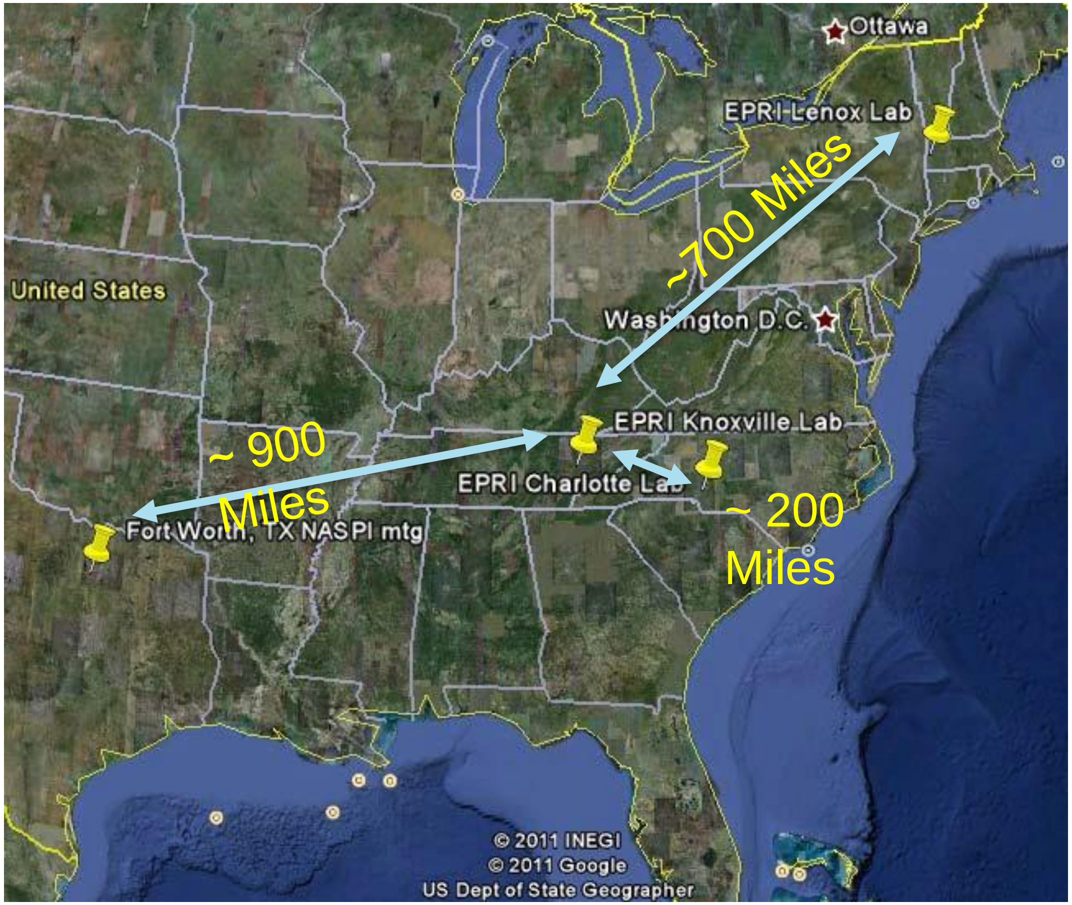
# Real-Time PMU data over IP network

**EPRI NASPInet:**

Lenox & Charlotte PMUs signals sent to Knoxville

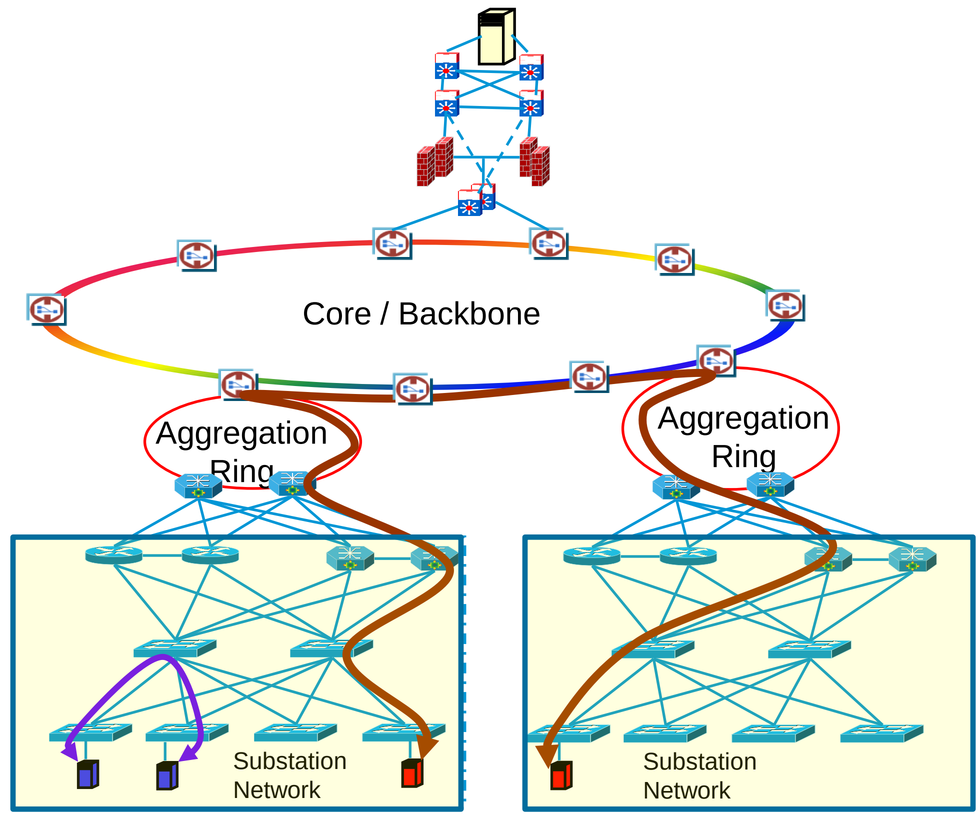
Knoxville simulating Corporate center and sending data to Fort Worth

Local PMU at Fort Worth also integrated into demo North American




**NASPI**: North American SynchroPhasor Initiative

# Sub-Station Tele-Protection



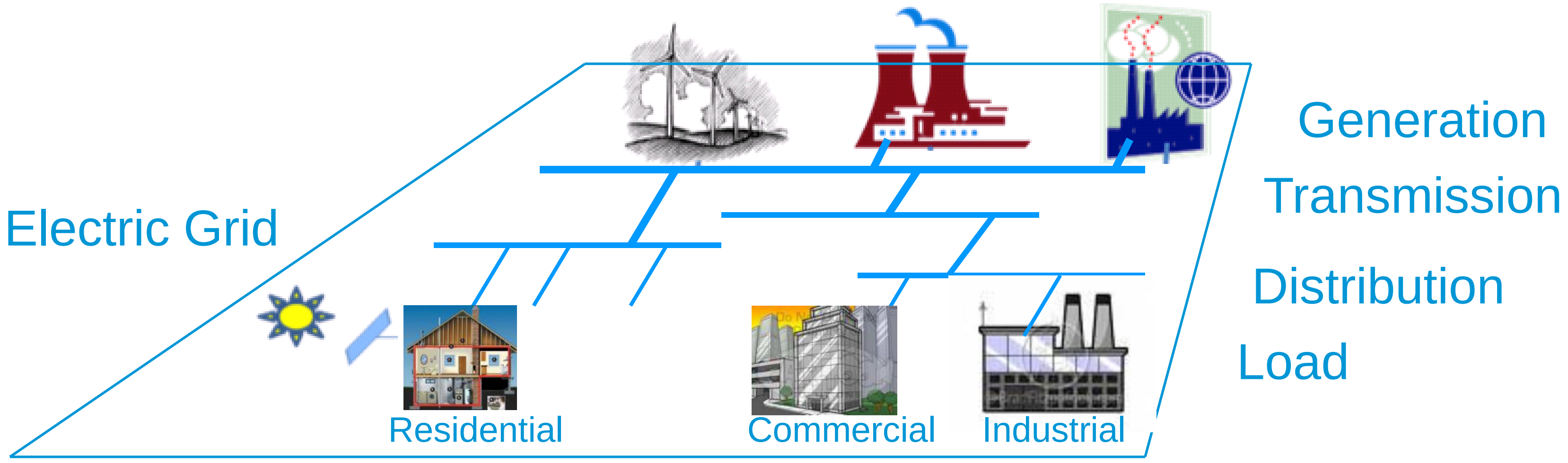

**Key:**

**Substation**

## Key Specifications

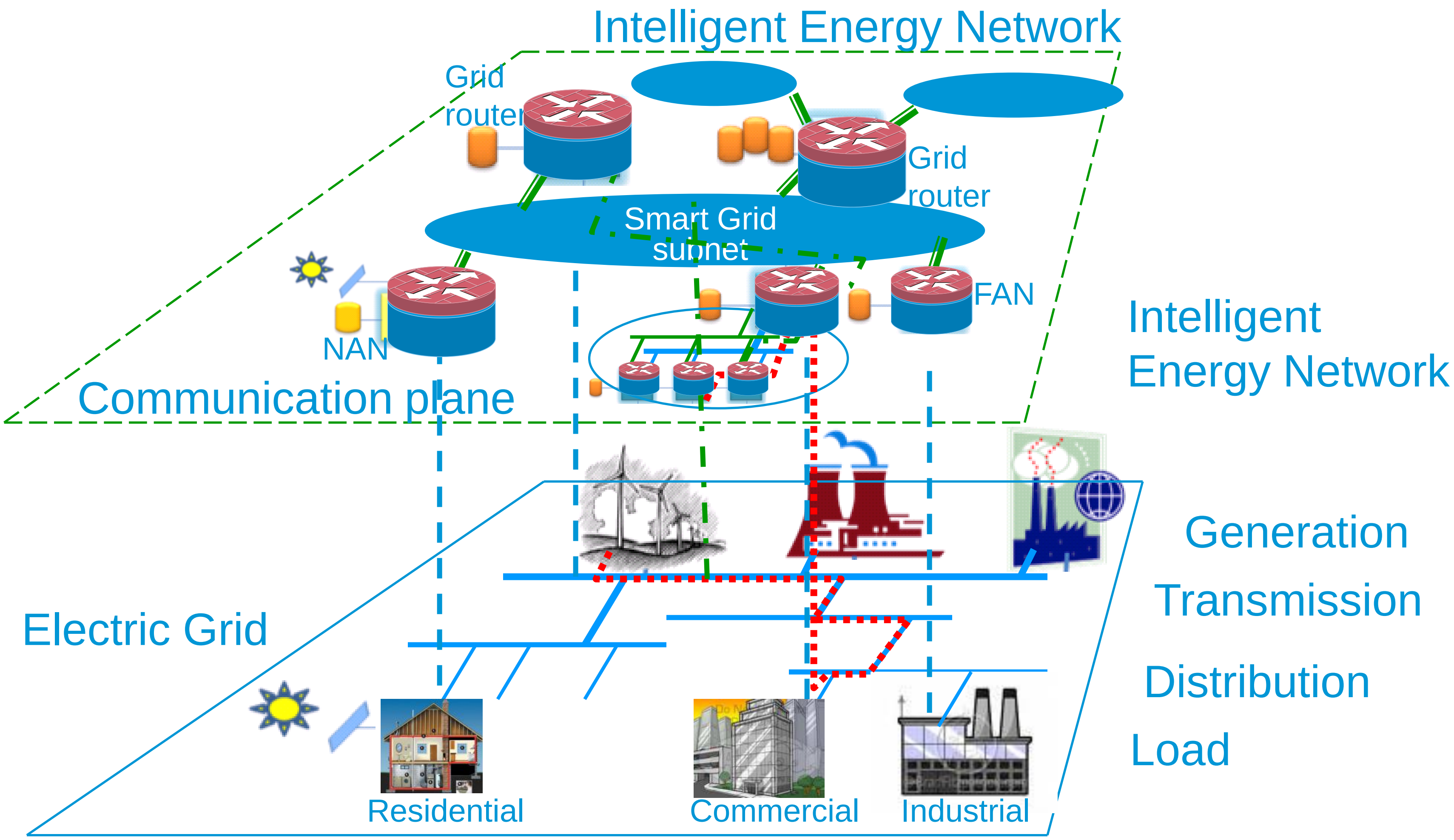
- Able to provide end to end intra-substation one way latencies under 0.25 msec over 0.2 km of fiber
- Able to provide substation to substation one way latencies under 4 msec over 200 km of fiber
- Redundancy options for fault containment, high availability

# The Energy Grid




Adapted from Berkeley LoCal

# Information Overlay to the Energy Grid

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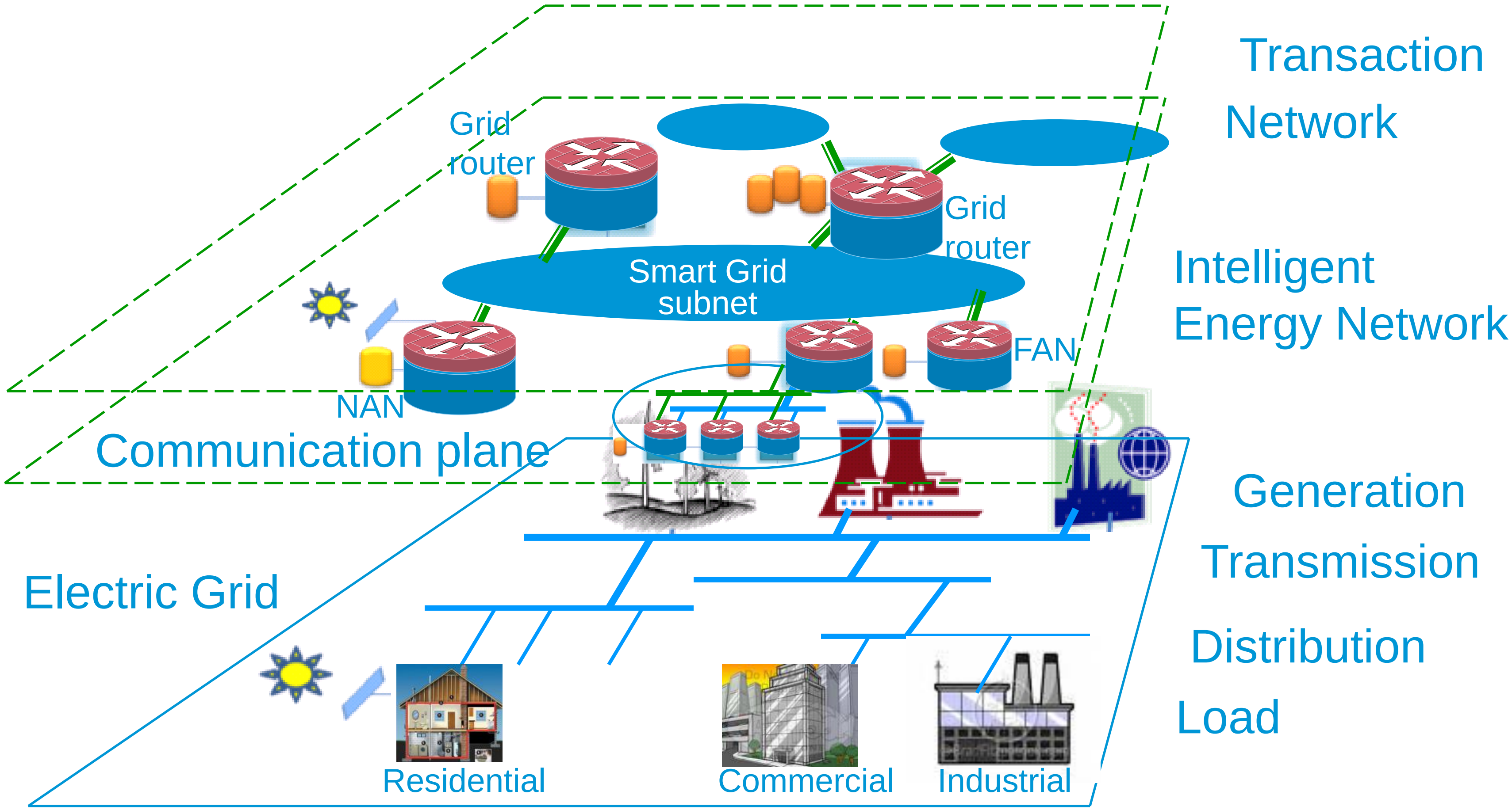
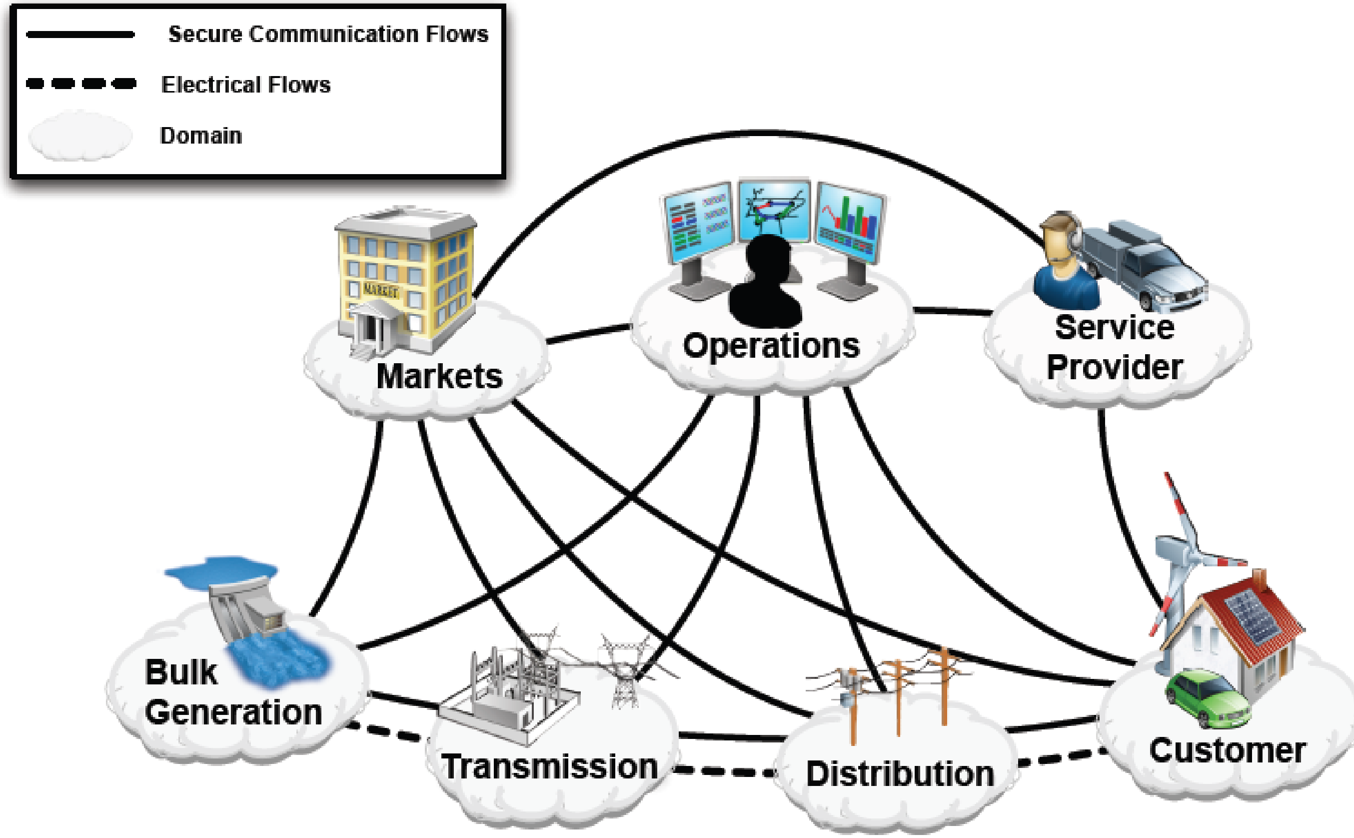



Adapted from Berkeley LoCal

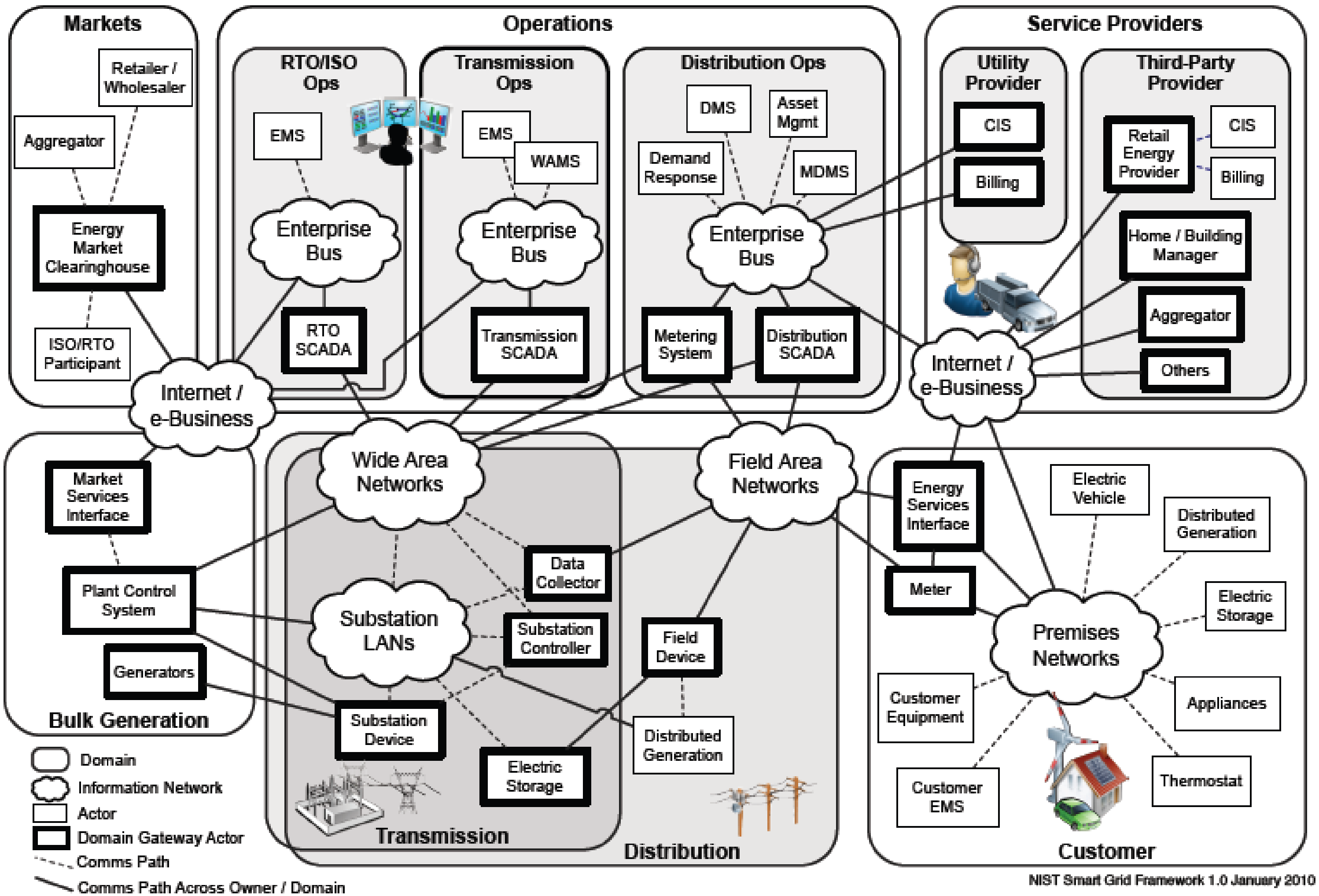
# Domains and Actors in the Smart Grid Conceptual Model



NIST Smart Grid Framework 1.0 January 2010

NIST Smart Grid Framework

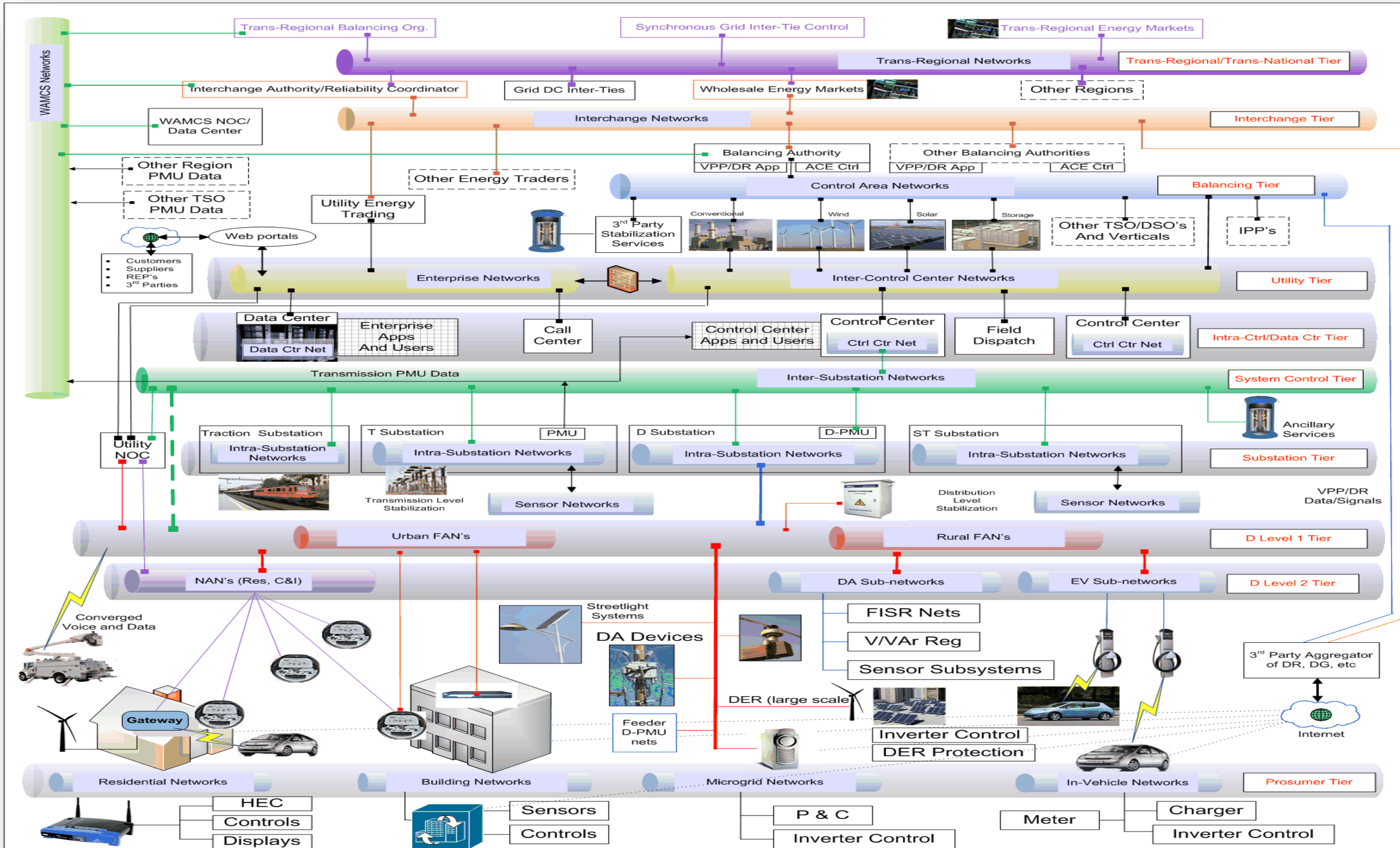
# Conceptual Reference Diagram for Smart Grid Information Networks



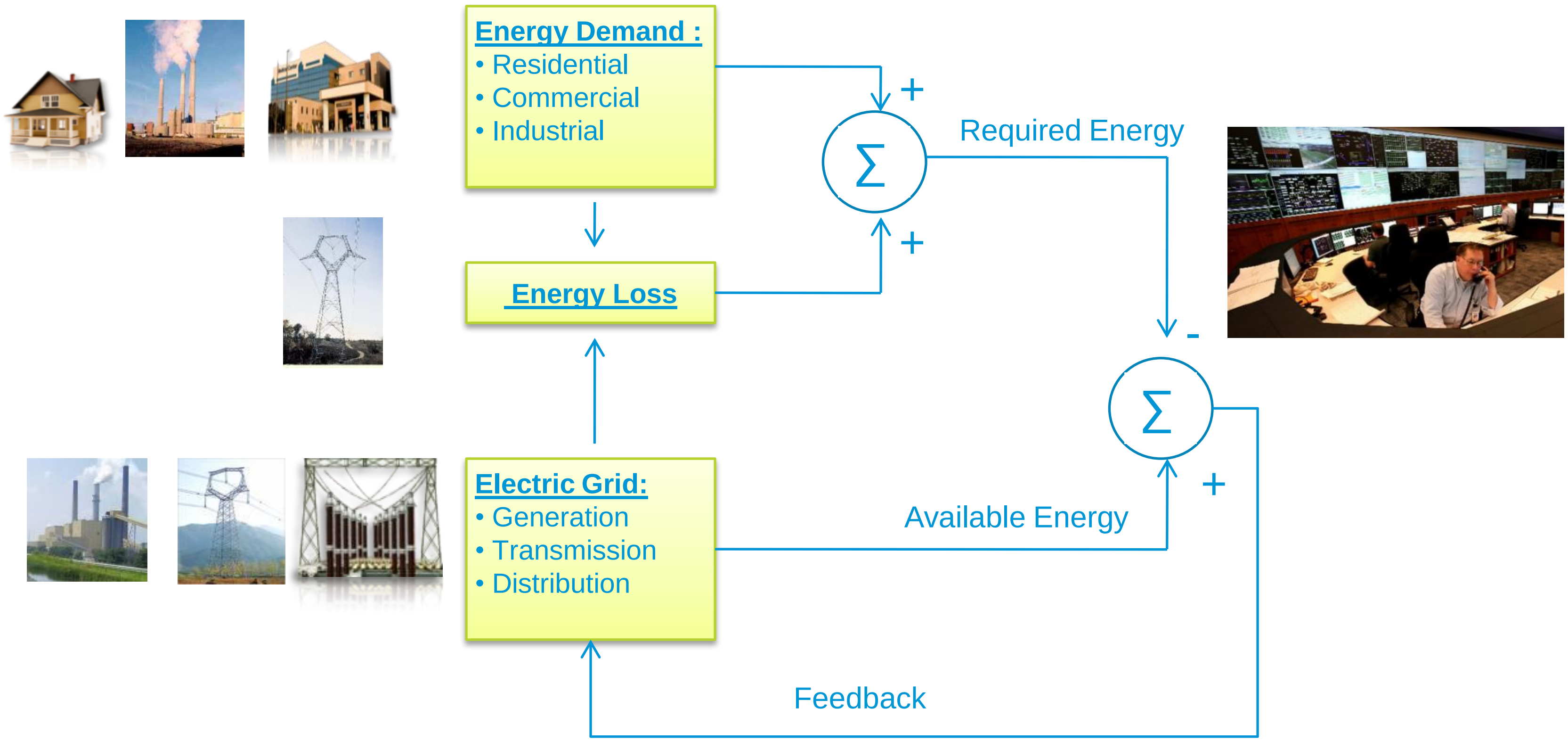

**Source: NIST Conceptual Reference Diagram**

# Cisco Connected Grid Architecture

## Reference Model



# Controlling the Electric Grid




**Grid Operations**: Meeting Energy demand while dynamically optimizing grid operations and resources

# Controlling the Electric Grid

## Grid States:

Active and reactive power, voltage, current, topology, phase, etc.

- State Measurements
- State estimation:

  Data for busses and lines which are not measured

  Calculate parameters such as impedances, load

  Identify bad data (Data Validation)

  Reduce measurement errors

# Fast State Estimation

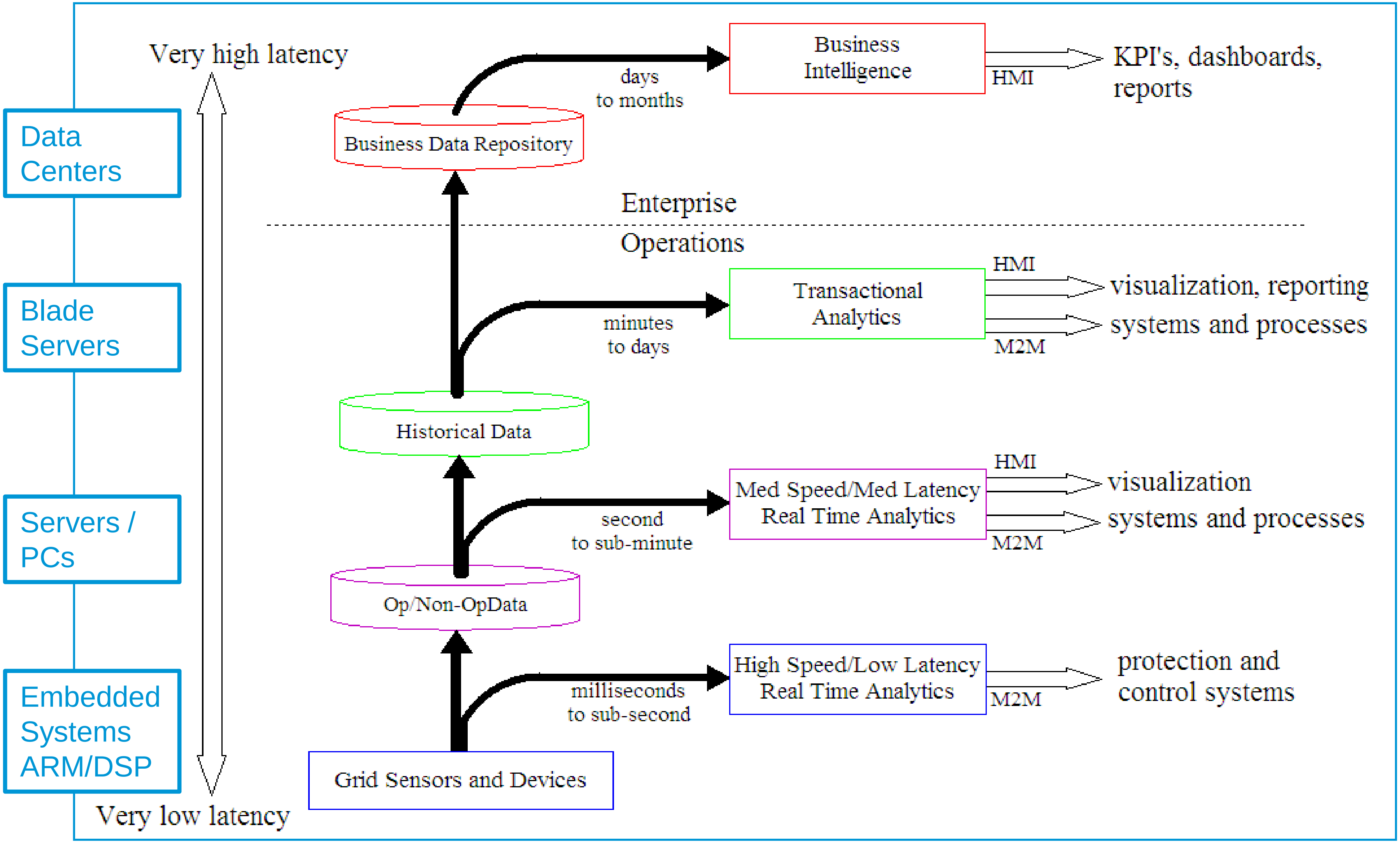
## Central Computing:

- Use high performance computing
  - Large and expensive data centers
- Simplify algorithms reduce regions
  - Limited and inaccurate data

## Distributed Computing:

- Distributed computing devices share tasks that need to be done
- interconnected via high speed networks
- The network is the computing platform

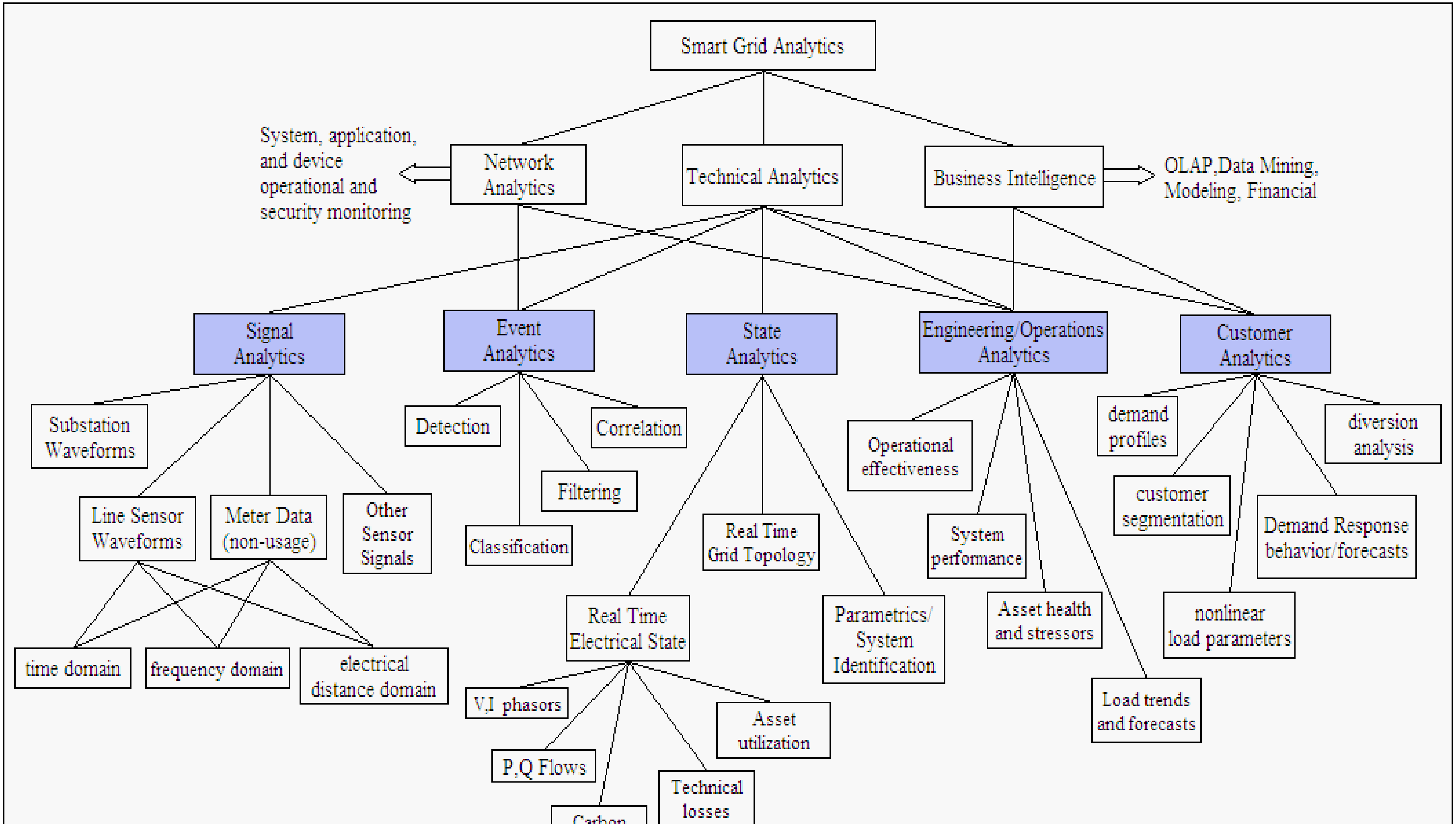
# What is Real Time in a Smart Grid?




Key:

M2M – Machine to Machine
HMI - human–machine interface
KPI - Key Performance Indicator

# Analytics for Power Grids



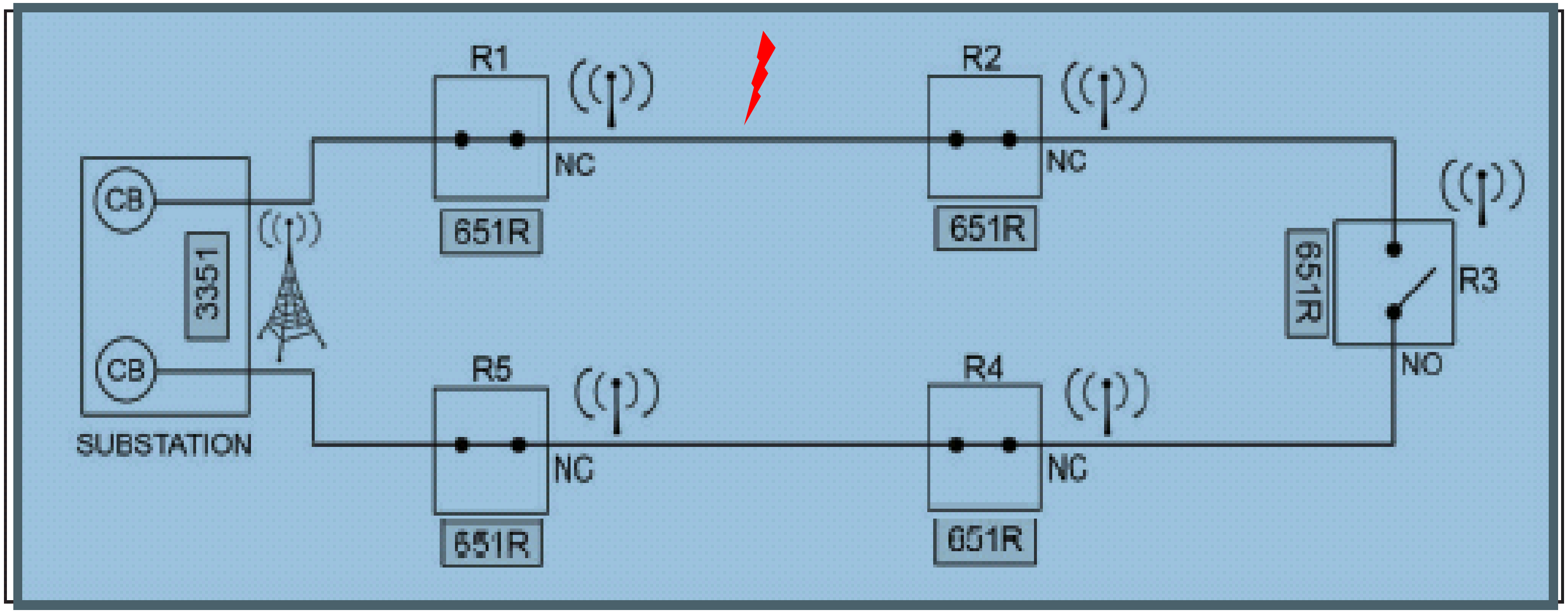

**Smart Grid Analytics Taxonomy/Relationship Diagram**

# Grid Management and Optimization

- **Volt-VAR optimization**
- **Conservation voltage reduction**
- **Optimal network reconfiguration**
- **Predictive fault location**
- **Distribution contingency analysis**
- **Renewable integration**
- **Predictive maintenance**
- **Grid utilization**
- **Remote Connect/ disconnect**
- **Fault location isolation and restoration (FLIR)**

# Controlling the Grid: Fault Protection

## Single feeder loop:




*The 3351 processor communicated via radio to each of the recloser 651R controls. The 651Rs were also individually programmed to sense and isolate a fault even if communications were lost.*

Fault Location, Isolation, and Restoration (FLIR)

- Open one (or two) switches to isolate a fault
- Close a single switch to restore power to affected segment(s)

# Controlling the Grid: Fault Protection

## Multiple feeder loops:

Identify the optimal switch operation for fault location, isolation, and restoration (FLIR)

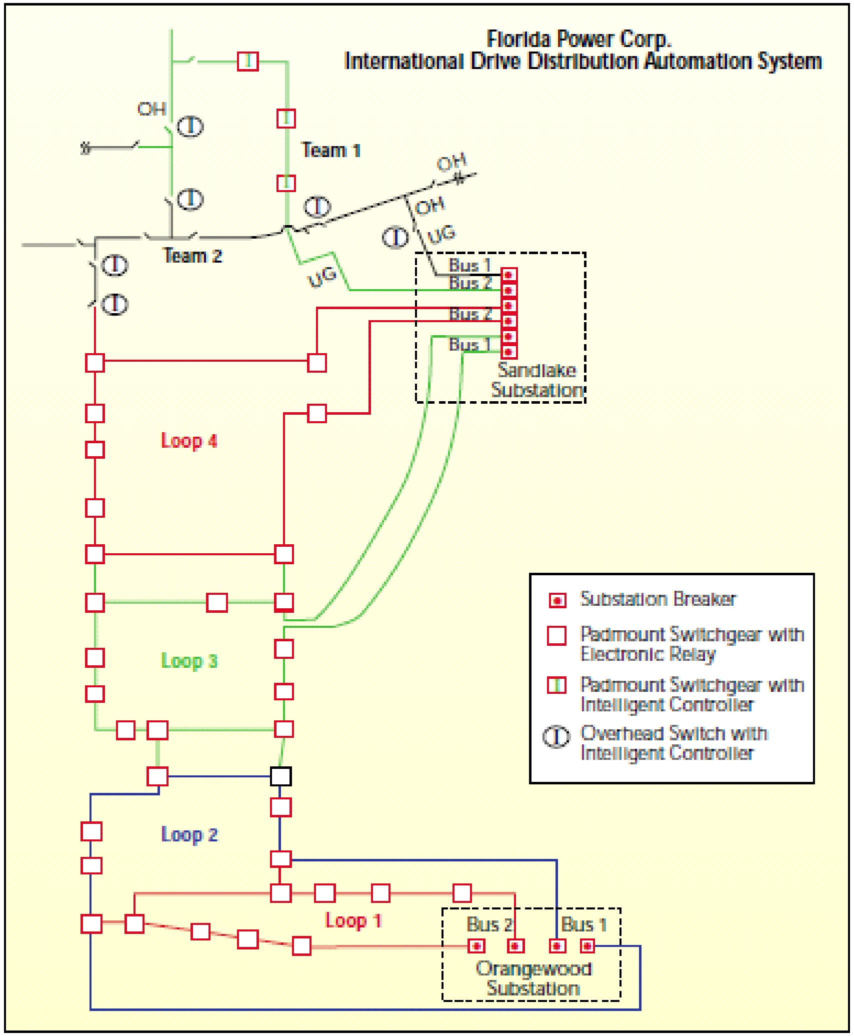
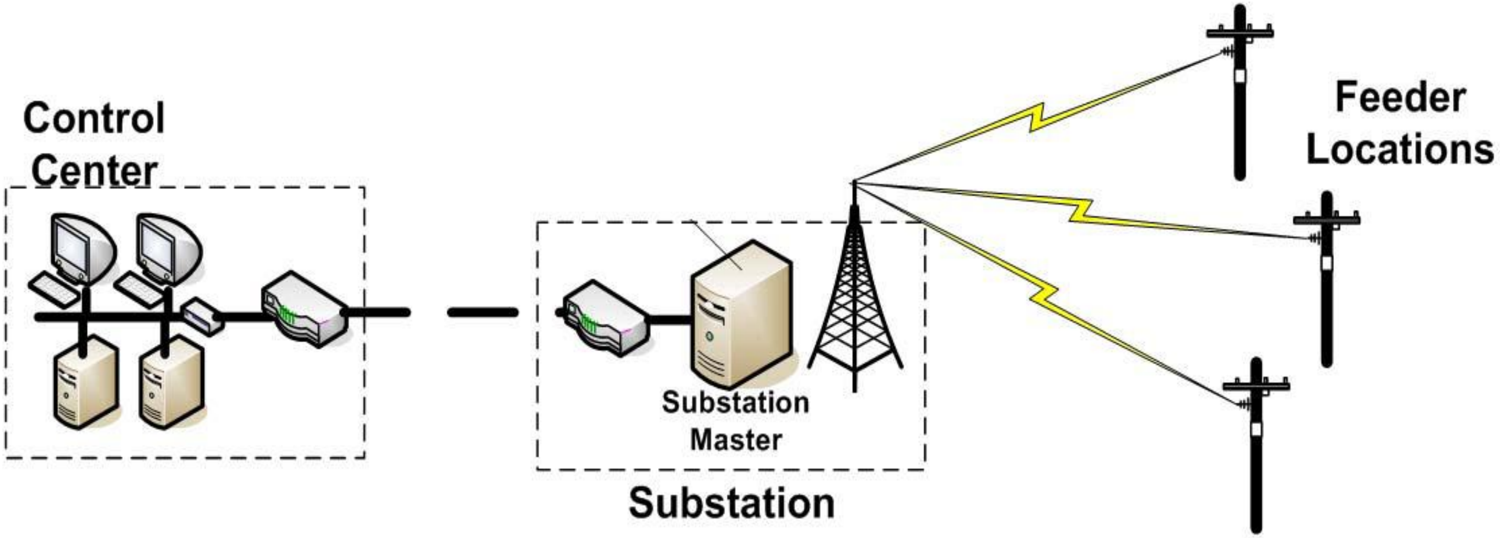



Fig. 3. Primary network and intelligent switching circuits serving the International Drive area.

# Centralized vs. Distributed Control

**Centralized** | **Substation Centralized** | **Distributed (peer 2 peer)**




**Refers to the location where the main network logic resides**

# Centralized vs. Distributed Control

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Substation Centralized

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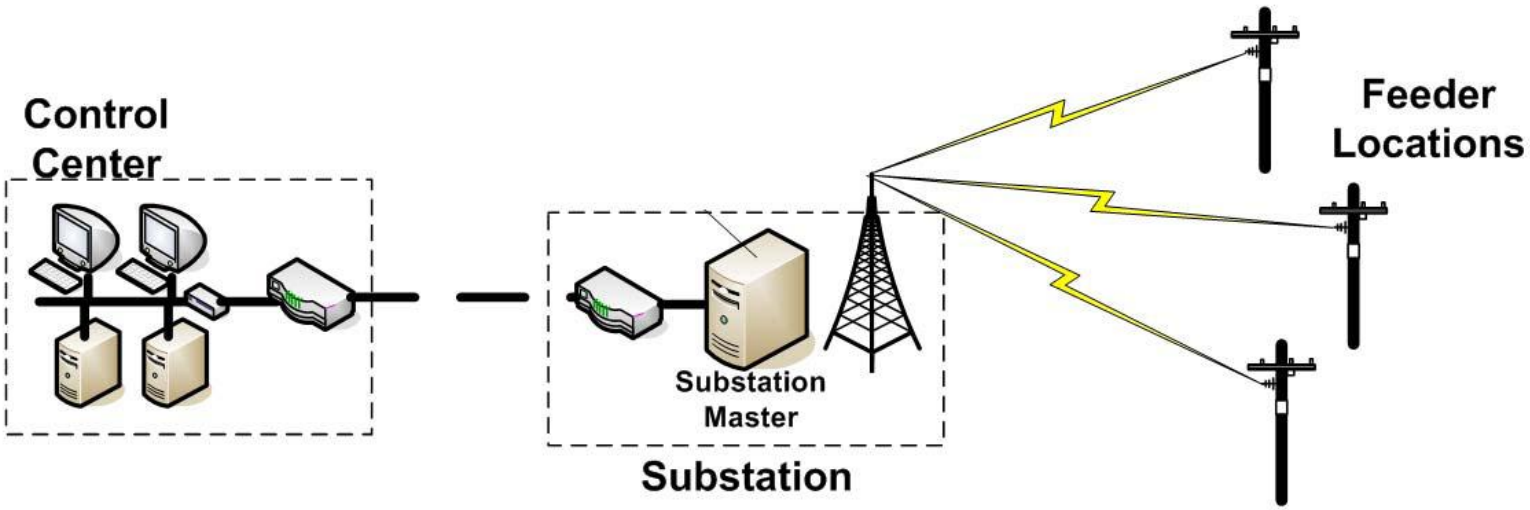


Main Logic
Resides here

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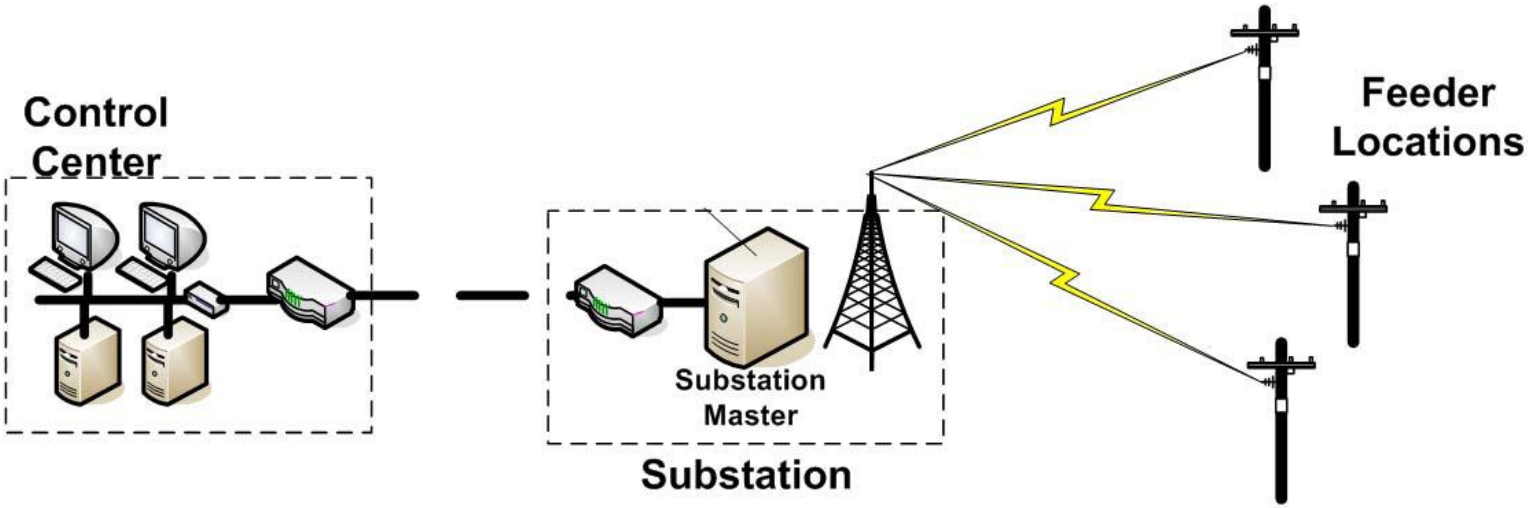


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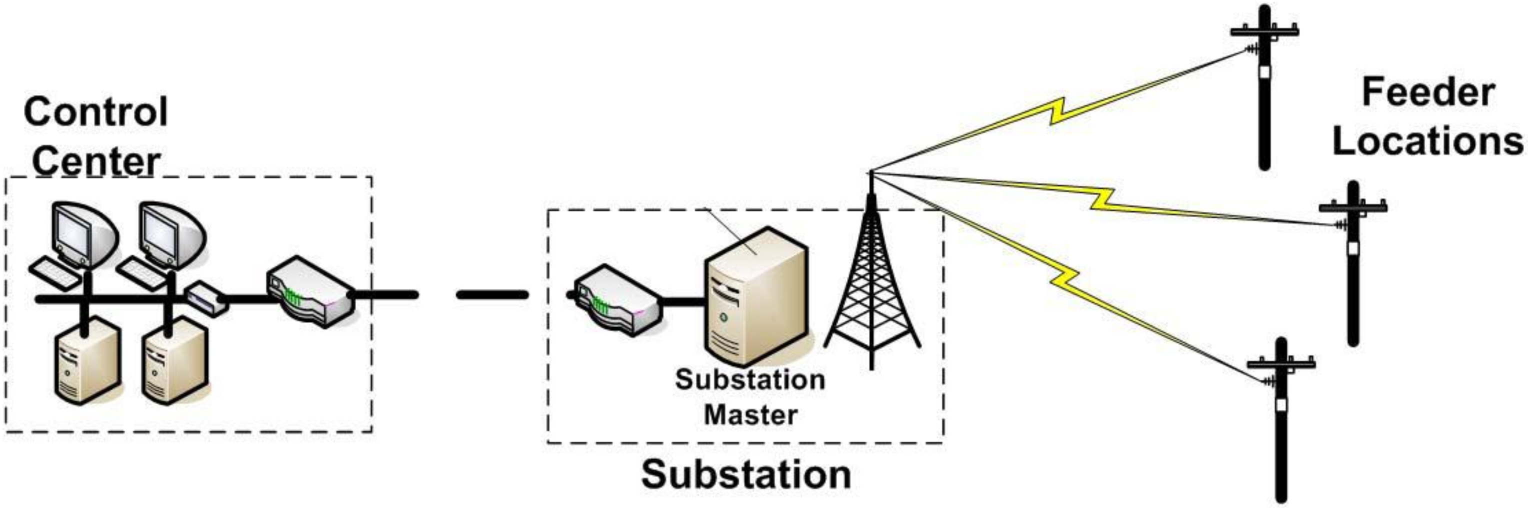


Main Logic
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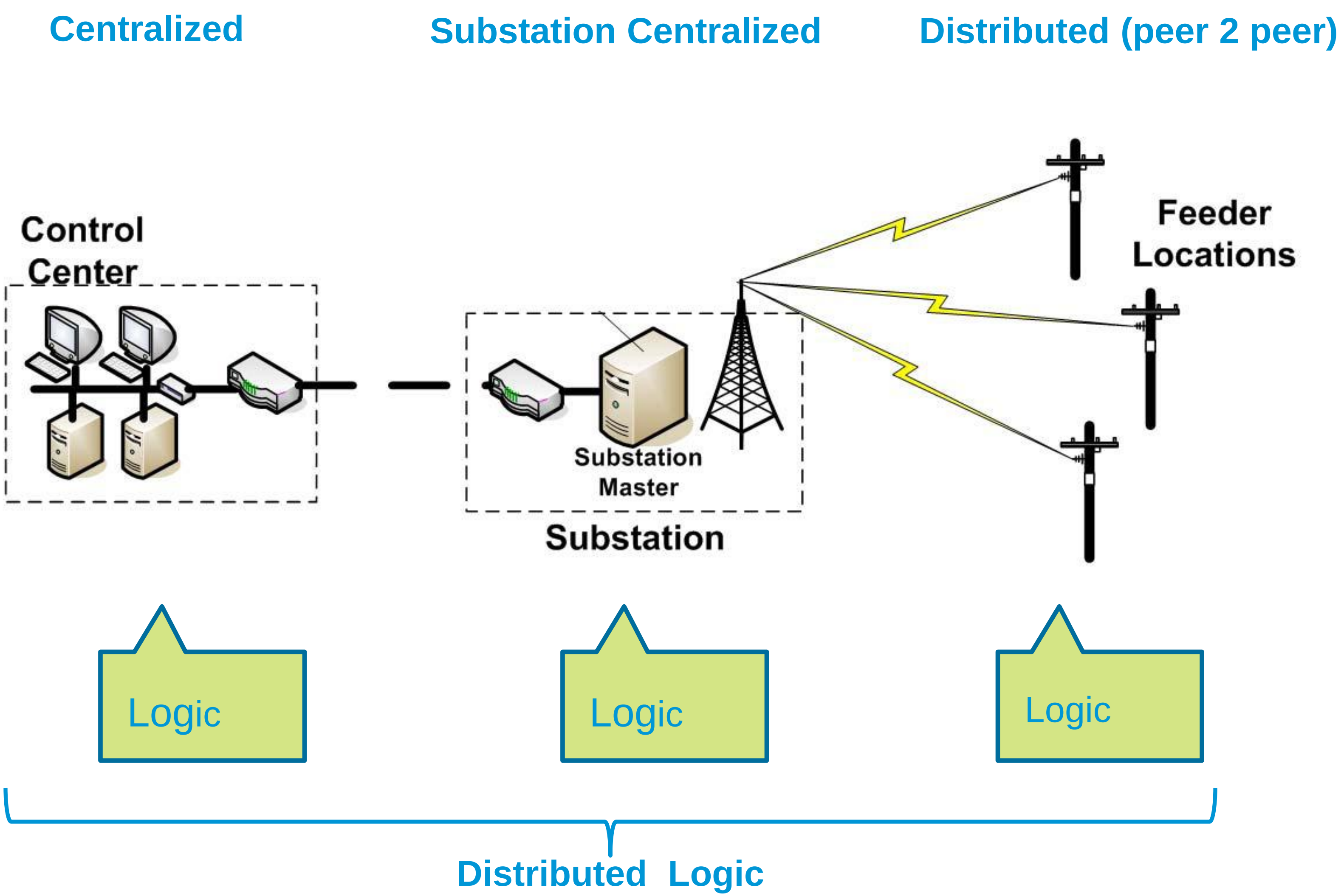
# Distributed Grid based Control



# Design Criteria (traditional)

| Criteria | Centralized | Substation-Centered | Distributed |
| --- | --- | --- | --- |
| # of DA Feeders | High % of feeders automated | All feeders at selected substations automated | Small # of geographically dispersed feeders |
| Operator Visibility | Nothing happens without operator being informed | Can tolerate some control actions without operator notification | Can tolerate control actions without operator notification |
| Availability of suitable communication facililties | Requires high-speed wide area comunications | Requires local area commmunications (sub-pole, sub-sub) | Requires local area commmunications (pole-pole, sub-pole) |
| Applications | VVO, FLIR, ONR | VVO, FLIR, DFA | FLIR |
| Data Processing | Limited by data transfer capabilities | Well suited for waveform analysis and equipment condition monitoring | Little or no capabilities |

VVO–Volt VAR Optimization
FLIR–Fault Location, Isolation, and Restoration
ONR–Optimal Network Reconfiguration
DFA–Distribution Fault Anticipator

# Design Criteria (New)

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| Applications | VVO, FLIR, ONR | VVO, FLIR, DFA | VVO, FLIR, DFA |
| Data Processing | Data Centers<br>Optical Networks | Fast Ethernet<br>Computing power<br>WAN Connectivity | AMI / NAN<br>HAN<br>EC |

Smart Grid infrastructure adds Communication bandwidth and distributed computation power

VVO–Volt VAR Optimization

FLIR–Fault Location, Isolation, and Restoration

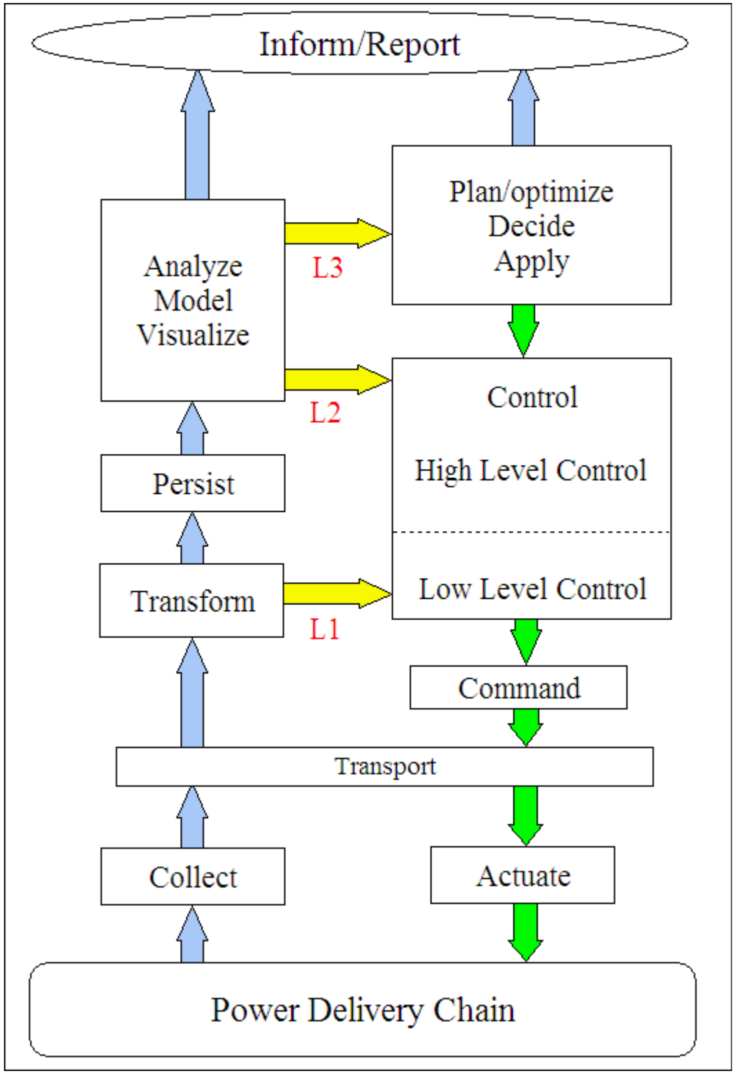
ONR–Optimal Network Reconfiguration

DFA–Distribution Fault Anticipator

EC - Energy Controller

# Utility Nested-Loop Control Architecture

- Present grids function on a nested loop architecture
- The innermost loop is for protection and control (low level)
- Next loop is high level control (SCADA/EMS/DMS)
- Outermost level is mostly business processes
- “Real time” may apply at any of these levels
- More levels of control are being added (WAMS, etc)



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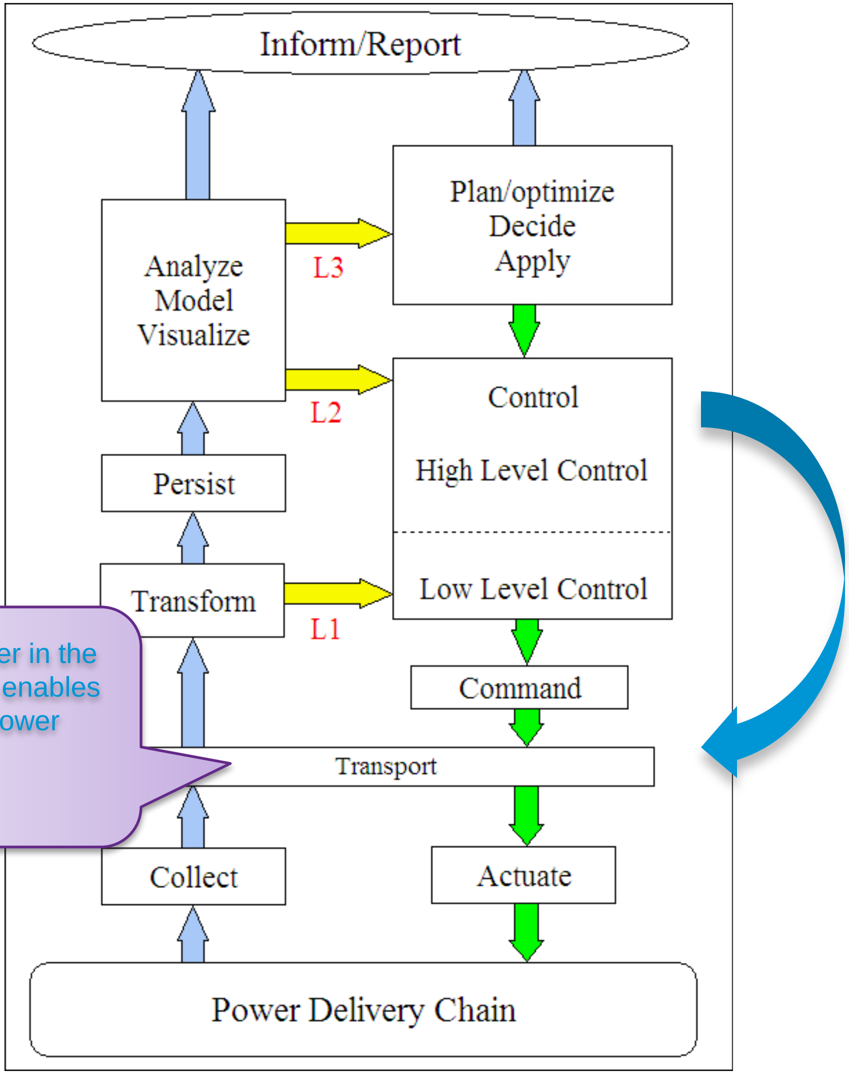
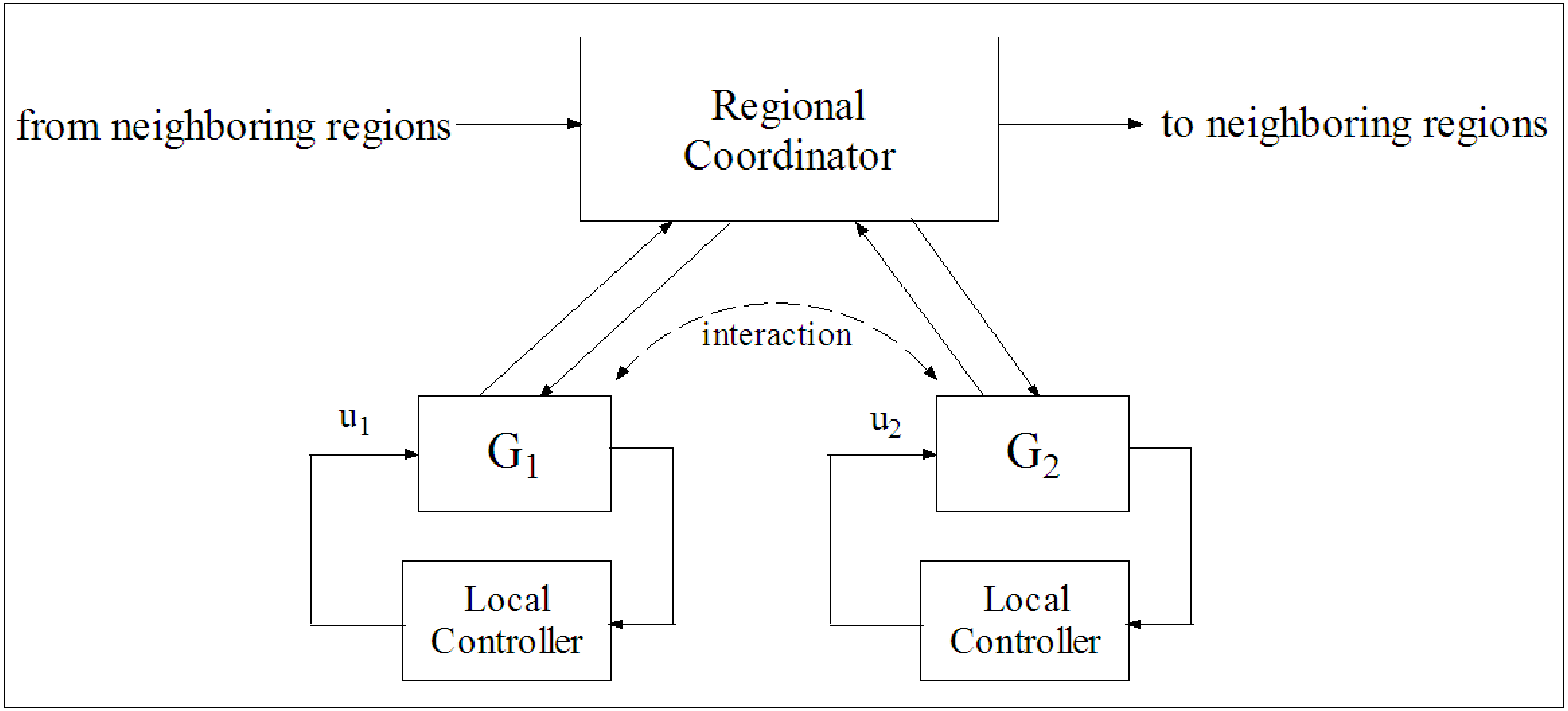
Computation power in the network transport enables control closer to power delivery devices



# Hierarchical Distributed Control



# Distributed Grid Intelligence

**Advantages:**

- Scalability
- Latency minimization for real time functions
- Robustness and graceful degradation in the presence of component or subsystem failure
- Incremental implementation and expansion
- Flexibility – adapt to new functions, applications, etc as the problem domain evolves

**But watch for:**

- **Distribution of intelligence**

  Communication channel overload
- **Security vulnerabilities**

  Reliability of the system under cyber attack
- **Debugging capabilities**

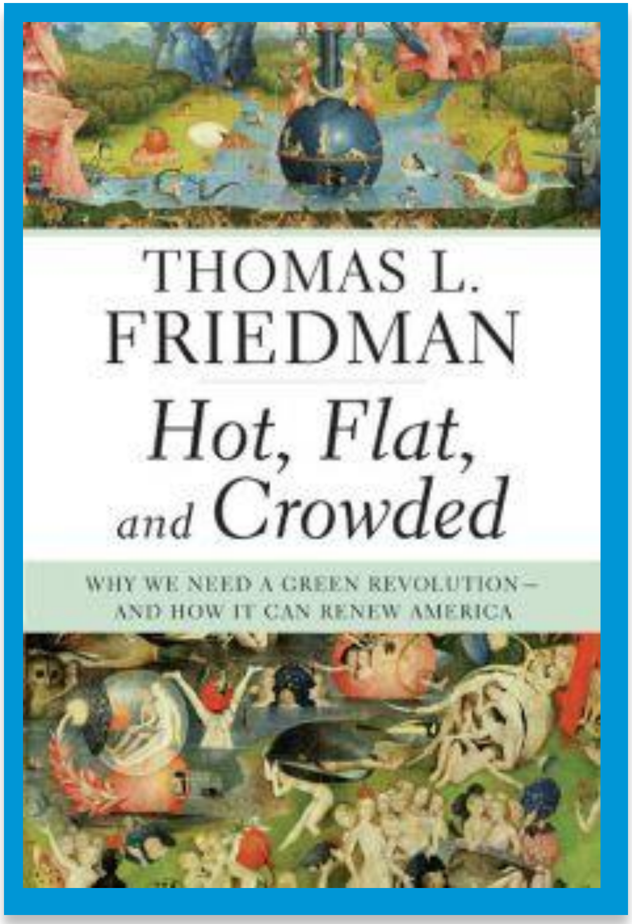
  Message flow tracing, root cause isolation, bug fixes, new code deployment

# Current Research Focus

1. Automation to improve reliability
2. Advanced applications for distribution management (e.g. fault location)
3. Assuring safety (arc flash, contact voltages)
4. Green Circuits –reducing losses
5. Using the distribution system to save energy and reduce demand – voltage optimization
6. Advanced sensors and equipment diagnostics
7. Advanced metering –where does it fit in?
8. Integrating distributed generation
9. Integrating renewable (e.g. photovoltaic, wind, wave, etc)
10. Integrating energy storage
11. Integrating electric vehicles
12. Integrating energy efficiency
13. Assuring power quality
14. Standards for Interoperability

# Five critical issues

- Energy age
- Biodiversity loss
- Climate change
- Energy poverty
- Petro dictatorships



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