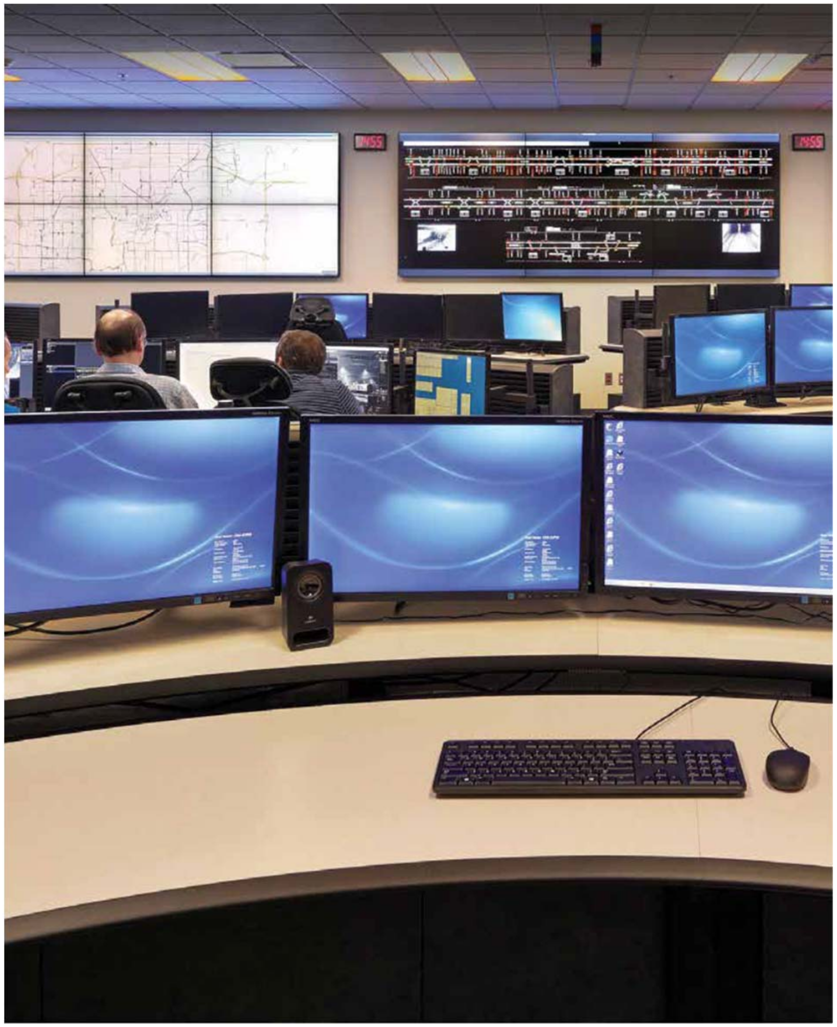
Digitalization of Hydropower

Salto Grande

August 27 and 28, 2018

International Hydropower Association (IHA)



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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

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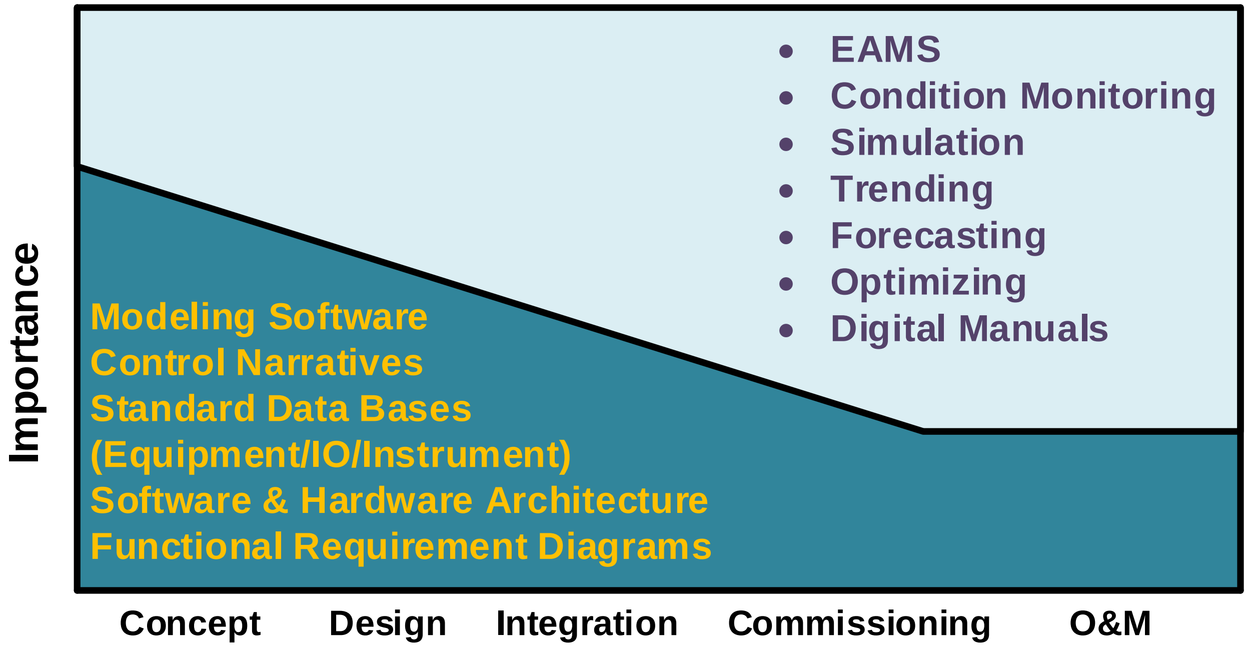
Digitalization Lifecycle

Digitalization Lifecycle



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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)

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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)

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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)

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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

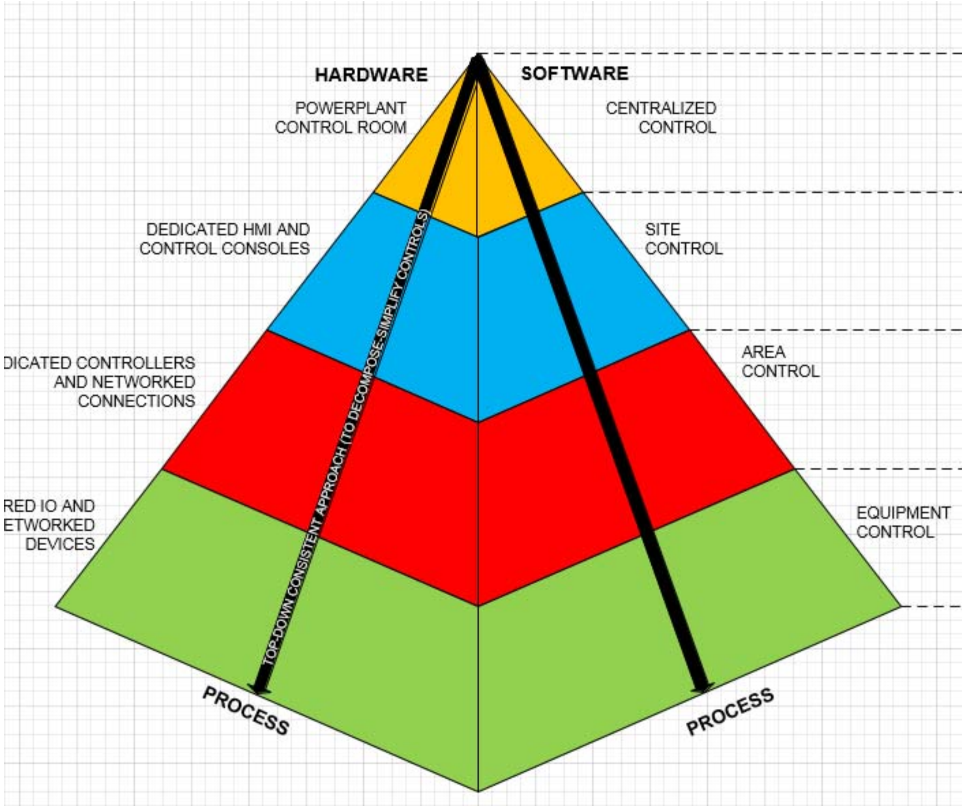
- Top Level

  (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)



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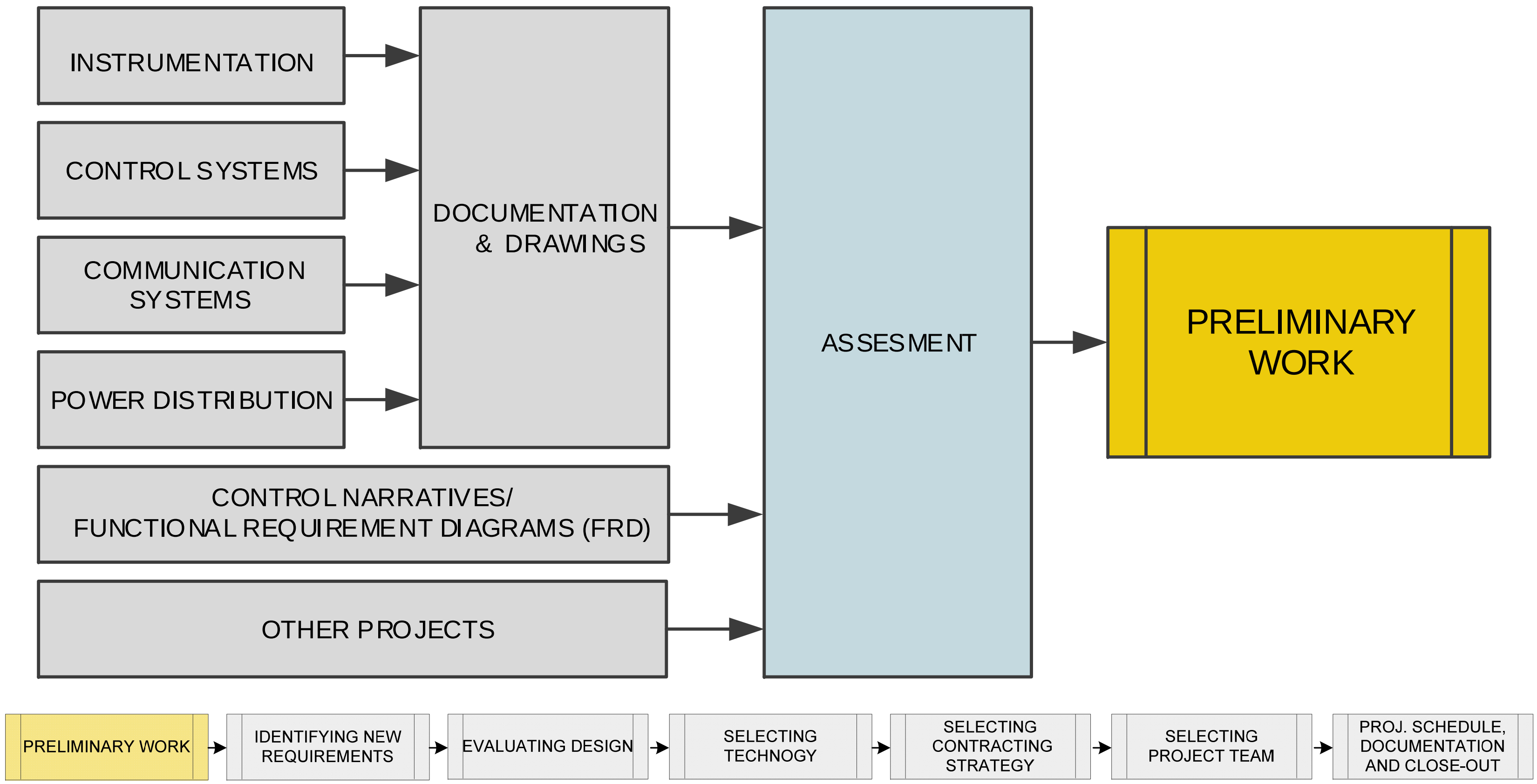
Digitalization Process

Digitalization Process



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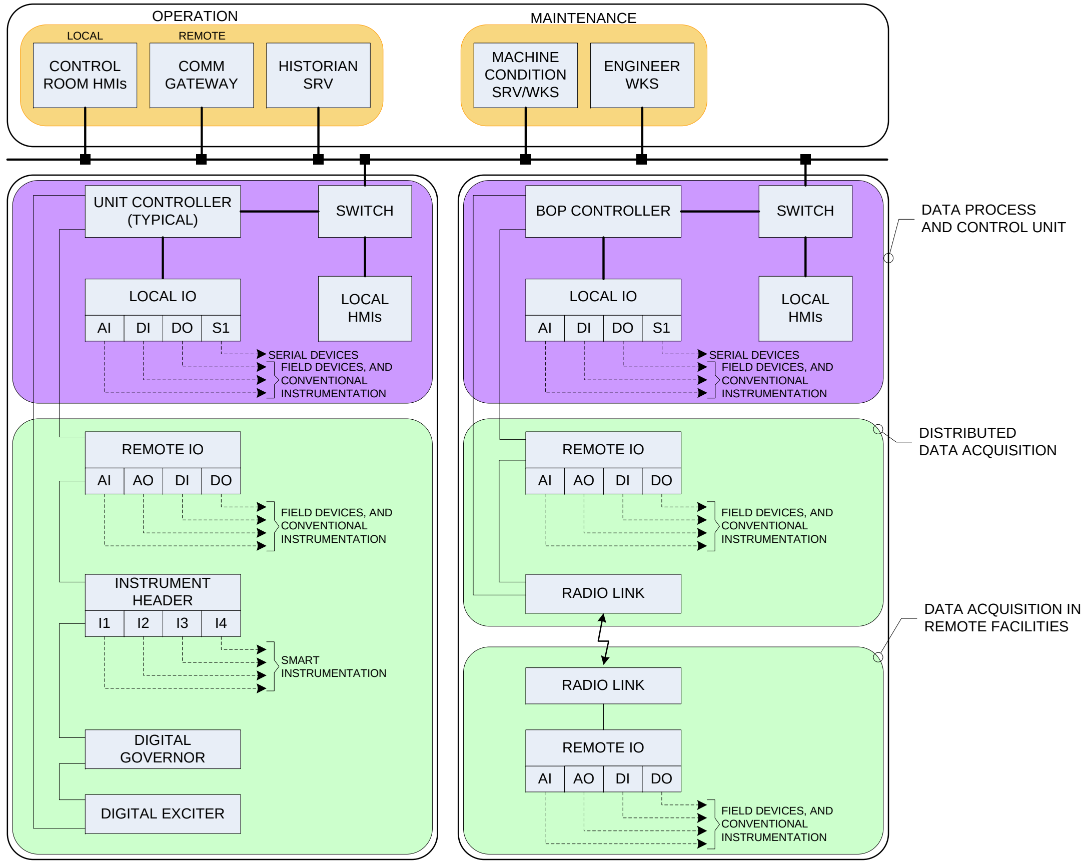
DATA MANAGEMENT

DATA PROCESS & CONTROL

DATA ACQUISITION



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

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.

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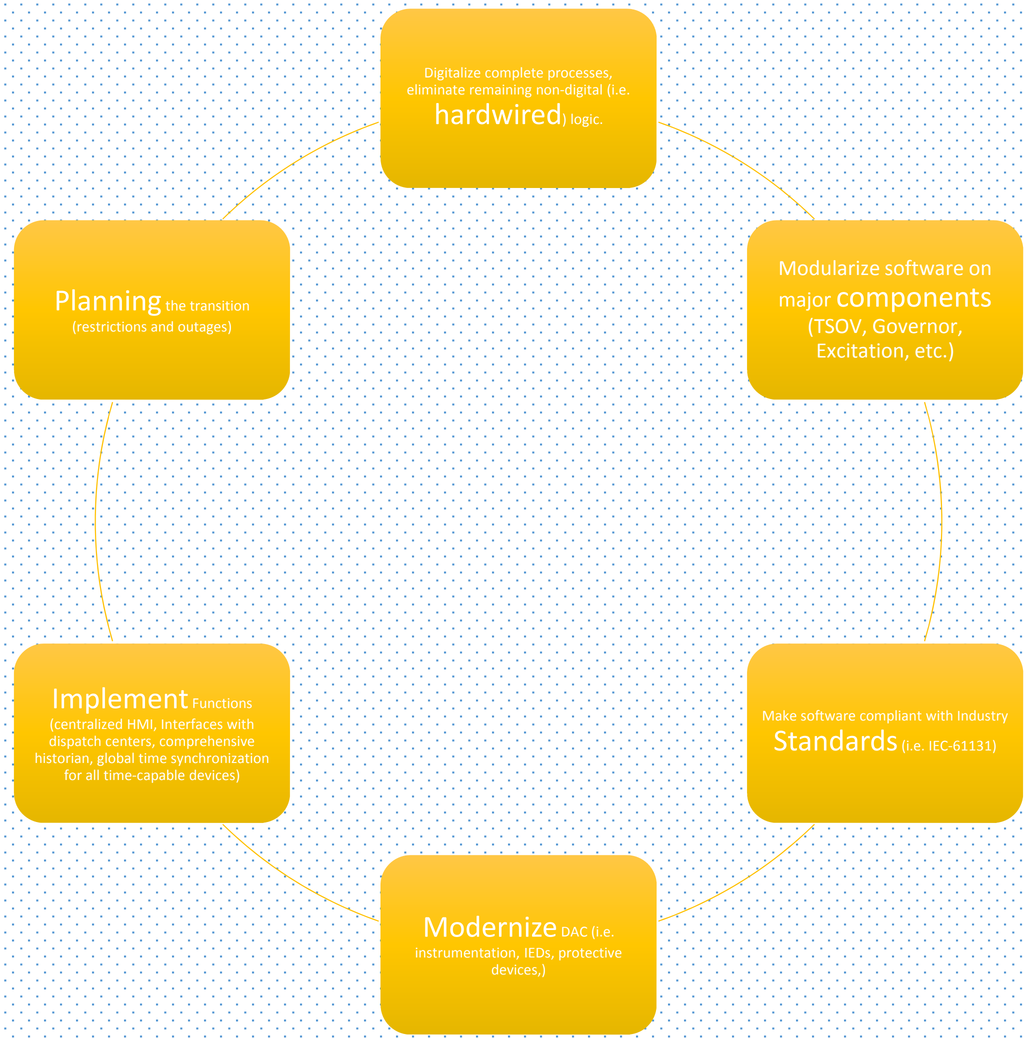
Digitalization Challenges



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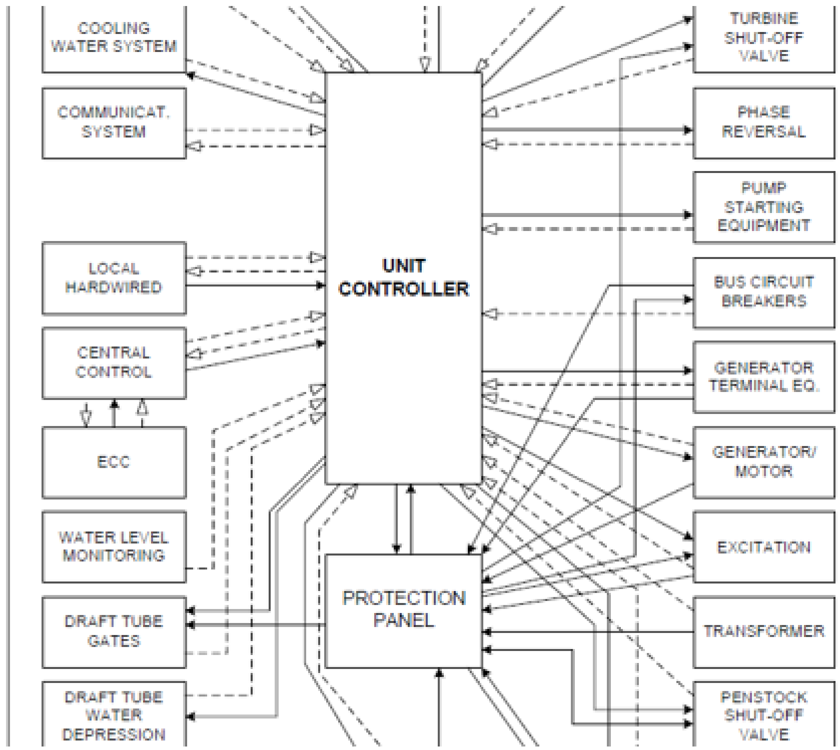
Digitalization Process

- 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.



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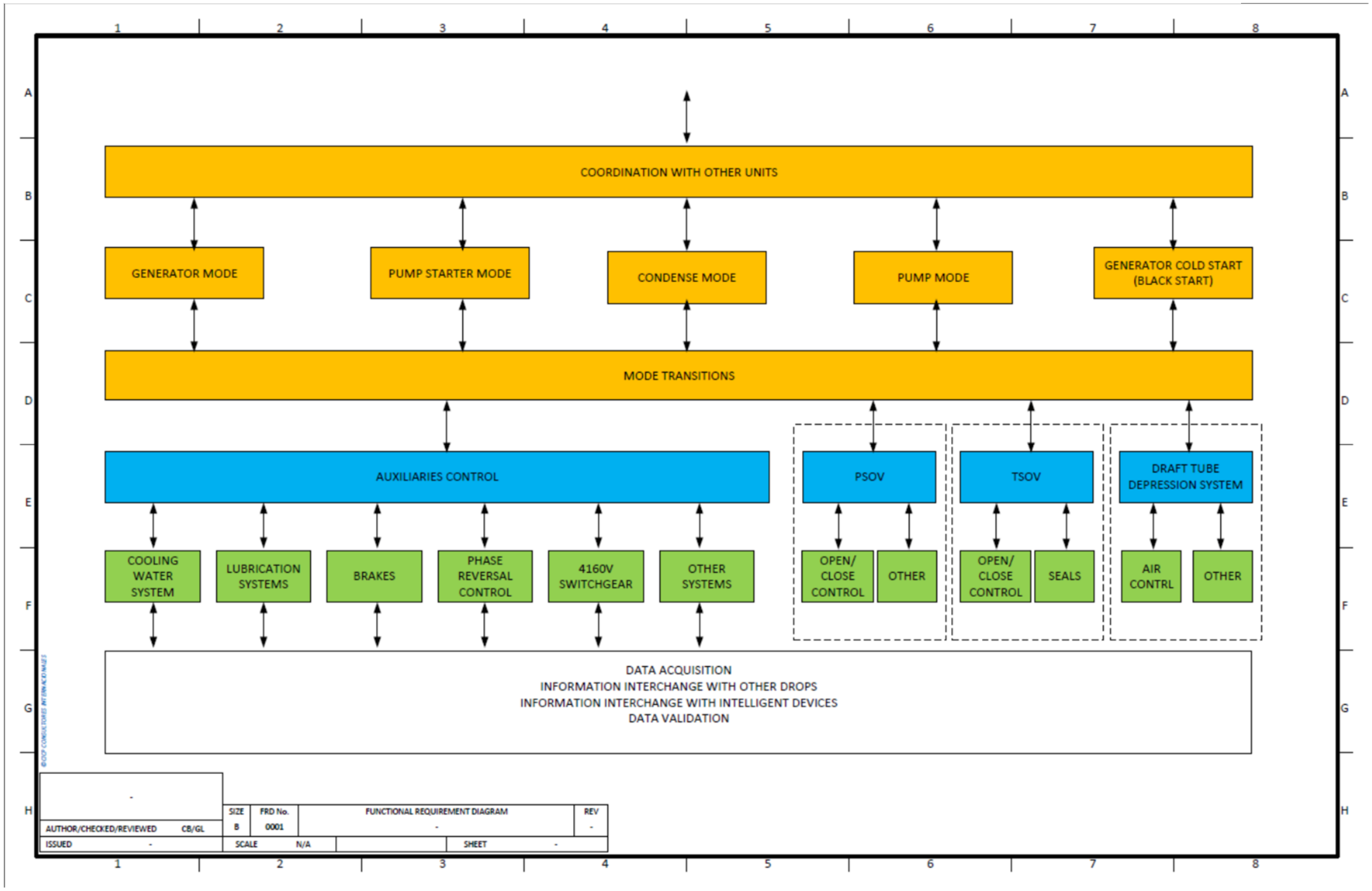
Software Map



Unit Applications

	START SEQUENCE	STOP SEQUENCE
GENERATOR MODE	• PRE-START CONDITIONS • AUXILIARIES START • GOVERNOR START • EXCITATION START • SYNCHRONIZATION • UNIT LOAD	• UNIT UNLOAD • UNIT OFFLINE • STOP EXCITATION • STOP GOVERNOR • STOP AUXILIARIES

	START SEQUENCE	
GENERATOR COLD START	• PRE-START CONDITIONS • AUXILIARIES CONFIGURATION • GOVERNOR START • EXCITATION START	• SYNCHRONIZATION • UNIT LOAD

	START SEQUENCE	STOP SEQUENCE
CONDENSE MODE	• PRE-START CONDITIONS • AUXILIARIES START • GOVERNOR START • EXCITATION START • SYNCHRONIZATION • WATER LEVEL DEPRESSION • REACTIVE LOAD	• UNIT UNLOAD • WATER LEVEL NORMALIZATION • STOP AUXILIARIES

	START SEQUENCE	STOP SEQUENCE
PUMP STARTER	• PRE-START CONDITIONS • AUXILIARIES START • SYNCHRONOUS STARTING • SYNCHRONIZATION • GENERATOR HOLD	• UNIT OFFLINE • STOP EXCITATION • STOP GOVERNOR • STOP AUXILIARIES

	START SEQUENCE	STOP SEQUENCE
PUMP MODE (FOR THE STARTER UNIT)	• PRE-START CONDITIONS • AUXILIARIES START • WATER LEVEL DEPRESSION • SYNCHRONOUS STARTING • SYNCHRONIZATION • PUMP PRIMING	• STOP PUMP • STOP AUXILIARIES

MODE TRANSITIONS	GENERATOR TO SYNCHRONOUS CONDENSE
	SYNCHRONOUS CONDENSE TO GENERATOR

CONTROL MODE TRANSFER	LOCAL <> CENTRAL CONTROL <> ECC

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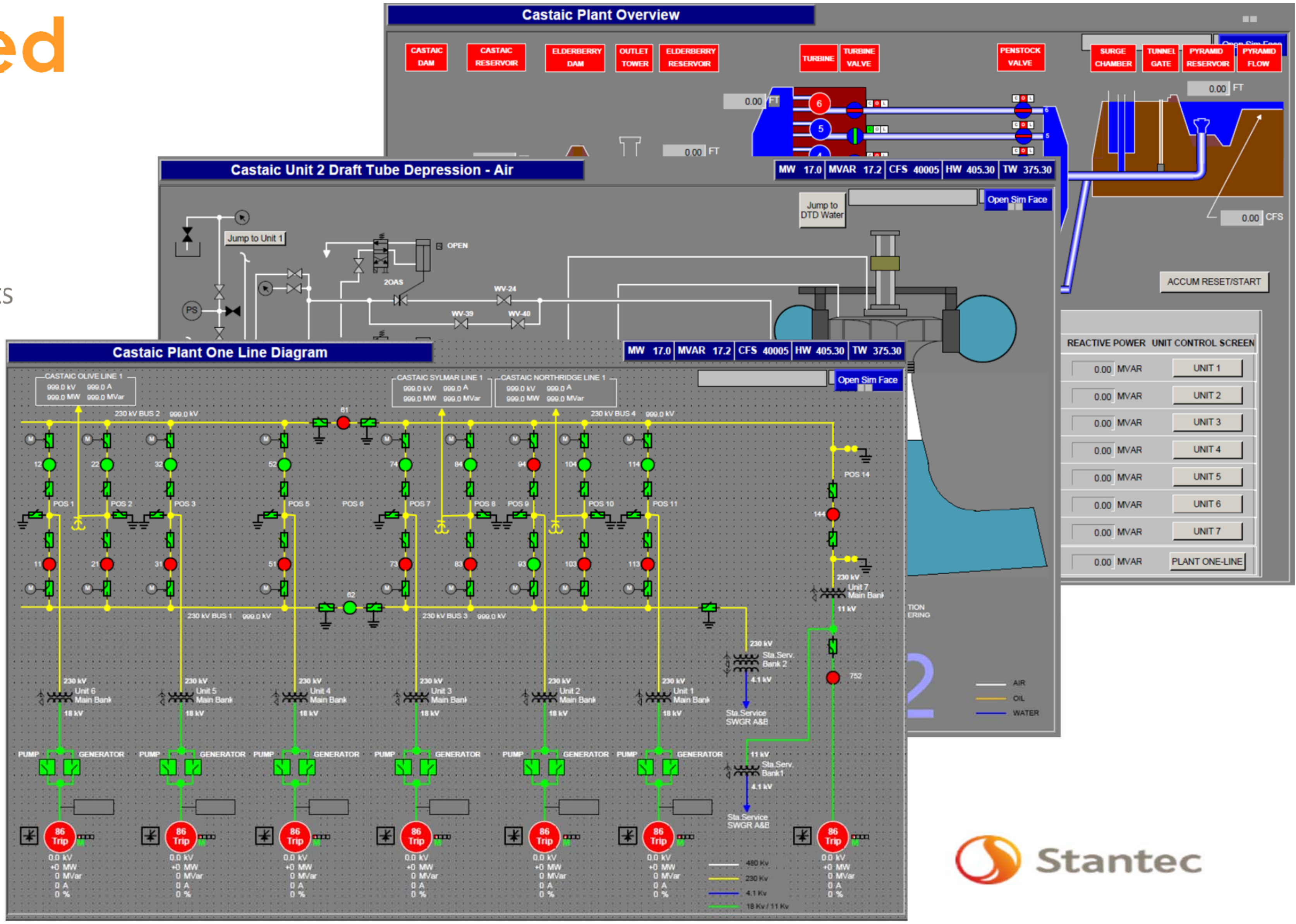
Digitalized System

- 4300 HW IO Points
- 500 new instruments
- 300 displays
- Two control centers



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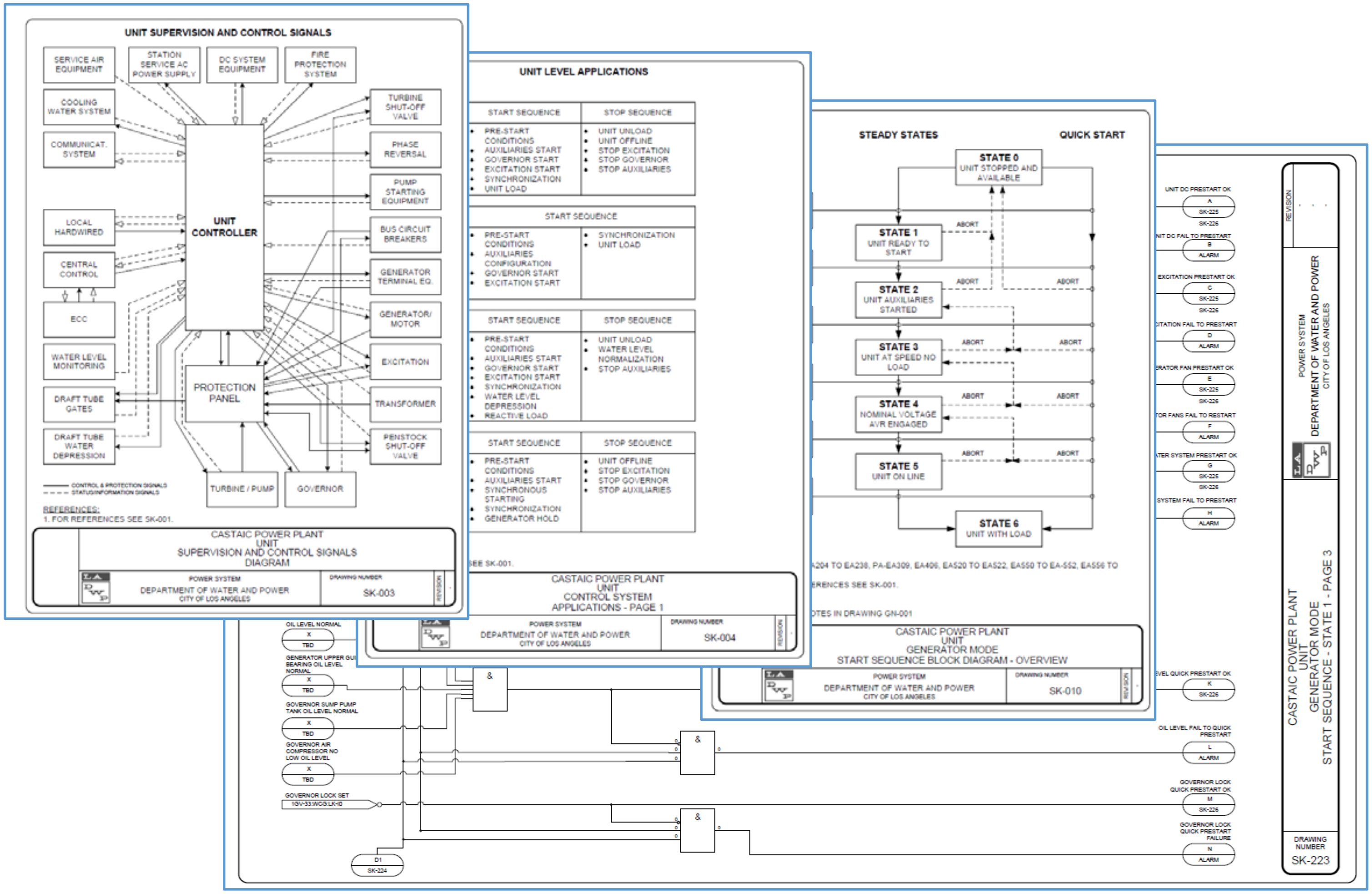
Digitalized System (cont.)

- >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)

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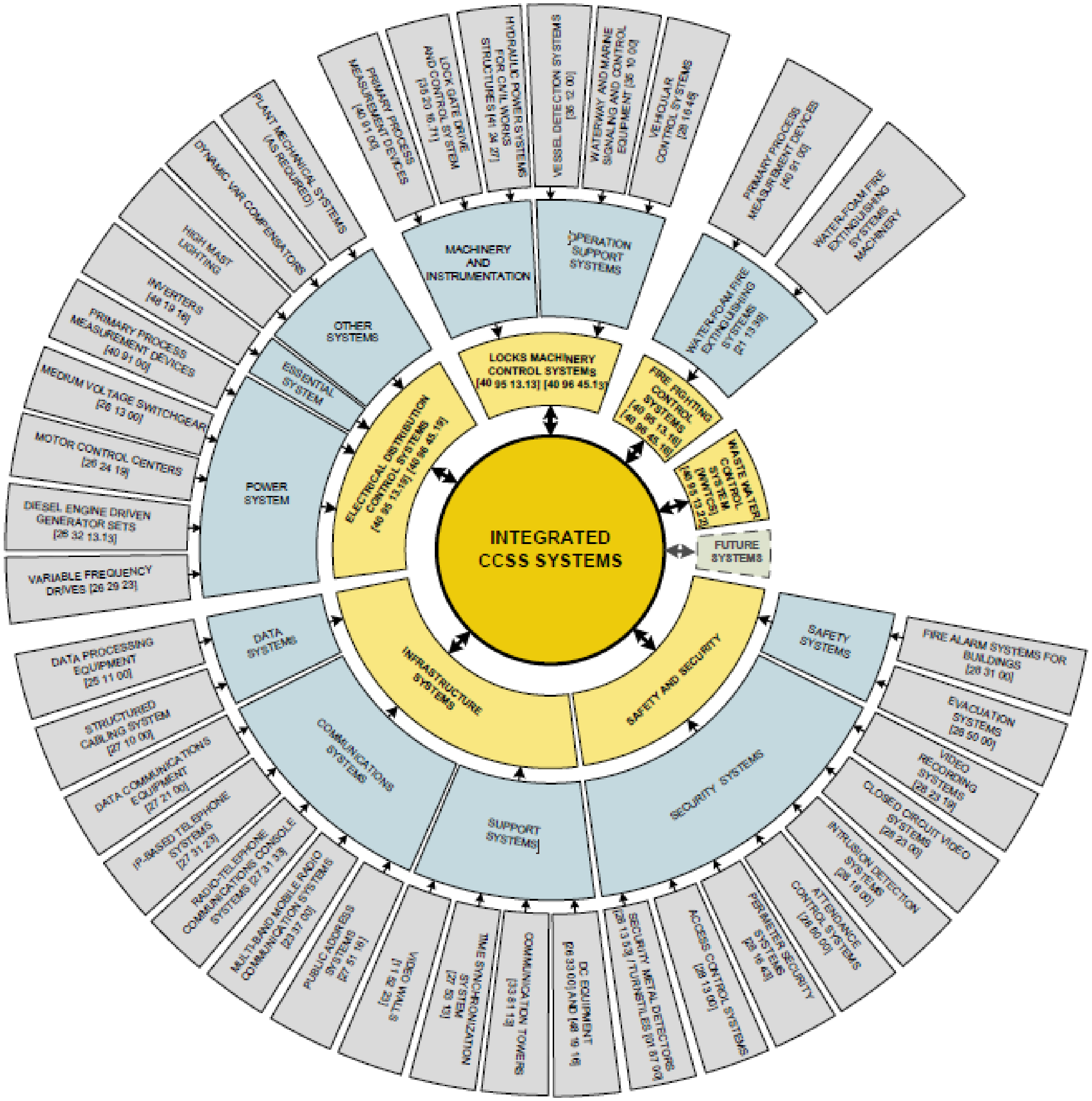
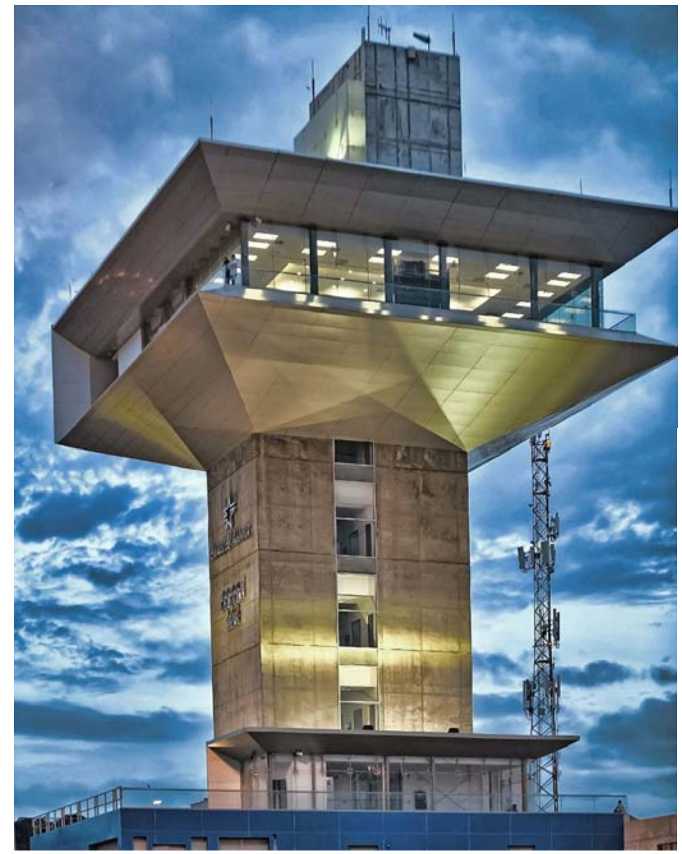

INTEGRATED CCSS SYSTEMS
LOCKS MACHINERY CONTROL SYSTEMS [40 95 13.13] [40 96 45.13]
FIRE FIGHTING CONTROL SYSTEMS [40 95 13.16] [40 96 45.16]
WASTE WATER CONTROL SYSTEM (WWTCS) [40 95 13.22]
FUTURE SYSTEMS
SAFETY AND SECURITY
INFRASTRUCTURE SYSTEMS
ELECTRICAL DISTRIBUTION CONTROL SYSTEMS [40 95 13.19] [40 96 45.19]
MACHINERY AND INSTRUMENTATION
OPERATION SUPPORT SYSTEMS
WATER/FOAM FIRE EXTINGUISHING SYSTEMS [21 13 39]
SAFETY SYSTEMS
SECURITY SYSTEMS
SUPPORT SYSTEMS
COMMUNICATIONS SYSTEMS
DATA SYSTEMS
POWER SYSTEM
ESSENTIAL SYSTEM
OTHER SYSTEMS
PRIMARY PROCESS MEASUREMENT DEVICES [40 91 00]
LOCK GATE DRIVE AND CONTROL SYSTEM [35 20 16.71]
HYDRAULIC POWER SYSTEMS FOR CIVIL WORKS STRUCTURES [41 24 27]
VESSEL DETECTION SYSTEMS [35 12 00]
WATERWAY AND MARINE SIGNALING AND CONTROL EQUIPMENT [35 10 00]
VEHICULAR CONTROL SYSTEMS [28 16 48]
PRIMARY PROCESS MEASUREMENT DEVICES [40 91 00]
WATER/FOAM FIRE EXTINGUISHING SYSTEMS MACHINERY
FIRE ALARM SYSTEMS FOR BUILDINGS [28 31 00]
EVACUATION SYSTEMS [28 50 00]
VIDEO RECORDING SYSTEMS [28 23 19]
CLOSED CIRCUIT VIDEO SYSTEMS [28 23 00]
INTRUSION DETECTION SYSTEMS [28 16 00]
ATTENDANCE CONTROL SYSTEMS [28 60 00]
PERIMETER SECURITY SYSTEMS [28 16 43]
ACCESS CONTROL SYSTEMS [28 13 00]
SECURITY METAL DETECTORS [28 13 53] TURNSTILES [01 87 00]
DC EQUIPMENT [26 33 00] AND [48 19 16]
COMMUNICATION TOWERS [33 81 13]
TIME SYNCHRONIZATION SYSTEM [27 53 13]
VIDEO WALLS [11 52 23]
PUBLIC ADDRESS SYSTEMS [27 51 16]
MULTI-BAND MOBILE RADIO COMMUNICATION SYSTEMS [27 37 00]
RADIO-TELEPHONE COMMUNICATIONS CONSOLE SYSTEMS [27 31 33]
IP-BASED TELEPHONE SYSTEMS [27 31 23]
DATA COMMUNICATIONS EQUIPMENT [27 21 00]
STRUCTURED CABLING SYSTEM [27 10 00]
DATA PROCESSING EQUIPMENT [25 11 00]
VARIABLE FREQUENCY DRIVES [26 29 23]
DIESEL ENGINE DRIVEN GENERATOR SETS [26 32 13.13]
MOTOR CONTROL CENTERS [26 24 19]
MEDIUM VOLTAGE SWITCHGEAR [26 13 00]
PRIMARY PROCESS MEASUREMENT DEVICES [40 91 00]
INVERTERS [48 19 16]
HIGH MAST LIGHTING
DYNAMIC VAR COMPENSATORS
PLANT MECHANICAL SYSTEMS (AS REQUIRED)



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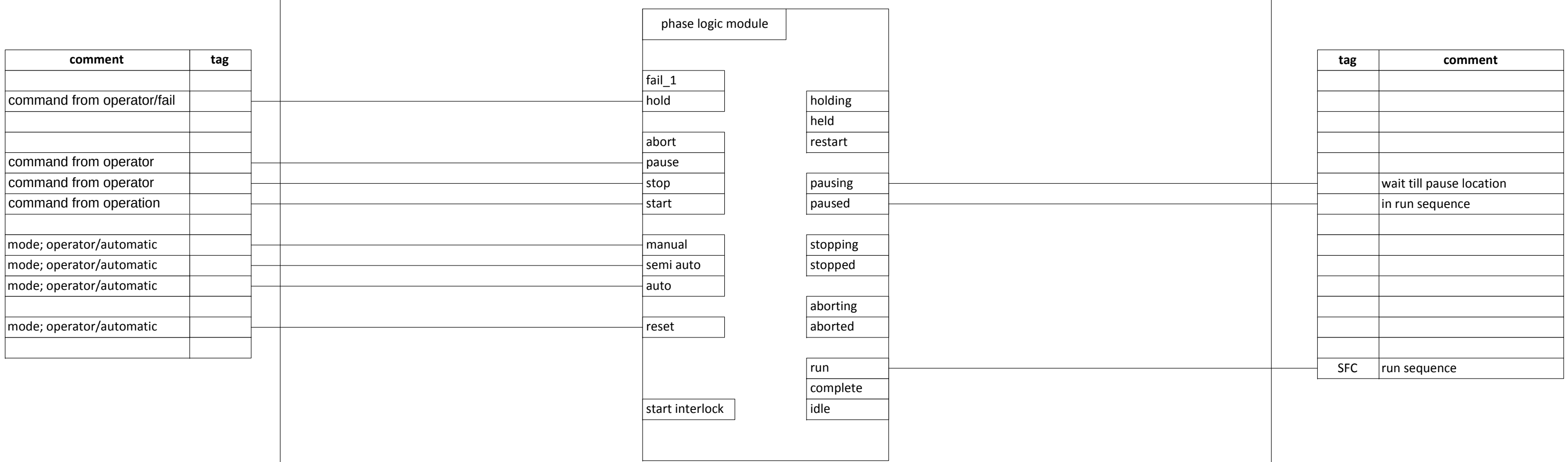


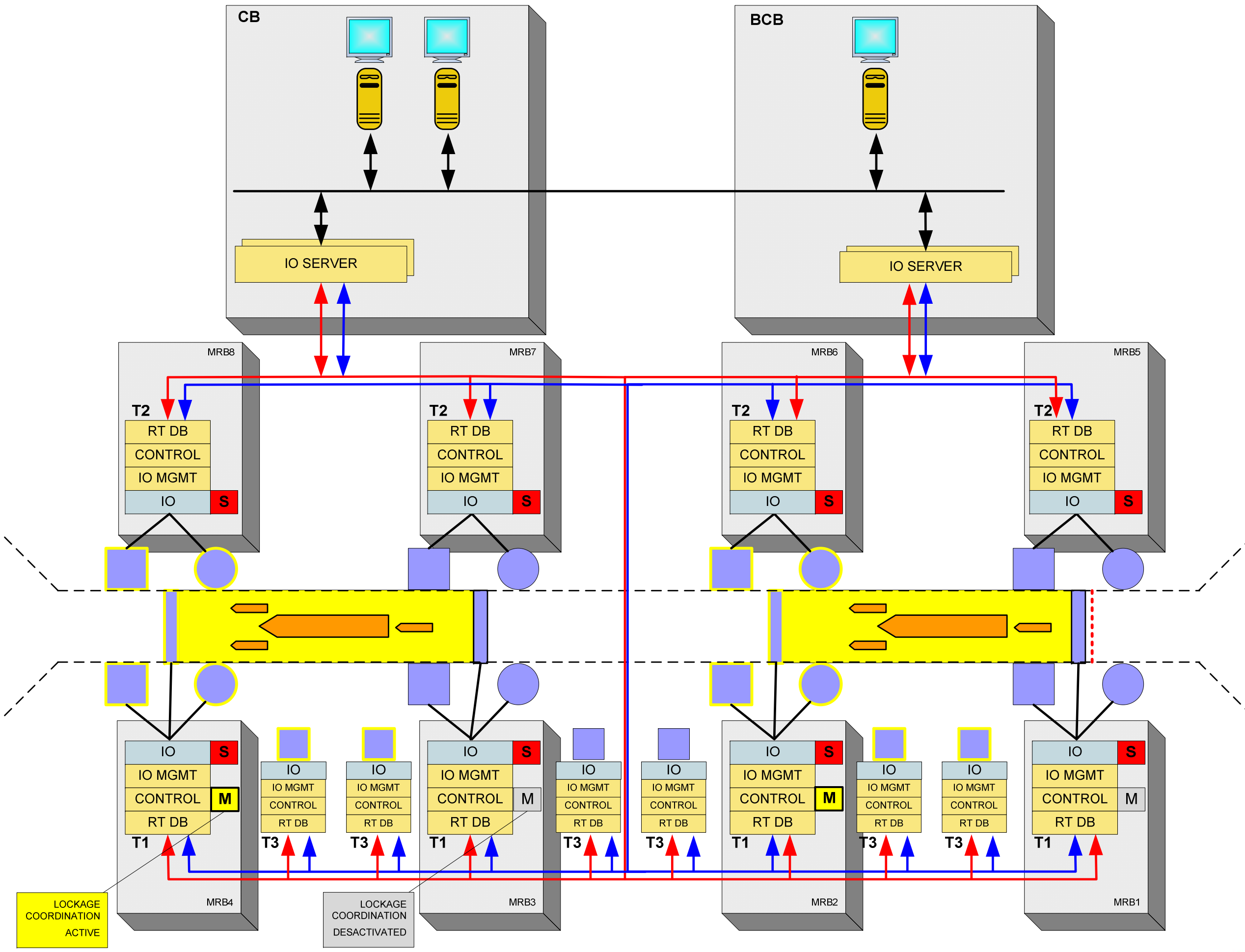
Parameter	Description
General	This is a general functional description of the function block
hold	This is a functional description of the parameter “hold” of the function block
Etc.	Etc.

TITLE OF THE FUNCTIONAL REQUIREMENT DIAGRAM

Digitalization of MCC/VFD data

System	Signals
VFD	Motor Winding Temperature
	Motor Load Bearing Temperature
	DC Power Alarm
	AC Power Alarm
	Surge Protection Device Alarm
	Circuit Breaker Closed
	Start Forward
	Start Reverse
	Run Inhibit
	LMCS PLC Fault
	VFD Reset
	VFD Run
	VFD Fault
	VFD Remote
	VFD Drive Speed
	Motor Torque
	VFD – Frequency
	VFD – Current
	VFD – Voltage Phase
	VFD – Power Factor
	VFD – Power (Apparent)
	VFD – Energy
	Motor Speed

System	Signals
MCC	Supervision and Control of Feeders: Op
	Feeder Connected
	Feeder in Remote
	Feeder – Frequency
	Feeder – Current
	Feeder – Voltage
	Feeder – Power Factor
	Feeder – Power (Apparent)
	Feeder – Energy
	Feeder – Test Position
	Supervision and Control of Tie Connect
	MCC Ethernet Switch Status
	MCC – Power Failure
	MCC – Surge Protection Device Alarm


CB
BCB
IO SERVER
IO SERVER
MRB8
MRB7
MRB6
MRB5
T2
RT DB
CONTROL
IO MGMT
IO
S
MRB4
MRB3
MRB2
MRB1
M
T1
T3
LOCKAGE COORDINATION ACTIVE
LOCKAGE COORDINATION DESACTIVATED

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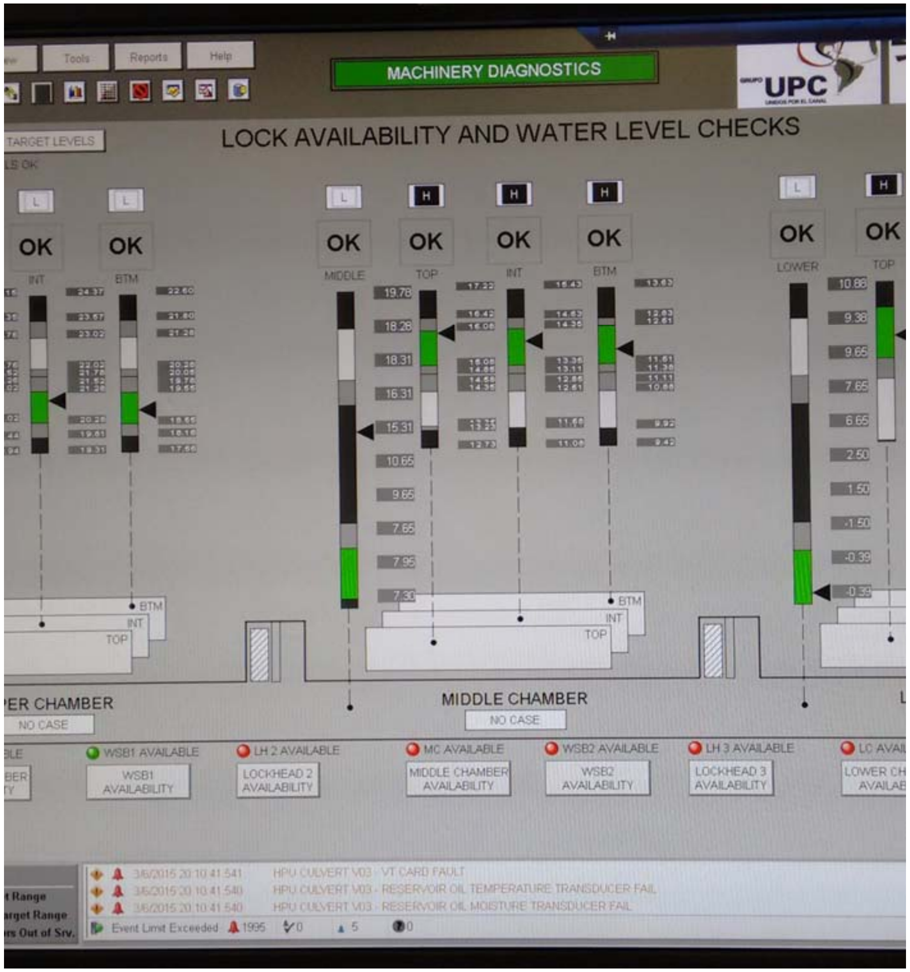
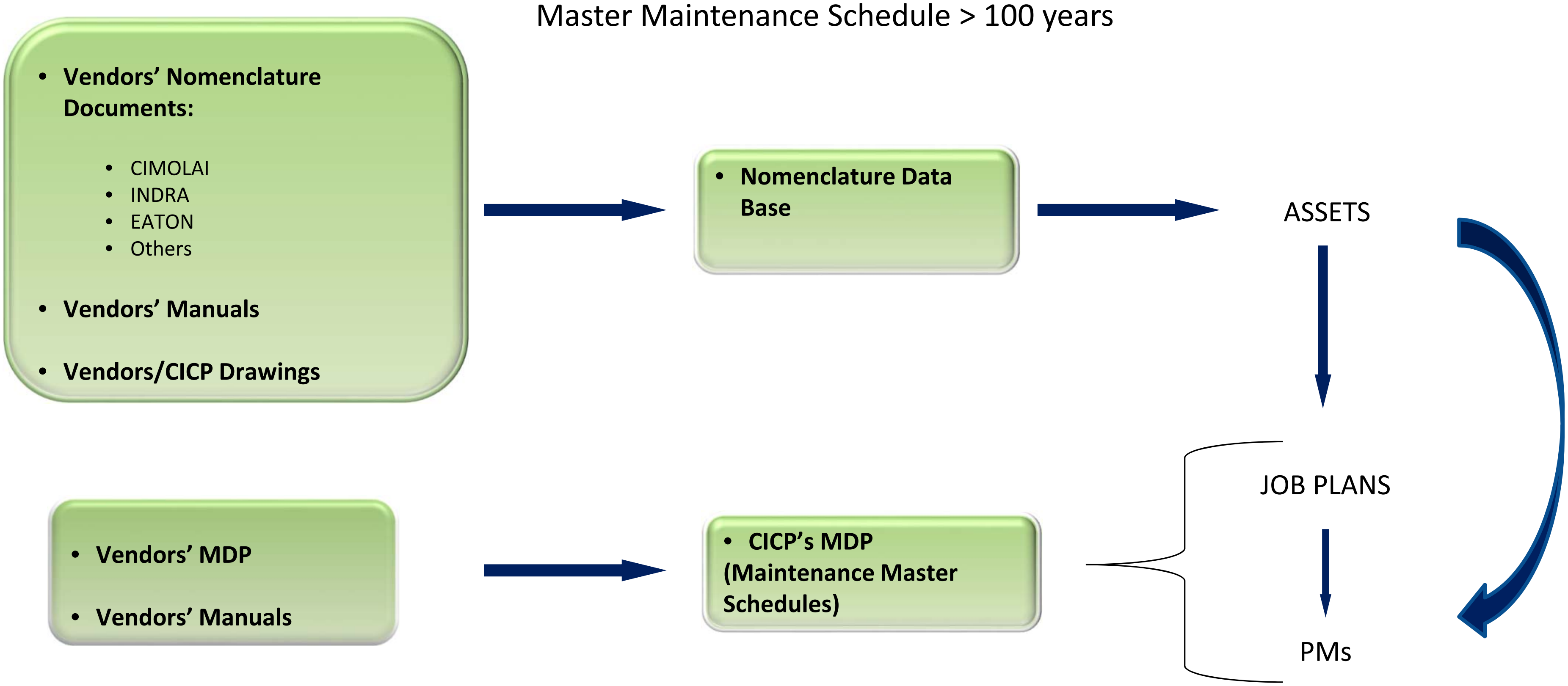

Tools
Reports
Help
MACHINERY DIAGNOSTICS
UPC
LOCK AVAILABILITY AND WATER LEVEL CHECKS
TARGET LEVELS
OK
MIDDLE
TOP
INT
BTM
LOWER
MIDDLE CHAMBER
NO CASE
WSB1 AVAILABLE
LH 2 AVAILABLE
MC AVAILABLE
WSB2 AVAILABLE
LH 3 AVAILABLE
WSB1 AVAILABILITY
LOCKHEAD 2 AVAILABILITY
MIDDLE CHAMBER AVAILABILITY
WSB2 AVAILABILITY
LOCKHEAD 3 AVAILABILITY
HPU CULVERT V03 - VT CARD FAULT
HPU CULVERT V03 - RESERVOIR OIL TEMPERATURE TRANSDUCER FAIL
HPU CULVERT V03 - RESERVOIR OIL MOISTURE TRANSDUCER FAIL
Event Limit Exceeded

Enterprise Asset Management System (EAMS)

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



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Digitalization of Manuals

Documents in Aconex:

✓ **180.000+ Documents**

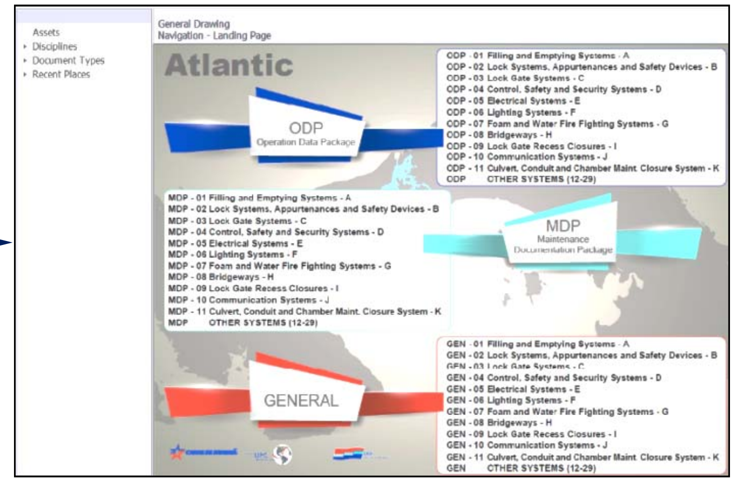
Documents Selection →

Handover Manual

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

✓ **5.000+ Selected**

Publish (by Aconex) →



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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

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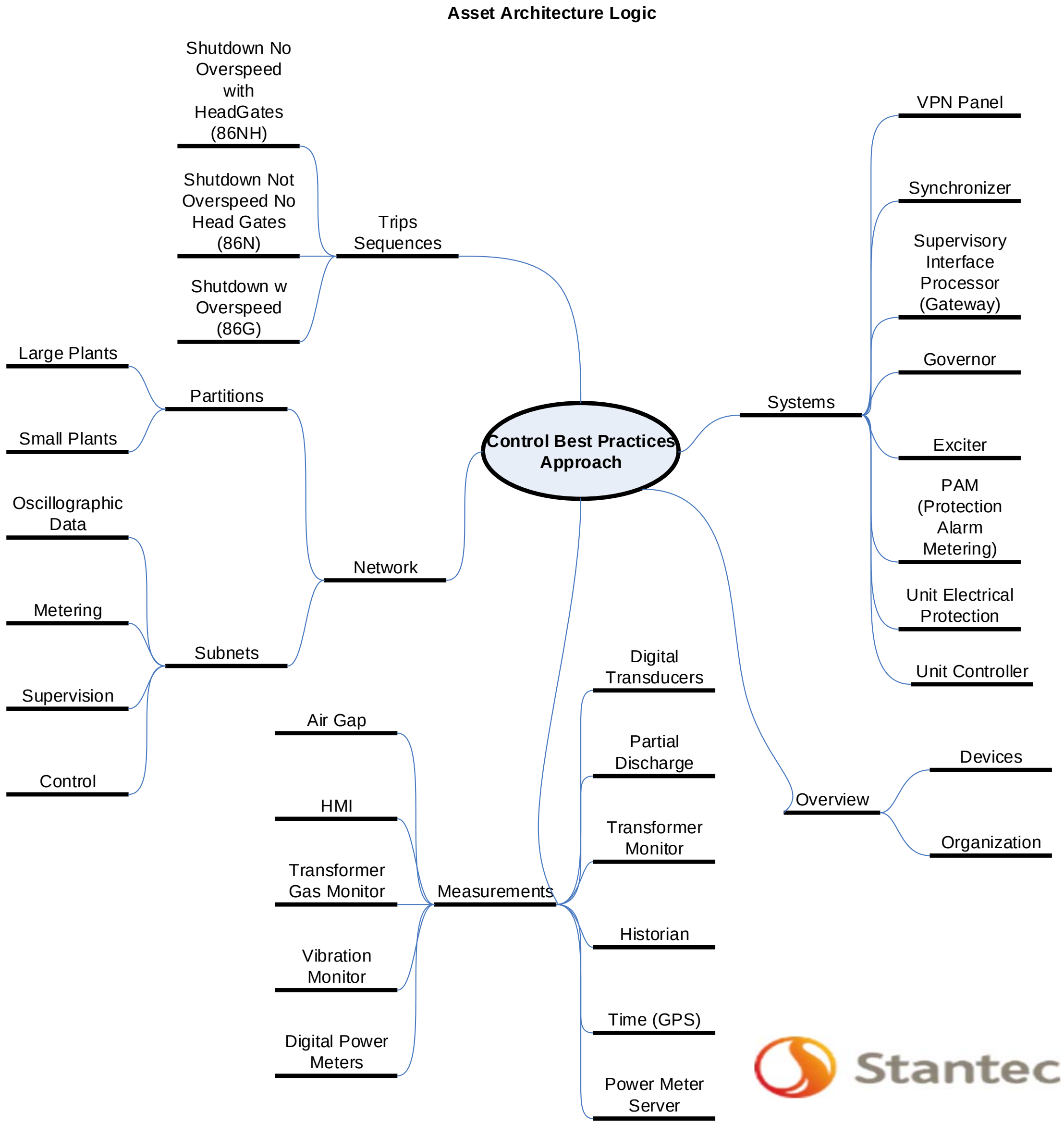
QUESTIONS?

Function	Comments
Generator	
Air gap	Includes rotor and stator shapes
Partial discharge	For machines above 6 kV
Rotor flux (shorted pole turns)	
Stator frame vibration	
Air temperatures	
Winding temperatures	
Thrust bearing temperature	
Thrust bearing oil film thickness	
Thrust bracket vertical vibration	
Shaft vibration (runout)	
Generator guide bearing temperature	
Turbine	
Shaft vibration (runout)	
Turbine guide bearing temperature	
Head cover/draft tube vibration	
Transformer	
Continuous dissolved gas in oil analysis	
Internal winding hot spot temperature monitoring	Not yet a general industry practice



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