Digitalization of Hydropower
Salto Grande
August 27 and 28, 2018
International Hydropower Association (IHA)
Designing an Integrated System of Hardware and Software Components to support the digitalization of hydroelectric powerplants

Agenda

• Digitalization Lifecycle
• Trends in Digitalization
• Digitalization Process
• Digitalization Examples
Digitalization Lifecycle
Digitalization Lifecycle

- EAMS
- Condition Monitoring
- Simulation
- Trending
- Forecasting
- Optimizing
- Digital Manuals

Modeling Software
Control Narratives
Standard Data Bases
(Equipment/IO/Instrument)
Software & Hardware Architecture
Functional Requirement Diagrams
Trends in Digitalization
Trends in Digitalization

• Modeling Software
  (i.e. standard databases & nomenclature and identification system)

• Standard Hydropower Programming Libraries
  (i.e. turbine governors & exciter models/start-stop sequences/Joint Control MW/MVAR)

• Distributed Controllers
  (i.e. universal IO cards (DI/DO/AI/AO) and improved interfaces with Intelligent Electronic Devices (IEDs))

• High Performance HMIs (Dashboard)
  (i.e. optimizing/improving visualization of processes)

• Cloud Based VPN
  (i.e. third party controlled communications network)
Trends in Digitalization (cont.)

Software as a Service (SaaS)

Cloud based services for analysis and interpretation of data (i.e. MCM, EAMS)

• Processing of large volume of machine data
  (i.e. access to data bases for similar machines)
• Simplified licensing
  (i.e. for clients, no need for updates, upgrades or dedicated servers)
• Seamless integration
  (i.e. provides data/receives <web based> diagnostics)

EAMS

Enterprise Asset Management System

• Improves decision making
  (i.e. operations and maintenance)
• Balanced maintenance program
  (i.e. structured approach, minimize unnecessary outages)
• Spare parts management and budgeting
  (i.e. just in time parts for preventive maintenance)
Trends in Digitalization (cont.)

Cybersecurity

Benefits

• Protection of assets – Equipment and Systems
  (i.e. a must first step on all digital designs)

• Enables compliance with international regulations
  (i.e. licensing/permitting)

• Continuous evolution and approaches
  (i.e. some utilities using military technology such as data diode)

Approach

• Start early in the conceptual design phase
  (i.e. definition of interfaces, selection of protocols, strategies, real needs for external access)

• Consider equipment outside of traditional digital equipment
  (i.e. data processing - DPE and communication equipment - DTE)

• Firewalls starting at the data acquisition level
  (i.e. firewalled communications with IEDs)

• Code Monitoring
  (i.e. dedicated equipment to monitor command sequences and validation of logic in progress)
Trends in Digitalization (cont.)

Futureproofed Systems

Approach
• Top-down & modular
  (i.e. facilitates testing and maintenance; provides flexibility, safety, security and reliability of controls)
• Vendor independent
• Validates hardware, software and instrumentation
  (i.e. identifies needs and gaps early in the project)

Architecture
• Top Level
  (i.e. overall Processes and Interfaces with other systems)
• Intermediate Level
  (i.e. equipment control processes)
• Low level
  (i.e. interface processes with component level)
• Data Acquisition Level
  (i.e. data exchange with intelligent and field devices including validation)
Digitalization Process
Digitalization Process

INSTRUMENTATION
CONTROL SYSTEMS
COMMUNICATION SYSTEMS
POWER DISTRIBUTION
CONTROL NARRATIVES/ FUNCTIONAL REQUIREMENT DIAGRAMS (FRD)
OTHER PROJECTS

DOCUMENTATION & DRAWINGS

ASSESSMENT

PRELIMINARY WORK

PRELIMINARY WORK
IDENTIFYING NEW REQUIREMENTS
EVALUATING DESIGN
SELECTING TECHNOLOGY
SELECTING CONTRACTING STRATEGY
SELECTING PROJECT TEAM
PROJ SCHEDULE, DOCUMENTATION AND CLOSE-OUT

Stantec
Digitalization Examples
1555 MW Castaic Pumped Storage Hydro, LADWP, Los Angeles, USA

- Pump storage plant, inaugurated in 1978
- 6-250MW P-G (Francis) units and 1-55MW conventional (Pelton) unit.
- Back-to-Back Starting method
- In 2006:
  - partial modernization
    (1 unit commissioned, 1 partially commissioned, 5 units not modified).
  - Pump starting panel remains fully hardwired logic.
- Situation of the software on the partially modernized units:
  - Dependent on hardwired logic (i.e. pump starting panel) for complete operation.
  - Concentrated software on unit controllers (not modular nor distributed)
  - Embedded non-standard software, not reusable on the other units.
Digitalization Challenges

- **Planning the transition** (restrictions and outages)
- **Implement functions** (centralized HW, interfaces with dispatch centers, comprehensive historians, global time synchronization for all time-capable devices)
- **Digitalize complete processes, eliminate remaining non-digital (i.e. hardwired) logic**
- **Modularize software on major components** (TSOV, Governor, Excitation, etc.)
- **Make software compliant with Industry Standards** (e.g. IEC-61850)
- **Modernize DCC (i.e. instrumentation, IEDs, protective devices)**
Digitalization Process

• Collect/capture information
  ➢ Retrieved and analyzed current design (~400 dwg. - one-lines, schematics, wiring)
  ➢ Validated all processes & instrumentation
  ➢ Documented operation and maintenance requirements and issues

• Development of the new control system
  ➢ Overall control diagram
  ➢ Control narratives
  ➢ Modularization of applications, state diagrams, sequences, Permissives and control block diagrams
  ➢ Communication with two remote control centers.

• Evaluate the design approach
  ➢ Select the right technology
  ➢ Identify restrictions (i.e. pump starting panel), plan the design & outages accordingly.
Unit Applications

**Generator Mode**

**Start Sequence**
- Pre-Start Conditions
- Auxiliaries Start
- Governor Start
- Excitation Start
- Synchronization
- Unit Load

**Stop Sequence**
- Unit Unload
- Unit Offline
- Stop Excitation
- Stop Governor
- Stop Auxiliaries

**Generator Cold Start**

**Start Sequence**
- Pre-Start Conditions
- Auxiliaries Configuration
- Governor Start
- Excitation Start

**Stop Sequence**
- Synchronization
- Unit Load

**Condense Mode**

**Start Sequence**
- Pre-Start Conditions
- Auxiliaries Start
- Governor Start
- Excitation Start
- Synchronization
- Water Level Depression
- Reactive Load

**Stop Sequence**
- Unit Unload
- Water Level Normalization
- Stop Auxiliaries

**Pump Starter**

**Start Sequence**
- Pre-Start Conditions
- Auxiliaries Start
- Synchronous Starting
- Synchronization
- Generator Hold

**Stop Sequence**
- Unit Offline
- Stop Excitation
- Stop Governor
- Stop Auxiliaries

**Mode Transitions**
- Generator to Synchronous Condense
- Synchronous Condense to Generator

**Control Mode Transfer**
- Local <-> Central Control <-> ECC
Digitalized System

- 4300 HW IO Points
- 500 new instruments
- 300 displays
- Two control centers
Digitalized System (cont.)

- >20 control narratives & > 350 drawings produced
Panama Canal Third Set of Locks (2016)
Panama Canal TSL, Panama

- BIM designed and integrated using a “Top-Down” approach
- Resulted in a distributed system requiring minimum operator intervention
- >50 high capacity controllers, >64,000 signals, >10 Million lines of code and 45-Trillion combinations of hydraulic and equipment conditions
- Process control system availability exceeding 99.99%. Overall 99.6%. (24-h/7-d/365 d/y)
- Designed to comply with Safety Integrity Level (SIL) 2 standards
- Equipped with an integrated communication system, safety system and security system
- All highly complex and critical processes (hydraulic, electrical, safety and security) documented using “Functional Requirement Diagrams” (FRDs)
- FRDs translated to code and use for training
- Used High Performance HMI
- Extensive use of Fault-Tree Analysis (FTA), Failure Modes Effects and Criticality Analysis (FMECA), and Reliability-Centered Maintenance (RCM)
- Fully Integrated (EAMS) Maintenance plan for the next 100 years (Maximo)
# Title of the Functional Requirement Diagram

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td>This is a general functional description of the function block</td>
</tr>
<tr>
<td><strong>hold</strong></td>
<td>This is a functional description of the parameter “hold” of the function block</td>
</tr>
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<td><strong>Etc.</strong></td>
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**Description**

This is a general functional description of the function block.

- **hold**
  - This is a functional description of the parameter “hold” of the function block.
  - Etc.
### Digitalization of MCC/VFD data

<table>
<thead>
<tr>
<th>System</th>
<th>Signals</th>
</tr>
</thead>
</table>
Enterprise Asset Management System (EAMS)

Assets: >17,000 per site; Job Plans: > 400 per site; PMs: > 160 per site
Master Maintenance Schedule > 100 years
Digitalization of Manuals

Documents in Aconex:

- 180,000+ Documents

Handover Manual

- Electrical Drawings
- Mechanical Drawings
- General Design Criteria
- General Architecture
- Vendors’ Manuals
- MDP/ODP

- 5,000+ Selected

Documents Selection ➔ Publish (by Aconex)
Lessons Learned

• Start digitalization early & follow a process
• Define digitalization goals and end users
• Define (module level) engineering requirements and implementation plan
• Perform extensive testing at module and integrated level
<table>
<thead>
<tr>
<th>Function</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td></td>
</tr>
<tr>
<td>Air gap</td>
<td>Includes rotor and stator shapes</td>
</tr>
<tr>
<td>Partial discharge</td>
<td>For machines above 6 kV</td>
</tr>
<tr>
<td>Rotor flux (shorted pole turns)</td>
<td></td>
</tr>
<tr>
<td>Stator frame vibration</td>
<td></td>
</tr>
<tr>
<td>Air temperatures</td>
<td></td>
</tr>
<tr>
<td>Winding temperatures</td>
<td></td>
</tr>
<tr>
<td>Thrust bearing temperature</td>
<td></td>
</tr>
<tr>
<td>Thrust bearing oil film thickness</td>
<td></td>
</tr>
<tr>
<td>Thrust bracket vertical vibration</td>
<td></td>
</tr>
<tr>
<td>Shaft vibration (runout)</td>
<td></td>
</tr>
<tr>
<td>Generator guide bearing temperature</td>
<td></td>
</tr>
<tr>
<td>Turbine</td>
<td></td>
</tr>
<tr>
<td>Shaft vibration (runout)</td>
<td></td>
</tr>
<tr>
<td>Turbine guide bearing temperature</td>
<td></td>
</tr>
<tr>
<td>Head cover/draft tube vibration</td>
<td></td>
</tr>
<tr>
<td>Transformer</td>
<td></td>
</tr>
<tr>
<td>Continuous dissolved gas in oil analysis</td>
<td></td>
</tr>
<tr>
<td>Internal winding hot spot temperature</td>
<td>Not yet a general industry practice</td>
</tr>
<tr>
<td>monitoring</td>
<td></td>
</tr>
</tbody>
</table>

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**Note:**
- The table lists various functions and their comments related to the items mentioned in the diagram. The comments provide additional details about the functions, such as inclusion of specific components or their relevance for machines above 6 kV.
- The diagram illustrates the asset architecture logic, focusing on control best practices, approach, overview, systems, devices, organization, and other related components.