Evolution of Control for the Power Grid

Anjan Bose
Washington State University
Pullman, WA, USA

PaiFest
In Honor of Prof. M. A. Pai
Urbana-Champaign, IL
October 15, 2015
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

- Analog measurements
- Digital states

Third Party

Control Center

RTU

RTU

RTU
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
Real Time Network Analysis Sequence
West European Power Grid
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
Operator Control of the Power Grid

• Change topology:
  ▪ Open/close Circuit Breakers

• Change control set points:
  ▪ Generation
  ▪ Voltage
  ▪ DC Line Power Flow
  ▪ AC Line Power Flow
Transmission Line Power Flow Control

Traditional

• Phase Shifting Transformer
  ▪ Controls taps to meet power flow setpoint

• Series Capacitors
  ▪ No control setpoint

FACTS

• Unified Power Flow Controller
  ▪ Large and expensive

• Smart Wires Router
  ▪ Modular and finer control
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
Phase I – MMI Upgraded to Workstations

RTU Channels

Dual Ethernets

Original Equipment
Upgrade Equipment

SCADA FEP
HOST
Gateway
Workstations
Phase II – Addition of new EMS Functions
Phase III – Completed Migration to Open EMS Architecture
EMS Database

• Real-Time Database
  ▪ SCADA measurements
  ▪ Exchanged data
  ▪ Calculated data

• Static Database
  ▪ Connectivity of the grid
  ▪ Limits
  ▪ Model parameters
  ▪ External model parameters

• Historical Database
Data Reliability

• Data Communications
  ▪ Dual (redundant) channels

• Database Backup
  ▪ Checkpoint
  ▪ Bumpless Failover

• Backup Control Center
  ▪ Hot Standby or Shared Responsibility
  ▪ Changing Responsibility

Is this design vulnerable to cyber attacks?
Model Maintenance

Static Database Updating

• Internal Model
  ▪ Rigorous procedure

• External Model
  ▪ Exchange models in timely manner
  ▪ Requires data standard (CIM?)
  ▪ Requires standard synchronized procedure across interconnection
Real Time Data Exchange

• SCADA data from neighbors
  ▪ All or selected?
  ▪ How often?

• For what applications?
  ▪ Operator visibility
    • Match with external model displays
    • External outage data should be quick
  ▪ State Estimation
    • Match with external model
    • Update data before each SE run
Data Exchange Vertically

Between EMS and DMS

• From DMS
  ▪ Generation on distribution feeders
  ▪ Dynamic load availability
  ▪ Aggregated or individual measurements?

• From EMS
  ▪ Control signals for load response
  ▪ Control signals for distributed generation

How about the customer side (microgrids)?
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 Measurements
PMU Applications

• Event Analysis
  ▪ Historical PMU data have had the largest use in after-the-fact event analysis (largely off-line)

• Oscillation Detection and mitigation
  ▪ Detecting of suspect modes and determining damping has been implemented
  ▪ Operator mitigation has been implemented but automatic correction is not

• Linear State Estimator
  ▪ Several pilot projects have been in progress showing feasibility
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
Pic of one feeder with the new equipment:

- Switched Capacitors
- Regulator
- Recloser

Francis & Cedar F3, Spokane, WA
DMS Applications

• Reconfiguration of feeder
  ▪ This is largely used to isolate a faulted section by remote control of switches
  ▪ Some implementations are doing this automatically

• Volt-VAr Control
  ▪ Conservation voltage reduction (CVR) lowers the voltage to save energy
  ▪ Optimal voltage profile is used to lower the losses
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