Lecture 5
Substation Automation Systems

Course map
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  - Substation Automation Functions
  - Communication within the Substation (Intro)
- Part 2 – Architectures.....
  - Smartgrids Architecture Reference Model

Part 1
Components & Architectures
The interfaces

- **Analog Input**
  - CT & VT for Current & Voltage measurements
  - Ranges 1-5A, 50-200 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**
Conventional Substations

Conventional architecture
Separate systems for protection, metering & operation
The Digital Substation

- Reducing Cabling
- Enabling interoperability
- Measure once – use many times

The Merging Unit
Architecture with “Intelligent” primary equipment

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
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
Terminology

- 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
  - IED, at the lowest level controlling a single object

- Relays and Bay controllers are also implemented in IEDs
  - Intelligent Electronic Devices

- The station controller is a industrial PC/server
Terminology

Station
Bay
Object
Part 1
Substation Automation Functions

Protection!

1. Overcurrent protection
2. Distance protection
3. Autoreclosure relay
4. Differential protection
5. Directional earth fault protection
6. Overload protection
7. Frequency relay
8. Voltage relay
9. Earth fault indication relay
10. Busbar protection system
11. Buchholz protection; thermal monitoring

Figure 6-18: Protection concept for a substation
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.

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 e.g. 4.9.2.1 & 4.9.2.2
Automatic Bus switch-over

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
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 (measured)</td>
<td>Medium</td>
<td>Spontaneous</td>
<td>Give 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 labor 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</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 automatic-like load shedding</td>
</tr>
<tr>
<td>Trip from protection</td>
<td>3 ms</td>
<td>High (directly influences the process via trip)</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
Smartgrids Architecture Reference Model

There are lots of ways to describe systems
One way to make control systems understandable,

perhaps not what we need

Another way
Some background first

- The EC has issued a mandate (M/490) for the standardization of Smart grid functionalities to CEN, CENELEC and ETSI.
- The expected framework will consist of the following deliverables:
  - A technical reference architecture, which will represent the functional information data flows between the main domains and integrate many systems and subsystems architectures.
  - A set of consistent standards, which will support the information exchange (communication protocols and data models) and the integration of all users into the electric system operation.
  - Sustainable standardization processes and collaborative tools to enable stakeholder interactions, to improve the two above and adapt them to new requirements based on gap analysis, while ensuring the fit to high level system constraints such as interoperability, security, and privacy, etc.

What is a reference architecture?

A Reference Architecture describes the structure of a system with its element types and their structures, as well as their interaction types, among each other and with their environment. Describing this, a Reference Architecture defines restrictions for an instantiation (concrete architecture). Through abstraction from individual details, a Reference Architecture is universally valid within a specific domain. Further architectures with the same functional requirements can be constructed based on the reference architecture. Along with reference architectures comes a recommendation, based on experiences from existing developments as well as from a wide acceptance and recognition by its users or per definition. [ISO/IEC42010]

In short: it is the specification of which language you should use to describe the system you are describing.
Example:
Reference architecture for Power systems

One-line diagram

A set of symbols

Rules on how you can combine them

Avoiding this...

We need this for communication & control systems

The context – the Smartgrid
### Architecture Domains

<table>
<thead>
<tr>
<th>Domain</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Generation</td>
<td>Representing generation of electrical energy in bulk quantities, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale photovoltaic (PV) power— typically connected to the transmission system</td>
</tr>
<tr>
<td>Transmission</td>
<td>Representing the infrastructure and organization which transports electricity over long distances</td>
</tr>
<tr>
<td>Distribution</td>
<td>Representing the infrastructure and organization which distributes electricity to customers</td>
</tr>
<tr>
<td>DER</td>
<td>Representing distributed electrical resources, directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3 kW to 10,000 kW). These distributed electrical resources can be directly controlled by DSO</td>
</tr>
<tr>
<td>Customer Premises</td>
<td>Hosting both - end users of electricity, also producers of electricity. The premises include industrial, commercial and home facilities (e.g. chemical plants, airports, harbors, shopping centers, homes). Also generation in form of e.g. photovoltaic generation, electric vehicles storage, batteries, micro turbines… are hosted</td>
</tr>
</tbody>
</table>

### Architecture Zones

<table>
<thead>
<tr>
<th>Zone</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Including both - primary equipment of the power system (e.g. generators, transformers, circuit breakers, overhead lines, cables, electrical loads …) - as well as physical energy conversion (electricity, solar, heat, water, wind …).</td>
</tr>
<tr>
<td>Station</td>
<td>Representing the aggregation level for fields, e.g. for data concentration, substation automation…</td>
</tr>
<tr>
<td>Operation</td>
<td>Hosting power system control operation in the respective domain, e.g. distribution management systems (DMS), energy management systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (EV) fleet charging management systems.</td>
</tr>
<tr>
<td>Enterprise</td>
<td>Includes commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders …), e.g. asset management, staff training, customer relation management, billing and procurement.</td>
</tr>
<tr>
<td>Market</td>
<td>Reflecting the market operations possible along the energy conversion chain, e.g. energy trading, mass market, retail market…</td>
</tr>
</tbody>
</table>
Complete Reference architecture

Component Layer

The emphasis of the component layer is the physical distribution of all participating components in the smart grid context. This includes actors, applications, power system equipment (typically located at process and field level), protection and tele-control devices, network infrastructure (wired / wireless communication connections, routers, switches, servers) and any kind of computers.
Function layer

The function layer describes functions and services including their relationships from an architectural viewpoint. The functions are represented independent from actors and physical implementations in applications, systems and components. The functions are derived by extracting the use case functionality which is independent from actors.
Information Layer

The information layer describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying canonical data models. These information objects and canonical data models represent the common semantics for functions and services in order to allow an interoperable information exchange via communication means.
Communication Layer

The emphasis of the communication layer is to describe protocols and mechanisms for the interoperable exchange of information between components in the context of the underlying use case, function or service and related information objects or data models.
Business Layer

The business layer represents the business view on the information exchange related to smart grids. SGAM can be used to map regulatory and economic (market) structures and policies, business models, business portfolios (products & services) of market parties involved. Also business capabilities and business processes can be represented in this layer. In this way it supports business executives in decision making related to (new) business models and specific business projects (business case) as well as regulators in defining new market models. The Business layer is addressed in more detail in paragraph 6.1.

Summary

- Substation Automation
  - Core functions are:
    - Protection
    - Interlocking
    - Automatic switching sequences
- Substation Automation Systems
  - Many conventional systems in operation
  - Slow transitions towards digital substations
- Architectures & Terminology vary a lot!
- We will use the Smartgrid Architecture model to design architectures.