Lecture 6
Substation Automation Systems
Course map
Contents of the Lecture

- Part 1 – Substation Automation
  - Components & Architectures
  - Substation Automation Functions
  - Communication within the Substation (Intro)
- Part 2 – Intro to Helinks
Part 1
Components & Architectures
Process Interface

Line bay

BI  Binary Input
BO  Binary Output
AI  Analog Input
FI  Filter
AD  Analog/Digital Converter

Intelligent electronic device (IED) for protection and control

Figure 6-3 Process connection to a typical IED
The interfaces

- **Analog Input**
  - CT & VT for Current & Voltage measurements
  - Ranges 1-5A, 100-200 V AC
  - Temperature

- **Binary Input**
  - Breaker status, Normally using two indicators to indicate intermediate status
  - Tap changer positions

- **Binary outputs**
  - Controlling the operation of circuit breakers/switches
  - Two BO in series for normal switching
  - One single BO for circuit breaker tripping

- **Analog outputs**
# Measurement accuracy

<table>
<thead>
<tr>
<th>Function/Device</th>
<th>Accuracy</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument transformer: transforms kV to range of +/-200 V</td>
<td>Relative accuracy at nominal value 0.5 %</td>
<td>An accuracy of 0.5 % in average, is normally used for plausibility check of measurands - more details see in chapter 5.</td>
</tr>
<tr>
<td>Interposing transformer from 200 V to 10 V</td>
<td>Relative accuracy at nominal value 0.1 %</td>
<td>Acts as barrier against disturbances as well</td>
</tr>
<tr>
<td>Filter</td>
<td>Influences frequency range only; no influence on the RMS value.</td>
<td></td>
</tr>
<tr>
<td>A/D converter 16 bit</td>
<td>Conversion inaccuracy can normally be neglected. The inaccuracy depends on the bit range that is used for the measurand range (e.g. full 16 bit signed used for needed range → accuracy is $2^{-14} = 0.006%$)</td>
<td>An 8 bit measurand (either for transmission, or from A/D conversion), leads to an accuracy of 2.5 %, a 12 bit measurand (11 bit + sign) to 0.25 %</td>
</tr>
<tr>
<td>Scaling</td>
<td>Can be neglected, if the result is a 32 bit floating point (accuracy better than 16 bit integer)</td>
<td>32 bit floating point has a mantissa of 24 bits</td>
</tr>
<tr>
<td>Communication oscillation suppression delta</td>
<td>Depending on the delta: to get a sufficient communication load reduction, often around 0.1 % of the measurand normal/nominal value is needed</td>
<td>The inaccuracy of cyclic sending is zero at the moment of sending. If the maximum change rate of the measurand is not known, no accuracy can be estimated in between.</td>
</tr>
</tbody>
</table>
Local systems

RTU - Remote Terminal Units
PLC – Programmable Logic Controllers
IED – Intelligent Electronic Devices
...

KTH
VETENSKAP
OCH
KONST

[Image of electrical equipment]

[Image of electronic components]
Traditional SAS architecture
Architecture with “Intelligent” primary equipment
Local systems

RTU - Remote Terminal Units
PLC – Programmable Logic Controllers
IED – Intelligent Electronic Devices
...

KTH

Remote Terminal Unit
Programmable Logic Controller
Intelligent Electronic Device
Substation automation
Common components

• Intelligent Electronic Device (IED)
  – Digital protective relay with added functionality
  – Can usually interface with RTU
    • Report events and measurement data
    • Receive commands from RTU/SCADA
  – Advanced functions need IEDs to communicate with each other
    • Horizontal communication
  – Control functions can include
    • Load tap changer controller
    • CB controller
    • Capacitor bank switches
    • Recloser controllers
    • Voltage regulators
Programmable controllers

PLC programming

- Automation of electromechanical processes
- Built for tough environments
- Hard real-time system – outputs in bounded time
- Fairly simple and cheap devices.
Programmable controllers
Substation automation
Common components

- Remote Terminal Unit (RTU)
  - For SCADA communication
  - Serial communication
  - Standard protocols
    - Modbus
    - IEC 60870-5-101/104
    - DNP3
    - ICCP

- Better suited to wide area telemetry than PLCs
Substation automation
Common components

- Human-Machine-Interface
• The terminology used for describing devices and Architectures varies significantly across vendors as well as with age and size of a particular substation

• In this course we will use three different terms:
  – *Station Controller*, the top level controller in a substation
  – *Bay controller*, the unit controlling a bay in a substation
  – *Relay*, at the lowest level controlling a single object

• *Relays and Bay controllers* are implemented in IEDs – Intelligent Electronic Devices

• The station controller is a Industrial PC/server

**Terminology**
Terminology
Terminology

Station

Bay

Object
Terminology
Part 1
Substation Automation Functions
Protection!

- Overcurrent protection
- Distance protection
- Autoreclosure relay
- Differential protection
- Directional earth fault protection
- Overload protection
- Frequency relay
- Voltage relay
- Earth fault indication relay
- Busbar protection system
- Buchholz protection, thermal monitoring

Figure 6-18 Protection concept for a substation
What do we want to automate?

<table>
<thead>
<tr>
<th>Functional area</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interlocking</td>
<td>CB’s</td>
</tr>
<tr>
<td>Tripping sequences</td>
<td>CB failure</td>
</tr>
<tr>
<td>Switching sequences</td>
<td>Automatic transformer changeover</td>
</tr>
<tr>
<td>Load management</td>
<td>Load shedding</td>
</tr>
<tr>
<td>Transformer supervision</td>
<td>CLTC control</td>
</tr>
<tr>
<td>Energy monitoring</td>
<td>Import/export control</td>
</tr>
<tr>
<td>Switchgear monitoring</td>
<td>AIS monitoring</td>
</tr>
<tr>
<td>Equipment status</td>
<td>Relay status</td>
</tr>
<tr>
<td>Parameter setting</td>
<td>Relays</td>
</tr>
<tr>
<td>HMI functionality</td>
<td>Access control, Trend curves, Interface to SCADA</td>
</tr>
<tr>
<td></td>
<td>Isolators</td>
</tr>
<tr>
<td></td>
<td>Interripping</td>
</tr>
<tr>
<td></td>
<td>Automatic busbar changeover</td>
</tr>
<tr>
<td></td>
<td>Load restoration</td>
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<tr>
<td></td>
<td>Load management</td>
</tr>
<tr>
<td></td>
<td>Energy management</td>
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<tr>
<td></td>
<td>GIS monitoring</td>
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<tr>
<td></td>
<td>CB status</td>
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<tr>
<td></td>
<td>Isolator status</td>
</tr>
<tr>
<td></td>
<td>Transformers</td>
</tr>
<tr>
<td></td>
<td>Switching sequences</td>
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<td></td>
<td>IED configuration</td>
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<td></td>
<td>System views</td>
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<td></td>
<td>Event logging</td>
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<td></td>
<td>Remote access</td>
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<tr>
<td></td>
<td>Disturbance analysis</td>
</tr>
<tr>
<td></td>
<td>512</td>
</tr>
</tbody>
</table>

Table 24.6: Typical substation automation functionality

- Different areas of automation that can be built into a Substation Automation System
Interlocking

- To ensure that operation of Switchgear is safe and in accordance with standards

- For instance preventing of moving of a disconnector carrying load

- Implemented as functions in a bay Controller that controls the switchgear in the bay.

See SAS Handbook, 6.3.3.3 & 6.3.4.3
Switching Sequences

- To ensure that switching operations are performed in a correct sequence, and to automate manual work

- For example, transferring a feeder from one busbar to another, or restoration after a fault

- Implemented in station or bay controller depending on scope of the sequence

*See SAS Handbook, 6.3.5.1*
Load Management

• Automation shedding of load, and restoration of load.

• For example as a result of under frequency conditions, feeders are disconnected.

• Implemented at station level control

See SAS Handbook, 6.3.5.5
Communication in the Substation (Intro)
# What to Communicate?

<table>
<thead>
<tr>
<th>Data type</th>
<th>Maximum allowed age</th>
<th>Data integrity</th>
<th>Exchange method</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alarm</td>
<td>1 s</td>
<td>Medium</td>
<td>Spontaneous</td>
<td>Alarms are urgent process changes that must be brought to the attention of an operator, to perform corrective actions</td>
</tr>
<tr>
<td>Commands</td>
<td>1 s</td>
<td>High</td>
<td>Spontaneous</td>
<td>Commands directly act on the process</td>
</tr>
<tr>
<td>Process state data</td>
<td>2 s (binary), 5-10 s (measurands)</td>
<td>Medium</td>
<td>Spontaneous</td>
<td>Gives the operator an overview on the process state</td>
</tr>
<tr>
<td>Time stamped events</td>
<td>10 s</td>
<td>Low</td>
<td>On request</td>
<td>Sequence of event data is used for later analysis of a problem</td>
</tr>
<tr>
<td>Interlocking data</td>
<td>5 ms (fast block)</td>
<td>High (directly influences the process via commands)</td>
<td>Spontaneous</td>
<td>Used to prevent dangerous commands</td>
</tr>
<tr>
<td>Interlocking data (state information), other Automatics</td>
<td>100 ms</td>
<td>High (directly influences the process via commands)</td>
<td>On request (upon a command)</td>
<td>Used for Interlocking to prevent dangerous commands; or for automatics like load-shedding</td>
</tr>
<tr>
<td>Trip from protection</td>
<td>3 ms</td>
<td>High (directly influences the process via trips)</td>
<td>Spontaneous</td>
<td>Used to clear dangerous situations</td>
</tr>
</tbody>
</table>
Substation Automation Development

- **Traditional Substation**
  - Functions tied to physical device
  - Measurement connection based on point to point links (Copper wires)
  - Some buses for relay communication
  - Limited standardisation & vendor integration

- **61850 Substation**
  - Information model separated from protocol implementation
  - Improved vendor interoperability
  - Point to multipoint Measurement access via sampled values (-9-2)
  - "Free" allocation of functions to devices.
Substation Communication Systems

Station Bus - 10/100/1000 MB Ethernet

Relay(s) Subscribe to Datasets
MU Publishes V/I/Status Datasets

IED

Process Bus 1/1/10GB Ethernet

Remote Access
Network

Clk1 MU PT1 I/O Optical CT

Clk2 MU PT2 I/O CT2 MU = Merging Unit

Optical I/O PT Optical CT