

Phasor Measurements for Blackout Prevention

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NASPI Meeting
Huntington Beach, CA
February 20-21, 2013



Monitoring the Power Grid (SCADA)

- **Visualization**
 - **Tables**
 - **System and substation displays**
 - **Trending, bar charts, etc.**
 - **Abnormal/anomalous analogs and status**
- **Alarms**
 - **Overloaded lines, out-of-limit voltages**
 - **Loss of equipment (lines, generators, comm)**
 - **All substation action produces alarms**
 - **Event not always clear**



Monitoring with Analysis (EMS)

- **State estimator**
- **Contingency analysis**
 - **Static analysis (n-1 outages)**
 - **Dynamic analysis (transient, oscillatory, voltage)**
- **Corrective or preventive operator actions**
 - **Pre-determined list of operator actions**
 - **Action tested on on-line power flow**
 - **Action determined by OPF**



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



Average Data Flows Today

- **Average Reliability Coordinator has 10 Balancing Authorities (control centers)**
- **Average Control Center has 100 high voltage substations**
- **Average substation has 100 measurement points**
- **Average polling rate for real time data is 5 seconds**

So

- **Average data rate from each substation is 20/sec**
- **Average data rate to a control center is 2K/sec**
- **Average data rate to a RC is 20K/sec**



Data Collection by PMUs

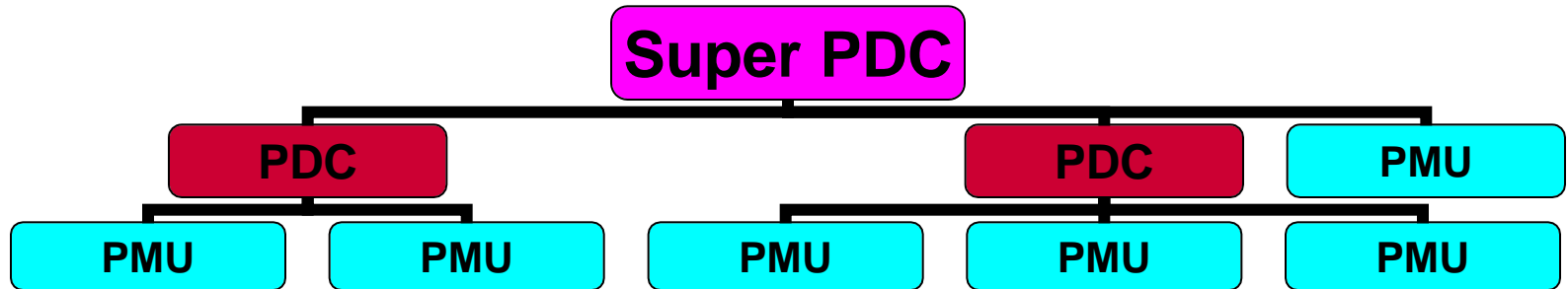
- PMU sampling rates: 30-120 per second
- Assume 100 values per second

If we assume all 100 points in a sub are PMUs

- Average data rate per sub is 10K/sec
- Average data rate for the total of 100 subs in a BA is 1M/sec
- Average data rate for the RC is then 10M/sec

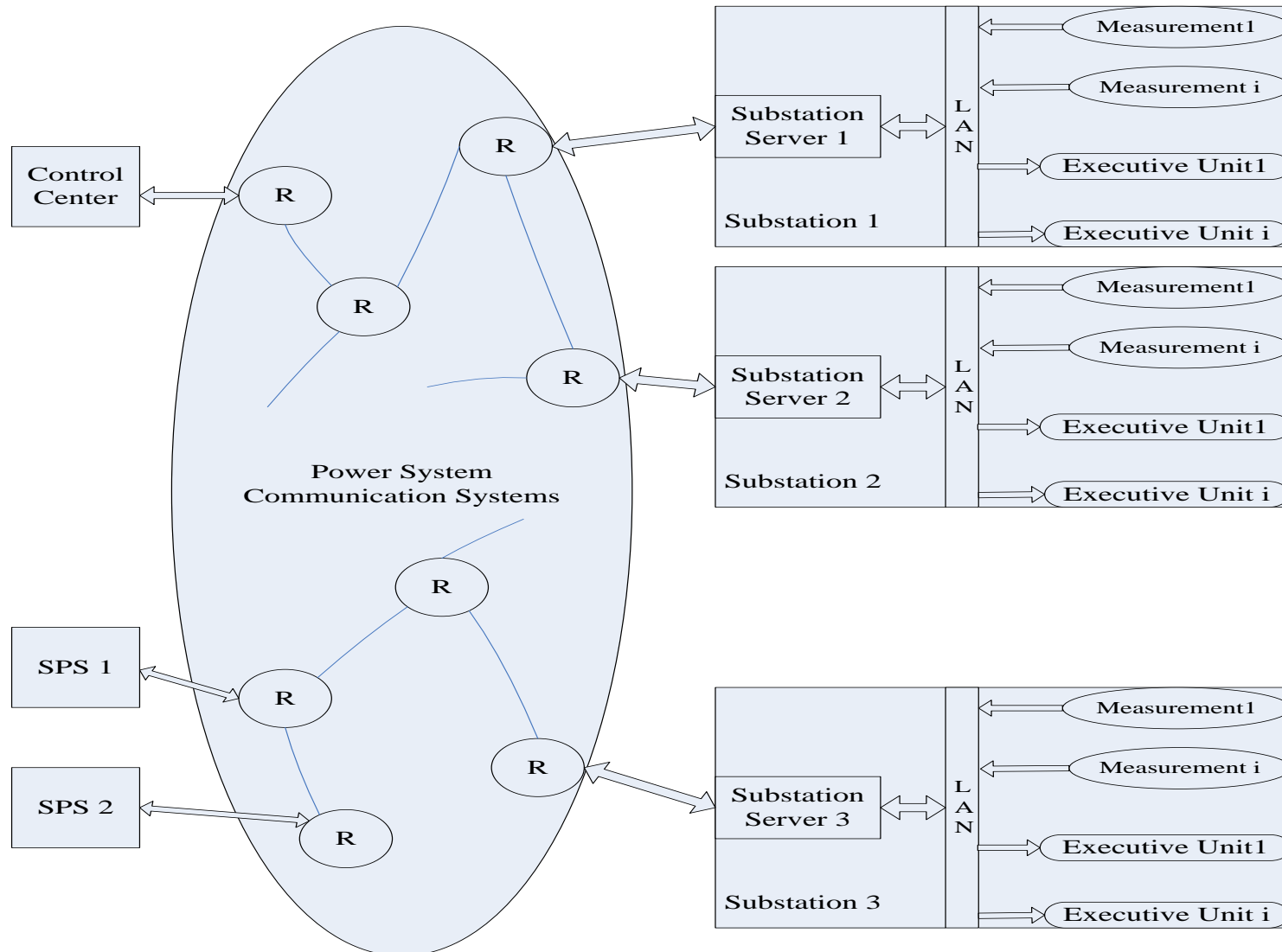


Phasor Measurements





Proposed Communications





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



Wide-Area Monitoring with PMUs

Issues

- **Scaling up – number of PMUs**
- **Visualization for the operator**
 - **How to display angle differences**
 - **How to display fast changes**
- **Do PMUs provide better alarming?**
 - **During disturbances managing alarms will be even more complex**

Best use has been post-event analysis

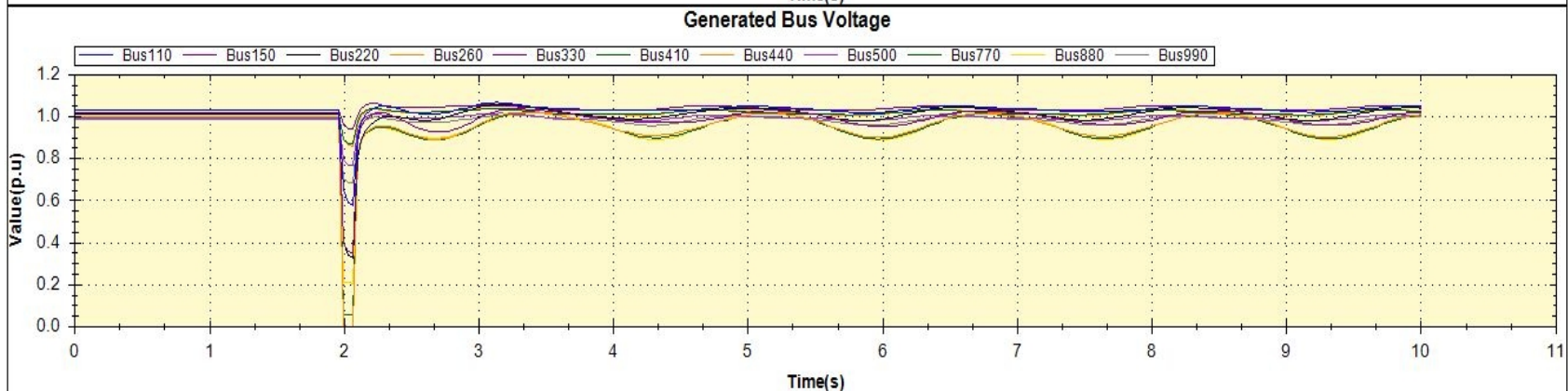
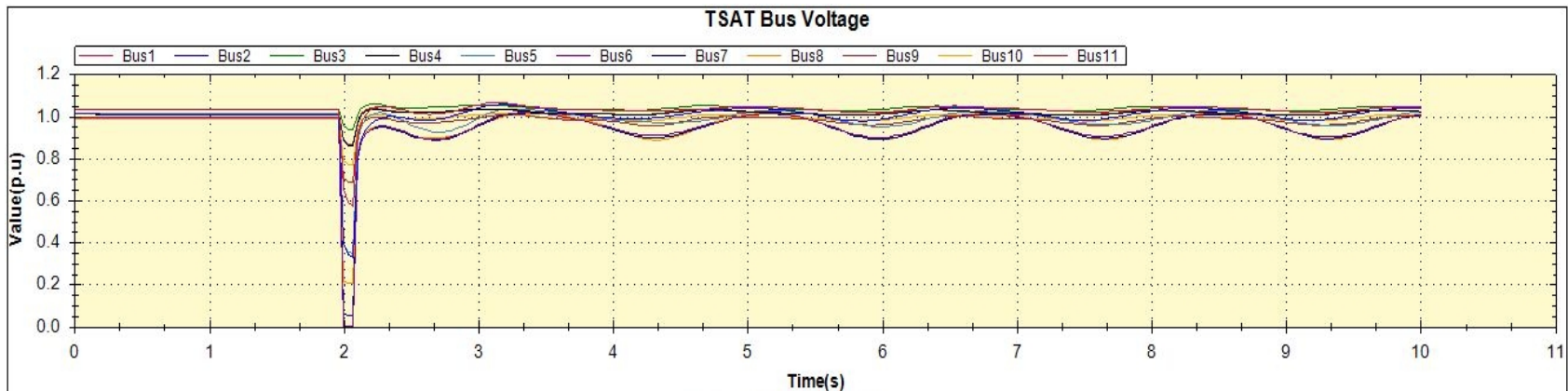


Monitoring with PMU Data Analysis

- **Oscillation Monitoring has been a great success**
- **Transient Instability?**
 - **How quick to be useful?**
- **Voltage Collapse?**
 - **Distance from nose tip**
- **Event Analysis**
- **State Estimation**
 - **Static or Dynamic**



Simulated Bus Voltages by Powertech TSAT Generated PMU Measurements 33 msec time steps

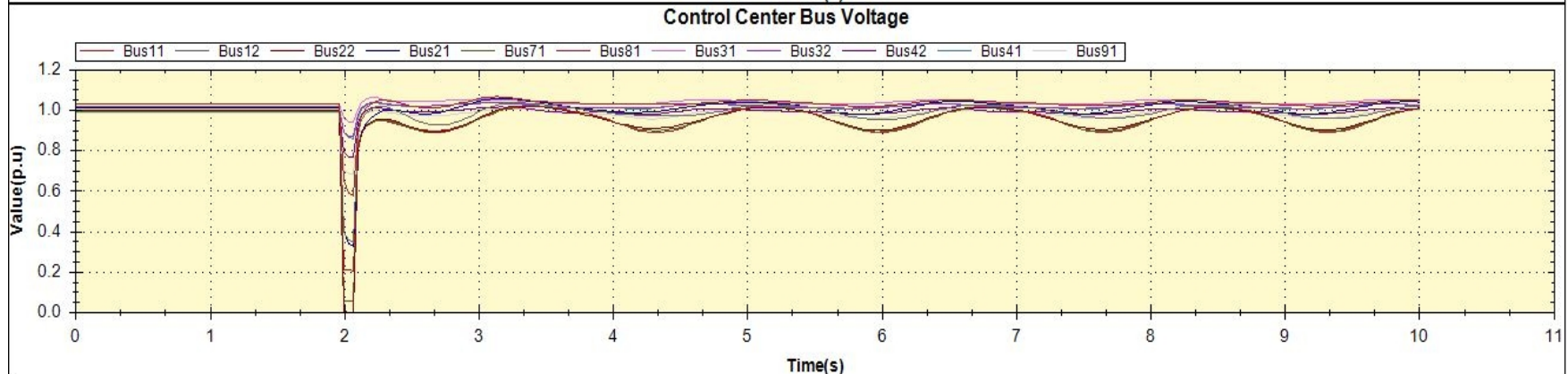
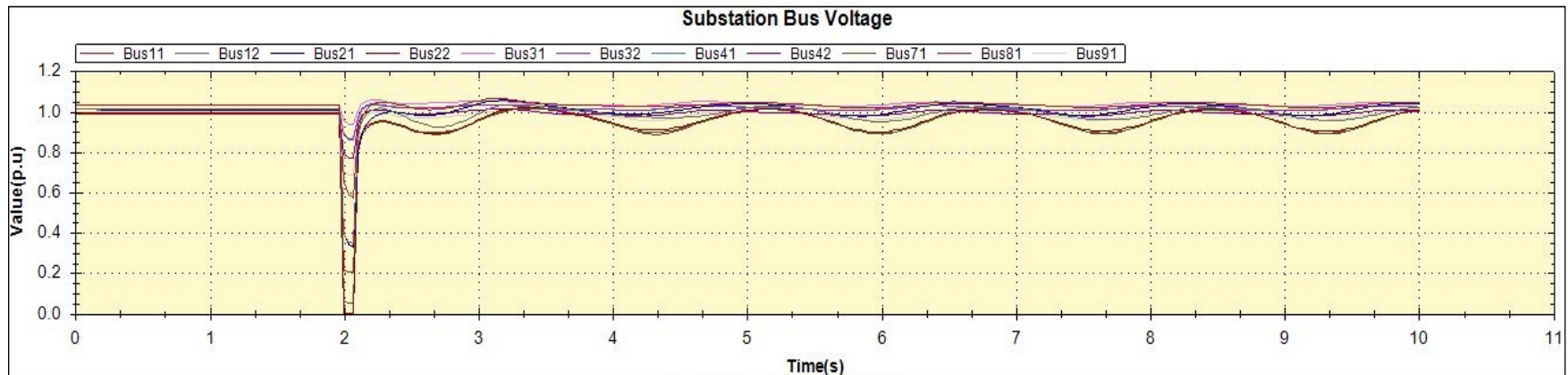




SE Solution at Each Substation

SE Solution at Control Center

30 times per second





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**



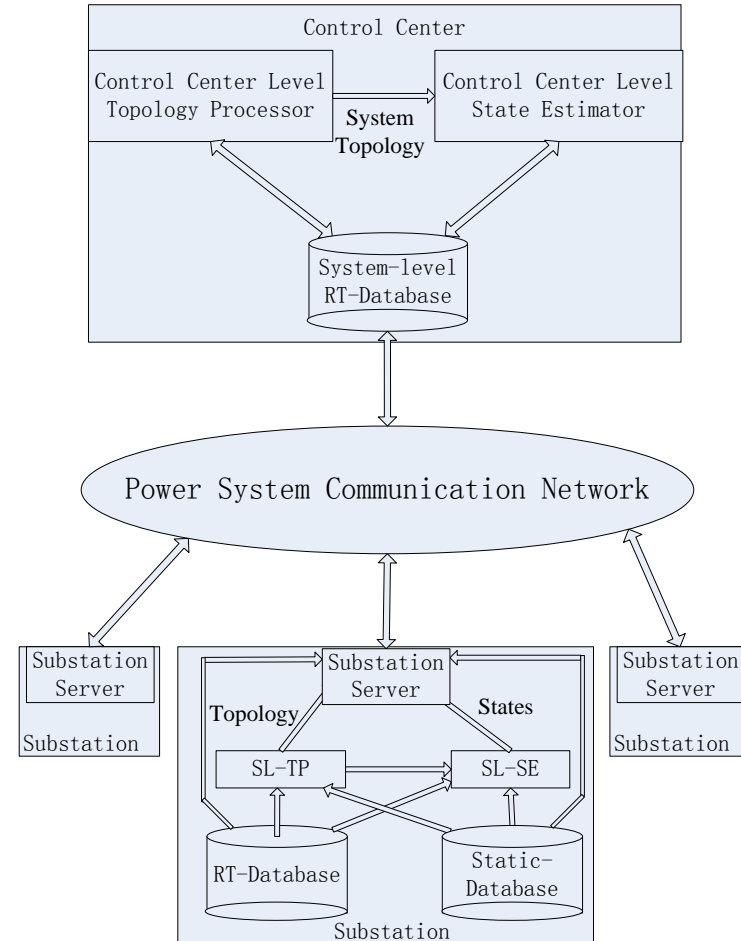
Two-Level Linear State Estimator

- **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**



Two level State Estimator

- Substation Topology and Bad Data Detection at Sub
- Filtered data to Control Center
- System Topology and Estimation at Control Center EMS



SL-TP: Substation Level Topology Processor

SL-SE: Substation Level State Estimator

RT: Real Time



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 Control?

- **Wide area implies 'not local' i.e. input-output signals not confined to one substation**
- **Control implies a controller that uses measurements as input signals to compute output signals for control equipment**
- **Input signals: frequency, currents, voltages, phase angles, watts, vars, switch status, etc.**
- **Output signals: generator output, transformer taps, HVDC, SVC, UPFC, switch status**



Wide Area Controls

- **Slow controls - AGC, regional voltage**
- **Fast controls – SPS (digital), FACTS (analog)**
 - **Event triggered**
 - **One-of-a-kind, expensive**

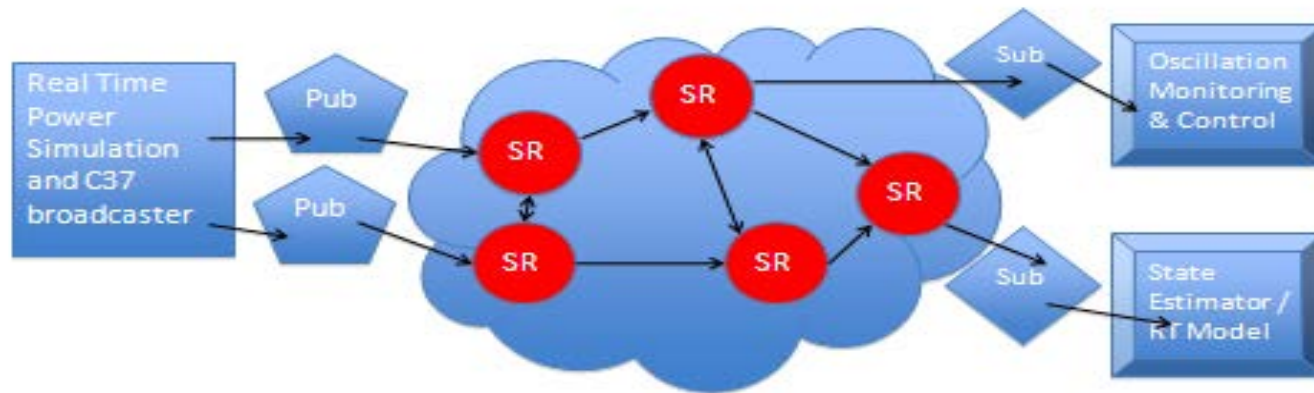
PMU based control

- **Can be triggered by event or analog value**
- **Design requires better tools**
- **Implementation requires communication system**



A Critical Missing Piece

Simulation Test Bed for PMU Control Applications





Model Based Control

Old Idea

- Real Time Model (SE) updated 60sec
- Hundreds of Contingency scenarios studied
- Remedial Action calculated by OPF

New Idea

- Real Time Model (SE) updated 30msec
- Run/update control action
- Send control signal