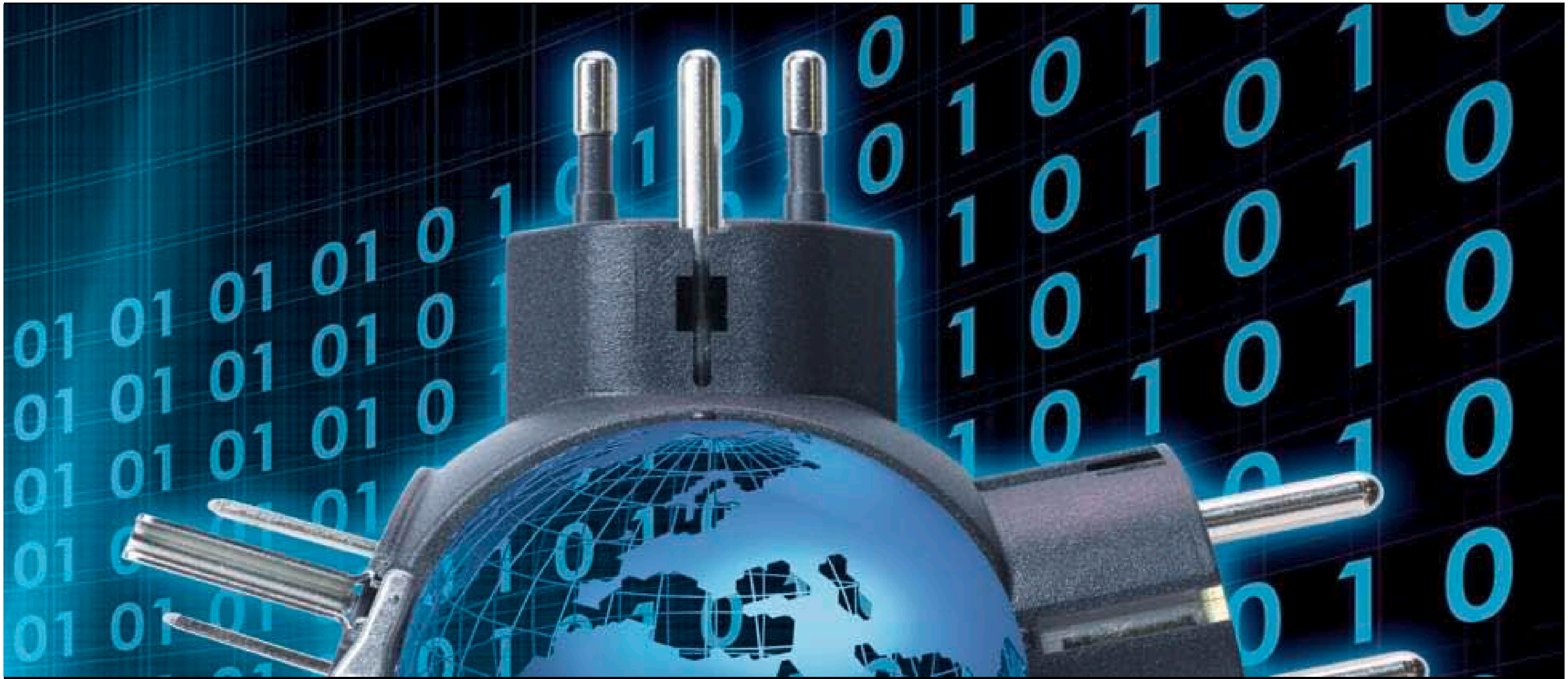


Khosrow Moslehi, Ranjit Kumar - ABB Network Management, Santa Clara, CA USA

Smart Grid – A Reliability Perspective

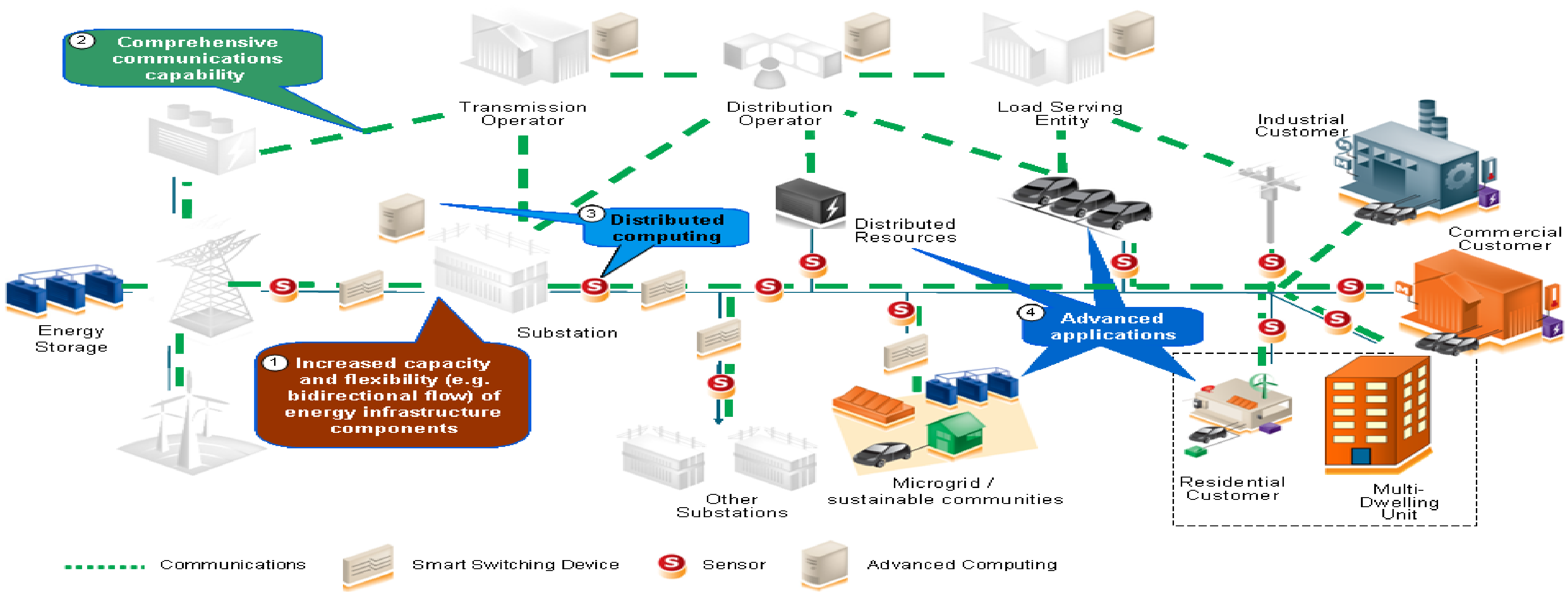
IEEE PES Conference on
Innovative Smart Grid Technologies, January 19-21, Washington DC

Outline

- **Smart*er* Grid**
- **Focus Areas**
- **Reliability Issues**
- **Architectural Approach**
- **Q/A**

Smarter Grid

- Utility industry has been utilizing communication and information technologies
- Increasing complexity of the grid, growing concerns for environment, energy sustainability, etc. accentuate the need for a quantum leap in application of such technologies
- This leap toward a "smarter" grid is referred to as "smart grid"

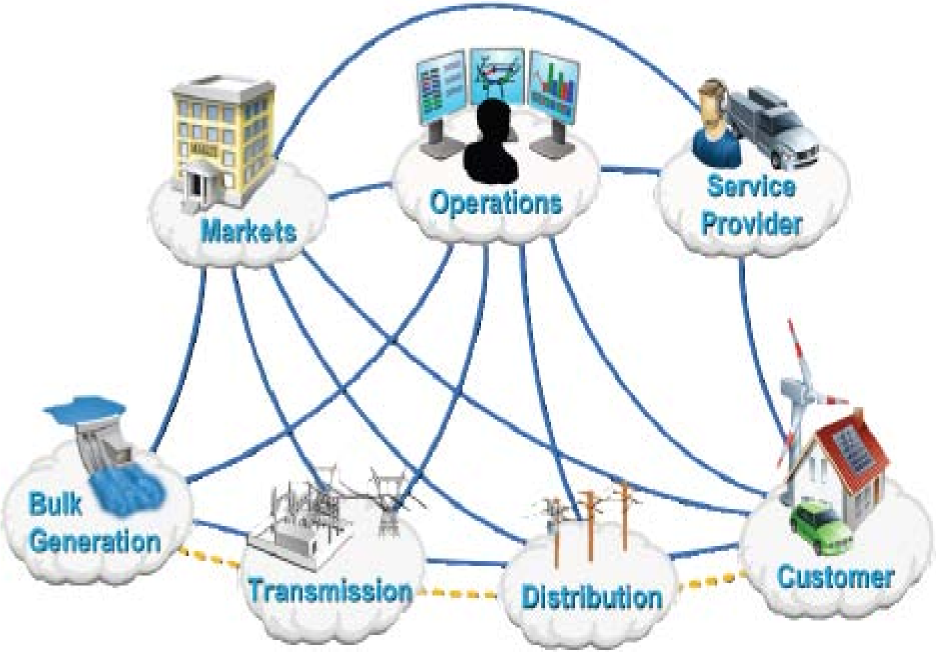


Smart Grid
Vision

- **Enhanced reliability**
- **Resiliency against malicious attacks**
- **Reduced emission and improved energy sustainability**
- **Enhanced efficiency and asset utilization**
- **Improved market efficiency**
- **Active consumer participation in managing their consumption and generation**
- **Higher quality of service**

Smart Grid Deployment Trends
Focus Areas

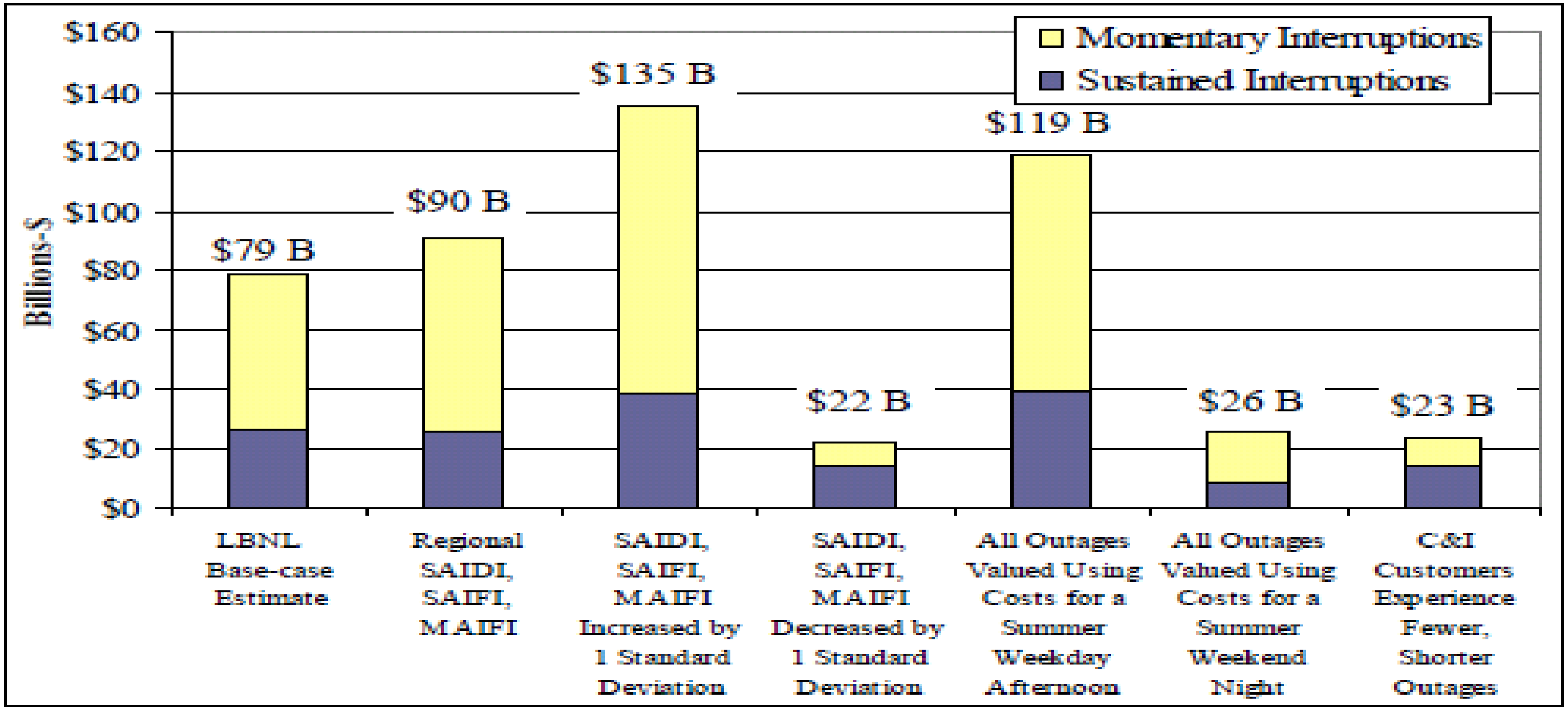
- **Reliability**
- **Renewable resources**
- **Demand response**
- **Electric storage**
- **Electric transportation**



- **Above trends also highlighted in "FERC Smart Grid Policy Statement"**

Reliability

Cost of Unreliability (2004 report LBNL-55718)



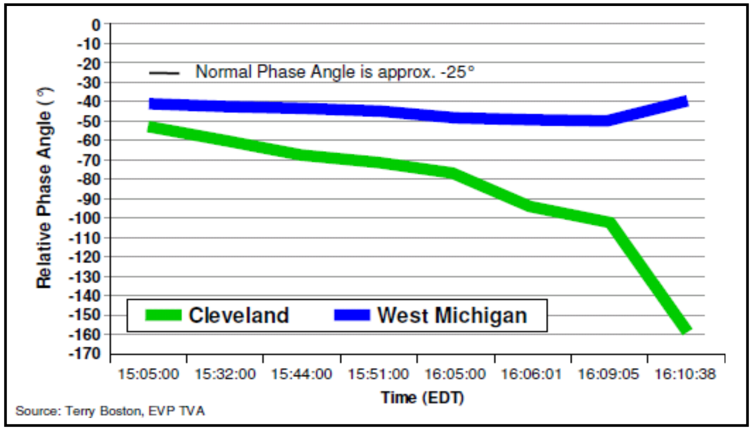
Summary of U.S. Cost of Power Interruption Sensitivity Cases

	Surveyed Populations	Non-surveyed Populations	Total
Power Outages	$46 billion	$58-118 billion	$104-164 billion
Power Quality	$7 billion	$8-17 billion	$15-24 billion
Total	$53 billion	$66-135 billion	$119-188 billion

System Average Interruption Duration Index
System Average Interruption Frequency Index
Momentary Average Interruption Frequency Index

Grid Reliability
Issues We Face

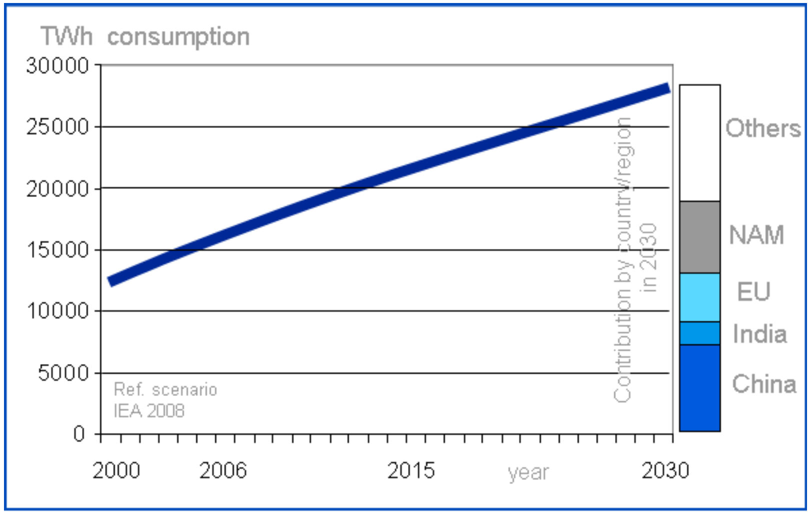
- "Insufficient" Investment in Grid and Load Growth
  - Contention for limited transfer capability
- Diversification of Energy and Storage Resources
  - Aggravating grid congestion and/or controllability
- Larger operating footprints
  - More complex problems
  - Smaller error margins
  - Shorter decision times
- More, larger and longer transfers
  - Volatility
  - Smaller margins

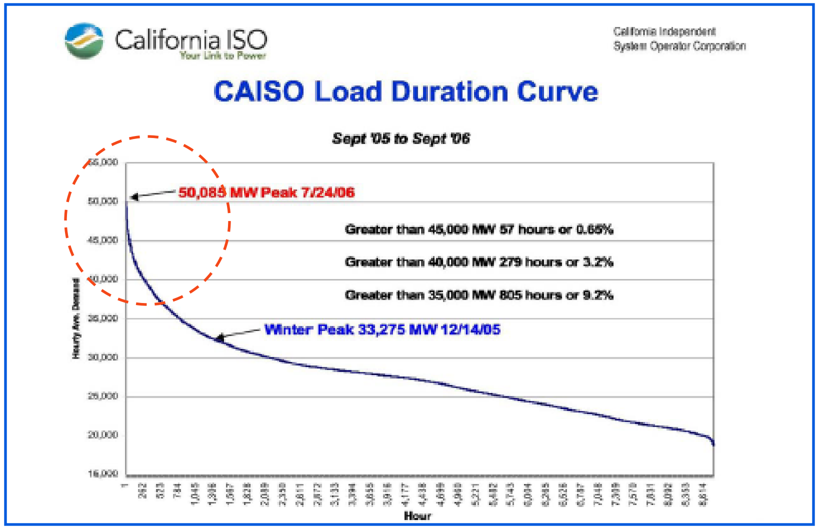


Increasing Demand
Consumption and Peak

- **Increasing energy consumption and peak demand creating contention for limited transfer capability**

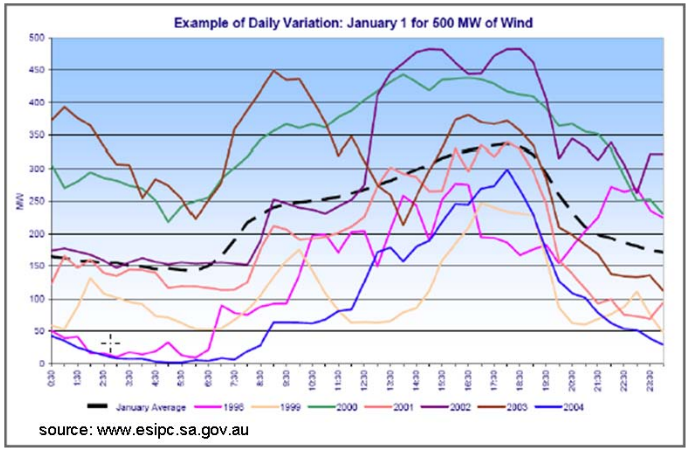
- **Resources required for the peak underutilized:**
- **ERCOT:**
  - Top 5% of capacity used less than 1% of time
  - Top 25% of capacity needed 10% of time
- **PJM hourly 2007 Load**
  - Less than 85 GWh for 62.2% of the hours
  - Less than 100 GWh for 88.8% ‘’ ‘’ ‘’
  - More than 130 GWh for only 15 hours.

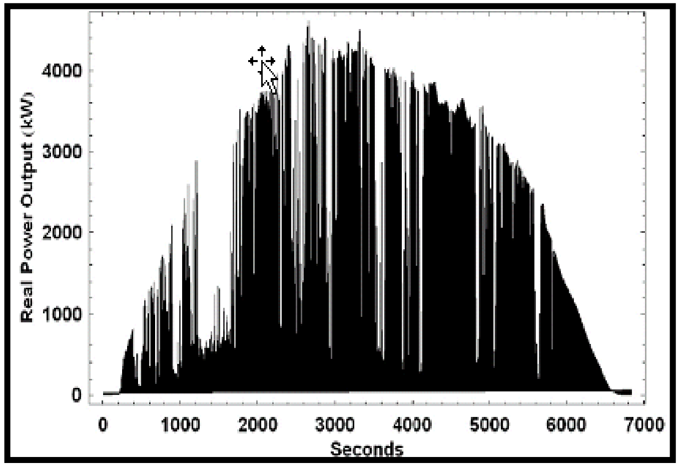




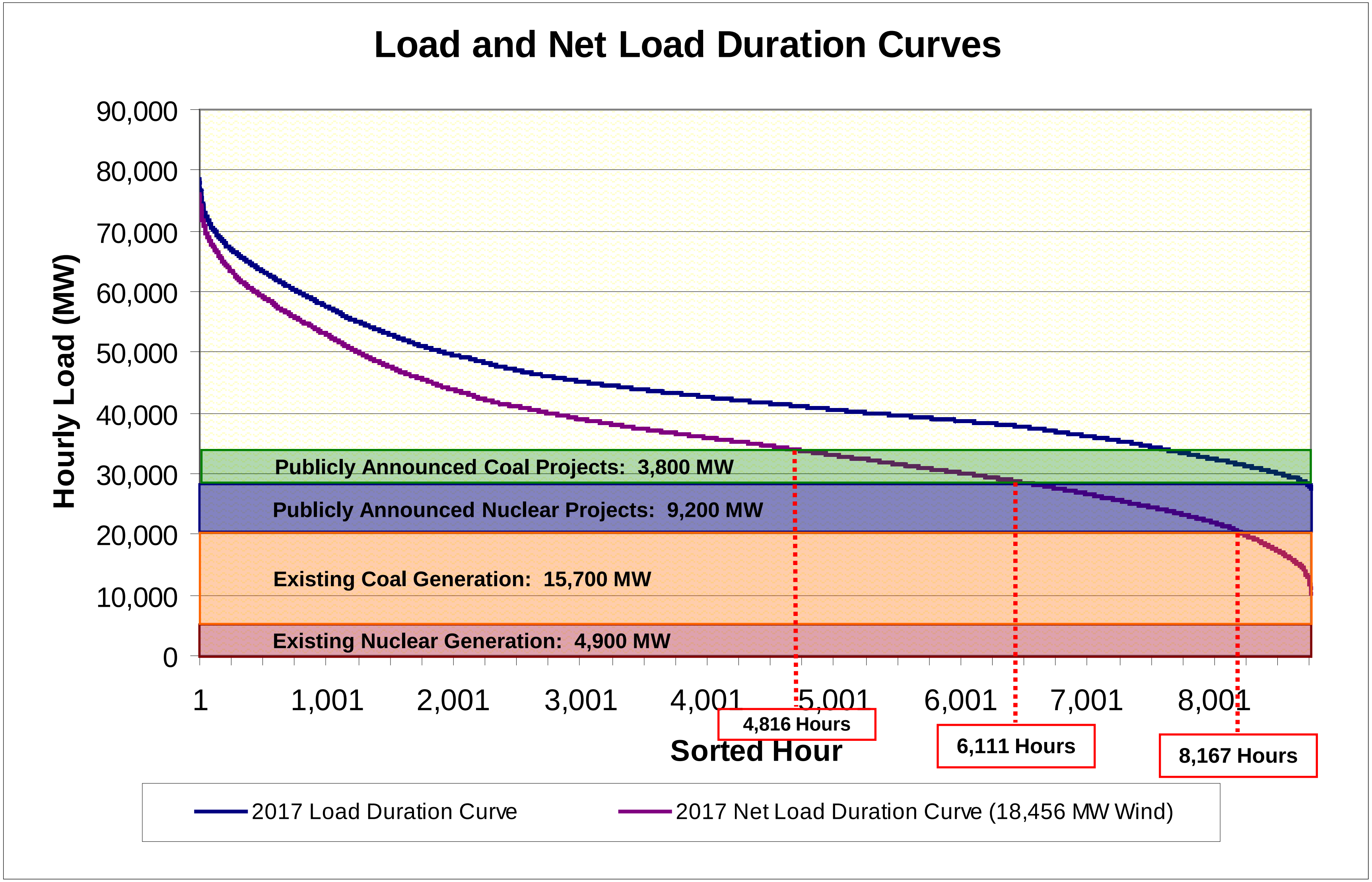
Reduced Emission and Energy Sustainability
Challenges of Renewables Integration

- **Intermittency**
- **Generation not align with load patterns**
- **Forecasts uncertainty**
- **Operational performance issues**
  - **Low system inertia**
  - **Voltage, congestion,…**
  - **Additional ancillary services**
- **Transmission**
  - **Large renewables are remote**



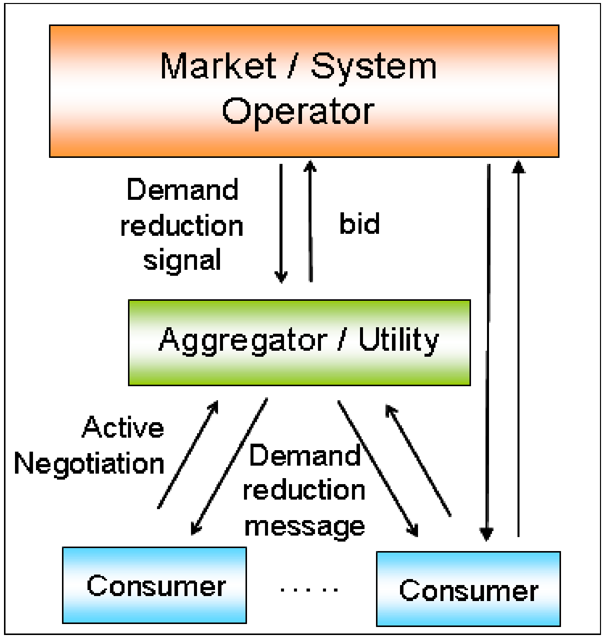


Impact of 18 GW of wind on ERCOT’s 70+ GW system



Managing the Load Profile
DR and Storage

- **Demand Response**
  - Non-emergency DR can reduce the need for additional resources
  - Automatic or manual response by consumer

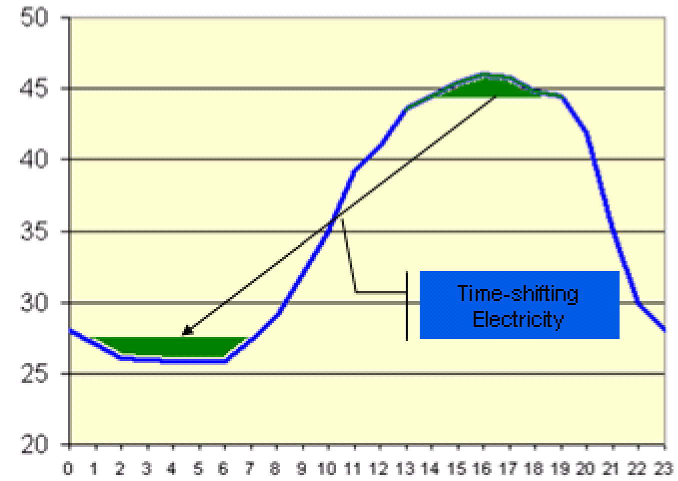


- **Storage**
  - Various technologies
  - Centralized, Distributed, Behind the Meter, etc.

- *Both add to the complexity*

Electric Transportation
PEV, eCAR, etc.

- **Motivations**
  - Environmental
  - Reduce reliance on fossil fuels
  - Demand Response / Storage
  - Others



- **Challenges**
  - 200 miles range requires about 50kWh of battery energy
  - Charge time
    - Fast charge – “distribution congestion”
    - Slow charge – unacceptable life style

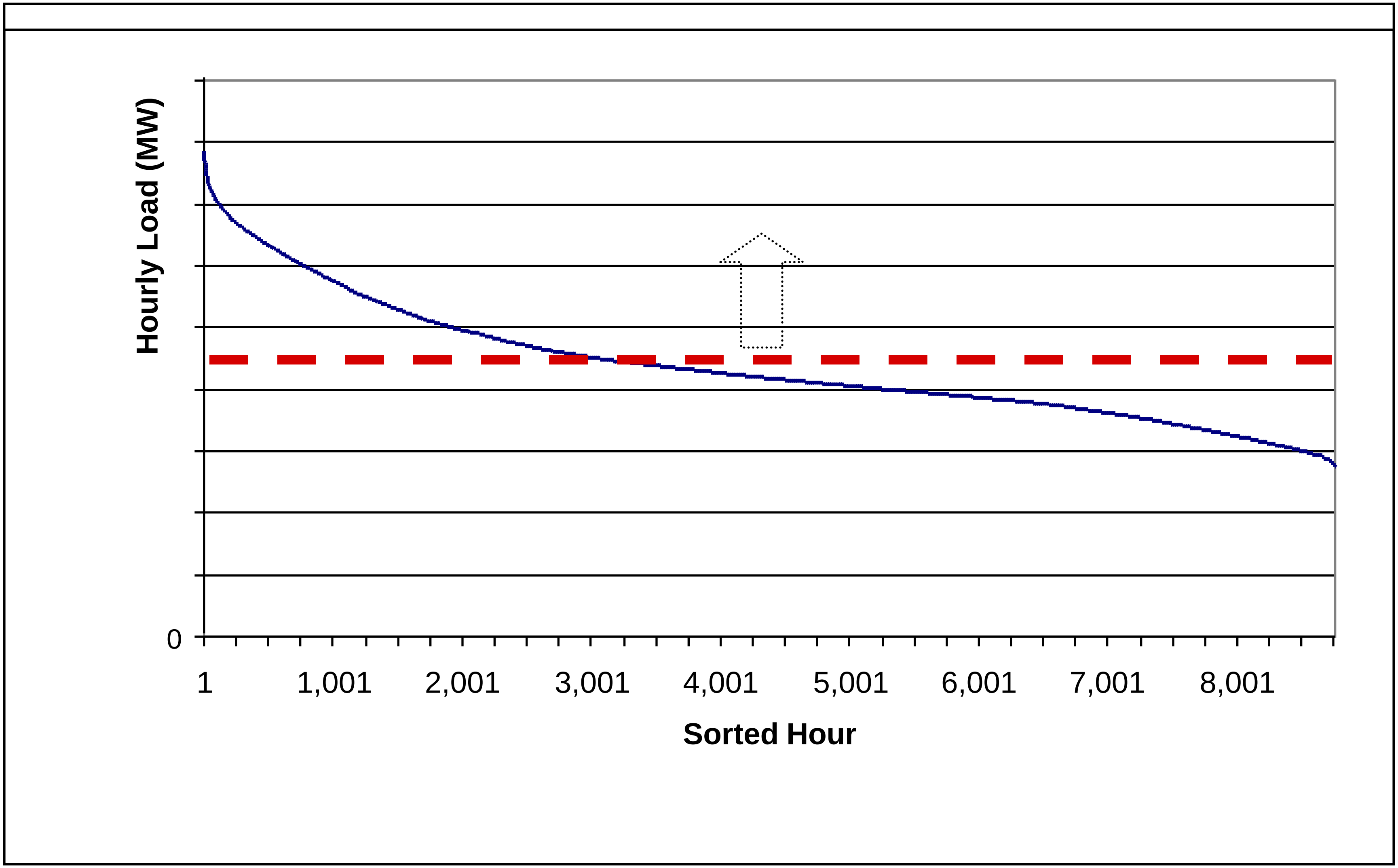
Ideally Successful Load Management Scenario

Higher Susceptibility to failure?

- **Close coordination of all resources such as:**
  - Demand response
  - Storage
  - Electric vehicles
- **Objective:**
  - Nearly flattened load profile
  - Initial improved reliability due to lower peak
- **“Unintended” Consequences Over Time:**
  - Grid operated closer to near-peak conditions most of the time
  - System pushed closer to its “edge” more often - higher susceptibility to failure due to:
    - **Net load growth**
    - **Forces of optimal T&D asset utilization**

System Pushed to the "Edge"

Higher susceptibility to failure



IT Infrastructure for Smart Grid
Addressing Reliability Concerns

- **Significant disturbances involve cascading events rapidly aggravated by uncoordinated local actions**
- **Maintaining a reliable system requires:**
  - Coordinated response
  - Timely automated intelligent response
  - Secure IT infrastructure
- **Harnessing modern communication and information technologies to enable:**
  - Grid-wide coordinated monitoring and control capabilities to address:
    - Grid operated much closer to its limits more often
    - A more volatile and qualitatively different operating environment
    - Automated on-line analyses for real-time decision making (to replace the inadequate off-line studies)
  - Fail-proof and timely bidirectional communications at all levels
  - Processing more data, more automation, more control

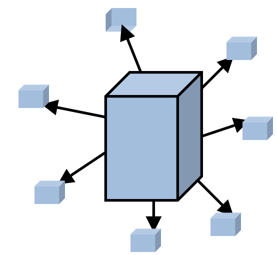
IT Infrastructure for Smart Grid
Distributed Intelligence

- **Centralized systems are too slow for this purpose**
- **Need distribution of intelligence throughout infrastructure to enable:**
  - Local data processing to minimize need for massive data exchanges, e.g. at substation level.:
    - Bad data detection
    - Feeder level forecasts
  - Timely local intelligent actions coordinated with higher level analysis
    - Even sub-second response is feasible with modern technology
- **Need a better coordinated, higher performance Monitoring & Control Infrastructure**
  - “Pervasive”, “Grid-wide/T&D”, “Timely”, “Secure”, “super EMS”…?

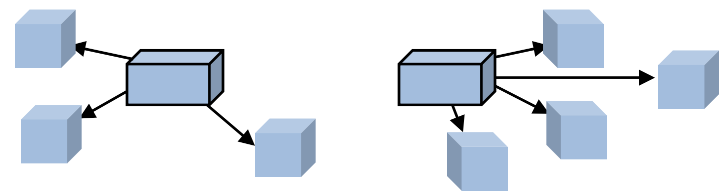
Distributed Autonomous Architecture
Coordinated hierarchical intelligence

- Timely local control coordinated with global information

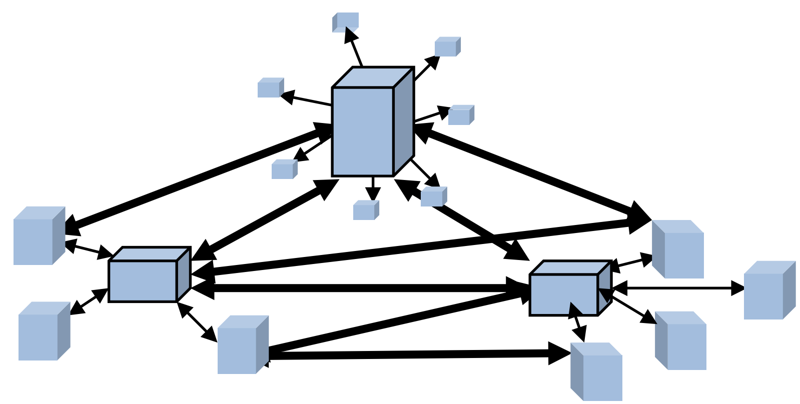
Centralized



Partially Distributed



Fully Distributed

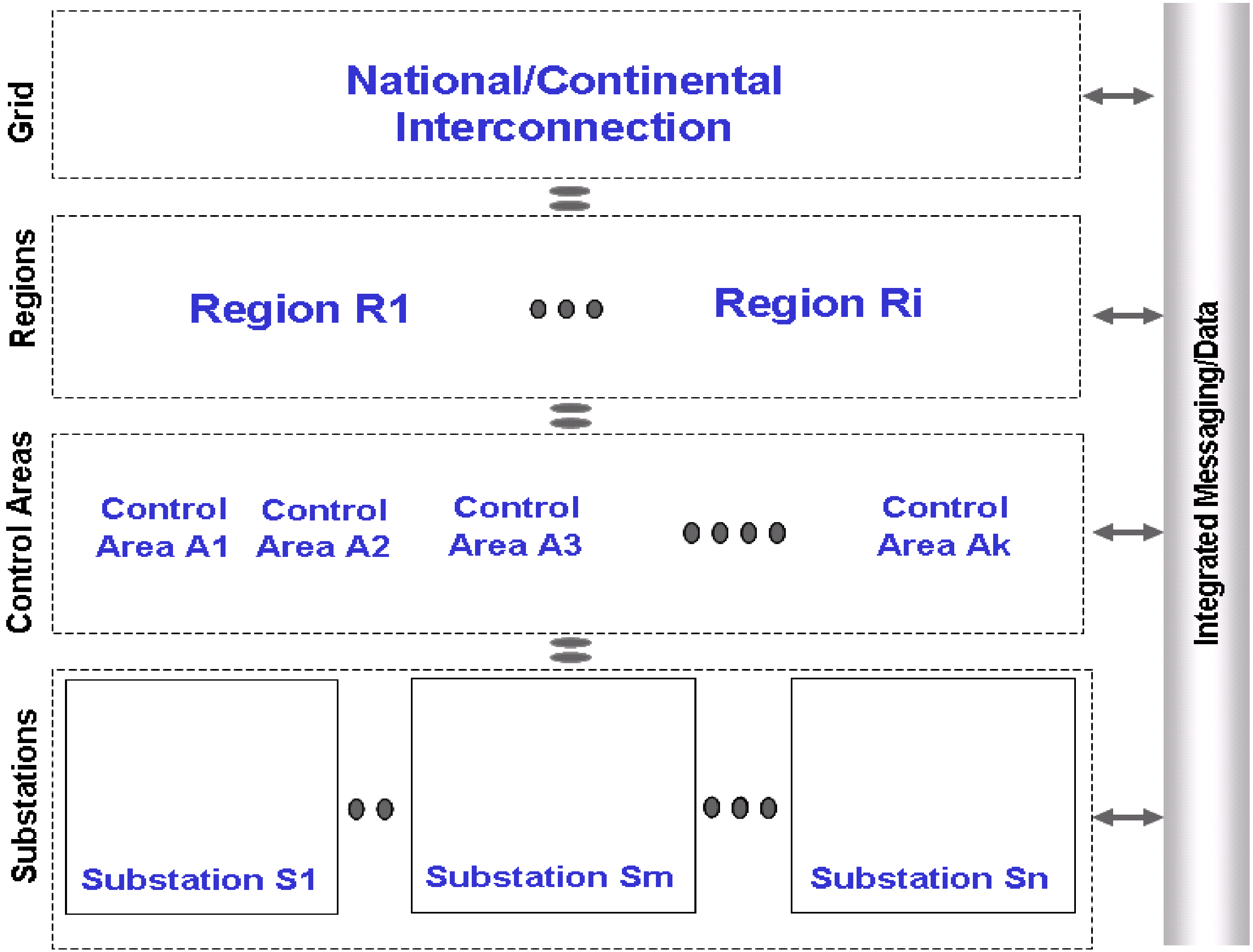


Architectual Dimensions

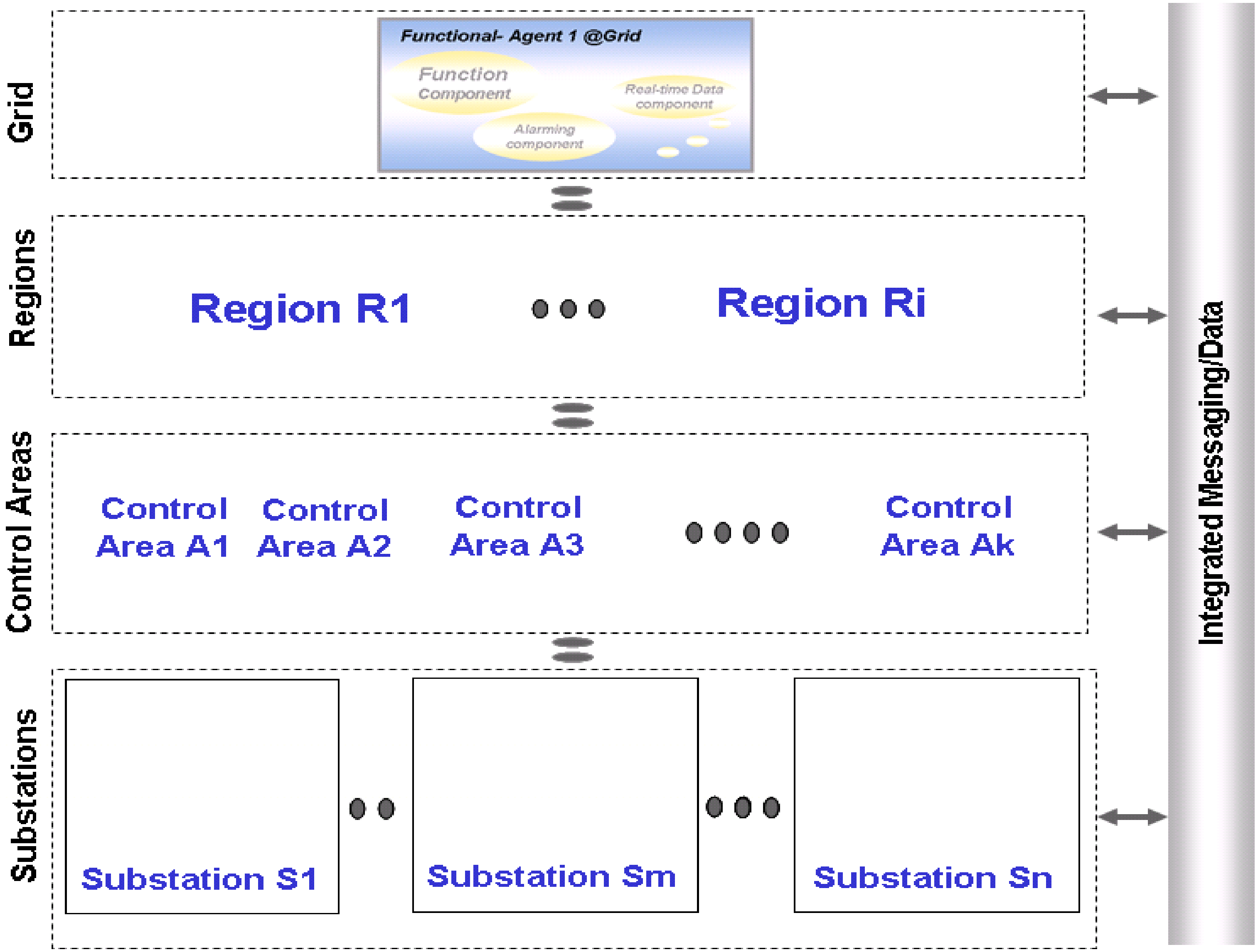
Distributed Based on Grid Operational Requirements

- **Distribution and coordination of functional tasks in a virtual hierarchy in three dimensions:**
  - **Organizational**
    - Grid, Region, …Control Area,…Substation
  - **Geographical**
    - Region 1, Region 2, … j…
    - ….
    - Substation 1, Substation 2,…n,
    - etc.
  - **Functional**
    - Forecasting
    - Alarming
    - Voltage control,
    - etc.

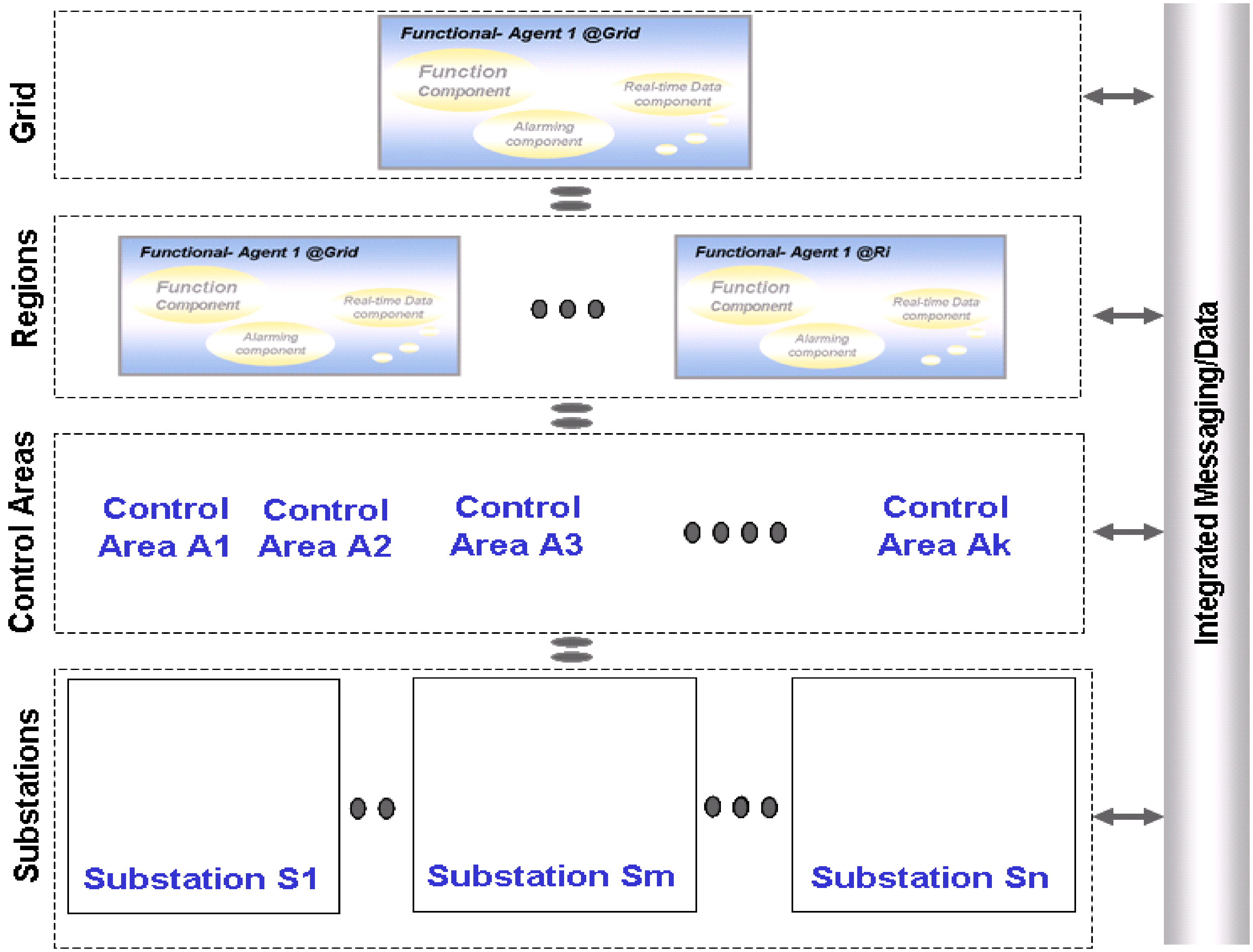
Geographical and Organization Dimension



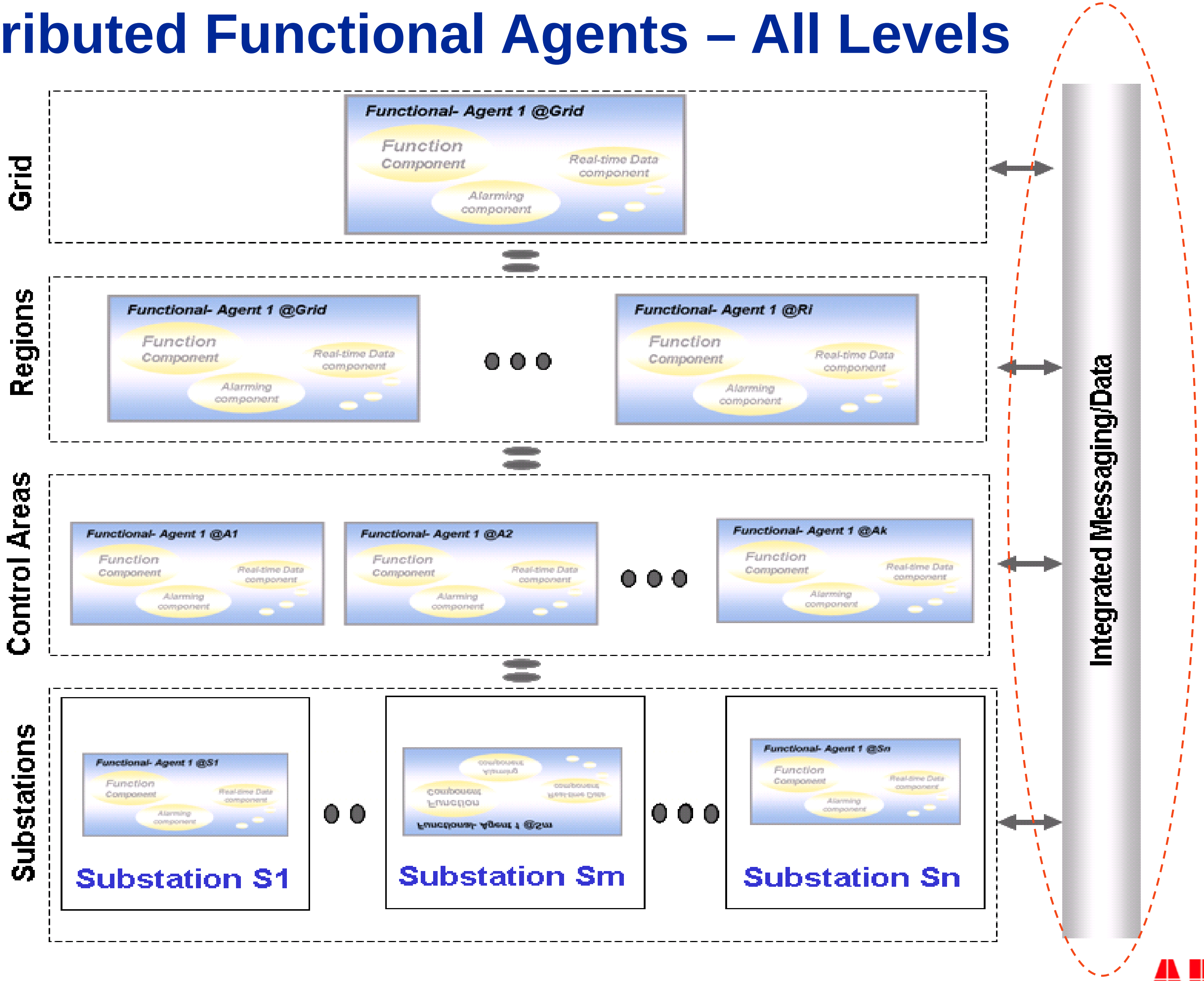
Conventional Functional Implementation: e.g. Grid Level



Distributed Functional Agents – Two Levels



Distributed Functional Agents – All Levels

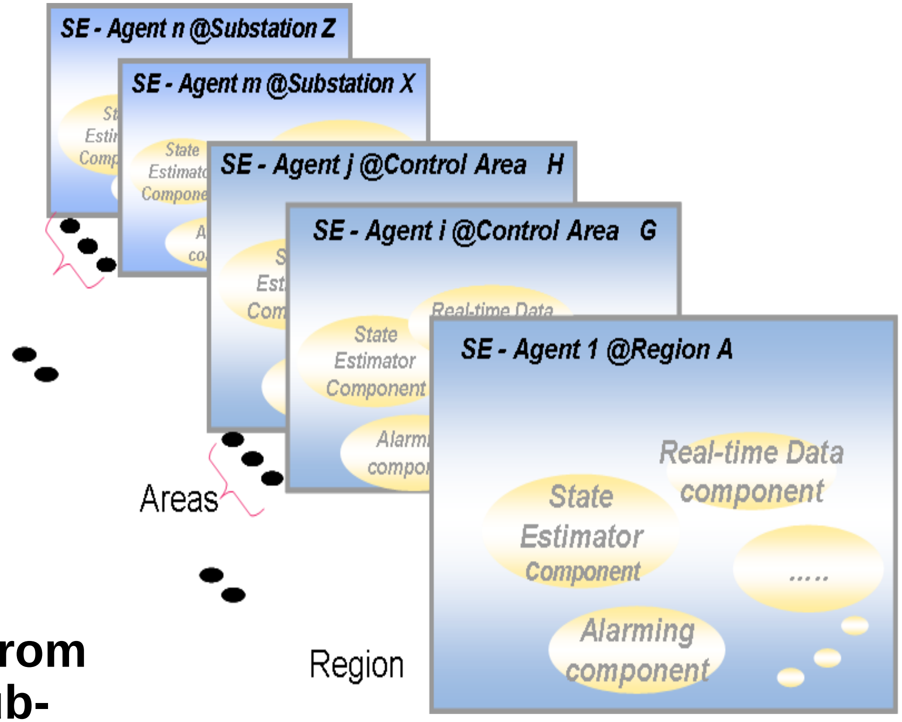


 IEEE ISGT Conference, Washington DC Jan 19-21 2010

Autonomous Intelligent Agents

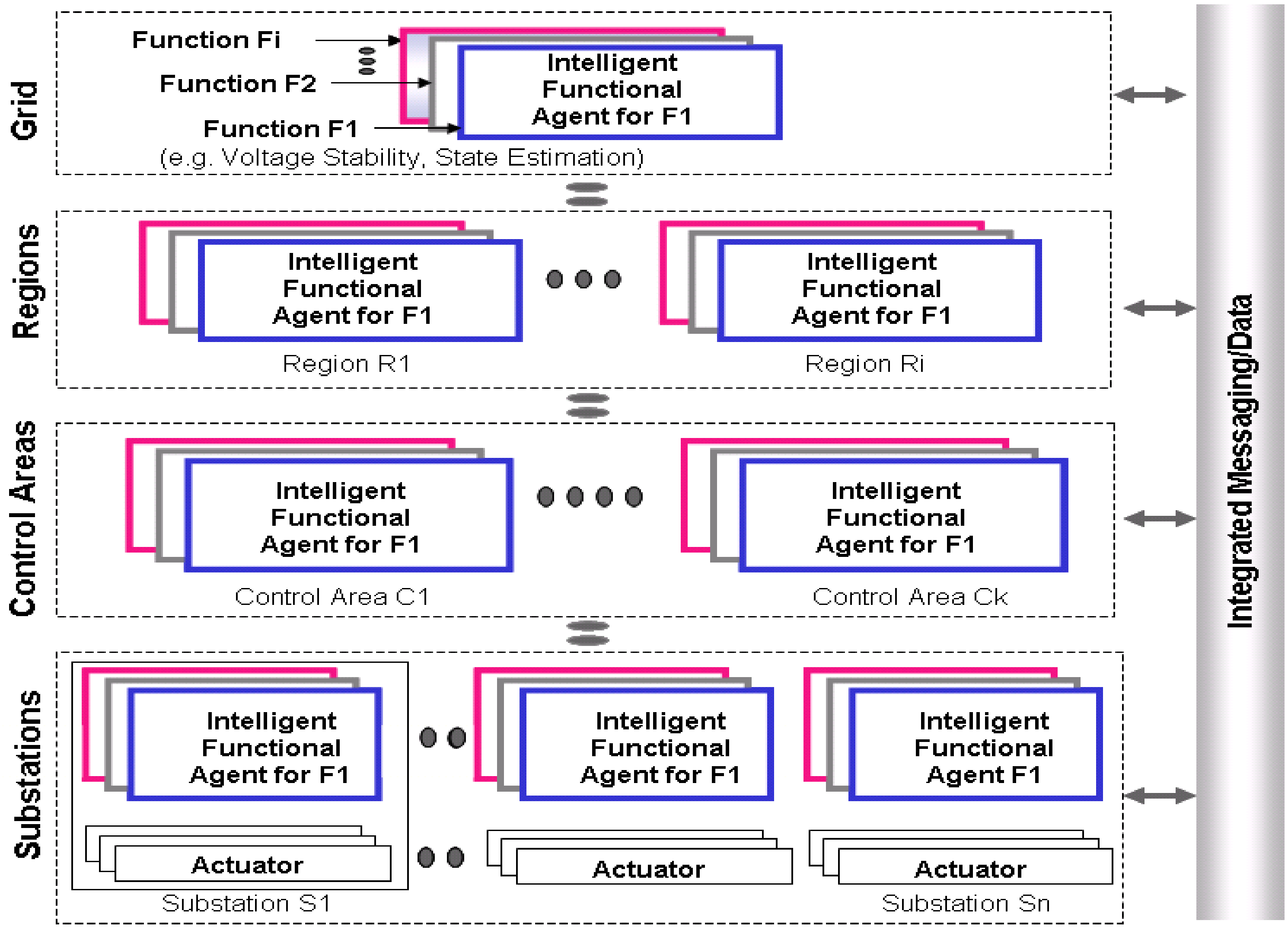
Distribution of Functional Responsibilities

- **Agents are deployed:**
  - In a virtual hierarchy
  - On a grid-wide computing network
- **Agents coordinate execution of functional tasks**
  - Data Processing
  - Monitoring
  - Reliability Enhancements
  - Control
- **Agents cover time scales ranging from Operational Scheduling through sub-second periods**



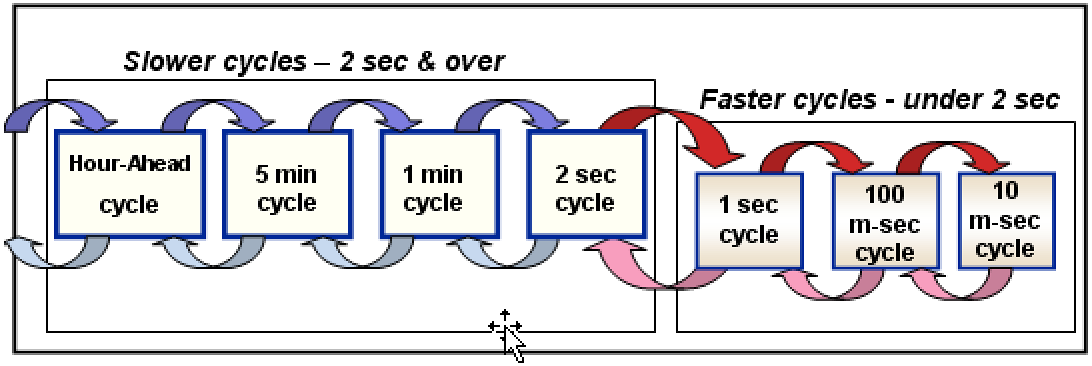
 IEEE ISGT Conference, Washington DC Jan 19-21 2010

Distributed Autonomous System

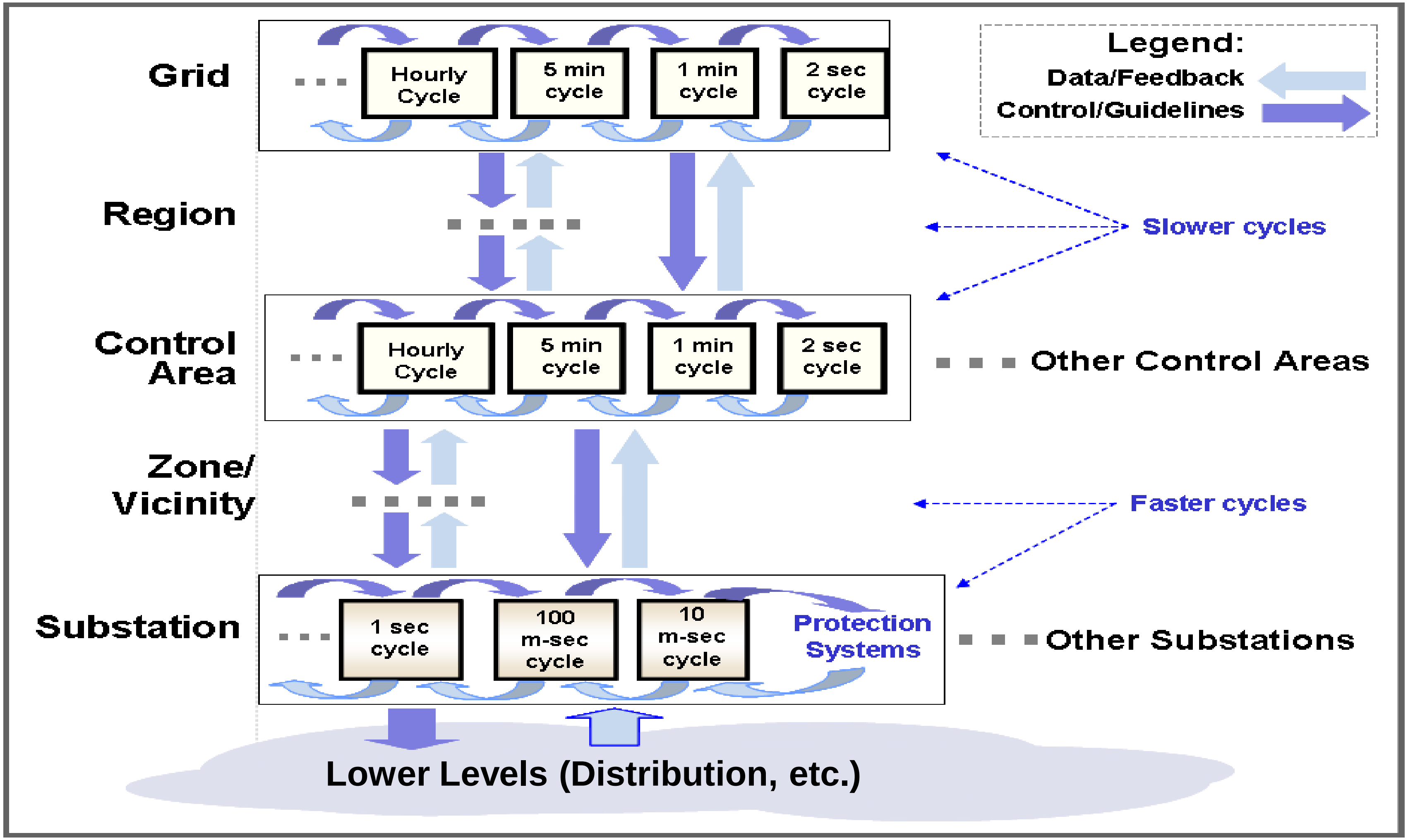


Temporal Dimension: Distinct Time Scales

- **Hour-ahead**
- **5-minute**
- **1-minute**
- **2-second**
- **1-second**
- **100-millisec**
- **10-millisec**
- **“continuous”**



Execution Cycles and Temporal Coordination

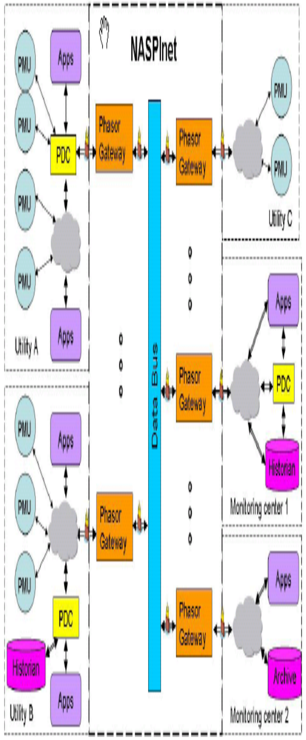


Technical Feasibility
Enabling Technologies

- **Better telemetry: PMUs - faster, time-stamped, accurate, sub-second scanning**
  - Possible to limit the time skew to 1 millisecond or even less
- **Faster control devices: Power electronics**
- **More robust controls: Adaptive protection and control settings**
- **Intelligent Embedded Devices (IEDs) to enable:**
  - Equipment level fault diagnosis
  - Constrained operation
  - “Intelligent” RAS/SPS, etc.
  - Autonomous local control / restoration of equipment
- **Enhanced computing capabilities supporting virtual hierarchical multi-agent environments**
- **Internet technology: to facilitate data exchange, process control and cyber security to implement Plug-and-play hardware and software components**
- **Integrated and secure communication infrastructure**
  - Support a virtual hierarchy where location of HW, SW and data is transparent to the user

Industry Trends
Synergy with Current Practices

- **Many of the smart grid technologies are already in place in various ad-hoc implementations:**
  - **wide-area monitoring and control**
    - **Phase angle and slow oscillation monitoring**
    - **Line thermal monitoring /dynamic rating**
    - **Geomagnetic disturbance recognition**
  - **Special protection schemes, as precursors of intelligent agents**
    - **Stability / Transfer Capability Enhancement**
  - **State estimation**
    - **PMU augmented state estimation**
  - **Forecasting**
    - **Multi-level**
  - **Infrastructure**
    - **Advanced Metering Infrastructure**
    - **PMU networks**
    - **Optical fibers connecting substations**

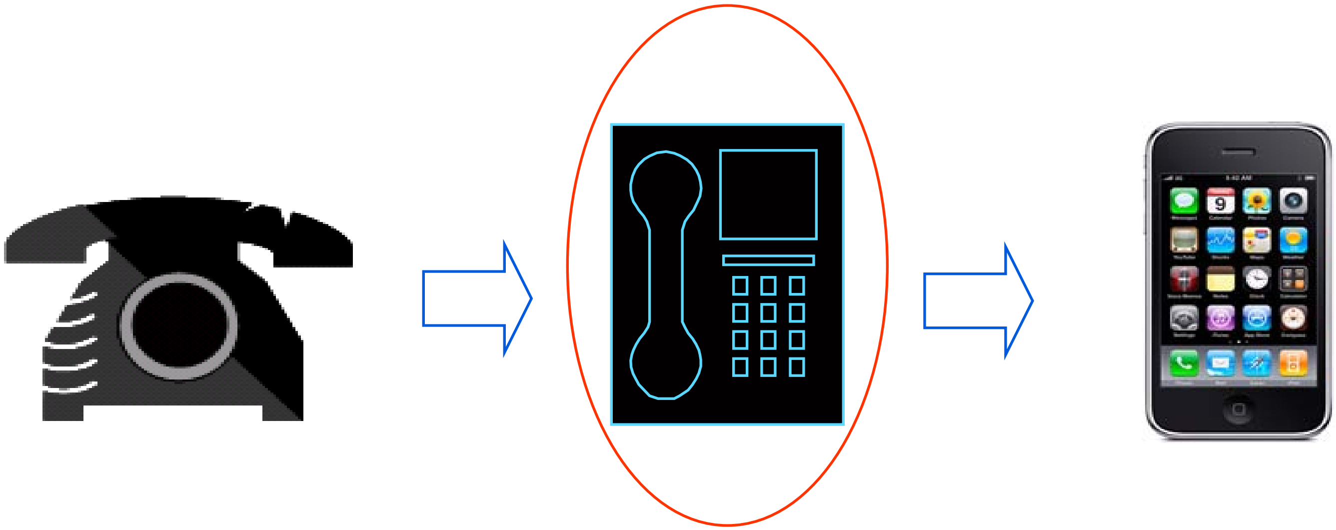


Smart Grid
Conclusion

- **Meeting reliability challenges is central to smart grid**
- **This requires a systematic approach to develop a common vision**
- **The proposed architectural framework is a concrete representation of such common vision**
- **This framework can be thought of as a “super EMS” consisting of a network of networks that allows for evolutionary implementation of the infrastructure.**
- **This vision facilitates a cohesive grid-wide integration of the enabling technologies and emergence of needed standards**

Smart Grid
Architectural Paradigm for Transformation of the Grid

- An architectural approach is essential for transforming the power grid to a “smarter grid”



- It was not because of a few specific applications that iPhone revolutionized the “phone” but for its architecture that led to an explosion of functionality.