Cyber Infrastructure for the Power Grid

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Data Management and Computing (Computation”)

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Administrivia

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  - Email: bakken@wsu.edu, Office: EME 55, Office hours: right after I lecture, or by email appointment.

- Any comments or questions so far I can answer?

- Meet someone across the EE-CS chasm!

- A little background on me

Schedule for This Segment

• **2/26**: #1--Utility IT infrastructures; control center structure & software;

• **2/24-3/3** Take Home midterm exam

• **3/3**: #2--CIMs, IEC 61850 and 61970

• **3/5**: #3--Distributed computing #1: basics (CDKB5 chap 1)
  • **3/10** #4: Distributed computing #2 (CDKB5 chap 2.1+2.3)
  • **3/12** #5: Overview of Fault-Tolerant Computing (CDKB5 2.4)
• Then Assignment #3 given out
• (Prof. Hahn starts on security on 3/24 and 3/26)

• **3/31**: #6--WAMS data delivery requirements and mechanisms, including NASPInet and GridStat
Caveats on the big picture

• On our generalized architectural descriptions:
  ▪ “All generalizations are false, including this one.”
    Pascal
  ▪ Result: NERC functional model

• Power industry moves very, very slowly…… esp. on information and communication technologies (ICT)
  ▪ Use of advanced ICT in the power grid is way behind that in other industries
    – E.g., middleware “best practices” in other industries for 15-20 years, barely used in the electricity sector
  ▪ “Utilities are trying hard to be first to be second”
    – Jeff Dagle (WSU MSEE), Chief Electrical Engineer, PNNL
  ▪ “Utilities are quite willing to use the latest technology, so long as every other utility has used it for 30 years”
    unknown
Reading for Computation Segment


Notes: #1-2,5-7 are in Blackboard: Assignments/Reading; #6-7 optional but may be useful and/or interesting.
Today’s Content

- Quick review of earlier big picture & Intro (I)
- Control Center Evolution (II)
- Conventional Control Centers (III)
- Changing Environment (IV)
- Modern Distributed Control Centers (VI)
- Future Control Centers (VIII)

Notes

- Much overviewed in first segment (Prof. Srivistava), going fairly fast for context
- Skipping cause in rest of this segment and others:
  - Enabling [ICT] Technologies (V)
  - Emerging [ICT] Technologies (VII)
Power System Structure

- Basics
- Generation & transmission
- Substations & transformers
- Control centers

Credit: Jim McCally, Iowa State

http://tcip.mste.illinois.edu/
control centers
Introduction (I)

• Impetus to have control centers came from big 1965 blackout in northeastern US

• Energy Management System (EMS) resulted
  ▪ Fairly crude ICT by 1980s standards
  ▪ Core largely obsolete by 2000 ICT standards

• Likely future: cloud-based infrastructure (“grid services” in paper)
  ▪ Very fast and reliable data acquisition
  ▪ Many more apps, with intelligence pushed in or towards substations
  ▪ Much more sharing of data between apps and between utilities and others (?DHS)
Control Center Evolution (II)

• 1950s: analog communications deliver “anlogs” to analog computers
  ▪ Load frequency control (LFC) and economic dispatch (ED)
    – Unit commitment (UC): schedules start/top for generators

• 1960s: SCADA and RTUs slowly begin to be used

• 1965 blackout recommendation: use digital computers more extensively and effectively for RT

• 1970s: power system “security”/reliability: ability of system to withstand disturbances/contingencies.
  ▪ Custom computers → general purpose computers running EMS
  ▪ SCADA installed in substations and distribution feeders → distribution management systems (DMS)
  ▪ SCED: security-constrained economic dispatch
Control Center Evolution (cont.)

- Host of supporting functions in grid to ensure reliability
  - Real power reserves
  - Ancillary services: additional capabilities (often inter-utility) to help ensure reliability (e.g., load following)
Control Center Evolution (cont.)

• Deregulation (of generation): mid-90s
  ▪ Old: vertically-integrated utility with all 3 fundamental roles in its territory
  ▪ New
    – Competition for generation
    – LSE: **load serving entity**
    – ISO/RTO to run transmission markets for LSEs
    – CC expanded from reliability-based EMS to also include economic/business functionality
    – Two-level structure of CCs in market…

• Two types of markets (complex, balance in RT!):
  ▪ **Bilateral contracts** between suppliers and consumers
  ▪ **Auction market**: generators submit bids
  ▪ Also markets for day-ahead, real-time balancing (5min), and ancillary services
Control Centers (CC) in the Market Environment

- **BMS**: business management systems
- **ISO/RTO operates market**
  - **MOS**: market operations system
- **Market participants**: Gencos, Trancos, LSEs, ISO/RTO, etc
EMS and BMS Interactions

- **SCUC**: security-constrained unit commit ~ 5min
- **SCED**: security-constrained economic dispatch
Conventional Control Centers (III)

• Looking from two angles: functions and architecture
• Functionality provided by power system application programs ("apps")

• Two main kinds of functions:
  ▪ Extensions of the first EMSs: reliability
    – Data acquisition
    – Generation control: NERC role balancing authority (BA)
    – Network (security) analysis and control: NERC role reliability authority
      • State estimation
      • Contingency analysis / security analysis
  ▪ BMSs for market operations: economics
    – (skipping details .... BMSs are not the focus of this overview)
Control Center Functions

Note: ERP and Data Warehouse discussed later
Control Center Architecture

• SCADA designed for vertically-integrated utilities and very little useful data in substations
  ▪ Star topology feeding into one computer: inflexible
• Today: substation automation adds many IEDs that could be quite useful
• Lots of data starting to be used by many different applications (historically in proprietary formats)
  ▪ Different subsets used by different apps
  ▪ Multiple copies have to be coordinated, synchronized, merged into DBs
  ▪ CIMs to the rescue (next lecture)
Conventional Control Center Architecture

- Substations have LANs connecting IEDs to RTU
  - Formerly: wires!
  - 61850 ....
- RTU P2P network link to front end (FE) to CC LAN
- SCADA developed when utilities vertically integrated monopolies; structure same
Changing Environment (IV)

• Very dynamic situation
  ▪ Vertically-oriented utility to deregulation
  ▪ Divestitures, mergers, acquisitions
  ▪ Control centers with non-contiguous territories
  ▪ New participants coming, some disappear
  ▪ ➔ “all generalizations are false”
  ▪ But now all control centers have to cope with changing business architecture (ouch!) above, below, and with peers

• Coarsely-integrated EMS, SCADA, DA, … morphs towards a coherent enterprise architecture

➔ Need flexibility in many dimensions and at many levels of the EA’s components…. modularity …. scalability, … expandability.
Changing Environment (cont.)

• Control center’s sensor and derived data contain (literally) a wealth of information
  ▪ Key issue: how to cleanly integrate (again, CIMs help here)

• Part of soln: sophisticated SW from other domains

• ERP: enterprise resource planning
  ▪ AKA enterprise resource management (ERM)
  ▪ Manages all aspects of business: production planning, material purchasing, maintaining inventories, supplier interactions, payroll, customer service, etc.

• Data warehouse: carefully integrated (and scalable) collection of utility’s data
  ▪ Bundled with statistical tools, e.g. SAS
  ▪ Can repackage easily for other subsets, applications, etc
Integration Needs of Control Centers

- CCs have to integrate in new ways
  - Vertically (both above and below)
  - Horizontally (new!)
- E.g., NASPI (North American Synchrophasor Initiative) and similar emerging
Modern Distributed Control Centers (VI)

- **Distributed Computing System**: system where apps and services are spread out over multiple computers that communicate only via message passing
  - I.e., no shared memory
  - A centralized EMS and BMS suite in one room matches (oops)

- Better definition/term: decentralized
  - E.g., distributed control logic pushed out of substation
  - E.g., RAS/SPS/SIPS not in CC or otherwise centralized

- Current trends in distributed control systems
  - Separation of “SCADA” (data acquisition), EMS, and BMS
  - IP-based distributed SCADA (DNP3)
  - Standard (CIM)-based distributed data processing
  - Middleware-based distributed EMS and BMS apps
Distributed Data Acquisition

- Data acquisition not tightly coupled with EMS
  - Now: IP/DNP3 “SCADA”
  - Soon: NASPInet/GridStat
Future Control Centers (VIII)

• Data acquisition: much higher amount & range of
  ▪ Rate of collection
    – DFRs: 720+ Hz
    – F/Net: 1440 Hz
    – Some home sensor apps ~5K Hz; broader uses?
  ▪ Latency required
  ▪ Criticality of application
  ▪ Quantity of data Geographic distance shared over
  ▪ Degree of sharing (#subscribers) per sensor

→ Far from “one size fits all” data acquisition and delivery!
Future Control Centers (cont.)

• Security monitoring and control (SE, contingency analysis, etc) based on steady-state models
  ▪ Reason: inadequate data acquisition (mainly) and computational power in CCs
  ▪ Result: only preventative control
  ▪ Possible: analytical tool for emergency control by system operators (or DHS/NERC?) ....
Future Control Centers (cont.)

- This (and much more) possible by
  - Cleanly decomposed and packaged application logic
  - Separate management of data acquisition, managing computational resources, information security, etc.
    - Cloud computing ("grid services" in paper)
    - ARPA-E project GridCloud with Cornell and WSU
  - Let the power folks and ICT folks both do what they are good at!
    - This clean separation enables new technology (both apps and ICT) to develop much faster!
    - It worked for the internet!
      * Though it now needs QoS at the waist
The Brave New World

• Cloud computing (**IF made mission critical!**) enables
  - Greatly expanded applications (and app providers)
  - Federations of enterprise grids, ancillary services, ...
  - Dynamic sharing of computational resources of all IEDS
  - Distributed services for data acquisition and data processing (aggregation, error collection, etc)
  - Distributed control center apps expressed in terms of layers and services (~SOA)
  - Use of standard cloud computing architectures and tools to manage ICT resources

“I don’t think we’re in Kansas anymore, Toto!”

Opportunities abound for a lot of fun and impact for newly-minted EE and CS grads working in this field!