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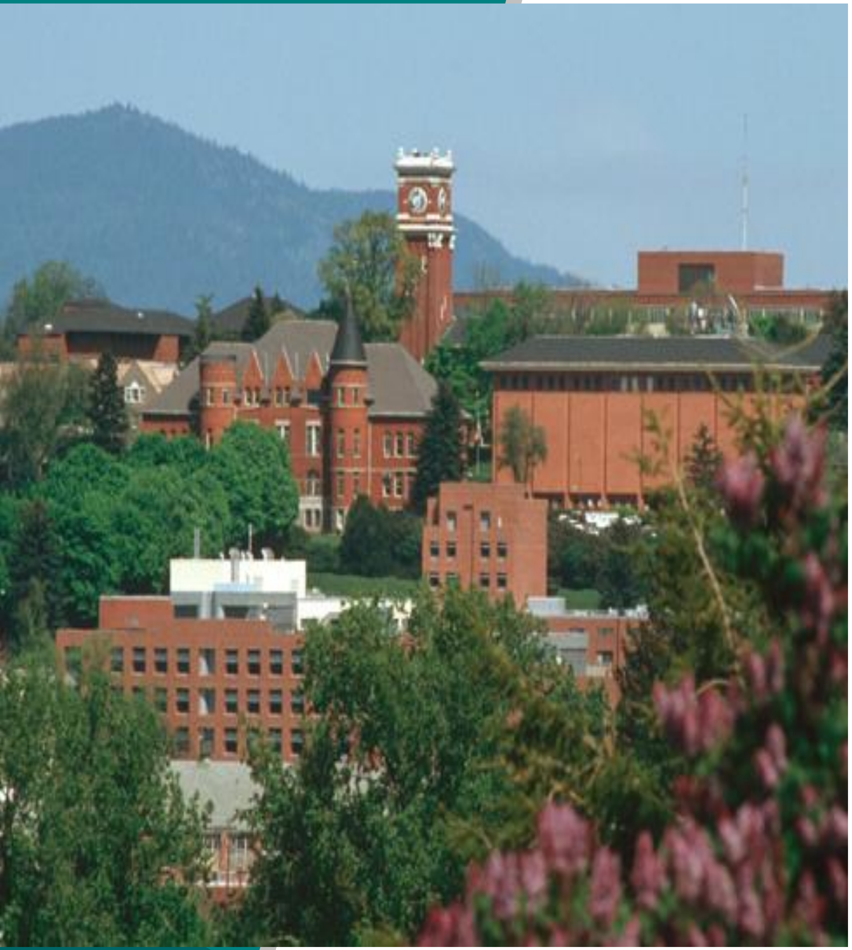


Evolution of Control for the Smart Grid

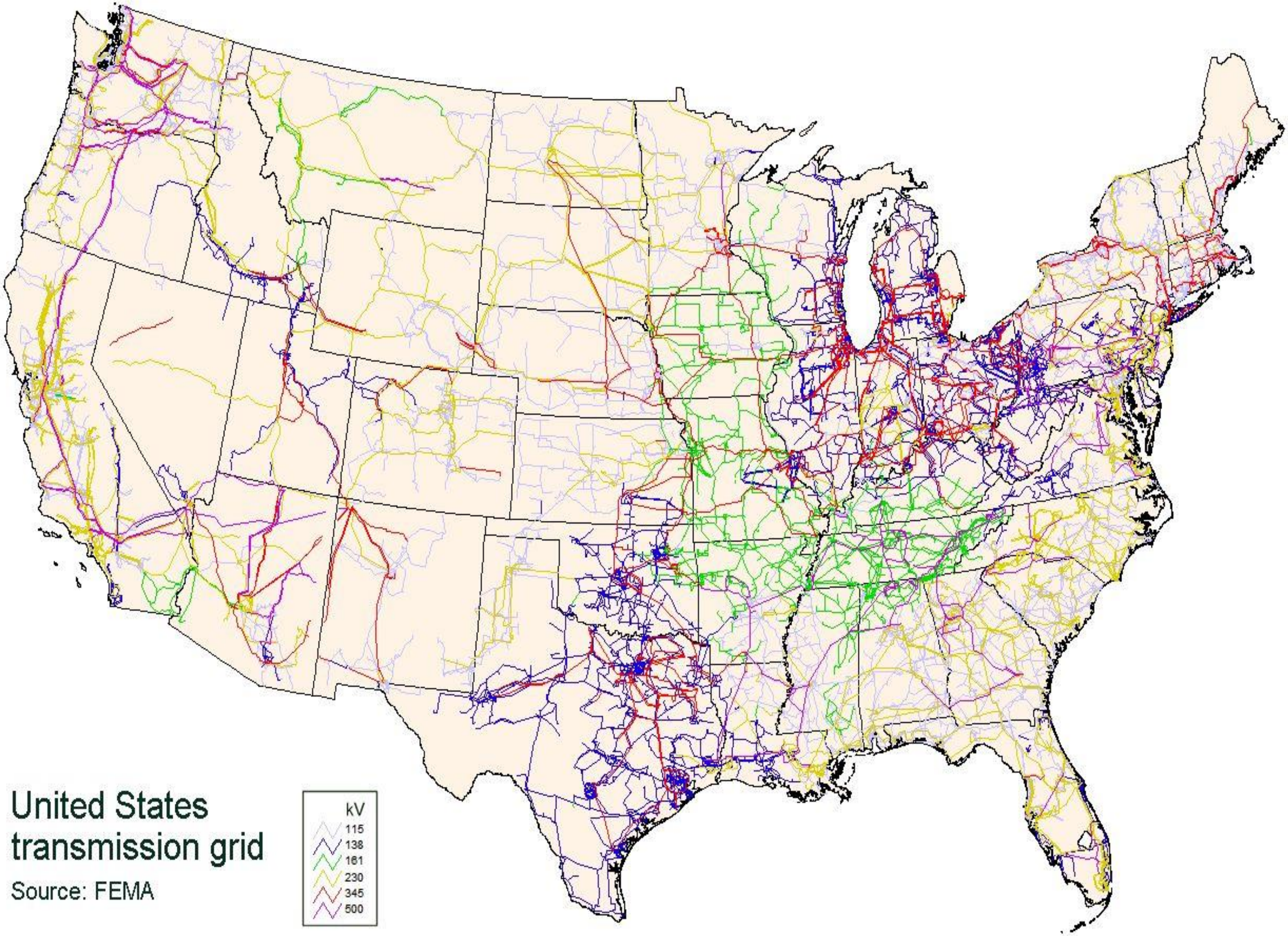
Anjan Bose
Washington State University
Pullman, WA, USA

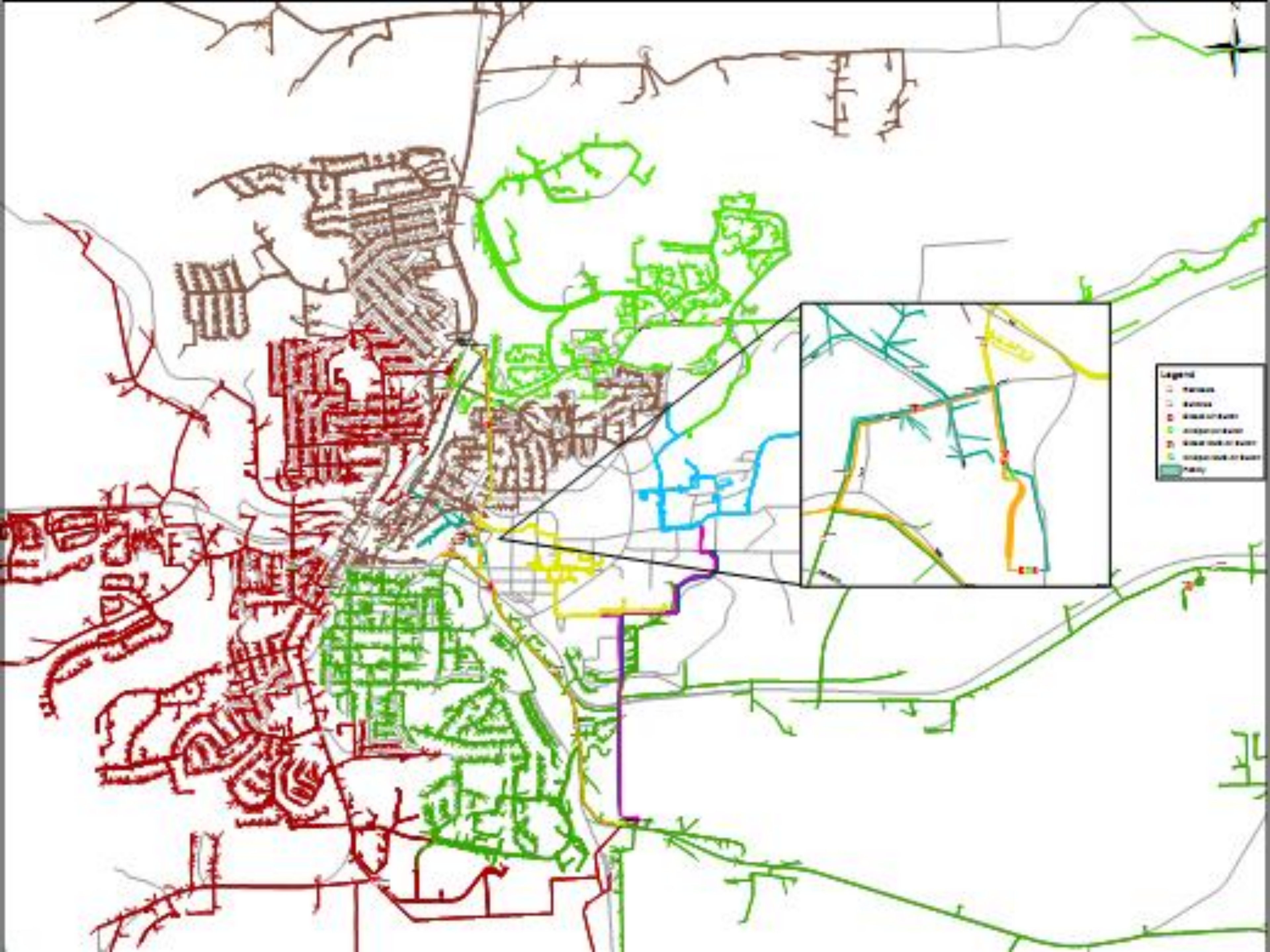
Distinguished Lecture

IEEE-PES Chapter

Seattle, WA

November 25, 2013


United States transmission grid
Source: FEMA
kV
115
138
161
230
345
500


Legend

Smart Grid Projects in USA

- $4.5 billion
- Investment Projects ($3.8B)
- Demonstration Projects ($600M)
- Training Projects ($100M)
- Transmission (PMUs)
- Distribution Automation
- Customer (smart meters)

What is a SMART Grid?

- Self-heals
- Motivates and includes the consumer
- Resists attack
- Provides power quality for 21st century needs
- Accommodates all generation and storage options
- Enables markets
- Optimizes assets and operates efficiently

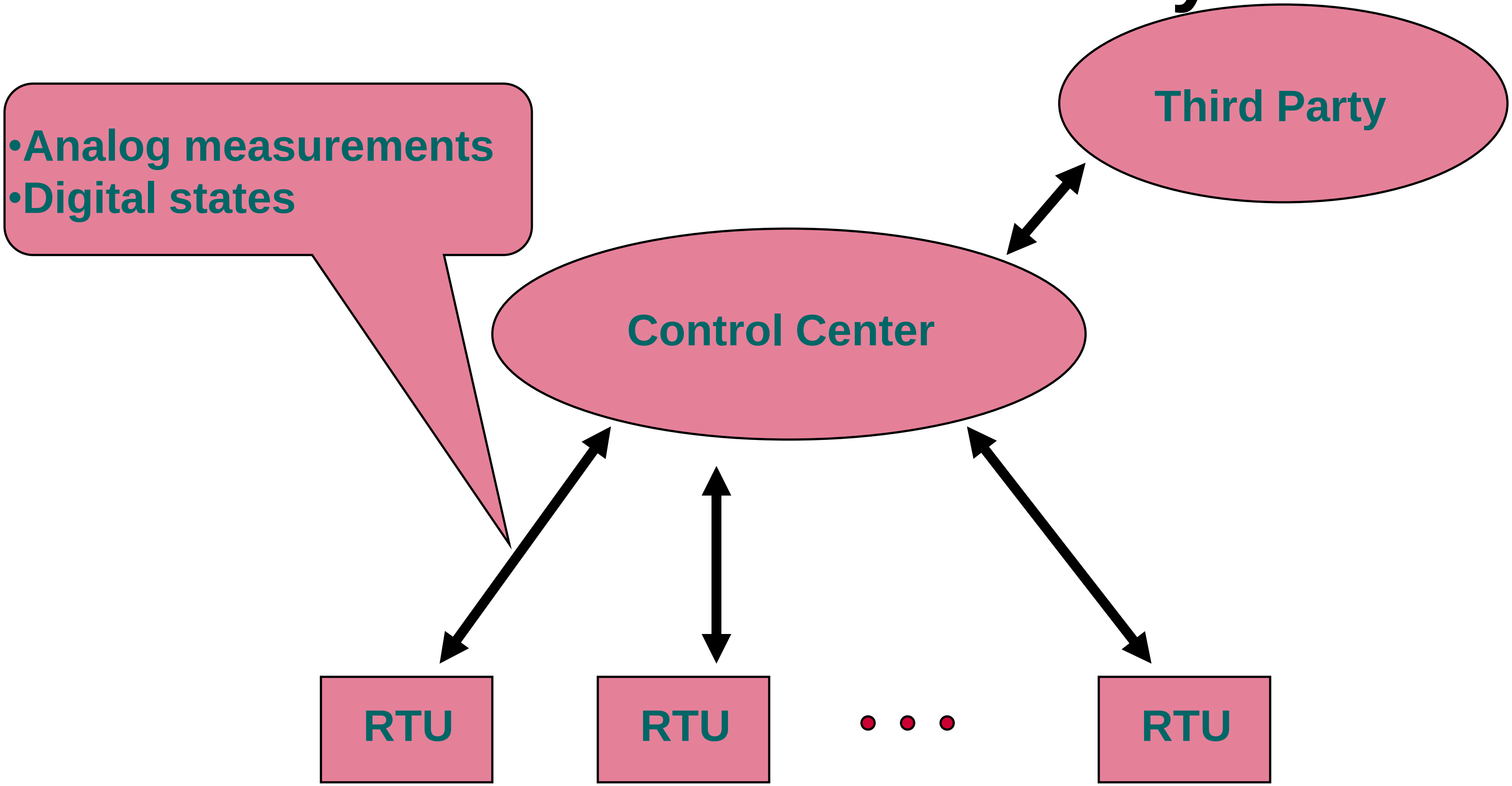
The Past (before 1960s)

- Hard wired metering
- Ink chart recording
- Light and sound alarming
- Hard wired remote switching
- Analog Load Frequency Control (1930s)
- Economic Dispatch (1950s)
- ED was first to go digital

The Present (since 1960s)

- The digital control center (SCADA-AGC)
- The RTU to gather digital data at substation
- Comm. channel from sub to control center (CC)
- The SCADA
  - The Data Acquisition from RTU to CC
  - The Supervisory Control signal from CC to RTU
- The screen based operator display
- Automatic Generation Control (AGC)
  - The digital algorithm for ED
  - The digital version of LFC

Communication for Power System

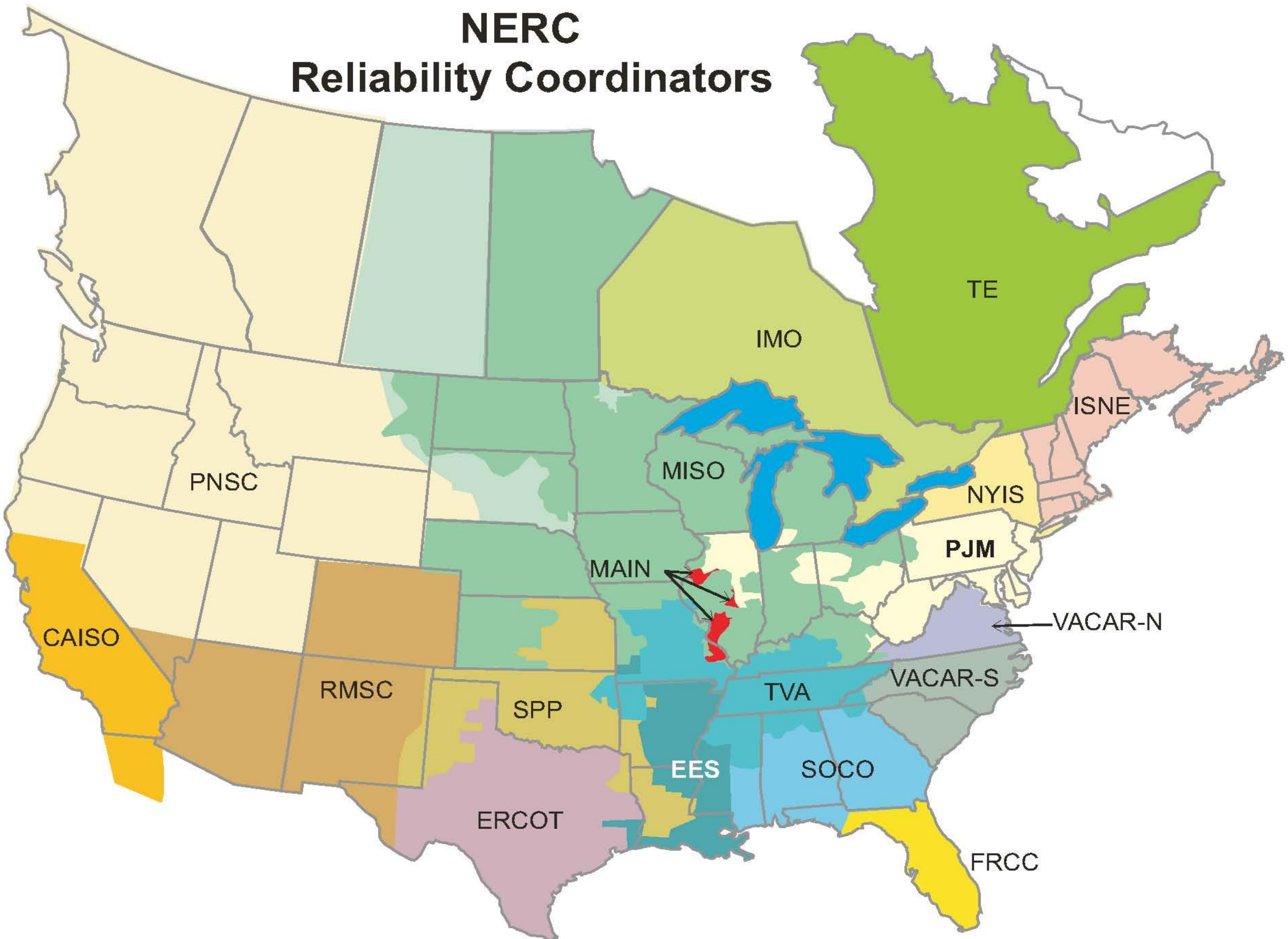


The Present (since 1970s)

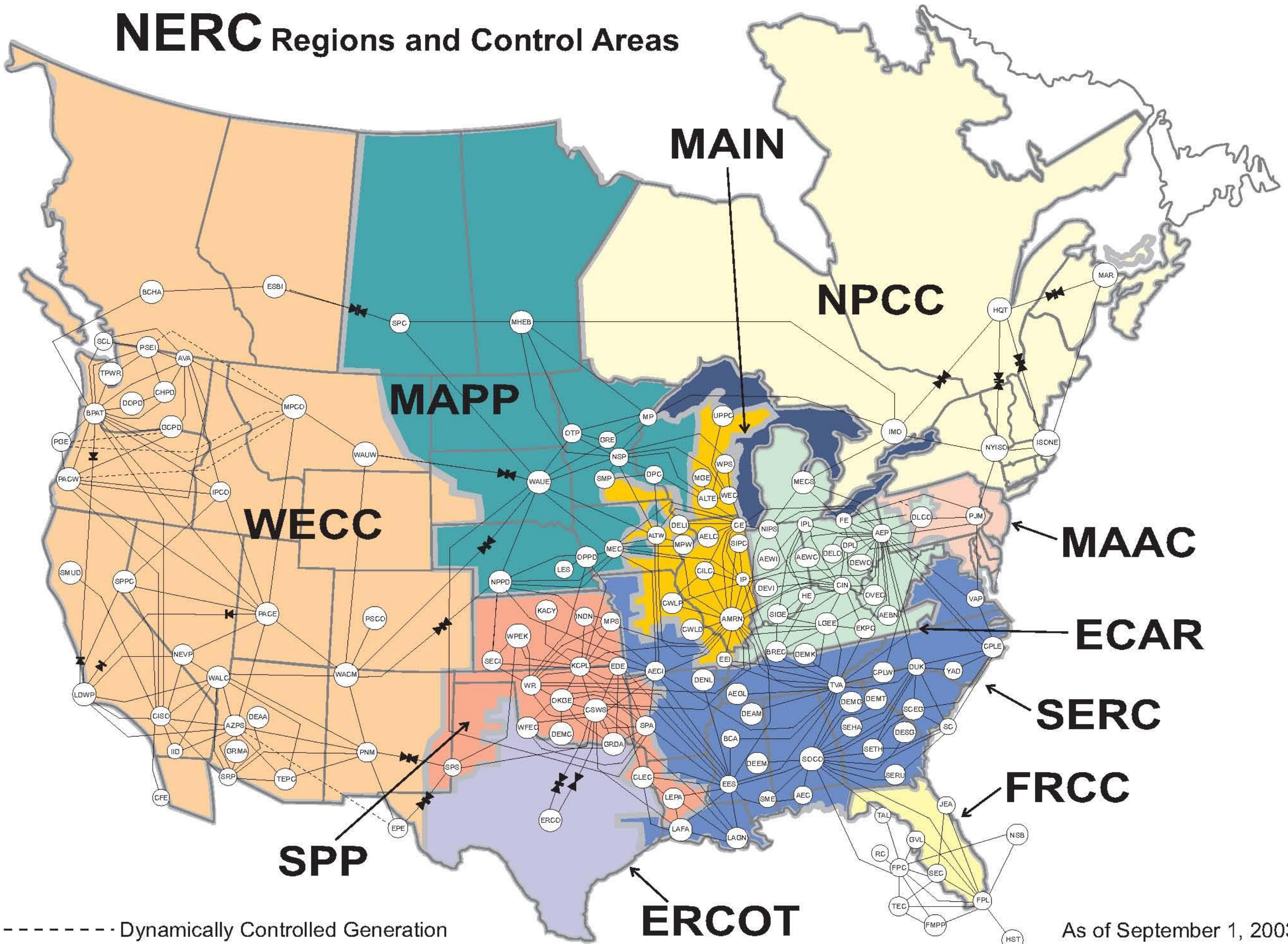
- The Energy Management System (EMS)
- State Estimation (SE)
- Static Security Analysis (n-1)
- Dynamic Security Analysis (stability)
  - Transient, Oscillatory, Voltage
- Optimal Power Flow based analysis
  - Preventive Action calculation
  - Corrective Action calculation

Evolution of Computer Architecture

- Special real time computers for SCADA-AGC
- Mainframe computer back ends for EMS
- Redundant hardware configuration with checkpoint and failover
- Multiple workstation configuration
  - Back-up is more flexible
- Open architecture initiated
- CIM (Common Information Model) standard


NERC
Reliability Coordinators
TE
IMO
ISNE
MISO
NYIS
PJM
MAIN
VACAR-N
PNSC
CAISO
RMSC
SPP
TVA
VACAR-S
EES
SOCO
ERCOT
FRCC

Balancing Authorities



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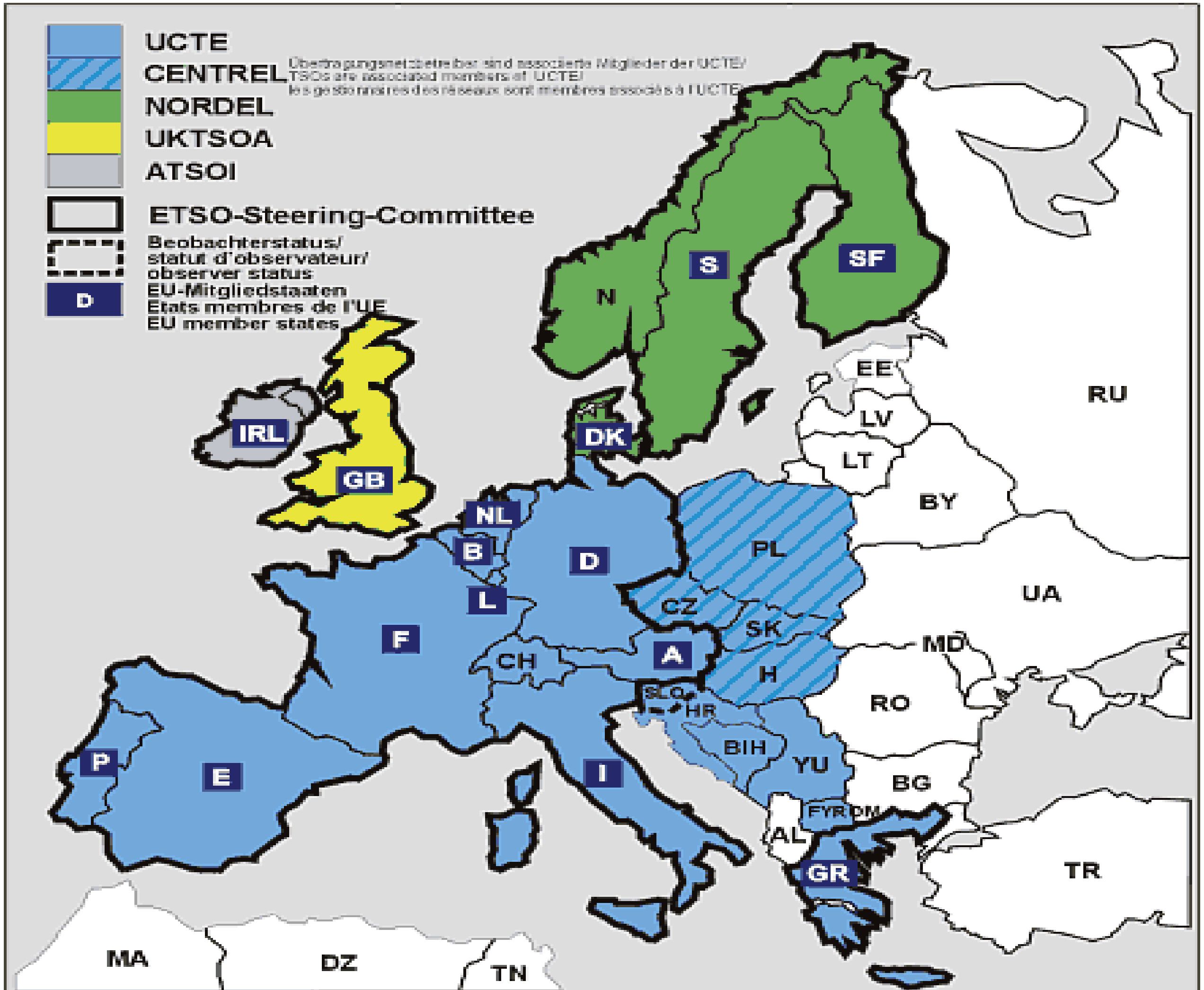
West European Power Grid



China Grid


Northeast
2 parallel 500 kV AC
XinJiang Autonomous Region
North
Northwest
1 500kV AC
1 BTB HVDC
Tibet
East
Central
3 HVDC
1 HVDC
South

Monitoring the Power Grid

- Visualization
  - Tabular, graphics
- Alarms
  - Overloaded lines, out-of-limit voltages
  - Loss of equipment (lines, generators, comm)
- State estimator
- Security alerts
  - Contingencies (loading, voltage, dynamic limits)
  - Corrective or preventive actions

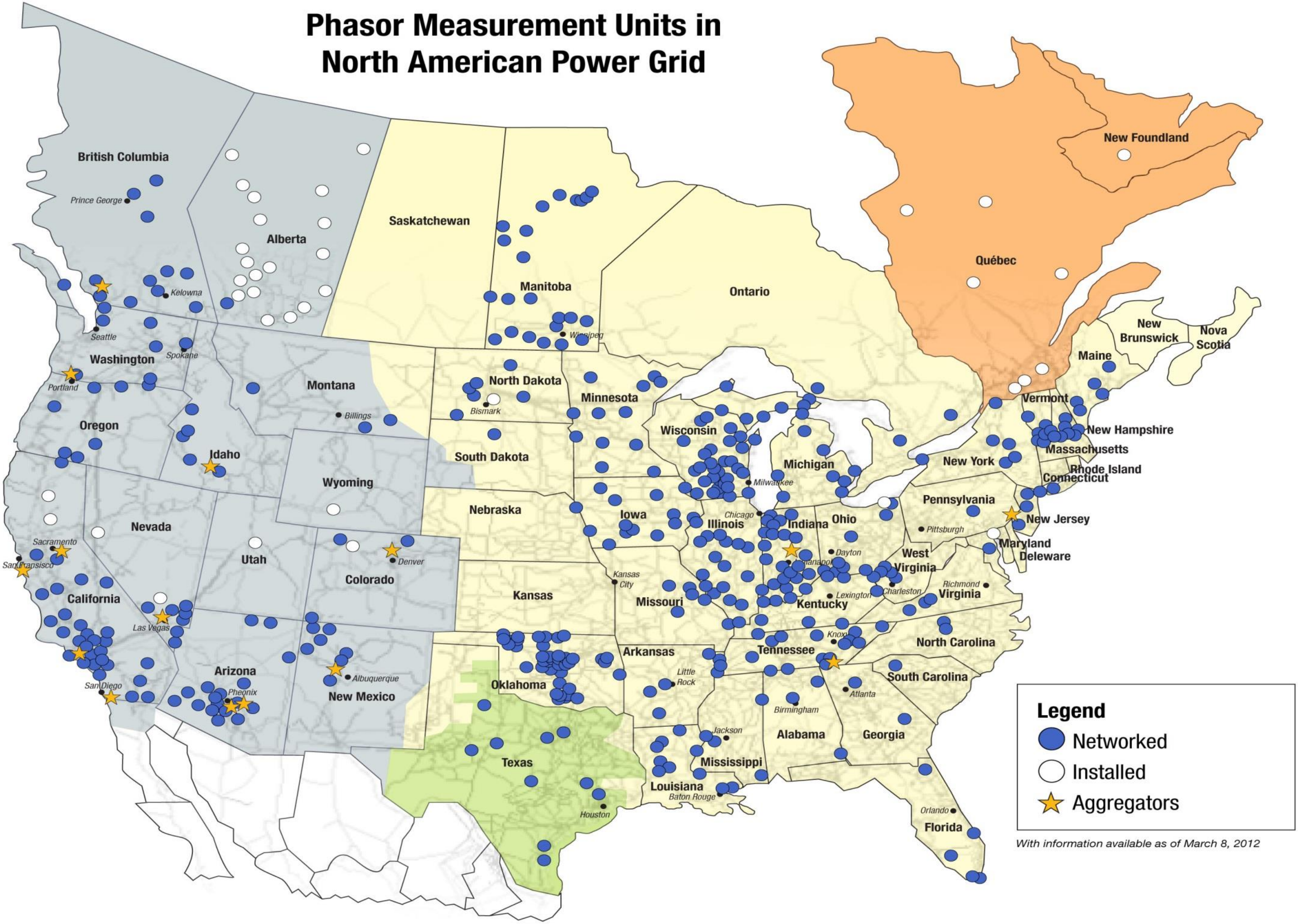
Control of the Power Grid

- **Load Following – Frequency Control**
  - **Area-wise**
  - **Slow (secs)**
- **Voltage Control**
  - **Local and regional**
  - **Slow to fast**
- **Protection**
  - **Mostly local, few special protection schemes**
  - **Fast**
- **Stability Control**
  - **Local machine stabilizers**
  - **Remote special protection schemes**
  - **Fast**

Substation Automation

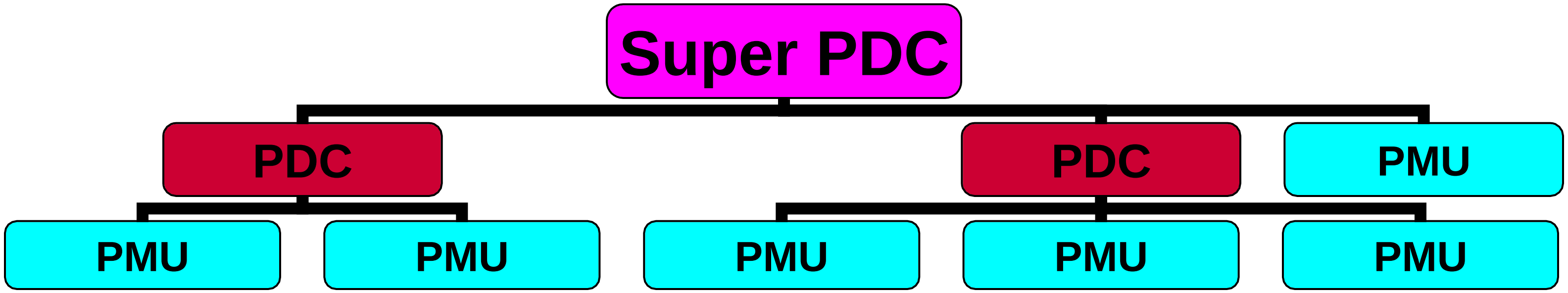
- Many substations have
  - Data acquisition systems at faster rates
  - Intelligent electronic devices (IED)
  - Coordinated protection and control systems
  - Remote setting capabilities
- Data can be time-stamped by satellite

Phasor Measurement Units in North American Power Grid

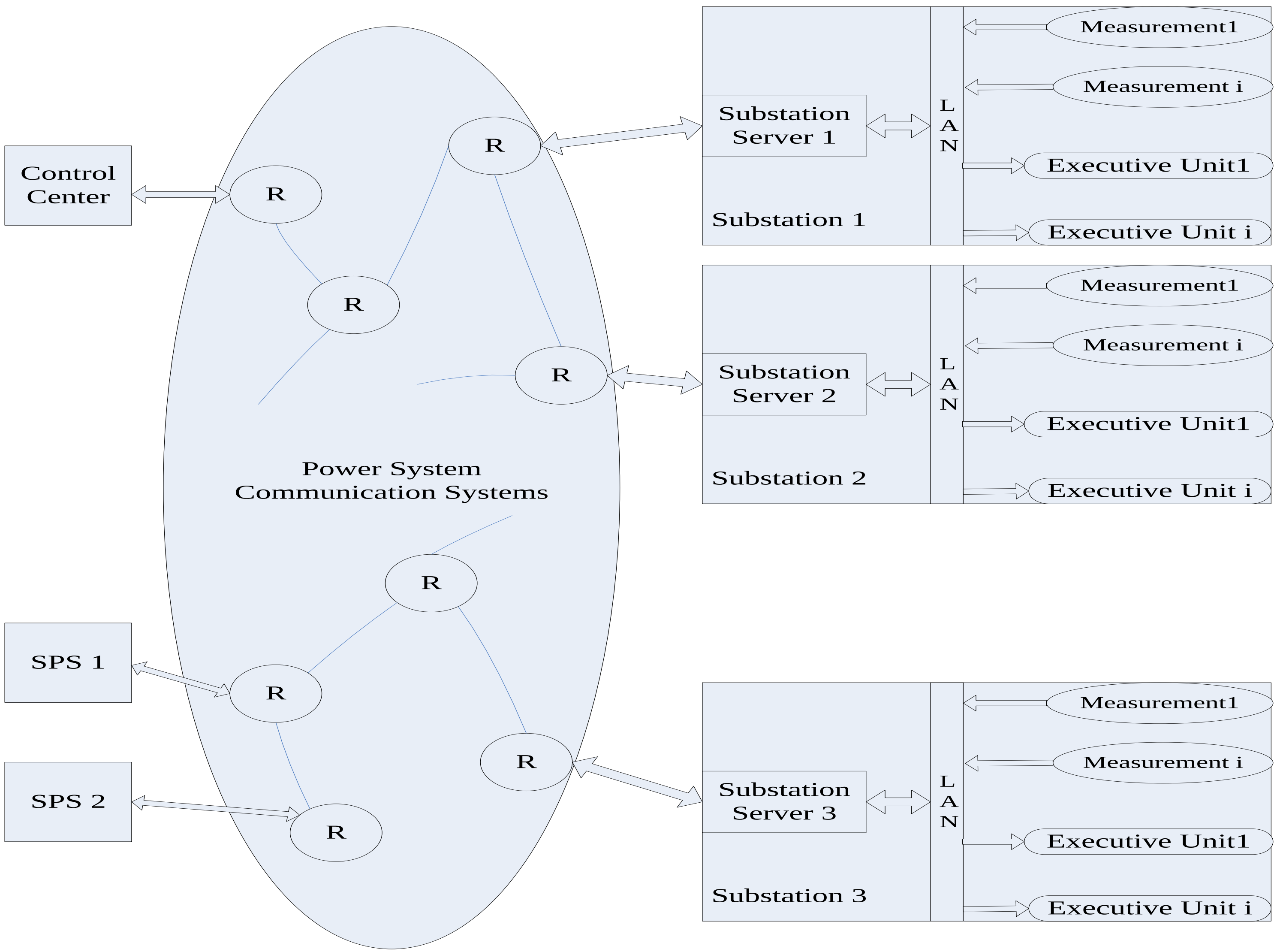


With information available as of March 8, 2012

Phasor Measurements



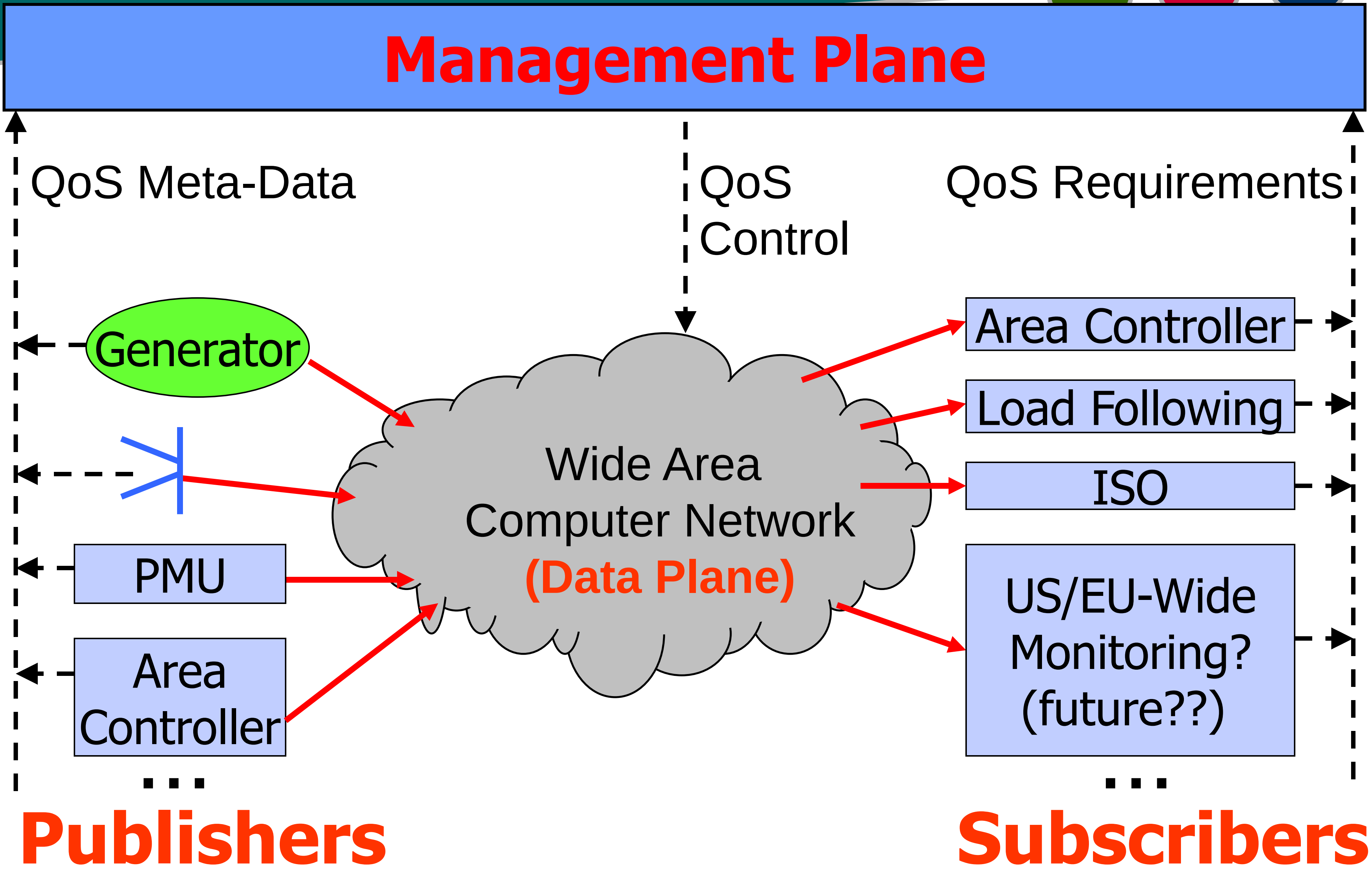
Proposed Communications



Each Application – Different Data

- Monitoring at the control center
  - Needs all data points
  - But at slow rates (every few seconds)
- Special Protection Schemes
  - Needs few data points
  - But at fast rates (many times a second)
- Each application must access this data in a different way
  - Moving real time data from source to application is a complex optimization task

Basic GridStat Functionality



Data Base Issues

- Real time data base must be distributed
  - Large amounts of calculated data must be part of this data base
- Static data base must be distributed
- Historical data base will require still another design
- Substation data bases and system level data bases have to be coordinated
- All data bases in the same interconnection will have to be coordinated
- Standards will be key

What is Wide-Area Monitoring, Protection and Control?

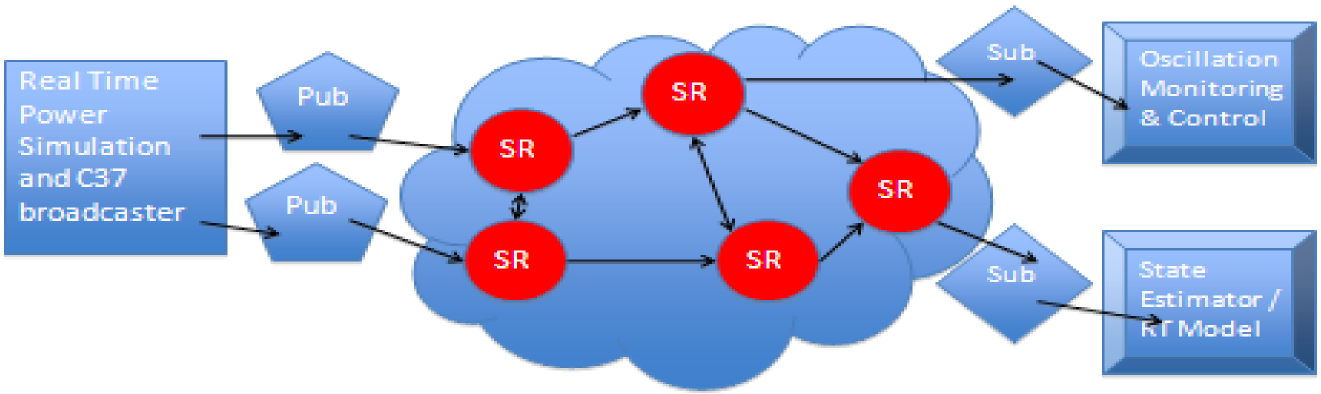
- Wide-Area Monitoring Systems (WAMS)
  - First installation of PMUs was called WAMS
- Wide-Area Protection
  - Event driven
  - Logic processing of non-local inputs/outputs
  - Switching
  - Now called SPS or SIPS
- Wide-Area Control
  - Multiple non-local input/output
  - Analog input/output

How do we check feasibility?

- Develop controller
- Test on simulation
  - Nonlinearities
  - Discontinuities (digital control)
  - Time delays (latencies)
- Test on real time data
- Test in real time (without closing the loop)

A Critical Missing Piece

Simulation Test Bed for PMU Control Applications



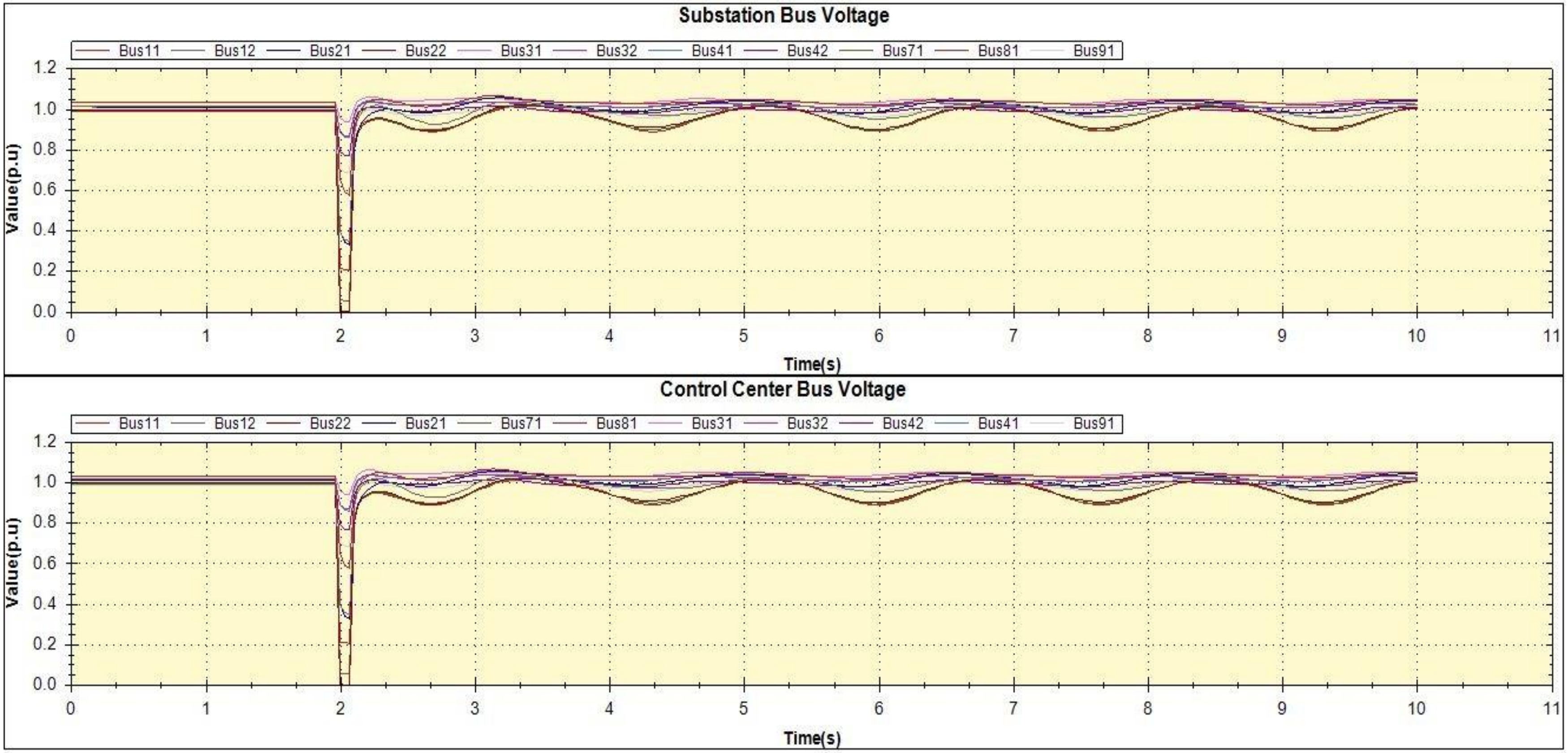
State Estimator and PMUs

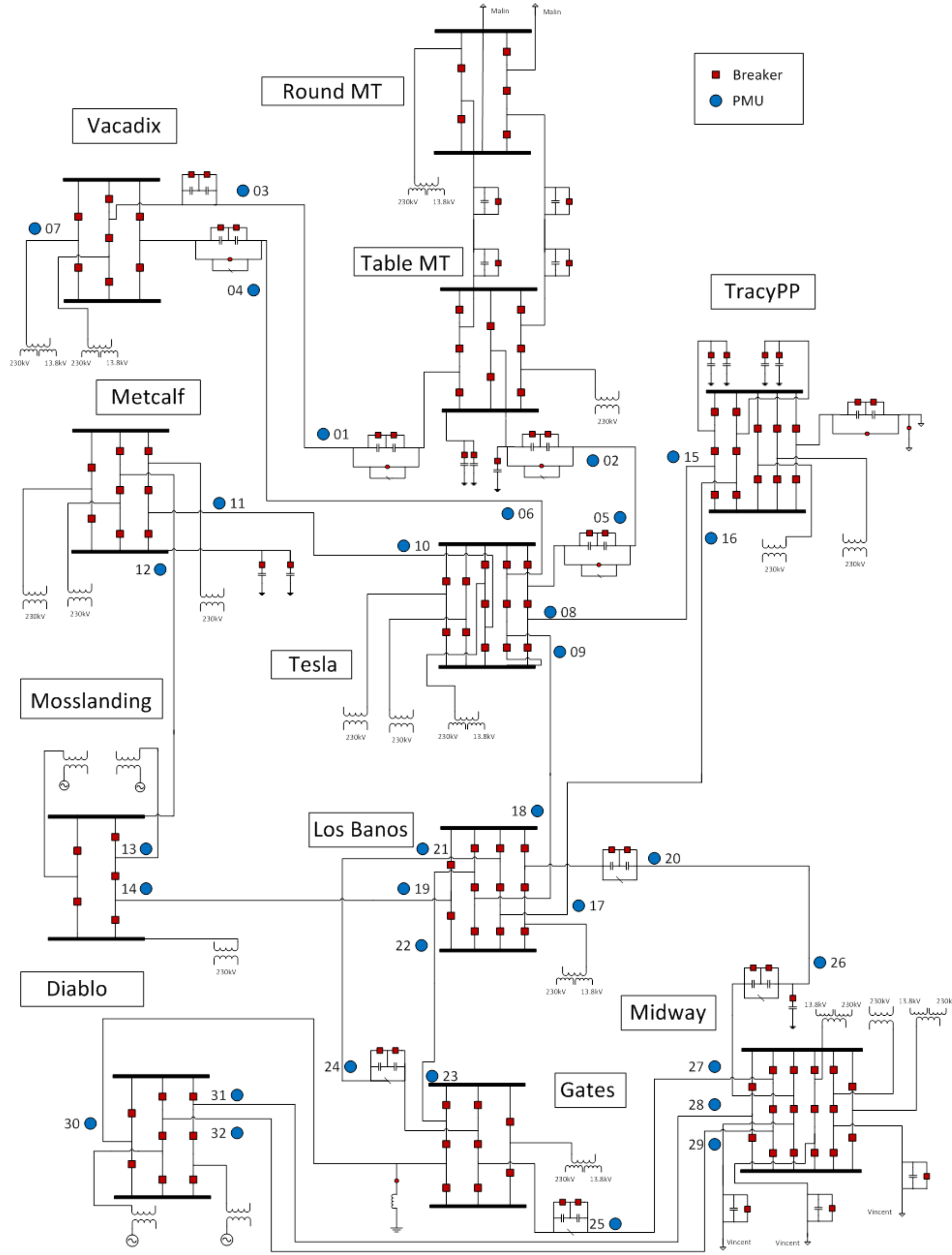
- Present
  - PMU measurements added to traditional SE
  - Marginal improvement in accuracy
  - No improvement in update frequency
- Future
  - PMU-only SE (observability required)
  - Linear, sub-second updates, higher accuracy
  - Substation level/Area level

Two-Level Linear State Estimator

- Substation Level
  - Substation Model
  - Circuit Breaker State Estimator
  - Bus Voltage State Estimator
  - Bad Data Detection & Identification
- Control Center Level
  - System Model
  - Topology Processor (system level)
  - State Estimator
  - Bad Data Detection & Identification

SE Solution at Each Substation SE Solution at Control Center 30 times per second




Breaker
PMU
Round MT
Vacadix
Table MT
TracyPP
Metcalf
Tesla
Mosslanding
Los Banos
Diablo
Midway
Gates
Malin
Malin
230kV
13.8kV
Vincent
Vincent
Vincent
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Model Based Control

- Real Time Model is updated by State Estimator
  - Static model updated in minutes
- Hundreds of Contingency scenarios studied
  - Operator is alerted
- Remedial Action can be calculated by OPF

Can the loop be closed?

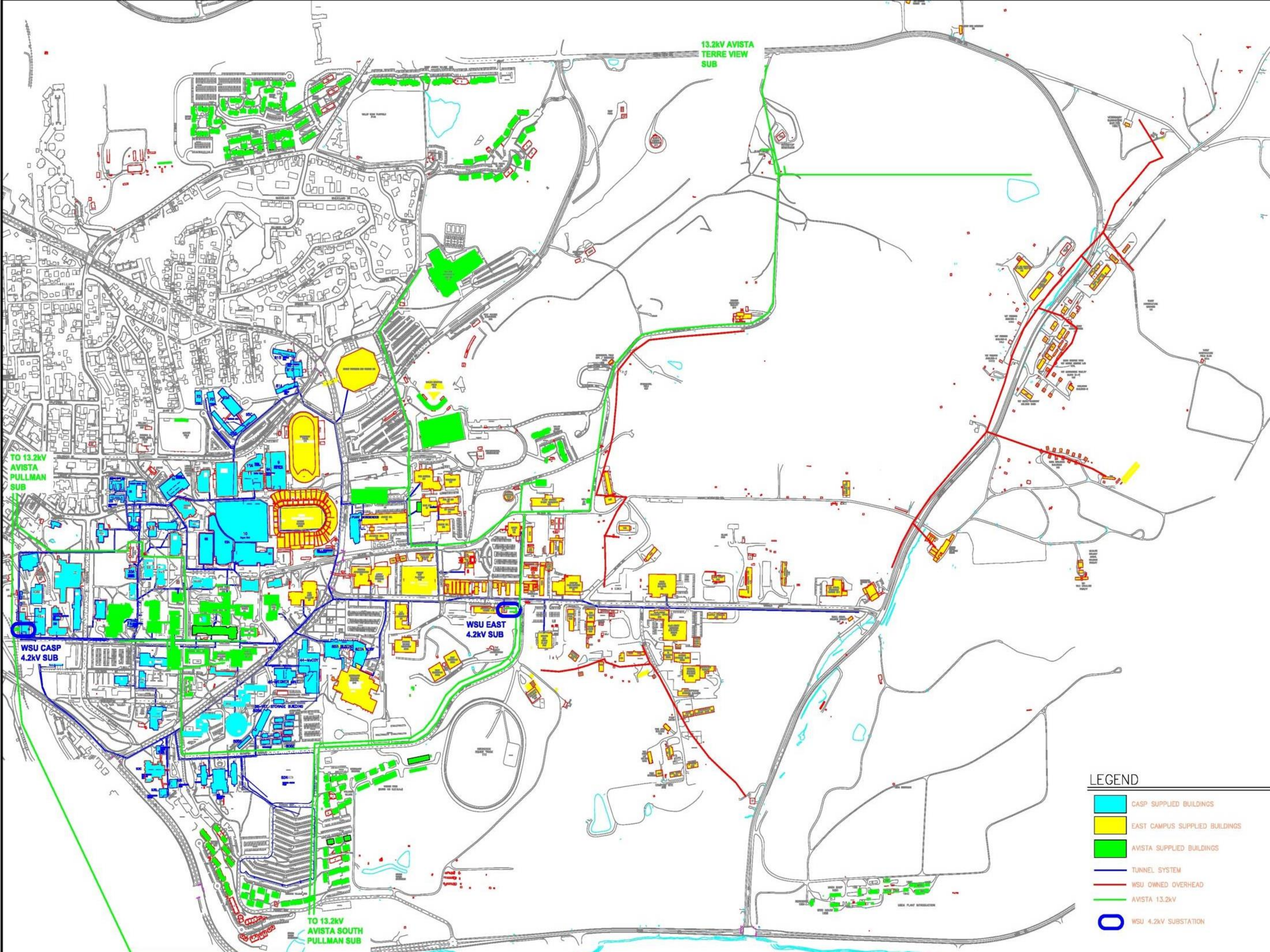
- Faster update of Real Time Model is needed

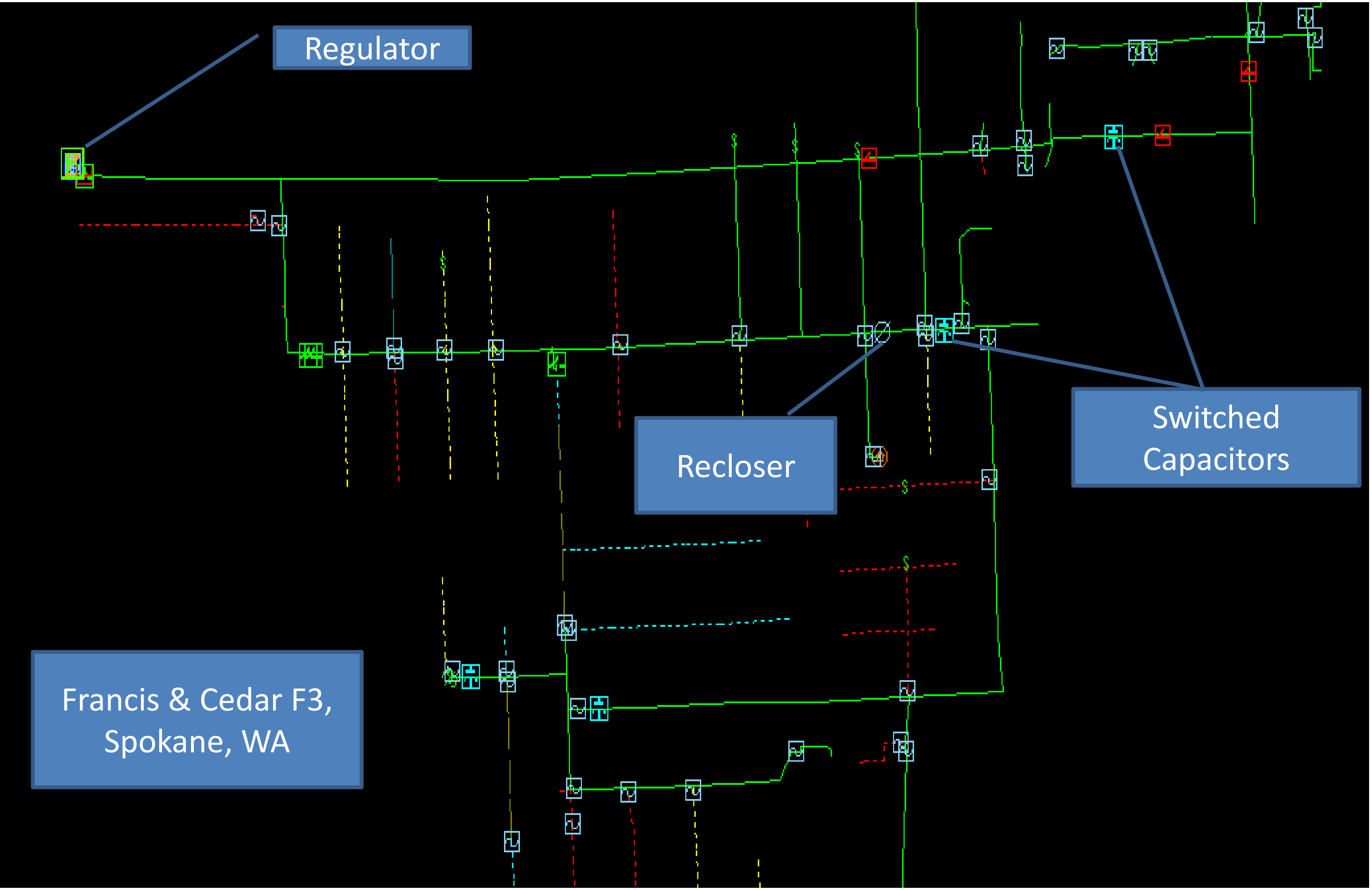
Closing the Loop

- SE can update faster than SCADA data today
- Use SE output for monitoring
  - Operator visualization
  - Alarming
- Calculate Preventive Control and close loop
- Calculate Corrective control
  - Is it fast enough to close loop?

DISTRIBUTION AUTOMATION

- **Measurements along the feeder**
- **Switches, transformer taps, shunt capacitor and inductor controls**
- **Communications: Radio, Power Line Carrier, Fiber backhaul**
- **Closer voltage control increases efficiency**
- **Greater switching ability increases reliability**
- **Better coordination with outage management**
- **Sets up for distributed generation, demand response, electric vehicles or local storage**


13.2kV AVISTA TERRE VIEW SUB
TO 13.2kV AVISTA PULLMAN SUB
WSU CASP 4.2kV SUB
WSU EAST 4.2kV SUB
TO 13.2kV AVISTA SOUTH PULLMAN SUB
LEGEND
CASP SUPPLIED BUILDINGS
EAST CAMPUS SUPPLIED BUILDINGS
AVISTA SUPPLIED BUILDINGS
TUNNEL SYSTEM
WSU OWNED OVERHEAD
AVISTA 13.2kV
WSU 4.2kV SUBSTATION


Regulator
Recloser
Switched Capacitors
Francis & Cedar F3, Spokane, WA

Backward Algorithm

1. **Enter ON-Case Data**
   - ZIP Parameters
   - Tap Settings
   - Capacitors Status
   - Demands (P & Q or KVA and P.F.)
2. **Check Switch Capacitors Status**
   - If it is ON then extract its value from Q and calculate new demands (KVA and P.F.)
3. **Do Loop**
   1. **Run Load Allocation**
      - Using ZIP parameter for each section
   2. **Find New Tap Settings**
      - Using EOL setting algorithm in SynerGEE for Voltage Regulator
   3. **Run Load Flow**
      - Get OFF-Case estimation as results
   4. **Check if change in voltages and demands are within acceptable range**
      - If YES
        - Finish loop
      - If NO
        - Do loop using new demands and voltages
4. **Find KVA, KW, and KVar Saving**
   - Compare with ON-Case

Building Automation

- Smart Meters
  - Gateway between utility and customer
  - Communication to utility and home appliances
  - Time-of-day and real-time rates
- Applications
  - Optimize energy efficiency and energy cost
  - Demand response
  - Can integrate generation (roof PV), storage (EV)
- Microgrids

Conclusions

- **Controls at the substation level get more sophisticated every day**
- **Real time data collection increases at the subs**
- **Utilizing these measurements and controls at the system level remains difficult**
- **The communication infrastructure to move this data has to be built**
- **The software infrastructure to handle the data has to be built**
- **Application development and testing environments are needed**