SCADA and Central Applications
An introduction

Course map
Outline of the lecture

• Power System Operation
  - Centralised Control Applications

• SCADA
  - SCADA architecture & Components
  - SCADA system functions
  - Non functional aspects

• Wide Area Monitoring and Control Systems
  - Architecture & Components
  - Functionality

Power System Operation

• System-wide monitoring, planning & optimisation for reliable and cost efficient operation of the power system
• Time scale: seconds to hours.
Deregulation – in theory

Wholesale level - Transmission

GenCo → GenCo → GenCo → GenCo

Retail level - Distribution

Customer → Customer → Customer → Customer

Deregulation – in practice

Area 1

Area 2

Area 3

Area 4

Area 5
Coordination between actors

Example – root event

1. Step-up transformer insulation fault
2. Fault is detected by protection system
3. Trip signal sent to breaker to disconnect generator
TSO - Frequency Control

1. Frequency dip detected at generators committed to Load Frequency Control leads to automatic increase of output
2. Continuous under-frequency measured are sent to SCADA system using IEC 60870-5-101
3. Control room operator activates secondary reserve by issuing order to GenCo via phone.
4. GenCo orders production increase in secondary reserve.
5. Order for production increase sent to plant from GenCo CC.
6. New measurements sent to neighbouring Grid Utility using ICCP.

TSO- Repair & Maintenance

1. Fault in transformer sent from SCADA system to work management system using e.g. IEC 61968-4
2. Repair crew sent to site from work dispatch
3. At site, work crew reports to control centre to initiate safe switching sequences
4. Station set to manual control, fault repaired (!) or report initiated for major overhaul.
5. After completed assignment, info on failure stored in maintenance database.
Central control & coordination

- On the deregulated Power market, all actors
  - Distribution Network Operators
  - Transmission Network Operators
  - Generating companies

- All need some central platform to manage their process

- Enter – the SCADA system

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Power System Control Center Functionality

- Three groups of functions on SCADA
  - Business Management
  - Energy Management
  - Generation management

What is SCADA?

Supervisory Control And Data Acquisition
- Collect measurements and status data from the process
- Remotely intervene in the process
- Centralized system platform
- Based on distributed I/O

Applicable Processes
- Oil or Gas production facilities
- Pipelines for gas, oils, chemicals or water.
- Railway/Transportation Process
- Nuclear, Gas, Hyrdo generation plants
The typical control room

What is controlled by SCADA

- Tap changers
- Switching devices
- Shunt capacitor/reactor
- Generator setpoints
  - Excitation & power output
- Sequential control
SCADA architecture


SCADA Components
Human Machine Interface - HMI

- Communication between operator and machine
- Input
  - Mouse, keyboard, touch screen
- Output
  - Screen, audio, print-outs or mimic board
- A weak link
  - Information overload/misinterpretation
SCADA components

Application Servers

- Application servers provide the computing platform for the SCADA System, included servers are:
  - Real-time database
  - Historical database
  - Energy Management applications
    - State Estimation
    - Optimal/Dispatcher Powerflow
    - Voltage Stability Assessment
    - Etc....
  - Geographic Information Systems
    - Distribution Management

SCADA Components

System Configuration Servers

- Allows configuration of the SCADA system environment, typical servers include:
  - Data engineering of the SCADA system providing manual data entry into the SCADA topology database including lines, circuitbreakers, stations, ..... 
  - Substation Device configuration, such as IED configuration tools and databases of IED configuration. Remote access tools for configuration
Data Engineering

**ENGINEERING ENVIRONMENT**
- DE 400
- Data Entry
- Graphical Editor
- Forms
- Import
- Customer’s Data Source
- Oracle MDB
- Data Loading
- Picture generator
- Avanti PDB
- Present
- Picture files

**RUN TIME ENVIRONMENT**
- Graphical Editor
- Data Loading
- Present
- Picture files
SCADA components

Communication Servers

- Variety of servers for communication
  - Communication to other Control centers using ICCP
  - Communication to office applications

SCADA components

Communication Front End

- Manages communication with the field devices
- Supports communication with variety of protocols
- Cyclic polling and event based communication, provides messages queuing
Remote Terminal Unit - RTU

- A remote terminal unit (RTU) is a microprocessors-controlled electronic device that interfaces objects in the physical world to a distributed control systems or SCADA by transmitting telemetry data to the system, and by using messages from the supervisory system to control connected objects.

Communication Topologies

- Radial serial circuit

- Multi-drop circuit

Networked solutions

Communication between Master Station (Front End) is via TCP/IP over a shared Wide Area Network


Communication Principles

- **Cyclic Polling**
  - Front-End communication server requests data periodically from each RTU.
  - Period times vary from 2-4 up to 10-15 seconds.
  - Real-time?

- **Report By Exception**
  - Cyclic polling as above
  - RTU only responds if a value has changed

- **Balanced protocols**
  - The RTU can send a request to be polled by the Front-End
Communication

- Wide Area Network
  - Analog point to point and multi-point modem networks
  - Frame relay/Cell relay type point to point and multi-point networks
  - Wireless Radio/Satellite networks
  - Fiber-optic based networks

- Protocols
  - Modbus
  - Profibus
  - IEC60870-5-101,104
  - DNP 3
  - IEC61850-90-2
  - IEC60870-6-ICCP (between control centers)

Distributed Network Protocol (DNP)

- Designed specifically for SCADA systems, i.e. a data acquisition and control communication protocol
- Predominantly a SCADA to RTU/IED or RTU/IED to RTU/IED communication
- Used in Electric automation and prominent in the North and South America, Australia
- Open Standard, not owned or control by a single private organization. All vendors have a say in the design and specification
IEC 60870-5-101/104

- International standards for open transmission of SCADA telemetry and control information
- Provides detailed functional description for telecontrol equipment and systems for controlling geographically widespread processes and specifically intended for electrical industries
- When reference to 60870-5 in the context of SCADA systems is made it is usually for 60870-5-101/104 titled "Companion Standard for basic telecontrol tasks.
- 101 protocol intended for transport of data over serial links
- 104 protocol is a TCP/IP implementation of 101.

101 & 104 message types

- 0 = not defined
- 1 = single-point information
- 2 = single-point information with time tag
- 3 = double-point information
- 4 = double-point information with time tag
- 5 = step position information
- 6 = step position information with time tag
- 7 = bits of 32 bit
- 8 = bits of 32 bit with time tag
- 9 = measured value, normalized value
- 10 = measured value, normalized value with time tag
- 11 = measured value, scaled value
- 12 = measured value, scaled value with time tag
- 13 = measured value, short floating point number
- 14 = measured value, short floating point number with time tag
- 15 = integrated total
- 16 = integrated total with time tag
- 17 = event of protection equipment with time tag
- 18 = packed start events of protection equipment with time tag
- 19 = packed output circuit information of protection equipment with time tag
- 20 = packed single-point information with status change detection
- 21 = measured value, normalized value without descriptor
- 22, 23 = reserved for further compatible definitions
- 30 = single-point information with time tag CP56TTime2a
- 31 = double-point information with time tag CP56TTime2a
- 32 = step position information with time tag CP56TTime2a
- 33 = bits of 32 bits with time tag CP56TTime2a
- 34 = measured value, normalized value with time tag CP56TTime2a
- 35 = measured value, scaled value with time tag CP56TTime2a
101 & 104 message types - control

- **CON 100**: interrogation command
- **CON 101**: counter interrogation command
- **CON 102**: read command
- **CON 103**: clock synchronization command
- **CON 104**: test command
- **CON 105**: reset process command
- **CON 106**: delay acquisition command

IEC 60870-6

- Inter Control-center Protocol (ICCP) or TASE.2
- To enable data exchange between control centers of:
  - Measurements
  - Time-tagged data, measurement series
  - Events
- Some variants exist, latest version TASE.2 based on MMS most popular presently.
IEC 61850-90-2

- Using Logical Nodes and Attributes from IUEC 61850 also in the SCADA system.
- Data is carried in MMS over TCP/IP

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- Wide Area Monitoring and Control Systems
  - Architecture & Components
  - Functionality
SCADA functions

- Data acquisition
  - Analog and discrete values
- Event and alarm processing
  - Event and alarm
- Control
  - Tap changer
  - Shut capacitor/reactor
  - Switching devices
  - Generator excitation (AGC)
- Data storage, archiving and analysis

Data acquisition

- Points
  - Measured values
- Pseudo points
  - Derived values
- Scan
  - process by which data acquisition system interrogates RTU/IED
- Scanning rate
  - 1 sample/2 seconds
- Time skew
  - elapsed time between the first measurement and the final measurement is taken

Reference: North-Corte Green Control & Automation of Electric Power Distribution Systems
SCADA: Data Acquisition (Cont.)

- Measurements and Status Indications Collected are stored in a Real Time Database.
- The Values are Time tagged in the database.
- As new Values come in from the RTUs/IEDs old values are overwritten (or archived).

Monitoring and Event Processing

- Events
  - Changing positions
    - Breaker / Disconnector opens or closes
    - Value above/below a threshold
  - Equipment activated
    - Reactor or capacitor engaged
  - Automatic changes
    - On load tap changer changes state
- Alarms
  - Critical events
  - It is a matter of definition
Alarm and Event Management

- Events
  - Changing positions
    - Breaker/Disconnector opens or closes
    - Value above/below a threshold
  - Equipment activated
    - Reactor or capacitor engaged
  - Automatic changes
    - Tap changer changes its position
- Alarms
  - Criticality
  - Sensitivity
Monitoring and Event Processing (cont.)

Time stamping

- Sequence of events is often important in analysis of chains of events
- Time stamping of Events
  - As close as possible to the source. For example the IED that collected the measurement
  - Requires time synchronisation of distributed devices
  - Additional Time-stamp at Front-End
SCADA: Data Storage, Archiving and Analysis

- Data Collected from the process is sometimes archived, this due to many reasons:
  - Regulations
  - Billing
  - Future Load planning
  - Performance Audits
  - Post Mortem Review, in case of disturbances or interruptions in the process.

- Changed Values are “archived” at cyclic intervals, the interval depends on the importance of the values. Examples of cyclic intervals are: every scan interval, every 10 seconds or every hour.

Sequence of Events recorders

- Local function implemented in Substation Controller that keeps a record of all events in the substation

- Not all events are sent to the SCADA system

- SER logfiles can be uploaded to the SCADA system to enable analysis
SCADA: Control Functions

• Individual Device Control
  • Direct open/close commands to individual devices
  • **Check-back before Operate** function.

• Control Messages to Regulating Equipment
  • E.g. Raising or lowering tap changer taps

• Sequential Control
  • E.g. in the case of a set of sequential switching steps to restore power through predefined backup configuration.

• Automatic Control
  • Triggered by an event of lapse of specific time period that invokes a control actions
  • E.g. automatically changing load tab changer due to voltage set point violation

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Non functional requirements

Functional requirements specifies what is a system suppose to do and Non functional requirements specifies how a system should behave.

- Availability
  - the ratio of uptime to the sum of downtime and uptime.
- Maintainability
  - Repairing time for hardware and software
- Scalability
  - How easy the system could be expand
- Security
  - See SCADA security guest lecture
- Interoperability/Openness
  - how easy can the system be integrated with systems from other vendors

Measurement Service Performance Requirements

<table>
<thead>
<tr>
<th>Enterprise/Function</th>
<th>Typical measurement service performance requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spike priority (%)</td>
</tr>
<tr>
<td>Tier 1</td>
<td></td>
</tr>
<tr>
<td>Substation operator indicators</td>
<td>Voltage, Bus</td>
</tr>
<tr>
<td>Switching and tagging</td>
<td>Voltage, Line</td>
</tr>
<tr>
<td>End element control</td>
<td>Real and Reactive Power, Line</td>
</tr>
<tr>
<td>Low-priority alarms</td>
<td>Real and Reactive Power, Equip</td>
</tr>
<tr>
<td>High-priority alarms</td>
<td>Current, Line</td>
</tr>
<tr>
<td>System monitoring</td>
<td>Current, Equip</td>
</tr>
<tr>
<td>Frequency/Phase Angle</td>
<td>1.5</td>
</tr>
<tr>
<td>Position, Regulator/valve</td>
<td>10</td>
</tr>
<tr>
<td>Ancillary value</td>
<td>10</td>
</tr>
</tbody>
</table>

### Status Update Performance Requirements

#### Typical monitoring services performance requirements

<table>
<thead>
<tr>
<th>Enterprise/Function</th>
<th>Example measured element</th>
<th>Uptime probability (%)</th>
<th>Accuracy (%)</th>
<th>Unreliability (times)</th>
<th>Latency (s)</th>
<th>Rejection (%)</th>
<th>Time to clear solution (s)</th>
<th>Time to close SCADA (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tie 1</td>
<td>Breaker trip, trip</td>
<td>99.9</td>
<td>4.0</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Substation operator</td>
<td>Substation RSM control</td>
<td>99.9</td>
<td>4.0</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Substation operator</td>
<td>Substation switch</td>
<td>99.9</td>
<td>4.0</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Substation algorithm</td>
<td></td>
<td>99.9</td>
<td>4.0</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>


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### Status Update Performance Requirements

#### Typical control services performance requirements

<table>
<thead>
<tr>
<th>Enterprise/Function</th>
<th>Example measured element</th>
<th>Execution time (s)</th>
<th>Availability (%)</th>
<th>Reliability (%)</th>
<th>Latency (s)</th>
<th>Single point multiple point</th>
<th>Feedback sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tie 1</td>
<td>Circuit breaker, capacitor switch</td>
<td>99.99</td>
<td>4.0</td>
<td>1</td>
<td>Single</td>
<td>SBO</td>
<td></td>
</tr>
<tr>
<td>Substation operator</td>
<td>Substation RSM control</td>
<td>99.99</td>
<td>4.0</td>
<td>5</td>
<td>Multiple</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Auto-sectionalizing</td>
<td>Substation or field device</td>
<td>99.99</td>
<td>4.0</td>
<td>5</td>
<td>Multiple</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Substation algorithm</td>
<td></td>
<td>99.99</td>
<td>4.0</td>
<td></td>
<td>Depends</td>
<td>Depends</td>
<td></td>
</tr>
</tbody>
</table>

Non functional requirements
- Performance

- Desired response time should be designed for each SCADA function. These response time should comply with power system control and operation procedure.
  - Normal state, quasi-steady-state. Response time should meet the requirements during normal state.
  - Emergency state, when power system operation constraints are violated. SCADA system are engineered to one specific emergency condition without degrading the performance.

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Wide Area Monitoring and Control Systems

• Based on real time measurements from the grid.

• Makes the model more representative of the actual dynamic process out in the field

• The measurements are of high resolution (e.g. 30 measurement samples per second)

• Less offline analysis, less hypothetical scenarios.

• Most importantly common time reference for measurements (increases accuracy and dependability).

• With advanced applications, enabler of the self healing grid.

Basic Components of a WAMC System

+ Control Functions
IEEE C37.118

- Protocol specially designed for carrying Phasor Measurements from Phasor Measurement Unit to PDC (Phasor Data concentrator) and from PDC to PDC.
- Contains address header and a number of phasors including quality checking data.
A WAMC test bed and prototype

- KTH’s Implementation of a WAMC Platform
- Integrating and utilizing several Open source technologies
- Support many protocols: C37.188, IEEE 1344, FNET, BPA PDCStream.

PowerIT Applications

- Implemented a Preliminary Mode Estimation System
- Implemented standard Frequency Monitoring
- System Overview Monitoring.

- Integrated apps added:
  - Historian Playback
  - Historian Viewer.
The End