Smart Grid Control Primer

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CYBER RESILIENT ENERGY DELIVERY CONSORTIUM

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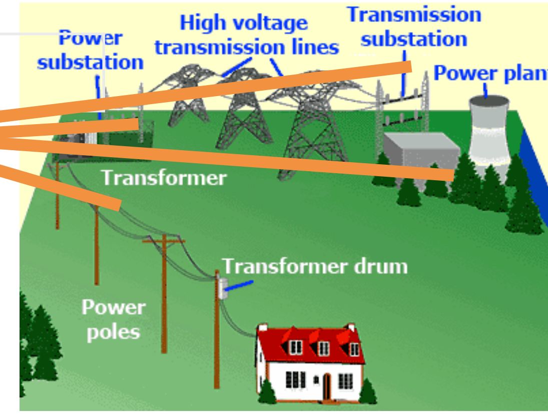
Smart Grid Goals

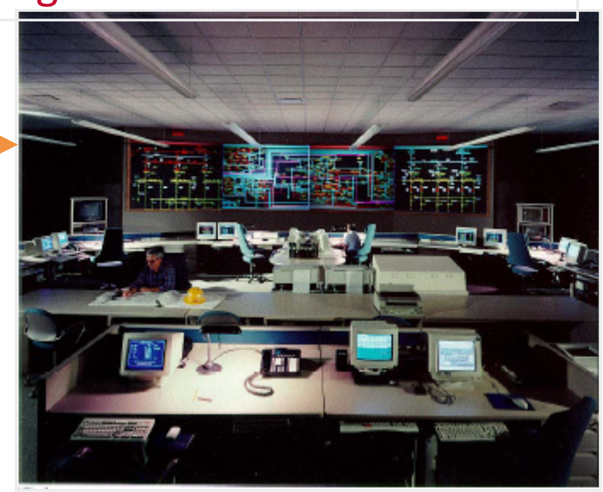
- Power System Operational Paradigm (reliability, economics, resiliency, sustainability)
  - Sense
  - Communicate
  - Compute
  - Visualize
  - Control
- Advancement in physical system, information network, control, human aspects

Sense



Communicate

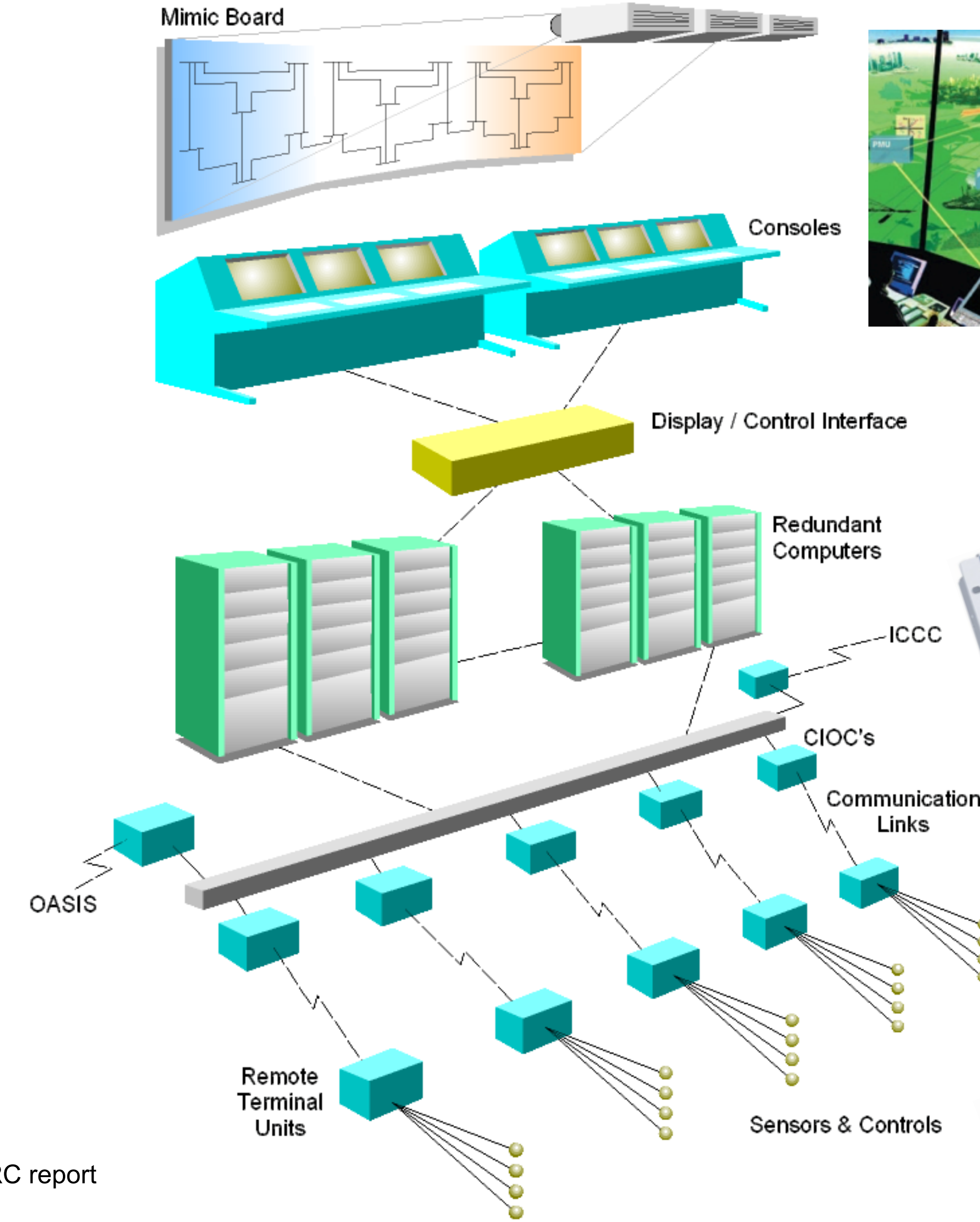
Compute and send Control Signal

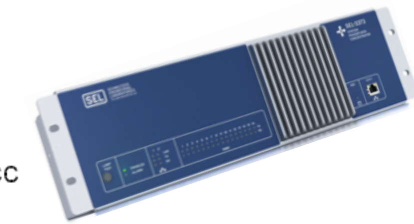


Control Objective and Multi-scale Dynamics in Power System

Action/operation	Time frame
Wave effects (fast dynamics, lightning caused over voltages)	Microseconds to milliseconds
Switching over voltages	Milliseconds
Fault protection	100 milliseconds or a few cycles
Electromagnetic effects in machine windings	Milliseconds to seconds
Stability	60 cycles or 1 second
Stability Augmentation	Seconds
Electromechanical effects of oscillations in motors & generators	Milliseconds to minutes
Tie line load frequency control	1 to 10 seconds; ongoing
Economic load dispatch	10 seconds to 1 hour; ongoing
Thermodynamic changes from boiler control action (slow dynamics)	Seconds to hours
System security monitoring	Steady state; on-going
Load Management, load forecasting, generation scheduling	1 hour to 1 day or longer, ongoing
Maintenance scheduling	Months to 1 year; ongoing
Expansion planning	Years; ongoing
Power plant site selection, design, construction, environmental impact, etc.	10 years or longer

Centralized Control





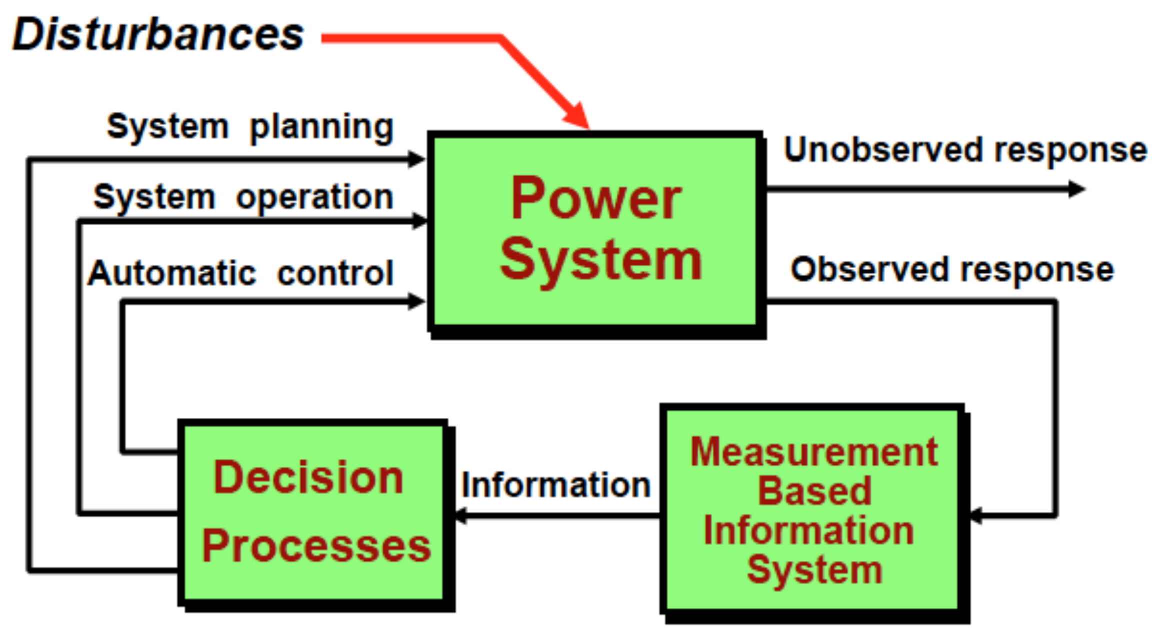
Local/ Decentralized Control

Credit: PSERC report

Smart Grid Control

- Voltage, frequency and power control
- Provide operators with up-to-date information on the condition of the power systems
- critical quantities are measured
  - voltages, currents, power flows, and the state of circuit breakers and switches
  - frequency, generator outputs, and transformer tap positions
- the measurements are sent to the control center
  - via the telemetry system

Better Information Supports Better Decisions



Source: John Hauer

Preventive and Corrective Control Mechanism

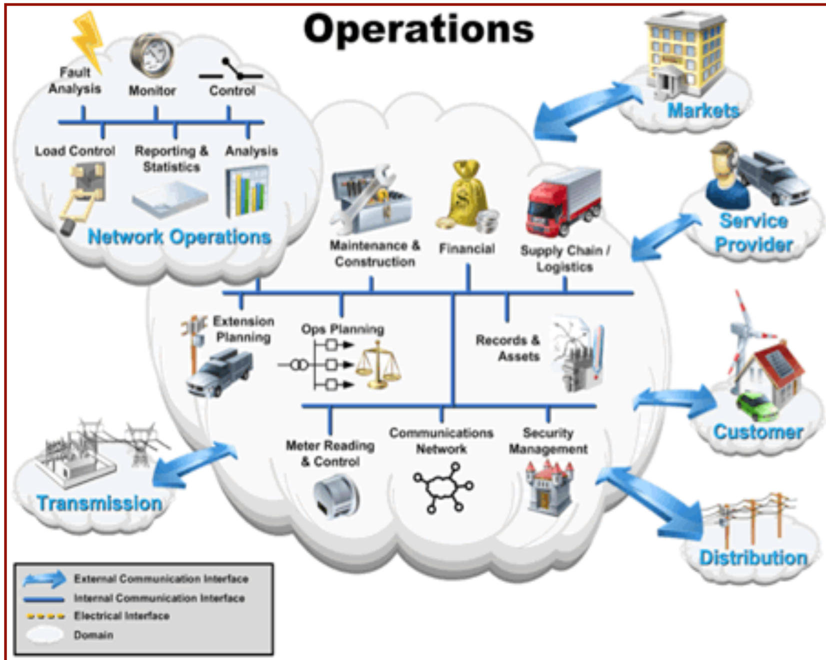
Preventive Mechanism

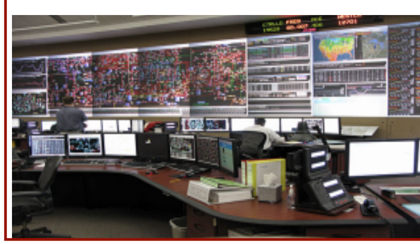
- Forecasting and planning (short term, long term)
- Security analysis against probable failures
- Human Operator

Corrective Mechanism

- Protection
- Frequency/ Voltage/ Stability Control
- Remedial Action Schemes/ Special Protection Scheme
- Wide Area Control
- System restoration
- Human Operator

Existing and Evolving Smart Grid Control





Centralized
- Slow
- Not Scalable
- Optimal
- Prone to failures

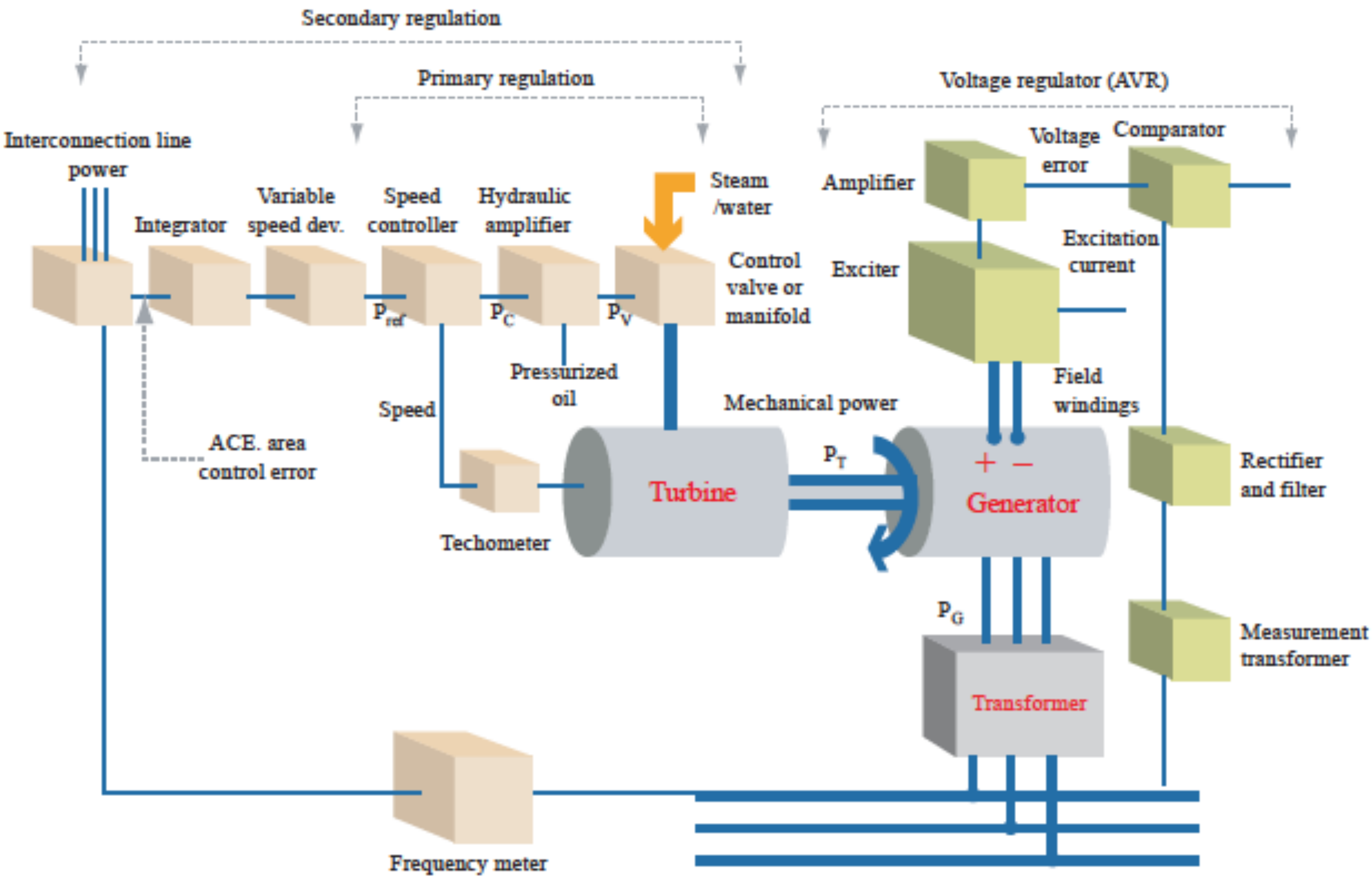
Local
- Fast
- Non-optimal
- Hard coded
- May fail for unexpected

Existing Monitoring and Control

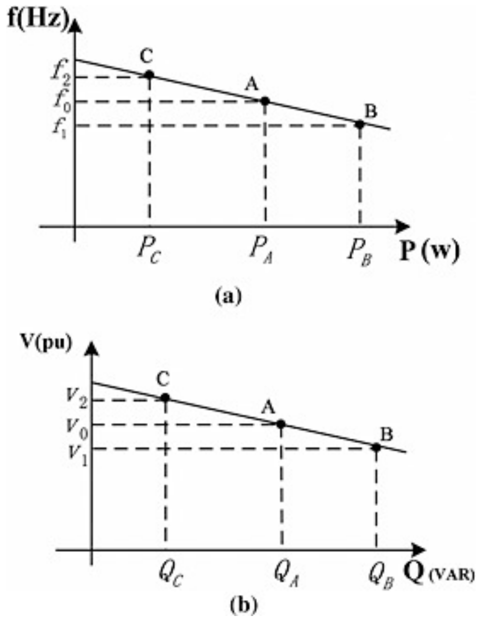
Distributed, Coordinated and Hierarchal
- Fast
- Scalable
- Sub-Optimal
- Fault-tolerant
- Supports Big data
- Supports IoT

Evolving Monitoring and Control

Local Control: Generation Control Loop



Local Control



Parameter:
Voltage,
frequency,
power flow

Power
System
Operation

Automatic Control

Protection
Droop Control
AVR
AGC
RAS
UFLS

Centralized Control

Centralized Control

Ownership:
Investor owned, public owned, IPP, co-op

Geographical:
Area, reliability coordinator, Interconnection

Timeframe:
Second, minutes, hours, day, months

Power System Operation

Situational Awareness

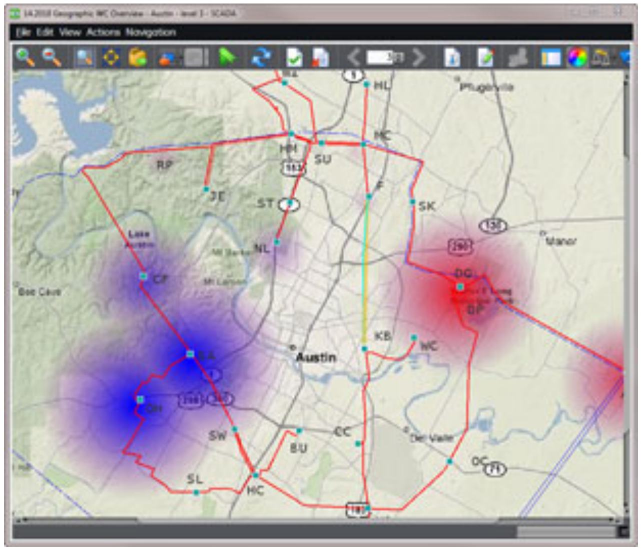
Decision Support

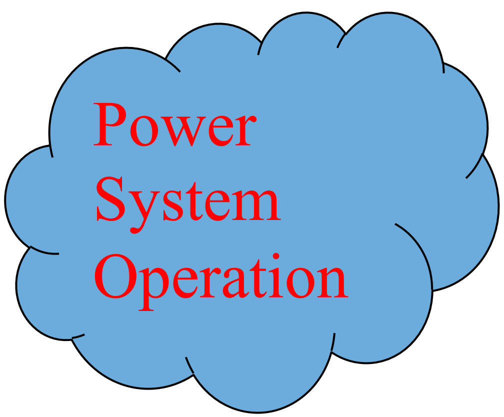
Asset: Gen, trans, dist

Regulatory Framework: vertical vs market operation

Parameter: Voltage, frequency, power flow

Centralized Control





Situational Awareness

- **SCADA**
  - **Sensors (CT/PT, PMU, switch status)**
  - **RTU, PDC merging units**
  - **Communication system**
  - **Data archival, historian**
- **State Estimation**
- **Control Center Display, organization**
- **Visualization tool**
- **Alarm, alerts**

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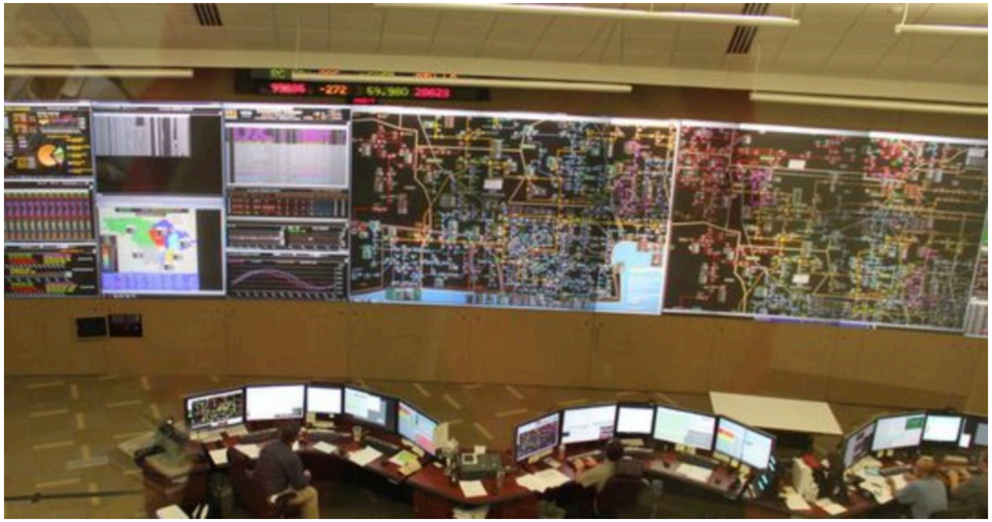
Centralized Control



Timeframe: Second, minutes, hours, day, months

- OPF
  - Unit Commitment
  - Economic Dispatch
  - Hydro-Thermal Scheduling
- Security Analysis
- Load and price forecasting
- Energy Interchange
- Market power analysis

Power System Operation

Decision Support

- **Real Time Operational**
- **Short Term Planning**
- **Long term Planning**

Operator Tasks

- Ensuring the reliable delivery of electricity to customers.
- Manage the power grid from a set of computer consoles within a control center.
- Interact over the phone with field crews, general personnel, substation personnel, and other system operators within their own utility and with neighboring utilities.

Managing an entity (electricity) that is:

- Invisible
- Travels in the speed of light
- Dangerous/ Fatal

Interchange Operator - monitoring interchange activities between different balancing areas.

Balancing Operator - adequate power generation for expected power demand

Transmission Operator - transmission switching, monitoring system line loading and voltage conditions.

Reliability Coordinator - stability and reliability of multiple areas, coordinating tasks with multiple entities, and maintain reliability over such areas.

Market Operators - separated from the reliability-oriented. Purchase or sell current and future energy assets to maximize profits.

Understand NERC Standards and constraints

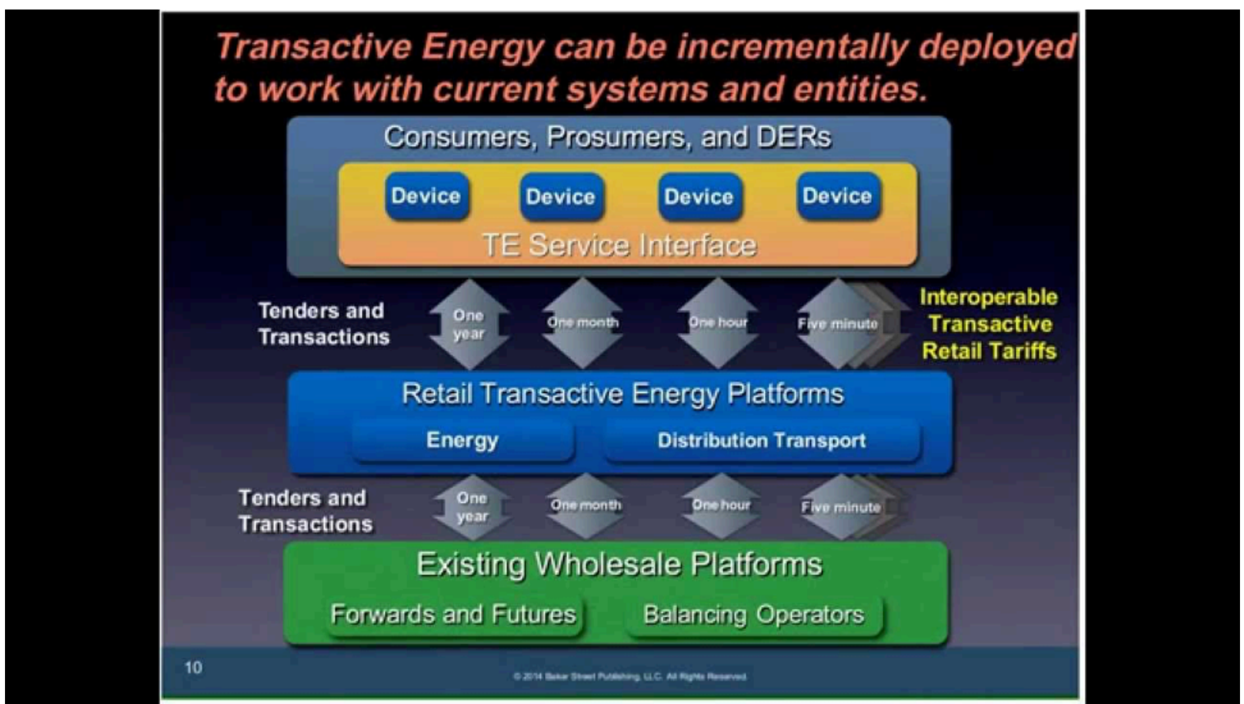
Renewable Operator

Operator Tasks

- React to alarms, i.e. investigate the cause and validity of the alarms and provide corrective actions.
- Control the station and transmission system voltages and ensure the voltage is within the schedule and specification.
- Facilitates all scheduled preventive maintenance.
- React to other non-forecasted events, i.e. car colliding with an electric pole that either resulted in damage to the pole and equipment or the fire department/police department or the city requesting that we remove from service the cables.
- Coordinate with generator operators when the units are either coming online or offline or when there is a need to adjust their loads.
- Work with engineering when an existing equipment or cable is approaching its capability or exceeded its capability.
- Prepare contingency plans for schedule outage, basically evaluate all the “what if scenarios” and providing corrective action for each scenario.
- Review impact of proposed schedule outage.

Evolving Control: Transactive Control

- Transactive energy is a means of using economic signals or incentives to engage all the intelligent devices in the power grid from the consumer to the transmission system to get a more optimal allocation of resources and engage demand in ways we haven’t been able to before.
- Enabled with the communication concepts we get with the smart grid.



Transactive Control

- Respond to system operation moving from deterministic to stochastic model by fully engaging all resources at all levels
- Use local conditions and global information
- Forecast as a feedback and function as incentive

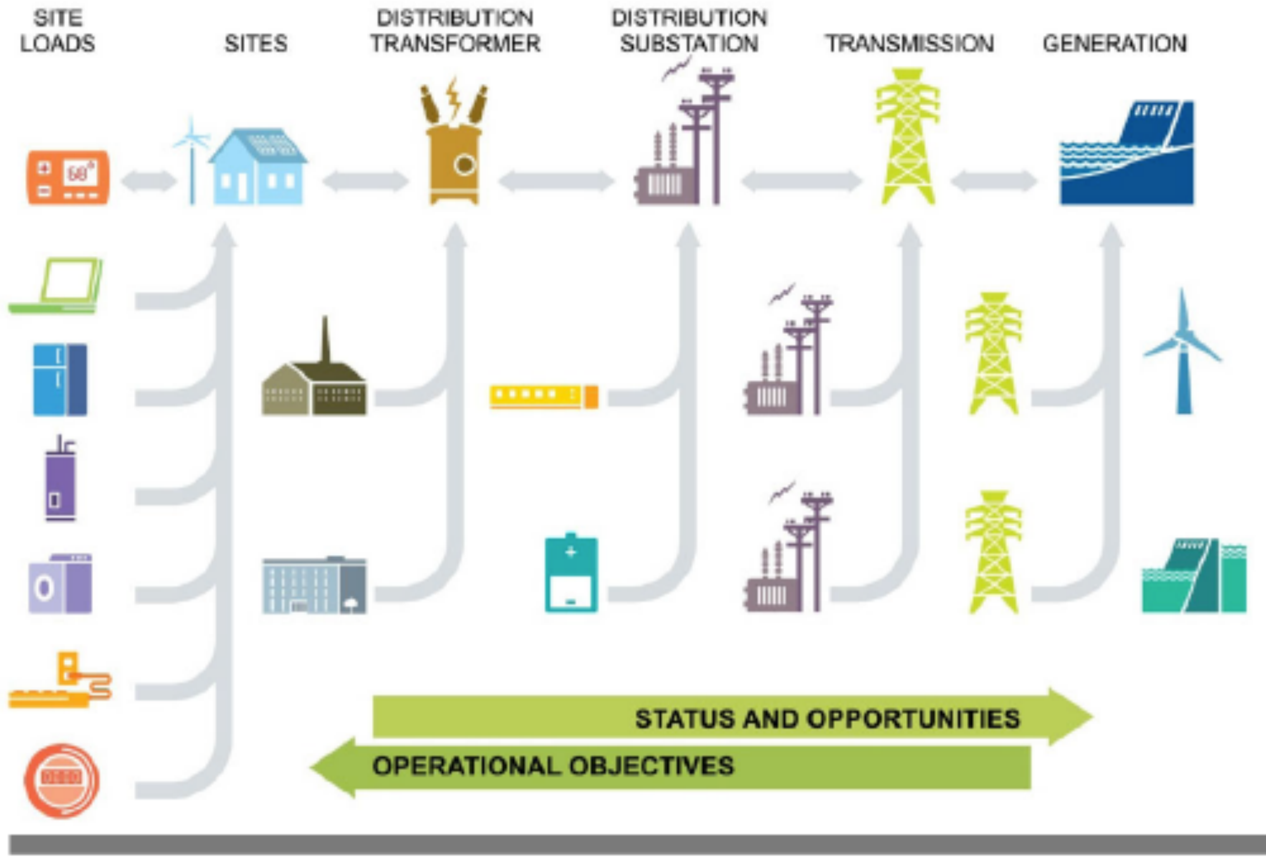
Transactive control & coordination

- Coordinates operation of distributed assets to meet multiple generation, transmission, & distribution objectives
- Manages controllable assets at the distribution level to mitigate load variability & that of supply-side as well

Transactive Control

Operational objectives

- Manage peak demand
- Facilitate renewable resources
- Address constrained resources
- Improve system reliability and efficiency
- Select economical resources (optimize the system)



Aggregation of Power and Signals Occurs Through a Hierarchy of Interfaces

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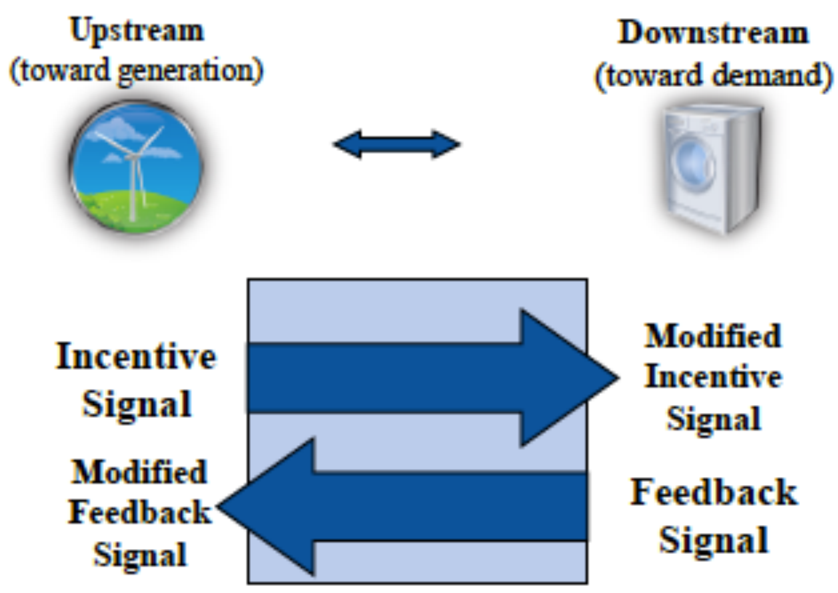
Transactive Control

- Transactive control is distributed way to respond to grid needs
- Incentive signal can be from big wind farm, transmission constraints, demand charges, imported energy
- Feedback signal can befrom HVAC thermostat, storage PHEV



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Resilient Control

Differences Between Reliability and Resiliency

Resiliency

- Measured in anticipation of some form of threat
- Assessed in extreme disturbance

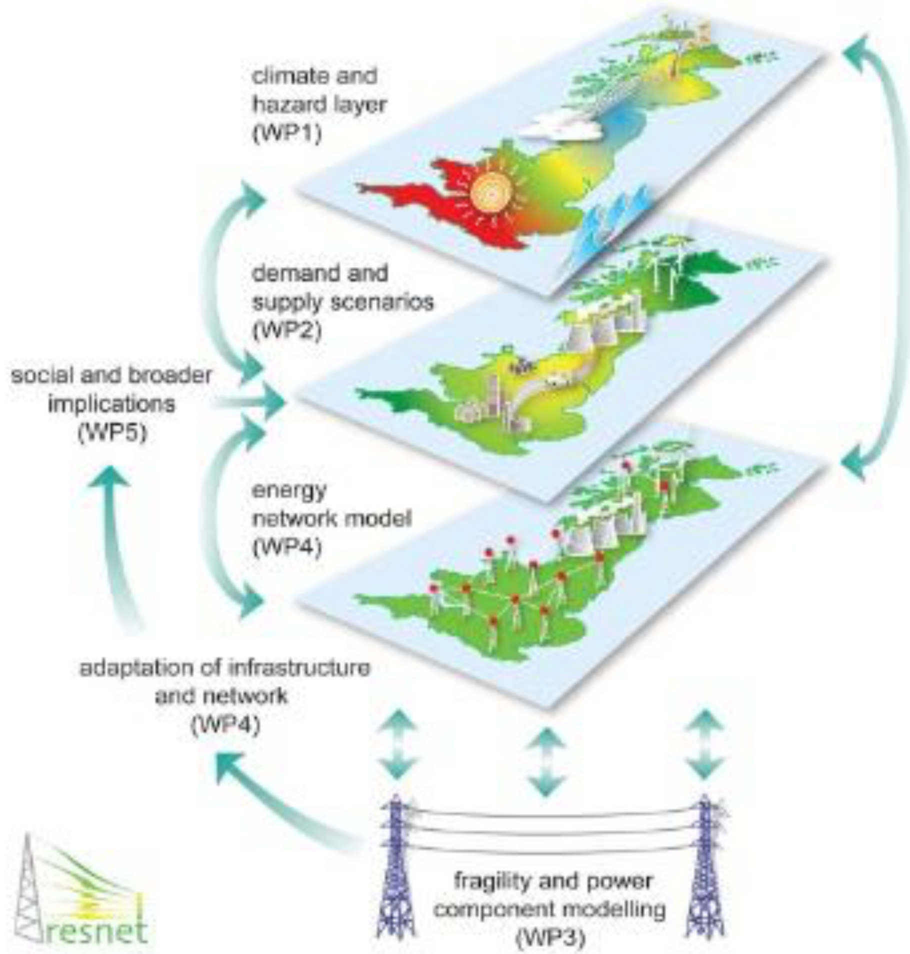
- Priority of critical loads is considered
- Resiliency is an indication of preparedness of a network to withstand or avert damage coming from outside the power system [like weather]
- No formal metrics

Reliability

- Measure of operational consistency and performance in meeting connected customers load

- No classification of load is reflected in measurement of reliability
- Reliability accounts for sustainable power lost due to normal operational or equipment damages or external factors. Momentarily outage ignored.
- SAIDI, SAIFI, MAIFI, etc

Designing Resilient Control



Weather Impact
- PowerWorld

Power System Analysis
- PowerWorld, PSLF

Dynamic Analysis Tool
- PSS/E

Control System Modeling
- Hypersim

Protection Modeling Tool
- CAPE

Cyber Modeling Tool
- NS-3, DeterLab

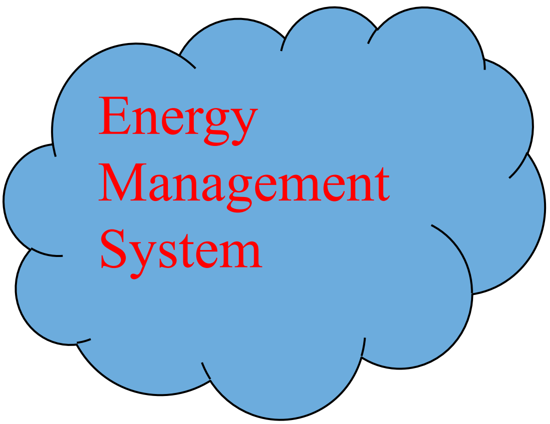
Contingency Modeling Tool

Interfacing

THE FUTURE GRID

IEEE Smart Grid Control Vision 2030

Future EMS and Control



- Renewables ... forecasting & variability management: Stochastic Control
- Demand Response & EMS integration
- Integration of EMS with DMS
- Growth of phasor analysis & Visualization
- Integrating IED data more intelligently
- Utilizing faster communication
- Synchronous time other than PMU
- Resiliency Metric and Value in Control
- Decentralized and Coordinated
- Fault Tolerant
- Cyber –resilient, delay aware

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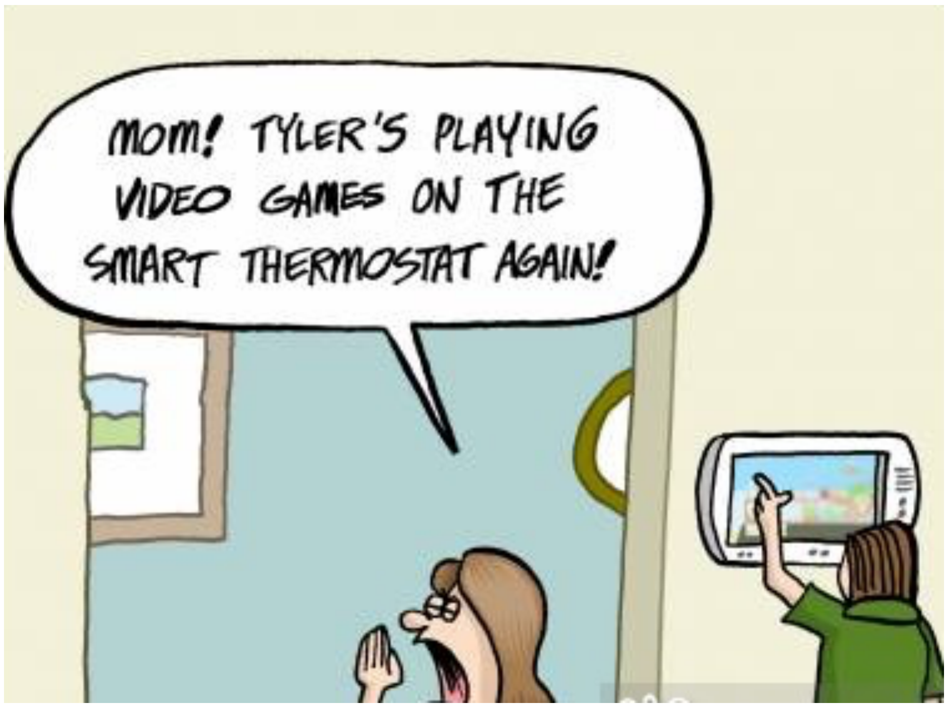

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