

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Technical guidelines for smart hydroelectric power plant

Lignes directrices techniques d'une centrale hydroélectrique intelligente



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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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ELECTROTECHNIQUE
INTERNATIONALE

ICS 27.140

IEC ISBN 978-2-8322-6197-2
IEEE ISBN 978-1-5044-9467-0 STD25986

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TECHNICAL GUIDELINES FOR SMART HYDROELECTRIC POWER PLANT

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This document is published as an IEC/IEEE Dual Logo standard.

The text of this International Standard is based on the following IEC documents:

Draft	Report on voting
4/448/FDIS	4/451/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

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- amended.

INTRODUCTION

In the past few decades, the widespread use of automatic control systems in hydroelectric power plants, including computer-based control systems, brought a number of benefits including improved work efficiency, enhanced reliability and real-time capability, as well as optimized Operating Expense (OPEX).

Nowadays, tremendous changes occur in hydroelectric power plants and their external environment, thereby posing challenges in operation, maintenance, scheduling and management.

The evolution of power grid codes and electricity markets, the growing sensibility of the public about the environmental impact and such risks generated by operating hydroelectric power plants as control of flow variation downstream, and the increasing demand for multi-purpose utilization of water resources lead to the increasing difficulty in generation scheduling decision-making. Giant unit/plant capacity enhances the role of hydroelectric power plants in maintaining grid stability. The rationale for developing cascade hydroelectric power plants has been widely recognized, as integrated operation and maintenance requirements have become increasingly prominent. The latest technologies such as cloud computing, Artificial Intelligence (AI), big data, Internet of Things (IoT), mobile terminal, and Virtual Reality (VR) are triggering a revolution in hydroelectric power plant automation systems.

Newly installed, renovated and partially refurbished hydroelectric power plants and remote control centers need innovative technologies to strengthen information sharing and coordination among equipment and applications. With the goal to realize multi-dimensional information sensing, comprehensive data display, interactive applications and intelligent warnings and decisions, and to cope with the challenges of operation, maintenance, dispatching and management, innovation involving multiple elements regarding system architecture, information model, integrated standards, software structures, business procedure, applications, optimized models, etc., should be conducted. The innovation based on such elements is multi-dimensional, flexible and open to different demands, rather than a mere improvement of certain technologies, so that hydroelectric power plants and remote control centers where those innovations are put into use can be called a smart hydroelectric power plant.

In the present document, open architecture has been proposed for a smart hydroelectric power plant and technical requirements for each part have been specified, thus improving the safe, reliable, efficient and economic operation of hydroelectric power plants/remote control centers, enhancing the interaction with the smart grid and facilitating ecological and environmental responsibility. The overall system structure and functionality are mainly determined by the scales, types, importance and complexity of specific smart hydroelectric power plants. The document describes a representative set of architectures, components and functionalities. The appropriate selection, extension or modification tailored to the needs of a specific power plant shall be chosen in a specific project. The document can be used as a reference for engineers of hydroelectric power plants/remote control centers, consultants or automation system vendors in helping the design of smart hydroelectric power plants, development of hardware and software products, implementation of projects, and compilation of related documents.

TECHNICAL GUIDELINES FOR SMART HYDROELECTRIC POWER PLANT

1 Scope

This document describes the integrated control and management of smart hydroelectric power plants and groups of plants using the latest proven and widely accepted digital equipment. The descriptions are applicable to all types of hydroelectric power plants except tidal and ocean power plants.

Based on internationally standardized communication models, this document incorporates guidelines for communication networks, sensors, local monitoring and control equipment, Integrated Control and Management Platform (ICAMP) as well as intelligent applications. In addition, special attention is also given to cyber security.

This document considers the future structure of completely digitalized power plants equipped with digitalized sensors and actuators as well as the intelligent control and management of power plants with existing instrumentation.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. ISO, IEC, and IEEE maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>
- IEEE Standards Dictionary Online: available at: <http://dictionary.ieee.org>

3.1

smart hydroelectric power plant

hydroelectric power plant or group of plants which is featuring digitalized information, networked communication, standardized integration, interactive applications, optimized operation, and intelligent decision

Note 1 to entry: Smart hydroelectric power plant uses Intelligent Electronic Devices (IEDs) and intelligent equipment for the automatic acquisition, measurement, control, protection and other basic functions, and possesses economic operation, analysis evaluation & decision support, security and safety interaction and other intelligent applications based on the Integrated Control and Management Platform (ICAMP) in compliance with grid and regulatory requirements.

3.2

process level

level of the architectural model which realizes data acquisition and command execution throughout the power generation process, typically consists of transducers/smart transducers, intelligent terminal, intelligent equipment, etc.

3.3

unit level

level of the architectural model which realizes monitoring, control and protection of equipment related to different units according to the pre-set strategy, typically consists of various IEDs

3.4

plant level

level of the architectural model which realizes monitoring, control, analysis, etc. for a plant, typically consists of computers, network equipment, ICAMP, and various intelligent applications, whose equipment is deployed in different physical locations such as a central control room and server room

3.5

group-of-plants level

level of the architectural model which realizes monitoring, control, analysis, evaluation, decision-support etc. for a group of plants, typically consists of computers, network devices, ICAMP, and various intelligent applications including economic operation, condition-based maintenance of a generation fleet, emergency command support, etc. whose devices are distributed in different physical locations of a remote control center such as a control room, reservoir scheduling duty office and server room

3.6

process bus

communication network which connects process-level and unit-level devices

3.7

plant bus

communication network which connects devices within the unit level and plant level, and connects unit-level to plant-level devices

3.8

group-of-plants bus

communication network which connects devices within the group-of-plants level and connects plant level to group-of-plants level devices

3.9

system

collection of parts and relationships among these parts that may be organized to accomplish some purposes

[SOURCE: IEC 62357-1:2016, 3.1.3]

3.10

control zone

zone with applications of real-time monitoring and control functions

3.11

non-control zone

zone with applications which are potentially required for the generation process, but not involved in control directly.

3.12

production control zone

zone consisting of control zone and non-control zone

3.13

management information zone

collection of management information systems outside the production control zone for power generation utilities

3.14

Intelligent Electronic Device IED

device within the unit level or process level incorporating one or more processors with the capability of receiving or sending data/controls from or to an external source (for example, electronic multi-function meters, digital relays, controllers)

3.15

smart transducer

analog or digital sensor or actuator combined with a microprocessor, a signal conditioning unit and a communication interface

3.16

intelligent terminal

IED which realizes data acquisition or command output, supports unified information model, has capabilities of self-diagnosis and self-recovery within the process level, connecting various sensors of pressure, flow, temperature, position, status, etc. or actuators through cables, as well as connecting other IEDs within the unit level through process bus, usually deployed near terminal boxes or equipment

3.17

merging unit

interface unit that accepts multiple analogue CT/VT and produces multiple time synchronised IEC 61850-9-2 compliant frames to provide data communication via the logical interface 4

[SOURCE: IEC TS 61850-2:2019, 3.109]

3.18

intelligent equipment

integration of electromechanical equipment or hydraulic facilities with electronic devices and transducers, featured with digital measurement, networked communication, unified information model, self-diagnosis and interactive information, and supports functions like monitoring, control and protection

3.19

data management

function which realizes uniform storage and management of models and data, and provides uniform data access service interfaces

3.20

basic service

technologies realizing background functionalities, for example, data communication, data processing, data access, chart service, log management, authority management, task management, workflow management, process management, Geographic Information System (GIS), alarms, expert system etc.

3.21

basic application

software realizing basic business functionalities of hydroelectric power plants, for example, supervision and control, reservoir scheduling automation, plant condition monitoring, dam safety monitoring, comprehensive information display and analysis, mobile application, etc.

3.22

Integrated Control and Management Platform ICAMP

software platform which consists of data management, basic services and basic applications, deployed separately in the control zone, non-control zone and management information zone, supporting the unified modeling of devices and other resources in hydroelectric power plants, providing standard interfaces and services for the integration of equipment, systems and intelligent applications, realizing data sharing, centralized control & management and collaborative interaction

3.23

intelligent application

application serving decision support of hydroelectric power plants, such as economic operation, Condition-based Maintenance (CBM), emergency command support, dam safety analysis and evaluation, intelligent alarm, etc., which is accomplished by modules deployed on the ICAMP or individual decision support system

3.24

Automatic Generation Control AGC

capability to control the power output of selectable units in response to total plant/group-of-plants output, tie-line power flow, and power system frequency

3.25

Automatic Voltage Control AVC

capability to control a specific power system voltage, via adjustment of unit excitation within the limits of unit terminal voltage and reactive power (VAR) capability

3.26

joint control

functions that enable the automatic control to coordinate the power/water across the system, e.g. AGC, AVC, water control of power plants or reservoirs

4 General principles

The general principles of smart hydroelectric power plants are as follows:

- 1) With the process bus, plant bus and group-of-plants bus as backbone network, a smart hydroelectric power plant should adopt a "level and zone" architecture. Furthermore, it should be based on smart transducers and IEDs within the process and unit levels, ICAMP within the plant level or group-of-plants level as the software platform, and intelligent applications deployed in correspondent zones as business requirements, promoting the safe and reliable operation of hydroelectric power plants. Before defining the final system architecture in a power plant, a careful risk analysis should be conducted on the dependencies and consequences of failures, etc. An analysis should also be conducted on maintenance needs, costs, effectiveness, etc., to meet the requirements in practical operations and those of the supervisory authorities.
- 2) An information model with the capability of self-description should be adopted. Such an information model enables IEDs and ICAMP to identify measured data correctly. The information model makes application functions independent of communication protocols. International standards described in 5.3 should be adopted in the model definition for electrical and mechanical equipment, hydraulic facilities, and functions, thus realizing object-oriented data management and enhancing the capability of fulfilling data sharing, application collaborations and intelligent data analysis.

- 3) Network communication should be adopted for information transmission. From the perspective of project practice and cost-effectiveness, smart transducers or "traditional transducer plus intelligent terminals" should be considered while highly efficient process, plant and group-of-plants buses should be used. Wireless networking (e.g. cellular data, Zigbee, LORA) can also be considered to increase system flexibility and reduce system installation and commissioning.
- 4) IEDs should embody interoperability. Interoperability is the ability of two or more devices either from the same vendor or from different vendors to exchange information for the correct execution of specified functions; it is the ability to operate in the same network or the same communication path sharing information and commands.
- 5) Smart hydroelectric power plants should realize integrated operation and management. Based on the ICAMP, it should facilitate integrated monitoring and data sharing for such basic applications as supervision and control, reservoir scheduling automation, plant condition monitoring, dam safety monitoring, protection information management and basic support systems like Closed Circuit Television (CCTV) and firefighting. Comprehensive data analysis and interactions among applications should be realized to promote the operation reliability and efficiency of a single power plant or group-of-plants. Integrated operation and management should meet demands such as unattended operation, coordinated dispatching of water resources and electricity, and remote fault diagnosis.
- 6) Smart hydroelectric power plants should provide intelligent decision support. Based on the features of a specific plant or group-of-plants, intelligent applications like condition-based maintenance decision support, emergency command support, dam safety analysis and evaluation, and intelligent alarm should be deployed selectively. Expert knowledge bases should be established and expanded continuously. Various models of analysis, evaluation and optimization should be built to improve the optimized decision-making capability.
- 7) Smart hydroelectric power plants should be featured with openness and flexibility. An open and flexible architecture conforming to well-established international standards and compatible with conventional automation devices and IEDs should be adopted and be able to meet the need for thorough or partial refurbishment of smart hydroelectric power plants. ICAMP should be equipped with standard and open interfaces, thereby providing data and service access to third-party intelligent applications under the condition of cyber security.

5 System architecture

5.1 Architecture model

IEC 62357 proposes the Smart Grid Architecture Model (SGAM). According to SGAM, the domains are divided into generation, transmission, distribution, Distributed Energy Resources (DER) and customer premises. The smart hydroelectric power plant is an important part of the smart grid and belongs to the generation domain. The smart hydroelectric power plant architecture model is shown in Figure 1.

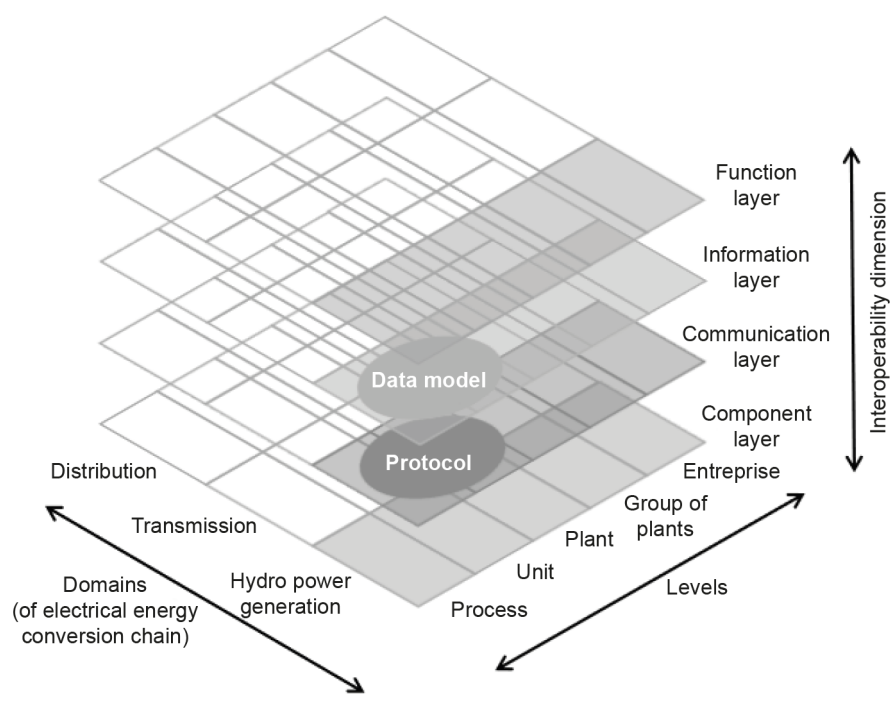


Figure 1 – System architecture model of a smart hydroelectric power plant

NOTE "Levels", "Unit", "Plant", "Group-of-plants" in this document correspond to "Zones", "Field", "Station" and "Operation" in IEC 62357 individually. The control center of the group is included in "Group-of-plants".

This document	IEC 62357
Levels	Zones
Unit	Field
Plant	Station
Group-of-plants	Operation

In the context of Clause 5, a system is a boundary which includes all layers of the architecture model of a smart hydroelectric power plant. Besides the domains of the electric energy conversion chain, the system architecture model of a smart hydroelectric power plant, as shown in Figure 1, is divided into two additional dimensions: for the first dimension based on the hierarchy of operation and management, the architecture model is divided into process level, unit level, plant level, and group-of-plants level, and each level is described in 5.2.2. The enterprise level is not included in the scope of this document. The process and the unit levels realize local control, the plant level realizes centralized control, and the group-of-plants level realizes off-site control. For the second dimension based on interoperability, the architecture model is divided into component layer, communication layer, information layer and function layer. The four layers are described below.

The component layer specifies the physical components involved in a smart hydroelectric power plant. It includes primary equipment, smart transducers, intelligent terminals, IEDs (generally located within the process and unit levels), network infrastructure (wired and wireless communication connections, routers, switches and firewalls), and any kinds of computers.

The communication layer describes mechanisms and protocols for the interoperable exchange of information between components in the context of the underlying functions, services and related information objects or data models.

The information layer describes the information being used and exchanged between functions and services. 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 achieve an interoperable information exchange via communication.

The function layer describes functions, services and their relationships. Functions are represented independently from their physical implementation in devices, applications and systems.

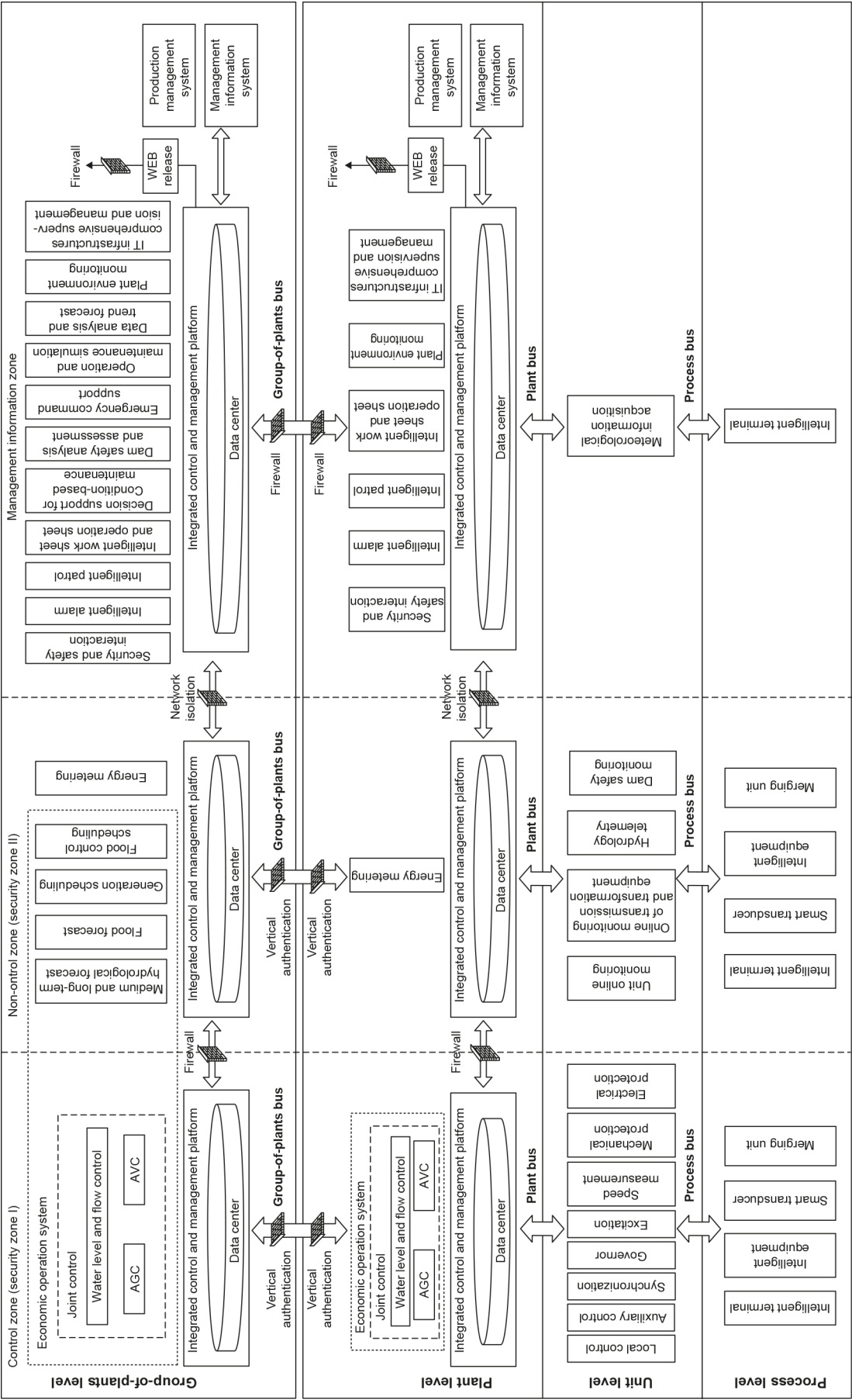
5.2 Logical architecture

5.2.1 Overview

In order to improve the system security and flexibility, the system architecture of a smart hydroelectric power plant should be "horizontally zoned and vertically leveled". Thus, a smart hydroelectric power plant should be horizontally divided into the production control zone and the management information zone horizontally. A zone can be established at one physical location or different physical locations. Detailed segmentation principles are described in 10.2. A single smart hydroelectric power plant should be divided into process level, unit level and plant level vertically. The process level and the unit level of the non-control zone and management information zone may be merged. The group-of-plants level can be set up according to business needs.

The overall system logical architecture of a smart hydroelectric power plant is shown in Figure 2. It represents the function layer within different levels, as well as the underlying communication structures according to the system architecture model in Figure 1.

The overall system structure is mainly determined by the scales and types of a smart hydroelectric power plant. The general architecture in Figure 2 shows a representative set of functions and components. An appropriate selection, extension or modification tailored to the needs of a specific smart hydroelectric power plant shall be chosen for a specific project.



NOTE Basic support system is a basic condition for the stable operation of a smart hydroelectric power plant and is not shown in Figure 2. Refer to Clause 6 for detailed information.

Figure 2 – Typical system logic architecture of a smart hydroelectric power plant

Figure 2 shows a typical deployment of smart transducers, IEDs, ICAMP and intelligent applications of a typical smart hydroelectric plant.

A smart hydroelectric power plant should include basic support systems including a time synchronization system, power supply system, CCTV System, firefighting system, access control system, etc.

For a detailed description of functions and components, see Clauses 6 to 9.

5.2.2 Description of levels and zones

For the production control zone and the management information zone, a scalable approach can be taken based on the size, importance and cost-effectiveness of a smart hydroelectric power plant. The security level is decreased in the sequence of the control zone, non-control zone and management information zone. Zone(s) with lower security may be merged into a zone with higher security.

Vertically, the functions and components of the levels are as follows:

1) Process level

The process level mainly covers data acquisition and command execution in support of power generation. It includes the acquisition of real-time electrical signals, non-electrical signals and execution of control commands. The process level physically consists of intelligent terminals, IEDs, intelligent equipment, smart transducers, etc.

2) Unit level

The unit level mainly covers local monitoring, control and protection of a smart hydroelectric power plant. In the production control zone, local control, auxiliary control, synchronization, governor, excitation, electrical protection and mechanical protection should be deployed in the control zone. Mechanical protection consists of two parts, one is realized by vibration protection devices, and the other one (temperature, pressure, etc.) is realized by local control devices. Unit online monitoring and hydrology telemetry should be deployed in the non-control zone. In the management information zone, dam safety monitoring, CCTV (closed-circuit television) and other functions should be deployed. Some special functions should be deployed in corresponding zones according to the respective safety requirements. For example, the firefighting function which triggers the unit emergency shutdown should be deployed in the control zone, while those without such triggers should be deployed in the non-control zone.

3) Plant level

The plant level consists of computers, network devices, ICAMP, intelligent applications, which are realizing monitoring, control, analysis, evaluation, etc. The devices of the plant level may be distributed in different physical locations of a hydroelectric power plant, such as a central control room and/or server room.

In terms of the deployment of basic applications, supervision control should be deployed in the control zone, while reservoir scheduling automation and plant condition monitoring should be deployed in the non-control zone. The comprehensive information display, mobile application, etc., should be deployed in the management information zone. In addition, the ICAMP performs the gathering and storage of information acquired from the production control zone, management information zone and basic support systems, and thus forms the data center of a smart hydroelectric power plant.

In terms of deployment of intelligent applications, joint control should be deployed in the control zone, protection information management and energy metering should be deployed in the non-control zone. Security and safety interaction, intelligent alarm, intelligent patrol, intelligent work sheet and operation sheet, plant environment monitoring, IT infrastructure monitoring and management, etc., should be deployed in the management information zone.

4) Group-of-plants level

The group-of-plants level covers monitoring, control, analysis, evaluation, decision-support etc., for a group of plants. It typically consists of computers, network devices, ICAMP, and various intelligent applications including economic operation, condition-based maintenance of generation units, emergency command support, etc. The devices within this level are distributed in different physical locations of a remote control center, such as a central control room, reservoir scheduling duty office and server room.

The deployment of basic applications within the group-of-plants level is the same as that of the plant level. For intelligent applications, joint control should be deployed in the control zone. Medium and long-term hydrological forecast, flood forecast, generation scheduling, flood control scheduling, protection information management and energy metering should be deployed in the non-control zone. Security and safety interaction, intelligent alarm, intelligent patrol, intelligent work sheet and operation sheet, decision support for condition-based maintenance, dam safety analysis and assessment, emergency command support, data analysis and trend forecast, plant environment monitoring and IT infrastructure monitoring and management should be deployed in the information management zone.

For smart hydroelectric power plants which do not have a group-of-plants level, the above-mentioned intelligent applications may be deployed within the plant level according to the project's needs.

5.3 Information model

A smart hydroelectric power plant should adopt a unified information model to facilitate the exchange of information. Otherwise, it would be difficult to exchange information between power plants, applications and equipment from different vendors.

A smart hydroelectric power plant should adopt object-oriented information models of mechanical and electrical equipment, hydraulic facilities, functions, etc., so as to improve interoperability of devices and system flexibility, and to promote system compatibility with the smart grid.

A smart hydroelectric power plant may adopt the following information models:

- 1) The information model specified in IEC 61850 is used to define the abstract syntax and semantics of the information exchanged between IEDs and is presented in terms of data object classes and types, attributes, abstract object methods (services), and their relationships. More descriptions of the information model can be found in IEC 61850-7.
- 2) Common Information Model (CIM) specified in IEC 61970 and IEC 62325 includes equipment, functions and their attributes for power system management, analysis and related use cases. More descriptions of the information model can be found in IEC 61970-301 and IEC 62325-301.
- 3) The information model specified in IEC 62264 includes five levels (level 0 to level 4): physical processes level, smart devices level, monitoring and controlling level, manufacturing operations management level, and business planning and logistics level for integration of control systems to enterprise systems.
- 4) The information model specified in IEC 62541 adopts object-oriented technology, defines a unified address space to store real-time data, historical data, and event notifications, and provides services for other applications with a unified, safe and reliable interface.
- 5) IEC 81346 provides a Reference Designation System (RDS) for modelling the physical system hierarchy of the plant. The resulting tag can also be used as a designator in other data models, e.g. as the logical device structure in IEC 61850. It provides simplified object references that can bridge information systems together (such as process control, documentation and maintenance systems).

5.4 Network structure

5.4.1 General

A smart hydroelectric power plant should realize zone segmentation, dedicated networks, horizontal isolation and vertical authentication (see 10.2 for details). The communication network of a smart hydroelectric power plant should include process bus, plant bus, group-of-plants bus. Each network should adopt standard protocols.

- 1) The process bus may adopt GOOSE and SV network specified in IEC 61850, Fieldbus specified in IEC 61158, or other industry-recognized standards to communicate between process level devices and unit level devices, as well as between devices within the unit level.
- 2) The plant bus may adopt IEC 61850 MMS, OPC Unified Architecture (OPC UA) specified in IEC 62541, IEC 60870-5-104, IEC 61970, or other industry-recognized standards.
- 3) The group-of-plants bus may adopt IEC 61850 MMS, OPC Unified Architecture (OPC UA) specified in IEC 62541, IEC 60870-5-104, IEC 61970, or other industry-recognized standards.

For functions that require high availability, the process bus, plant bus and group-of-plants bus in the production control zone should adopt a network structure with high availability like dual network, ring network, etc. The results of the risk analysis should be taken into account, e.g. the physical separation of redundant components. For less critical functions, redundant network, power supply, key equipment and core applications are not required.

In addition, the process bus and the plant bus may be segmented into different subnets according to the real-time performance and security requirements of different applications.

Optical fiber is recommended to improve reliable network communication in the control zone.

Wireless communication may be adopted at all levels where suitable. Wireless technologies encounter more challenges in protecting against illegal intrusion compared to wired communication (e.g. because wireless signals do not stop at the property border of the power plant). This risk should be considered in cyber security analysis.

5.4.2 Network structure of plant level and group-of-plants level

A typical network structure of plant level and group-of-plants level of a smart hydroelectric power plant is shown in Figure 3. A smart hydroelectric power plant adopts network isolation to isolate the production control and the management information zones.

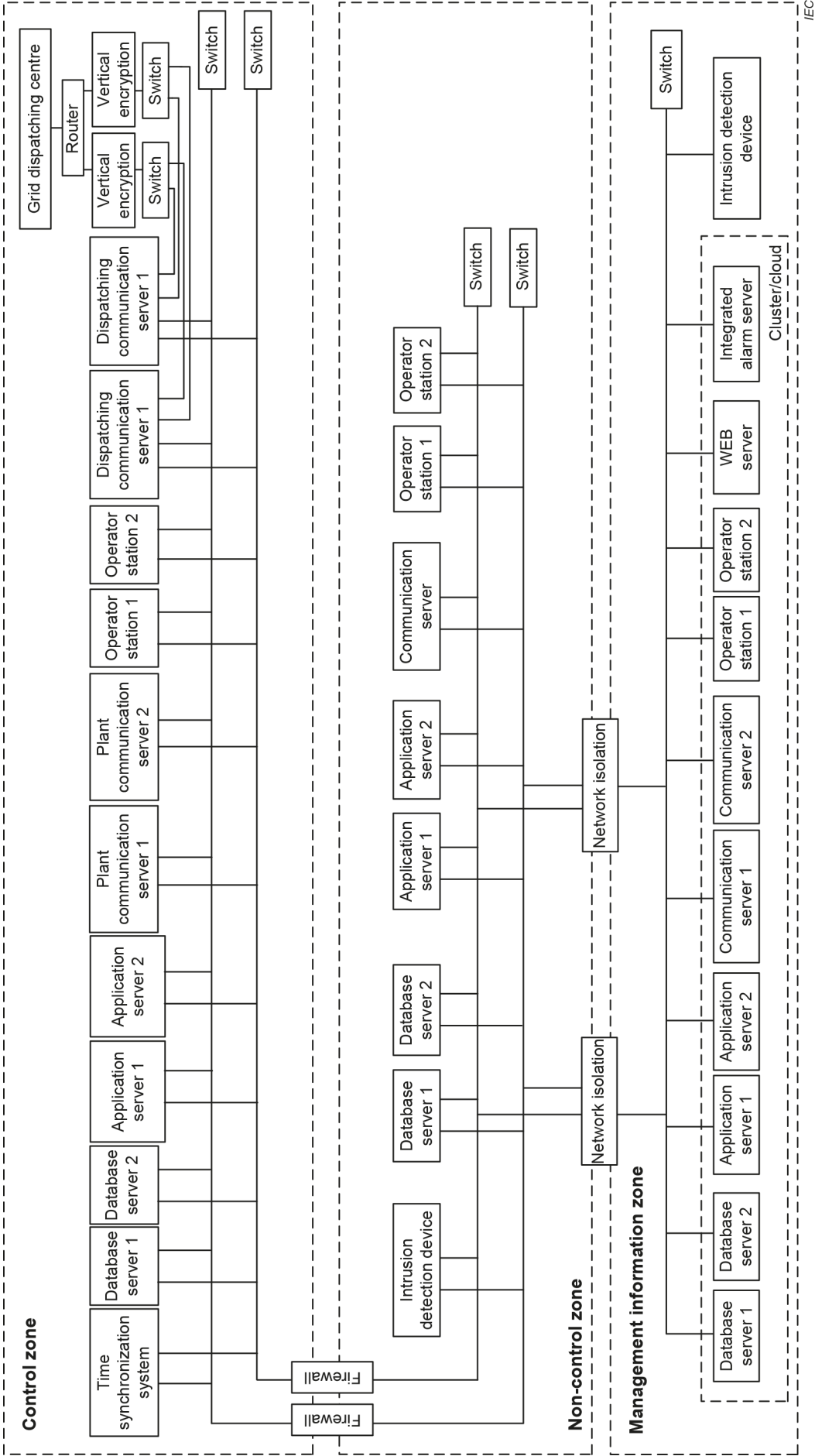


Figure 3 – Typical physical structure of plant level and group-of-plants level of a smart hydroelectric power plant

As shown in Figure 3, intrusion detection devices and switches should be deployed in the control zone and non-control zone. Network firewalls should be used to separate the control zone and non-control zone. For plants with higher cyber security protection between the production control zone and the management information zone, data diodes can be used or even be redundantly deployed.

The communication between plant level, group-of-plants level, and dispatching centers should adopt devices that provide Wide Area Network (WAN) boundary protection for the production control zone. Protection should include authentication and encryption functions as well as network management, anti-virus, security and integrity of transmitted data. In the management information zone, devices should be used to provide isolation and access control for communications between the group-of-plants level and the plant level.

For plants with high availability requirements, redundant server configurations can be deployed – either on-site or securely cloud-based.

5.4.3 Network structure of unit level and process level

A typical network structure of unit level and process level of a smart hydroelectric power plant is shown in Figure 4.

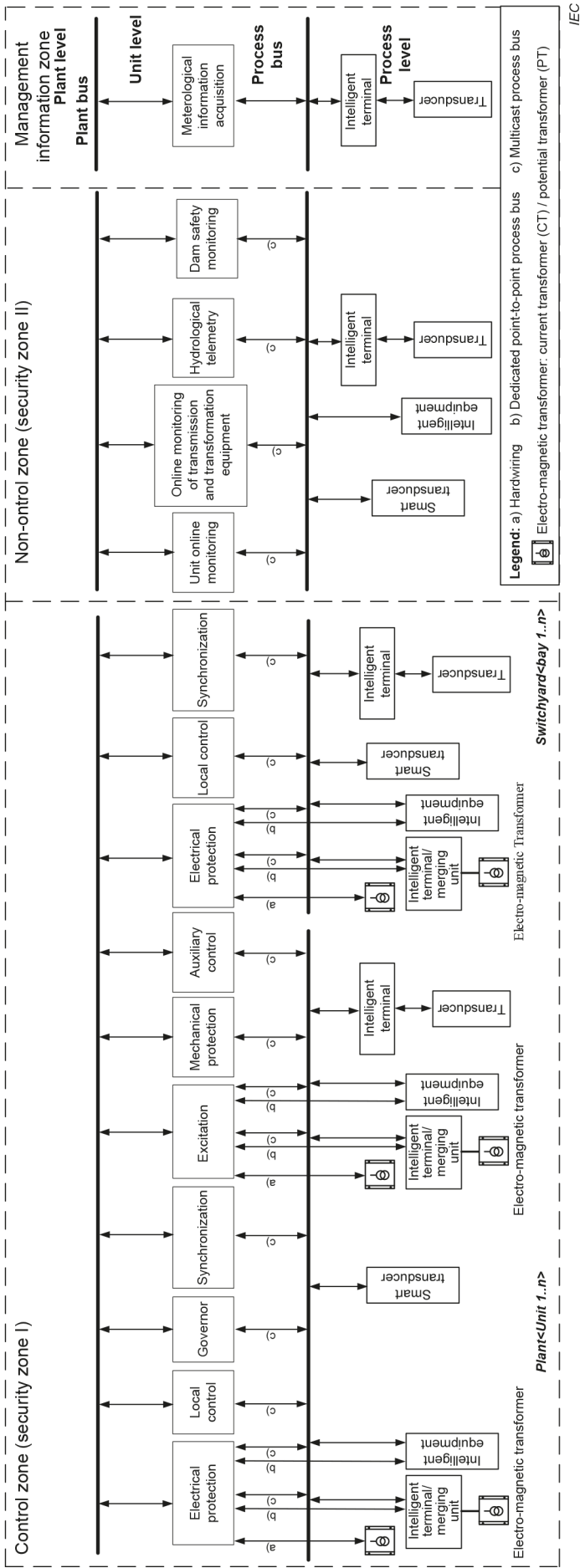


Figure 4 – Typical network structure schematic diagram of process level and unit level

Process level devices (including intelligent terminals, intelligent equipment and smart transducers) should be connected to the process bus. Unit level devices should be connected to the process and plant bus. As shown in Figure 4, unit level devices can be connected to sensors and actuators via multicast process bus (c), dedicated point-to-point process bus (b) or hardwiring (a). Dedicated point-to-point process bus or hardwiring is used to realize direct sampling/tripping.

In the case of hardwiring, the smart functionality shall be implemented in the device with hardwired interfaces. Redundancy, self-supervision etc., should be considered for the overall system design when determining which approach is adopted. Figure 4 shows an example of the physical connections of the protection and excitation function, which can be applied to other unit level functions like governor etc. accordingly.

The process bus should be divided into sub-networks according to units such as hydroelectric power units, switchyard, etc. Multiple switches can be used to form independent networks, or separated VLANs can be used to realize logical isolation.

The failure of a single device within the unit level should not affect the normal operation of other devices. When the plant bus fails, the unit level devices should be able to operate independently and meet the basic requirements of unit operation.

In summary, the smart hydroelectric power plant should adopt the network structure of "four levels and three buses". In terms of information modelling and communication protocol, it implements the unified information modelling of a hydroelectric power plant and networked and standardized communication for achieving interoperability among devices. Suggested examples of suitable modelling and communication structures are provided in 5.4.4. Based on the ICAMP, it implements data sharing and application integration.

5.4.4 Variants for the network structure

Due to the variety of hydroelectric power plants, it is advisable to consider the automation system status, equipment delivery situation, etc., during the construction and refurbishment of smart hydroelectric power plants.

The architectural Figure 5, Figure 6, Figure 7 and Figure 8 are to be understood as examples. A customized variant for a real project shall always be defined and specified according to the individual requirements of the project.

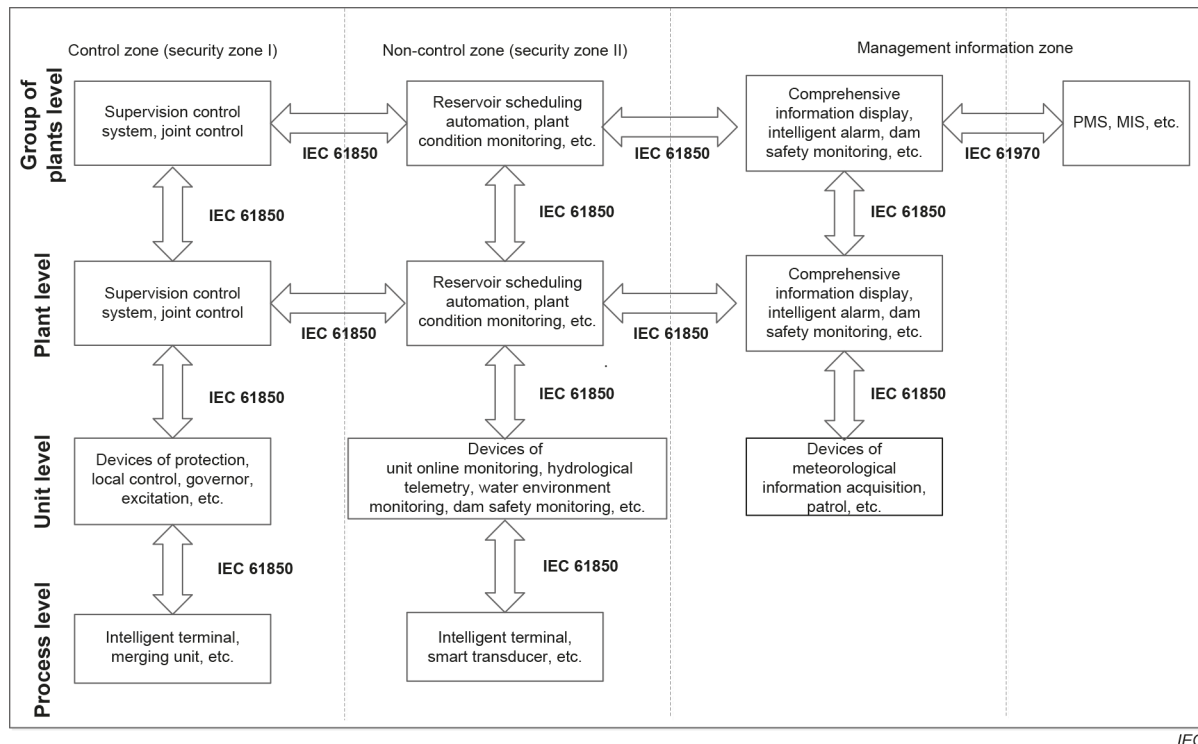


Figure 5 – Recommended communication network structures (Variant A)

As shown in Figure 5, the communication protocol of the process bus is recommended to adopt GOOSE, SV and MMS protocols. MMS is used for signals with slow change rates. The communication protocol of plant bus and group-of-plants bus is recommended to adopt MMS for the vast majority of data exchange. GOOSE can be used for the plant bus in the production control zone, for critical data exchanges in specific situations like interlocking and inter-trip between controllers. Within the plant level and group-of-plants level, if the network isolation device between the production control zone and management information zone can not support MMS protocol, dedicated protocols may be used.

IEC 61850 MMS protocol is recommended for communication between the control zone and the non-control zone within the plant level. IEC 61970 is recommended for communication between the applications of a smart hydroelectric power plant and other applications relevant to production management in the plant, such as Production Management System (PMS), Management Information System (MIS), etc. PMS is an integrated software platform used for asset management, monitoring, predictive maintenance, visual display, production safety and reliability management.

The recommended network conforming to IEC 61850 lays a foundation for a unified information model, effectively reduces the signal cables of hydroelectric power plants and improves project commissioning efficiency. In addition, the GOOSE communication protocol specified in IEC 61850 features high real-time performance and reliability.

For the redundancy design, IEC TR 61850-90-20 should be considered.

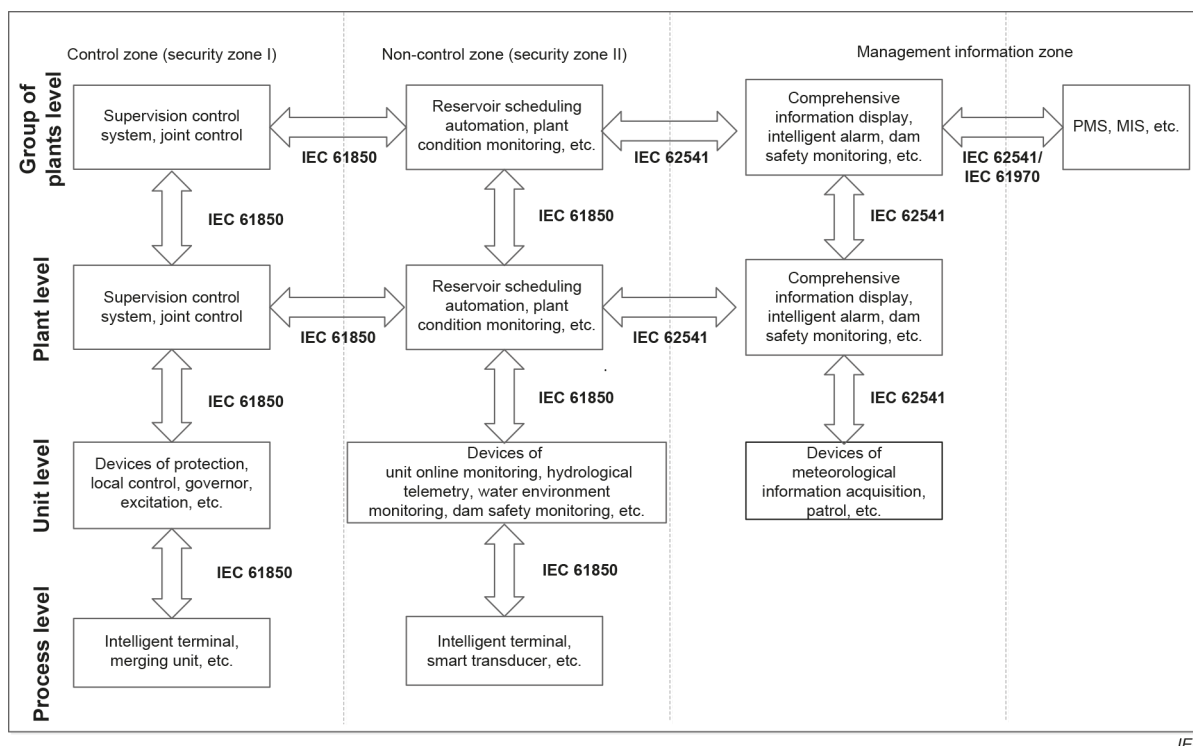


Figure 6 – Recommended communication network structures (Variant B)

As shown in Figure 6, the communication protocol of the process bus in the production control zone adopts GOOSE, SV and MMS protocols specified in IEC 61850. The communication protocol of the plant bus and group-of-plants bus in the production control zone adopts the MMS protocol specified in IEC 61850, and the communication protocol of the plant bus and group-of-plants bus in the management information zone adopts IEC 62541.

The communication between the control zone and non-control zone of the plant level is realized by IEC 61850 MMS protocol. The communication between the production control zone and management information zone is realized by IEC 62541. In the management information zone, the communication between the applications of a smart hydroelectric power plant and other applications in the plant such as PMS, MIS, etc., is realized by IEC 62541 or IEC 61970.

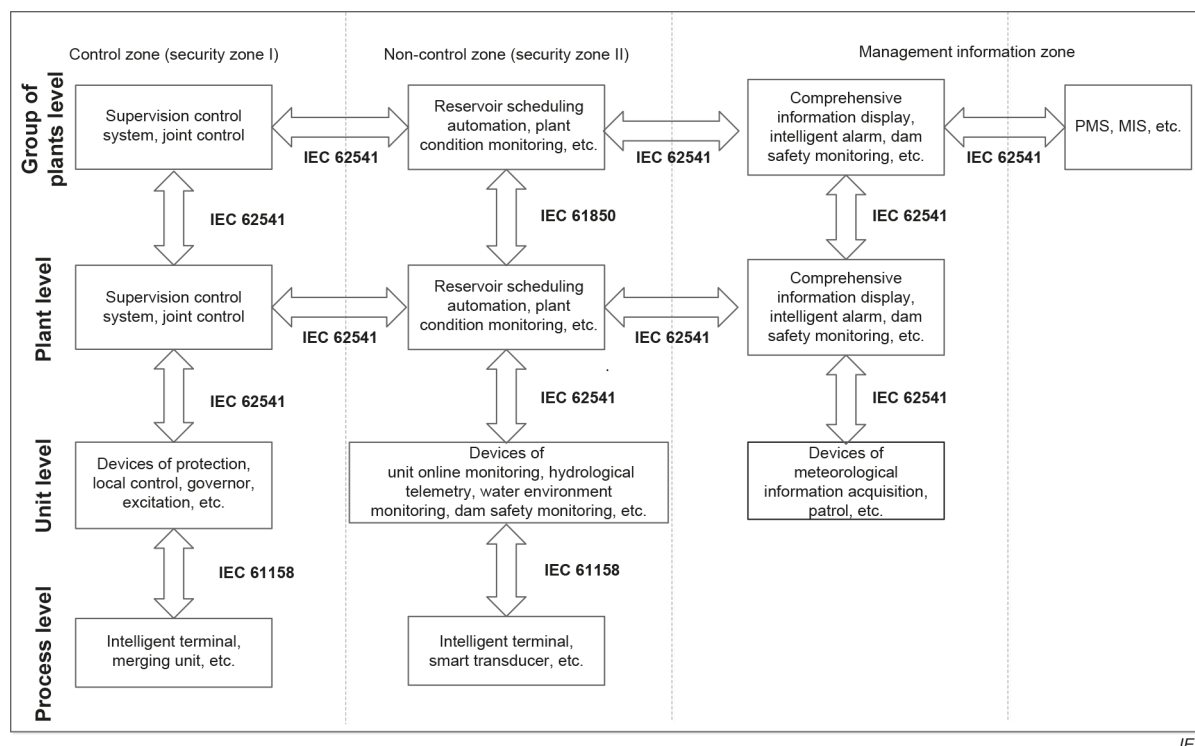


Figure 7 – Recommended communication network structures (Variant C)

As shown in Figure 7, IEC 61158 field bus is recommended for the process bus of a smart hydroelectric power plant, while IEC 62541 is recommended for the plant bus and group-of-plants bus. Furthermore, IEC 62541 is recommended for the communication between zones, as well as the communication between ICAMP and applications in the management information zone. Direct communication between the control zone and management information zone may be realized based on project needs.

In this structure, IEC 62541 is adopted consistently, except that IEC 61158 is adopted for the process bus. Because IEC 61158 involves more than 20 types of field buses and is supported by many manufacturers' alliances, many technologies and products can be selected within the standard. IEC 62541 has the characteristics of cross-platform, high reliability, high security and integrated data modelling, which can improve information sharing. IEC 62541 especially provides the functionality to connect smoothly to smart industrial automation.

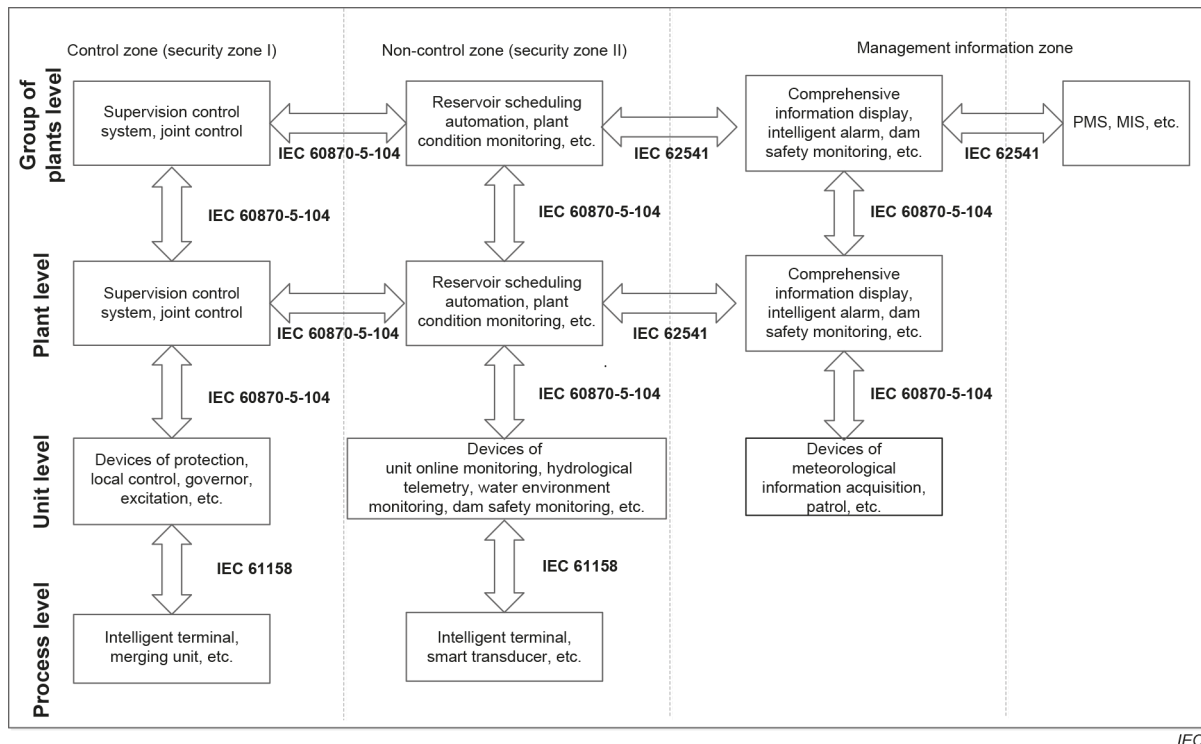


Figure 8 – Recommended communication network structures (Variant D)

As shown in Figure 8, IEC 61158 is recommended for the process bus of a smart hydroelectric power plant. IEC 60870-5-104 and IEC 62541 protocols are recommended for the plant bus and group-of-plants bus. IEC 60870-5-104 protocol is recommended for the communication between the control zone and non-control zone within the plant level and group-of-plants level. IEC 62541 is recommended for the communication between the production control zone and management information zone, and the communication between ICAMP and different applications in the management information zone.

This recommended network structure realizes the communication between devices within the group-of-plants level, between devices within the plant level, between group-of-plants level devices and plant level devices, and between plant level devices and unit level devices by adopting the protocol specified in IEC 60870-5-104. Because the protocol is open and widely used, the information exchange can be easily performed.

5.4.5 Network configuration of retrofit engineering

When retrofitting existing hydroelectric power plants, a decision needs to be made regarding the amount of existing control equipment to be replaced.

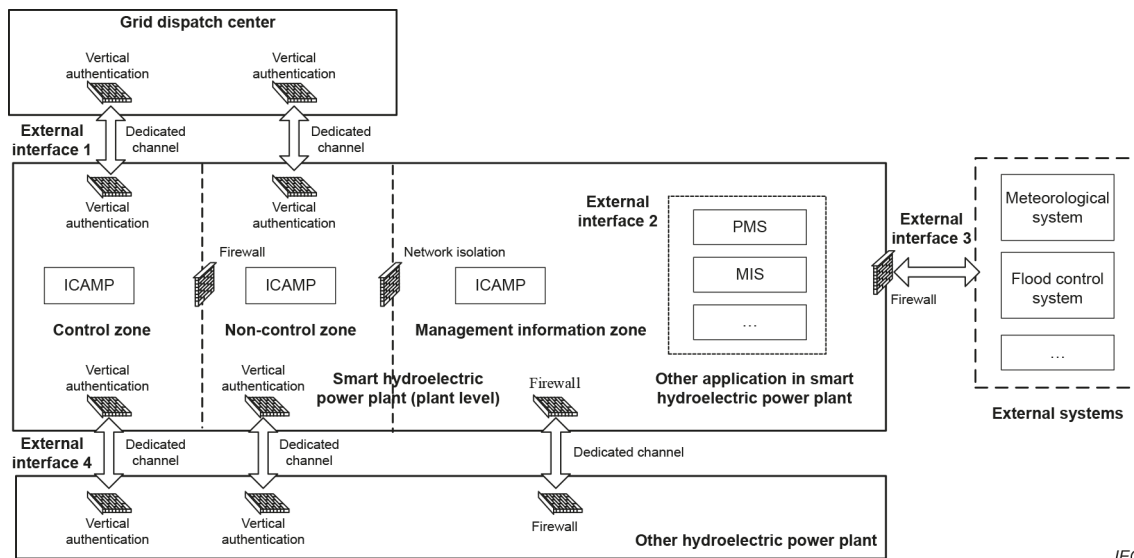
For retrofit projects of smart hydroelectric power plants which retain the original automation system, an ICAMP should be deployed. If the existing local automation devices have communication interfaces and information modelling tools related to variants A to D, they can be directly connected to the ICAMP. Otherwise, they can be connected to the ICAMP with the additional configuration of network protocols/protocol converters and information modelling tools.

IEDs within the process level and unit level and ICAMP should be deployed.

If only the sensors and actuators of the existing control system are being retained, then IEDs should be provided at the process and unit levels and integrated into the overall network structure via ICAMP as described in Figure 5 to Figure 8.

5.4.6 External communication interfaces

Interfaces connecting a smart hydroelectric power plant with external devices and systems are typically used for communication with a grid dispatching center, communication with other applications relevant to production management in a smart hydroelectric power plant, communication with external systems (systems of institutes other than hydroelectric power plants, like meteorological systems, flood control systems), and communication with other hydroelectric power plants. An example of external interfaces of a smart hydroelectric power plant is shown in Figure 9. External interfaces 1 to 4 of Figure 9 are bidirectional.



IEC

Figure 9 – Example of external interfaces of a smart hydroelectric power plant

- 1) Interface 1: The communication with the grid dispatching center mainly includes power dispatching communication in the control zone and generation scheduling communication in the non-control zone. The communication protocol should adopt IEC 60870-5-104, IEC 60870-5-101, etc. Vertical authentication and encryption devices should be deployed at the network perimeter of the smart hydroelectric power plant and grid dispatching center.
- 2) Interface 2: The communication with other systems such as the PMS, MIS, etc. in the smart hydroelectric power plant as well as with basic support systems such as firefighting systems, access control systems and CCTV systems, should conform to IEC 61970, IEC 62541 or other industry-recognized standards.
- 3) Interface 3: Because meteorological and flood control information comes from the public network, firewalls should be deployed at the network perimeter between the management information zone and external systems. The communication should follow IEC 61970, IEC 62541 or other industry-recognized standards.
- 4) Interface 4: The communication between hydroelectric power plants should conform to IEC 60870-5-104, IEC 62541 (OPC UA), IEC 61850, IEC 61970 or other industry-recognized standards. For communication with external hydroelectric power plants, authentication and encryption devices should be deployed respectively at the network perimeter of the power plants. The communication between hydroelectric power plants may also be performed by a remote control center (if group-of-plants level exists).

6 Basic support system

6.1 Overview

The basic support system is a condition for the stable operation of a smart hydroelectric power plant, generally including a time synchronization system, power supply system, CCTV system, firefighting system and access control system. A large screen display can be optionally included according to the needs of the project.

The design and manufacturing of the basic support system should conform to local legal requirements and existing standards. The newly added functions related to smart hydroelectric power plant applications should not affect its original functions, and those new functions should also conform to local legal requirements and existing standards as well.

6.2 Time synchronization system

The time synchronization system is applied for the time synchronization of devices in smart hydroelectric power plants. Without time synchronization, devices can not be synchronized with the standard time due to a time error. When critical events happen, the time difference of devices makes it difficult for event analysis.

Thus, a time synchronization system should be established to provide different kinds of time synchronization signals for all devices in the smart hydroelectric power plant, realizing the consistency between devices' time with the standard time.

For projects with high availability requirements, redundant clock hosts are recommended to be adopted. The clock host receives satellite time synchronization signals corresponding to certain countries or regions via antenna, a time synchronization message in compliance with NTP/SNTP specified in RFC 5905, or other external signals for time synchronization. Other external signals with a precise frequency can be used to improve the clock's time accuracy if the primary external time synchronization signal is lost. The adoption of a time synchronization signal source should be analyzed according to the project's needs. The time synchronization system should be equipped with a high precision clock inside. When the external time synchronization signal is lost, the system can keep timing via the internal clock. When the external time synchronization signal is restored, it should cease the use of the internal clock and restore the time synchronization with the external time synchronization signal. In both cases, the system should output the time synchronization information stably and continuously.

Network communication is widely applied in smart hydroelectric power plants, which enables time synchronization based on the network. The time synchronization system should have the function of generating time synchronization signals via the network. The Network Time Protocol (NTP) and the Simplified Network Time Protocol (SNTP) should be applied as time synchronization protocols. For equipment which requires very high time precision, the Precision Time Protocol (PTP) specified in IEC 61588 should be applied; e.g. for Phase Measurement Units (PMUs) or for IEC 61850 Sampled Values (IEC/IEEE 61850-9-3), which meets the highest time precision with errors no more than $\pm 1\mu\text{s}$. Apart from the network time synchronization, the time synchronization system should have the function of generating other forms of time signals like IRIG-B (AC) code, IRIG-B (DC, RS-485/422/TTL) code, and 1PPS/1 PPM/1PPH/1PPX pulse output which meets the requirements specified in IEEE/IEC 60255-118-1.

6.3 Power supply system

The smart hydroelectric power plant is usually equipped with multiple power supply systems, mainly including AC, DC, inverter power supply systems, Uninterruptible Power Supply (UPS) systems, power supply for communication systems, etc.

The power supply systems should have a networked communication function for displaying and analysis of real-time information such as current, voltage, temperature, load, battery status, etc. The power supply management application for performing this function may be part of the ICAMP or provided separately to communicate with the ICAMP. When an abnormality occurs in a power supply system, immediate alarms and handling guidance should be given to facilitate maintenance and reduce the potential impacts of power supply system faults.

6.4 CCTV system

The CCTV system is used to visually supervise critical systems, structures and personnel movement on the project. The quantity and placement of cameras should be commensurate with the level of reliability and security required by the project.

The CCTV system should support the remote control of the camera and Pan/Tilt/Zoom (PTZ). It should support image combination, zoom in/out and switch to any camera image as the main display. Provisions for video/audio recording and playback should be provided.

The CCTV system should operate independently. It should be equipped with communication interfaces with ICAMP, through which information from the CCTV system (including camera layout, work status, video/audio, alarms, etc.) can be transmitted to security and safety interaction applications. Commands from the application can be received to adjust the camera position to monitor relevant areas.

6.5 Firefighting system

The firefighting system consists of firefighting device(s), fire detector(s), and local control devices connected via a network or cables. When a fire is detected, the corresponding firefighting device alarms automatically and can optionally trigger a unit shutdown for protection.

The firefighting system should operate independently. It should be equipped with communication interfaces with ICAMP, through which corresponding information (including smoke or temperature sensor deployment, work status, fire signals, alarms, etc.) is sent to the security and safety interaction application. Firefighting devices should generate signals via hardwiring to other systems (e.g. CCTV, access control, etc.) to record relevant information and assist personnel in evacuating or dealing with the accident when a fire breaks out.

6.6 Access control system

The access control system should manage entry permission, control the doors in corresponding areas, and store access records for queries. The access control system may support access through induction cards, fingerprints, facial recognition, iris, etc. When the access control system detects abnormal operations like opening/closing the door without permission, keeping the door open excessively long, or using an invalid card, it should send out light and audio alarms, and send alarm information to the security personnel. For projects with high availability requirements, the smart hydroelectric power plant should be equipped with an access control system for all critical areas. Otherwise, a simplified perimeter access control system may be used.

The access control system should operate independently, and it should be equipped with communication interfaces with ICAMP, through which access control information including access status, entry/exit record and alarms, etc., should be sent to the security and safety interaction application. The access control system should receive operation commands via hardwiring from the firefighting system to execute relevant operations (e.g. unlock the doors along the escape passage) when there is a fire, which facilitates personnel evacuation.

6.7 Large screen display system

The large screen display system can be adopted to display the single line diagram of a hydroelectric power plant, the operation status of the main equipment, and important operation parameters like load, water level, etc. It can display multichannel data and graphs from different systems. The large screen displays can be split or merged according to requirements. The large screen display system should be adaptable to projects with high availability requirements.

The large screen display system should have a communication interface with ICAMP, through which its operation status information (including configuration parameter, internal temperature, running time, alarms, etc.) can be sent to ICAMP.

7 Smart transducer

7.1 Overview

The transducer plays a key role in the safe and stable operation of the plant. In addition to voltage, current, power, frequency, and other electrical signals, the sensing information of hydroelectric power plants also includes many non-electrical signals, such as temperature, pressure, flow, vibration, speed, and position. Each type of transducer realizes measurement of single or multiple physical quantities, mainly outputs an analogue signal, and uses two-wire, three-wire, or four-wire connection modes. The smart transducer enriches the sensing information, reduces cables, A/D, and D/A conversion losses, and additionally provides high signal transmission noise immunity. The smart transducer is provided with self-description, self-diagnosis, and self-adjustment (calibration) features, promoting the reliability of sensing information. The control execution can be applied in the same way for actuators as it is described for sensors in 7.2 and 7.3.

Smart transducers should be applied for smart hydroelectric power plants based on consideration of cost-effectiveness.

Conventional transducers combined with IEDs may also be applied.

7.2 General technical requirements

Currently, field bus (e.g. CAN, Profibus, HART, FF) has been widely applied for digitalization and networked applications of transducers. Smart transducers integrate sensing elements, transducing elements, microprocessors, and communication interfaces, and realize functions of sensing, information processing, and communication. Smart transducers should embody the following nine features, and more feature descriptions should refer to IEEE Std 1451.

1) Self-identification

The smart transducer automatically identifies its location, detects signals/orders sent by other transducers/devices and other information transmitted by the network (such as time).

2) Self-description

The smart transducer sends information to other transducers/devices to describe its functions, status, etc.

3) Self-diagnosis

The smart transducer conducts self-diagnosis to verify whether its components are working properly. In addition, it detects its conditions and locates the faults.

4) Self-calibration

The smart transducer automatically calibrates measurement deviation, and compensates for known errors (or error sources) through software or predefined calibration parameter.

5) Data processing

The smart transducer digitalizes the measured quantity, conducts data screening, calibration and analysis, calculation, etc., to realize automatic measurement, adjustment, balancing, and compensation.

6) Reasoning

The smart transducer conducts analysis and judgement based on results of data processing or information acquired by other means, and outputs the reasoning results.

7) Notification

The smart transducer sends notifications based on reasoning results via the network.

8) Remote configuration

The smart transducer offers remote configuration for easy maintenance.

9) Remote software upgrading

The smart transducer is accessible for remote upgrading of firmware or software programs.

Remote configuration and remote software upgrading should only be performed for limited conditions (e.g. commissioning status, special maintenance requirements, and cyber security upgrades) with full consideration of cyber security and authorization.

7.3 Structure of smart transducers

The smart transducer integrates sensor(s), signal conditioning, data conversion, microprocessor(s), communication interface(s), etc., to provide information sensing, processing and communication. Composite smart transducers should be applied for composite measurement points like bearing lubrication oil temperature and level, cooling water flow and temperature, to reduce transducer quantity and network nodes. The structure of smart transducers is shown in Figure 10 a) and b).

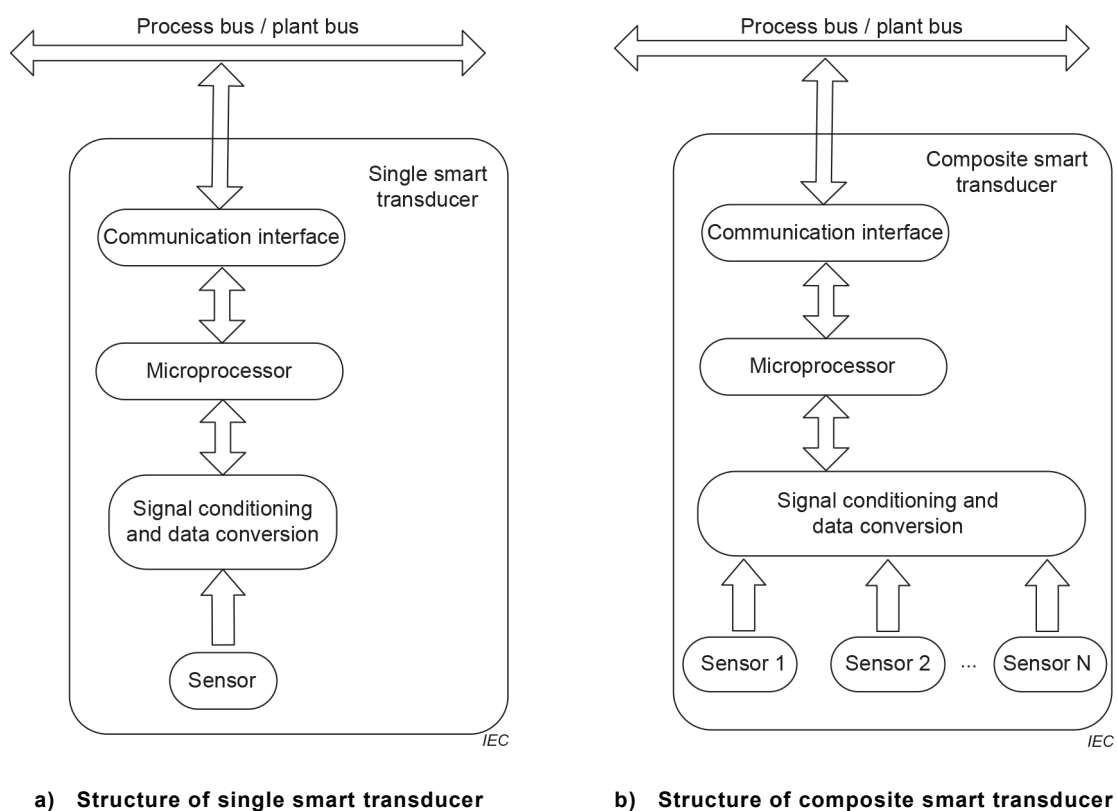
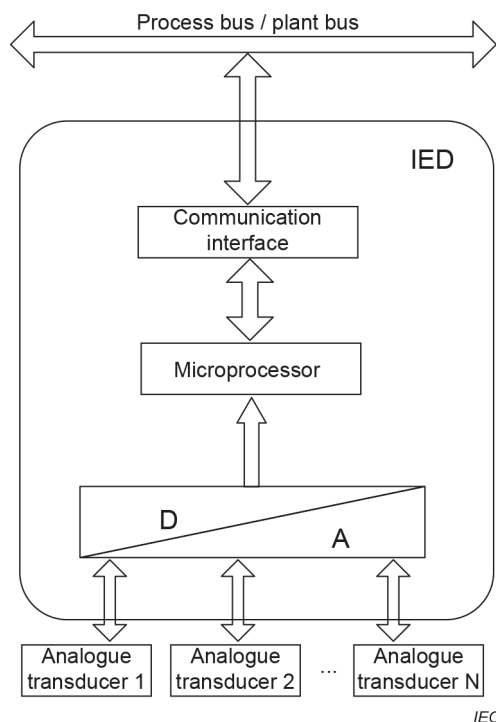


Figure 10 – Structure of smart transducers

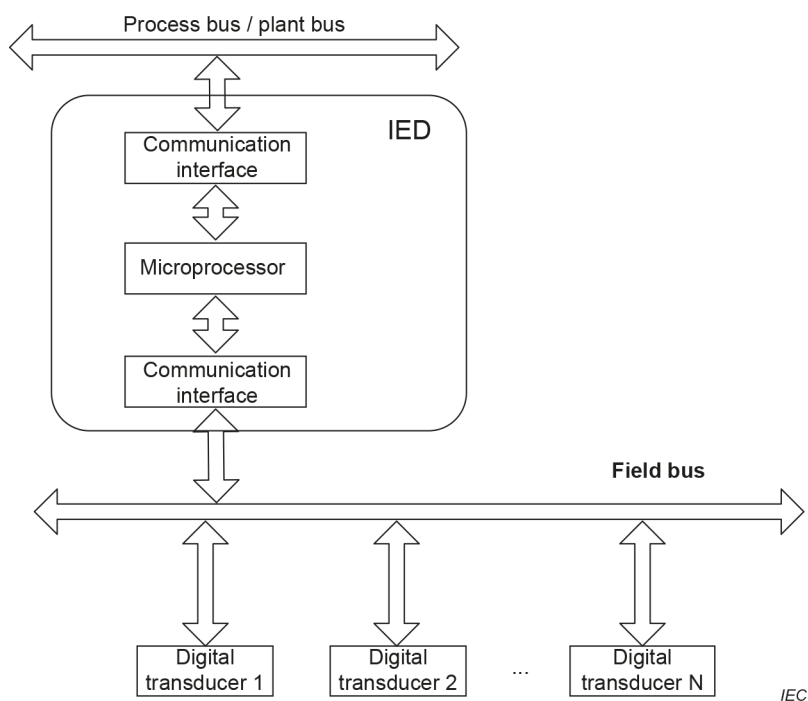
The smart transducer should adopt network communication interfaces and be usually connected to the process bus.

The smart transducer which is not involved in generation control directly (transducers for dam safety, meteorology monitoring, environmental monitoring, etc.) may be connected to the plant bus.

Existing hydroelectric power plants have large quantities of conventional transducers with analogue outputs or field bus communication interfaces. Conventional transducers may be applied in smart hydroelectric power plants configured as shown in Figure 11. Figure 11 a) is for analogue transducers, in which analogue/digital conversion, the microprocessor and communication interfaces, etc., are integrated into the IED. Figure 11 b) is for digital transducers, in which the microprocessor and communication interfaces are integrated into the IED.



a) Adaption of conventional analogue transducers



b) Adaption of conventional digital transducers

Figure 11 – Adaption of conventional transducers

8 Functional requirements of IEDs

8.1 Overview

IEDs of a smart hydroelectric power plant accomplish functions of measurement, control, monitoring, protection, etc. Usually, IEDs have advanced functions such as self-diagnostics, self-recovery, remote operation and maintenance. The IEDs should conform to unified standards.

The IEDs are logically deployed within the unit level and process level and should be physically located nearby the relevant equipment. IEDs within the process level should connect the sensors and the actuators via cables to acquire signals and give out commands, and communicate with the IEDs within the unit level via the process bus. IEDs within the unit level exchange data with each other via the process bus or plant bus and should communicate with ICAMP via the plant bus.

This clause provides a superset of functions for a smart hydroelectric power plant.

8.2 General technical requirements

The IEDs should meet the following technical requirements:

- 1) Modular design should be applied to meet the requirements of easy integration, extension, updating, and maintenance.
- 2) Standard communication interfaces specified in 5.4 should be provided to realize interoperation among devices, reduce hardwiring and maintenance load, and improve real-time performance and stability.
- 3) Object-oriented unified modelling should be supported, and the model should have a self-description function.
- 4) Hardware should be suitable for the environment. Corresponding requirements of electromagnetic compatibility, temperature, moisture, atmospheric pressure, insulation, anti-vibration, dust proof and anti-corrosion should be met.
- 5) Function of time synchronization, as well as identification and rejection of wrong time signals, should be incorporated. Time synchronization protocols like IRIG-B (DC) code, IEC 61588, etc., should be applied.
- 6) Human-machine interaction function should be incorporated, and typical human-machine interfaces include an indicator light, LED, push button, touch screens, etc. Other requirements should conform to IEC 62270/ IEEE Std 1249.
- 7) Abnormal settings of reference values, parameters and other critical user inputs should be blocked.
- 8) Functions of self-detection and self-diagnosis should be incorporated to automatically monitor and diagnose power supplies, communication links and I/O channels of devices. Diagnosis information should be displayed via indicators or a local screen and accessed through communication interfaces.
- 9) When determining if key measurements and outputs should be hard-wired or replaced by communication, the overall system design shall be considered (e.g. redundancy, self-supervision). Direct sampling via hardwiring should always be applied for the important signals, especially when involved in safety-relevant functions like mechanical protection, emergency and quick shutdown control, synchronization, governor, excitation, and electrical protection.
- 10) Logging functions should be incorporated, such as event/alarm recording and fault waveform recording. A recording or information query and an export function should be incorporated.
- 11) For key components, hot standby redundant design should be adopted, such as redundancy of communication, power supply and master processor to improve reliability.

- 12) Ease of maintenance should be taken into consideration. Hot plugging, remote commissioning and configuration, remote upgrading of firmware programs, and bumpless transfer should be supported for the device which can be maintained online.
- 13) Functions of online or offline simulation with configurable parameters should be supported. In which, the online simulation means that all input parameters are real-time data from the hydroelectric process.
- 14) According to the requirements of a specific project, a real-time database should be supported by unit level devices.

8.3 Measurement and control

8.3.1 Data acquisition and control execution

Intelligent terminals, merging units and other IEDs within the process level are applied for data acquisition of electrical signals and non-electrical signals, equipment operation status monitoring and control execution. The types of signals mainly include Digital Input (DI), Digital Output (DO), Analogue Input (AI), Analogue Output (AO) and other signals. The main functional requirements are as follows:

- 1) Acquisition of the signals of the whole plant, and command execution should be provided. Functions and parameters such as I/O signal type, quantity, etc., can be configured flexibly.
- 2) A common voltage level should be applied for DIs and DOs. Isolators like optocouplers or relays should be applied as interfaces to achieve electrical isolation from the internal circuit. DIs should have an under-voltage interlock and prevent reversed connection. DOs should meet the contact capacity and have functions such as avoidance of reversed connection and overload protection. Other requirements should conform to IEC 62270/ IEEE Std 1249.
- 3) The AIs and AOs should adopt the commonly used current and voltage level. The conversion precision and the load capacity should meet the relevant measurement/control requirements of the corresponding equipment. Other requirements should conform to IEC 62270/ IEEE Std 1249.
- 4) AC sampling input signals should be within the corresponding nominal value range and meet the requirements of the error grade. There should be an isolation circuit in the loop to enable access to electromagnetic Potential Transformer (PT) and Current Transformer (CT) signals. Alarm functions for the detection of abnormal PT and CT loops should be included.

8.3.2 Local control

The local control function should be fulfilled by IEDs within the unit level, to measure and control objects including units, transformers, switchgear, auxiliary equipment (including electrical and oil-hydraulic systems), gates, etc. The main functional requirements are as follows:

- 1) A process bus should be used to acquire measured data for processing and calculation and send out control and regulation orders. In addition, direct sampling via hardwiring should be applied for the important signals involved in the mechanical protection and emergency shutdown control.
- 2) The communication with ICAMP should be performed via the plant bus for uploading the DIs, AIs and the receiving control and regulation commands.
- 3) The sequence control(including the unit control) should be supported, and the control logic should be programmed to perform unit start/stop, active/reactive power regulation, etc. The programming language should comply with internationally accepted standards such as IEC 61131-3.
- 4) The graphic configuration and programmable software for online commissioning, troubleshooting and modifications should be provided.

8.3.3 Synchronization

Automatic and manual synchronization should be done by measuring the frequency, the voltage amplitude and the voltage phase on both sides of the synchronization point. The main functional requirements are as follows:

- 1) The commands of the voltage increasing/decreasing, speed increasing/decreasing, and breaker on should be sent out correctly and timely.
- 2) The function of automatically compensating the inherent phase difference of the voltage on both sides of the synchronization point should be incorporated.
- 3) Function of self-diagnosis should be incorporated, so that mal-operation shall not be performed when the function is faulted.
- 4) Fault recording function should be incorporated. The recording files should conform to international standards such as IEEE Std C37.111. These files should be capable of being saved, viewed, exported, etc.
- 5) Considering possible network failure, voltage inputs to the synchronization may be hardwired directly from the electromagnetic potential transformers. The key outputs of synchronization may also be hardwired.

8.3.4 Governor

The governing system is composed of an electronic governor, servomotor(s), electro-hydraulic equipment, oil pressure equipment (hydraulic pressure supply system), achieving the function of matching generation power with the isolated or grid-connected load, and adjusting the rotational speed according to the applicable grid code(s). The main functional requirements are as follows:

- 1) Start-up control, stop control, no load speed control (including load rejection), grid frequency follow-up control during synchronization, power output control, primary frequency control, isolated operation, and emergency shutdown control should be realized. The governor may also be capable of operation in other control modes as opening, water level or flow control modes. Technical requirements specified in IEEE Std 125, IEEE Std 1207 and/or IEC 61362 should be met.
- 2) DIs/DOs and AIs/AOs should be input/output through the intelligent terminal. Important signals of the generator circuit breaker, and signals like turbine speed and guide vane opening should be acquired by independent transducers and may also be acquired additionally via hardwiring.
- 3) Function of fault recording can be incorporated, and the preconditions of fault recording can be set. The device can record the measurements such as active power, guide vane opening, runner blade opening, unit frequency, water head, grid frequency and status of circuit breakers.
- 4) In cases where a high degree of reliability is required, redundant governor controllers which conform to IEC 61362 should be considered. The controllers should operate seamlessly with no disruption in service when switching between redundant controllers.
- 5) The measurement signals should include guide vane position, runner blade position (for Kaplan turbine), power, speed and water head. Functions of condition monitoring and fault diagnosis of measurement signals may be incorporated. According to the availability requirements of the project, redundant signals may be provided.
- 6) Monitoring and fault diagnosis of the main hydraulic components should be included in the electronic governor or other systems.
- 7) The status and self-diagnosis information, such as master/slave status and manual/automatic mode, power supply fault, feedback signal fault, controllers and I/O modules fault, should be transmitted to ICAMP via the plant bus.
- 8) Depending on requirements, the governor should be prepared to perform commissioning tests for static/dynamic governor performance, primary frequency regulation, parameter recognition, etc. The functions and interfaces required for performing these tests may be embodied in the governor or be complemented by external equipment like signal generators, data recorders, data analysers, etc.

- 9) For particular commissioning and maintenance purposes, it can be required to locally control the main hydraulic components, including the main distributing valve, electro-hydraulic control valve, servomotor (s), and oil pumps.
- 10) A simulation test function for isolated operation may be incorporated as it is described in IEC 60308. Additionally, other tests like simulation of closed-loop of start-up control, power output control, grid frequency follow-up control during synchronization, primary frequency control, emergency shutdown, no load speed control (including load rejection) and load shedding scenarios may be performed.
- 11) Information including active power setpoint, net water head, guide vane opening, unit speed, fault recording file, etc., should be transmitted via the plant bus to ICAMP.

8.3.5 Excitation

The excitation regulates the generator voltage, adjusts the reactive power for a single unit, and suppresses the low-frequency oscillation of the power grid. When the grid encounters failures, the excitation regulation should still operate normally. The main function requirements are as follows:

- 1) Excitation control should incorporate Automatic Voltage Regulator (AVR), Field Current Regulator (FCR), Power Factor Regulator (PFR), Reactive Power Regulator (RPR), Power System Stabilizer (PSS), meeting with technical requirements specified in IEEE Std 421 and IEC 60034-16. The PSS should conform to the requirements of IEEE Std 421.5, and be equipped with input and output interfaces for tests.
- 2) Auxiliary functions should be embodied, at least including an over-excitation limiter, an under-excitation limiter (P/Q limiter, load angle limiter, minimum field current limiter), a voltage/frequency limiter (V/F) and a PT disconnection.
- 3) DIs/DOs and unit speed measurement should be input/output through the intelligent terminals. Signals such as generator stator voltage, stator current, field current, etc., should be directly acquired via the transducers, e.g. conventional or optical PT/ CT equipment.
- 4) Information including the generator stator voltage, stator current, field current, active power, reactive power, etc., should be transmitted via the plant bus to ICAMP.
- 5) For hydro units with high availability requirements, hot standby regulation channels should be configured. The regulation channels should be capable of being switched remotely and manually.
- 6) Self-diagnosis information such as the status of the power supply, regulator channels, thyristor modules, cooling system, and field current breaker should be transmitted to ICAMP via the plant bus.
- 7) Fault tolerance of the generator circuit breaker position should be embodied.
- 8) The limiter signals should include under excitation, over excitation and voltage/frequency (V/F). The alarm signals should include the rectifier cabinet overheat, an abnormal output current of parallel rectifier bridges, abnormal position of the generator circuit breaker and the field current breaker, abnormal sampled values, etc. The fault signals should include a power loss of the regulator stabilized voltage supply, a power loss of the operation control circuits, the power supply fault of the cooling system in the rectifier cabinet, over-voltage protection of the excitation winding, the fusion of the rectifier bridge fuse, missing of trigger pulses, a field flashing failure, a regulation channel switching, a PT disconnection, etc.
- 9) A simulation should be included to perform closed-loop regulation tests of unit start/stop, limiter functions, step response, PSS, etc.

8.3.6 Speed measurement

A speed measurement mainly measures the rotation speed of the turbine shaft, and generates relevant alarms according to the measurement results. The main functional requirements are as follows:

- 1) Various electrical (e.g. PT signal, including conventional PT) and mechanical measurement (e.g. tooth wheel) approaches of the unit speed should be supported.
- 2) Inputs and outputs should be implemented by the intelligent terminal.

- 3) Digital outputs should be configurable corresponding to the different requirements of speed output.
- 4) Function of unit creeping monitoring and alarm should be incorporated.

8.4 Monitoring

8.4.1 Unit online monitoring

Unit online monitoring is applied for the automatic acquisition, processing, storage, analysis and diagnosis of relevant operation condition parameters of hydraulic turbines and generators. The monitoring data should be displayed locally and transmitted to ICAMP via the plant bus. The main functional requirements are as follows:

- 1) The condition monitoring shall include a unit vibration measurement.
Water pressure pulsation, air gap and magnetic flux density measurements should be included.
A partial discharge measurement may be included.
Signals like temperature, flow, level, pressure, guide vane opening, etc., which are related to the unit operation, should be obtained from other IEDs.
- 2) Signals of vibration, air gap, magnetic flux density and pressure pulsation should be acquired and processed continuously and synchronously.
- 3) Partial discharge signals of the generator stator windings may be acquired and calculated.
At least one measurement per day should be carried out.
- 4) A characteristic value calculation and out-of-limit alarms should be included. For velocity signals, characteristic values should include the root-mean-square (RMS) velocity, as well as the amplitude and phase of the rotational frequency. For the displacement signals of bearing vibration, the characteristic values should include the peak-to-peak displacement, as well as amplitude and phase of the rotational frequency. For the displacement signals of shaft vibration, the characteristic values should include, for example, the maximum displacement (S_{max}), peak-to-peak displacement, mean displacement (gap), as well as amplitude and phase of the rotational frequency.
- 5) Measurements and evaluation of vibration and the water pressure pulsation of hydraulic units should conform to ISO 20816-5 and ISO 10817-1.
- 6) Measurements of the online partial discharge of the generator stator winding insulation should conform to IEC 60034-27-2.
- 7) For more detailed information about the condition monitoring and the diagnosis function of hydraulic units, see ISO 13372, ISO 13373, ISO 13374, ISO 13379, ISO 13381 and ISO 17359.
- 8) A function of recalling should be incorporated. The event/alarm and fault recording files should conform to IEEE Std C37.111, IEC 62541.

8.4.2 Online monitoring of transmission and transformation equipment

Online monitoring of the transmission and transformation equipment is applied for the automatic acquisition, processing, storage, analysis and diagnosis of related condition parameters of the transformer, the gas insulated switchgear, etc. The monitoring data should be made available locally and transmitted to ICAMP via the plant bus. The main functional requirements are as follows:

- 1) Transformer condition monitoring signals should include the amount of gas dissolved in the transformer oil, oil temperature and winding temperature. Depending on the availability requirements of the power plant, the signals may include the partial discharge of the iron core grounding current, clamping pieces grounding current, neutral grounding current, etc. The gas insulated switchgear condition monitoring signals should include the partial discharge, SF₆ gas pressure and moisture, On/Off of breakers and disconnectors.

- 2) Signals including the oil temperature and SF6 gas pressure should be acquired continuously. Signals including the transformer dissolved gas analysis and SF6 partial discharge should be acquired periodically. For example, at least one measurement per day should be carried out.
- 3) Functions of characteristic values calculation and an out-of-limit alarm should be incorporated. The partial discharge characteristic values should include the discharge amplitude, density, times and phase of each generator busbar. The characteristic values of the amount of gas dissolved in the transformer oil should include the concentration and variation rate of gases such as hydrogen (H₂), carbon monoxide (CO) and total hydrocarbon.
- 4) The sampling and analysis of dissolved gas in transformer oil should conform to IEC 60567 and IEC 60599.
- 5) The partial discharge measurements of the transformer and gas insulated switchgear should conform to IEC 60270.
- 6) The SF6 gas pressure and moisture content measurements of gas insulated switchgear should conform to the requirements of IEC 60480.
- 7) The modelling of condition monitoring, diagnosis and analysis of transmission and transformation equipment such as the main transformer, gas insulated switchgear, etc., should conform to IEC TR 61850-90-3.

8.4.3 Hydrology telemetry

The function of intelligent hydrology telemetry includes the acquisition, transmission, processing and storage of hydrological data. The main functional requirements are as follows:

- 1) It should support single or composite transducers. Rain gauge, water level gauge, gate opening indicator, flow meter, etc., should be included.
- 2) It should support the calculation methods of average, peak and accumulation of the acquired data.
- 3) Communication interfaces including field bus, ZigBee, GPRS/4G, and satellite should be used. The MMS protocol specified in IEC 61850, IEC 61158, etc., should be supported.
- 4) It should automatically perform periodic measurements and data storage according to the pre-set time interval.
- 5) It should have low-power consumption and be powered by a battery.

8.4.4 Meteorological information acquisition

The functions of intelligent automatic meteorological information collection include the acquisition, transmission, processing and storage of meteorological data. The main functional requirements are as follows:

- 1) It should support single or composite transducers. The six meteorological elements should be included, i.e. the wind speed, wind direction, temperature, air pressure, precipitation and relative humidity. The solar radiation intensity, soil temperature, soil moisture, sunshine duration, etc., may also be included.
- 2) It should support calculation methods of average, peak and accumulation of the acquired data.
- 3) Communication interfaces including field bus, ZigBee, GPRS/4G, and satellite should be used. The MMS protocol specified in IEC 61850, IEC 61158, etc., should be supported.
- 4) It should automatically perform periodic measurements and data storage according to pre-set time intervals.
- 5) It should have low-power consumption and be powered by a battery.

8.4.5 Dam safety monitoring

The functions of intelligent dam safety monitoring include the data acquisition, transmission, processing and storage of various dam safety monitoring items. The main functional requirements are as follows:

- 1) It should support single or multi-purpose transducers. Voltage, current, capacitance, resistance, piezo-resistive, inductance, vibrating wire, potentiometer, laser, etc., should be included.
- 2) Communication interfaces including field bus, ZigBee, GPRS/4G, and satellite should be used. The MMS protocol specified in IEC 61850, IEC 61158, etc., should be supported.
- 3) It should automatically perform periodic measurements and data storage according to pre-set time intervals.
- 4) It should have low-power consumption and be powered by a battery.

8.5 Protection

8.5.1 Overview

Protection is applied to improve the safe operation of the primary equipment of hydroelectric power plants, including the turbine, generator, station auxiliary transformers, generator step-up transformers, switchgear, buses, transmission lines, etc. Protection schemes for mechanical and electrical protections, including the scope of the sub-grouping (redundancy), should be based on the relevant standards, regulations and studies to match requirements for power system safety and availability.

8.5.2 Electrical protection

Electrical protection should realize the measurement of the electrical signals before and after the failure of the power plant electrical equipment or the power grid, calculation and analysis of the variation characteristics of electrical signals and actions (e.g., tripping, shutting down, unloading) to protect the equipment. When a failure occurs, the intelligent electrical protection quickly cuts off the faulted components to effectively improve the safe operation of electrical equipment and the stable operation of the power system. The main functional requirements are as follows:

- 1) The electrical protection should comply with the technical requirements on environmental conditions for the operation, mechanical tests, electrical insulation tests, and electromagnetic compatibility tests of protection devices defined in IEEE/IEC 60255.
- 2) The voltage and current of the protection can be measured by either an electromagnetic transformer or an electronic transformer. The communication between the merging unit and the electrical protection device should be point-to-point.
- 3) Direct tripping mode (e.g. by hardwiring between the electrical protection and switches/circuit breakers and/or by point-to-point communication between the intelligent terminal and the electrical protection) should be applied for the protection of the primary equipment (including the generator-transformer set, transformer, etc.) and the protection of the single bay. Other tripping modes meeting reliability and rapidity requirements (e.g. tripping via process bus) should be applied for the protection of multiple bays (e.g. busbar protection). The interlocking information between electrical protection devices and the breaker failure protection, etc., should be transmitted via the process bus.
- 4) Redundant protection devices should have no electrical connections between each other, with signals acquired from an independent PT/CT secondary winding. Each protection device should handle all faults with the independent protection function and an input/output acquisition.
- 5) When the external time synchronization signal is lost or the external clock fails, the protection function should still maintain the normal operation.
- 6) The electrical protection device should have functions of self-diagnosis and alarm. If any components in the device, except for output relays, are damaged, the function of the device should be disabled.

- 7) The faults of external devices, including the faults of optical fiber, intelligent terminals, switches within the process level, etc., should not cause malfunction of the electrical protection.

8.5.3 Mechanical protection

The mechanical protection includes the measurement of vibration as well as various other parameters like bearing temperature, oil levels, pressures in the accumulators, speed, digital governor failure, etc. A logical combination of those parameters can be used to shut down the unit. Mechanical protection should conform to functional safety standards such as ISO 13849.

Vibration protection realizes real-time monitoring for vibration of the bearing system and main shafts of the unit and generates unit shutdown signals when it detects an abnormal unit status. The main functional requirements are as follows:

- 1) Functions of vibration online measurement, operation status identification, calculation of vibration out-of-limit and unit shutdown logic, alarm and unit shutdown signals output, etc., should be incorporated.
- 2) A function of asynchronous acquisition of vibration and key-phase transducer signals should be incorporated. The bearing vibration measurement should apply magneto-electric velocity or piezoelectric acceleration transducer, while the shaft vibration measurement should apply an eddy-current or capacitive-type displacement transducer, and the rotation speed/key-phase measurement should apply an eddy-current displacement transducer or other suitable technologies like magnetic pickups, etc.
- 3) For technologies used for vibration protection (e.g. the S_{max} , peak-to-peak displacement, mean displacement (gap)), the synchronization of the sampling is not necessary. However, when technologies requiring synchronization of the sampling (e.g. the amplitude and phase of rotational frequency) are adopted, the sampling frequency should be adjusted automatically according to the key-phase signals in order to realize synchronous sampling of the original waveform of the transducers.
- 4) A function of calculation of vibration characteristic values should be incorporated.
The characteristic values of the velocity signals should include root-mean-square (RMS) velocity, as well as the amplitude and phase of the rotational frequency.
The characteristic values of the displacement signals of the bearing vibration should include the peak-to-peak displacement, as well as amplitude and phase of the rotational frequency.
For the displacement signals of the shaft vibration, the characteristic values should include, for example, the S_{max} , peak-to-peak displacement, mean displacement (gap), amplitude and phase of the rotational frequency.
The low-frequency characteristics of hydraulic units should be considered.
- 5) The unit vibration measurement and evaluation should conform to ISO 20816-5 and ISO 10817-1.
- 6) A function of logging should be incorporated. The event/alarm and fault waveform recording files should conform to international standards such as IEEE Std C37.111, IEC 62541, etc., which are transmitted to ICAMP via the plant bus.
- 7) The vibration over-limit alarm threshold and the unit shutdown logic should be set separately according to the different unit operation status, such as normal start/stop process, operation with rated load, operation in rough zone and load rejection process.
- 8) Functions of automatic calculation and an online correction of unit rough zones may be incorporated. The calculated rough zone data, which is applied for the joint control to avoid the unit operation in rough zones, is transmitted to ICAMP via the plant bus.

9 Platform and intelligent application

9.1 General

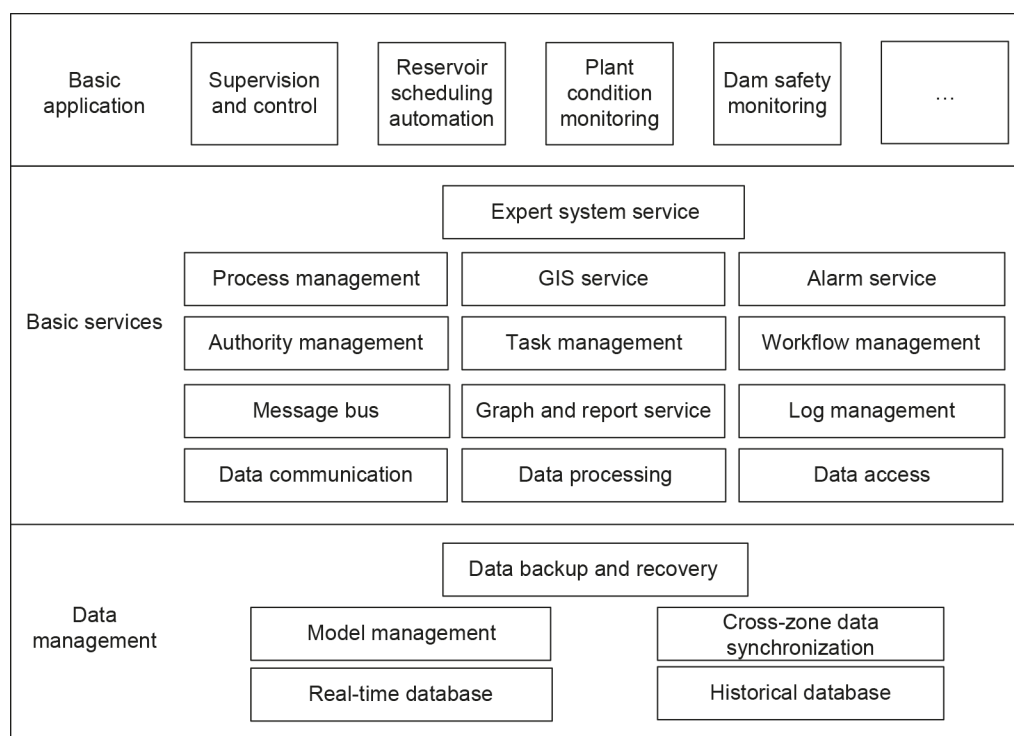
The platform and the intelligent applications are mainly determined by the scales and types of smart hydroelectric power plants. This clause describes a representative set of data management functions, basic services, basic applications and intelligent applications. An appropriate selection, extension or modification tailored to the needs of a specific smart hydroelectric power plant shall be chosen for a specific project.

9.2 Integrated control and management platform

9.2.1 General

The ICAMP consists of data management, basic services and basic applications, and can be distributed within the control zone, non-control zone and management information zone, which provides interfaces (see 9.2.2.1) and services for equipment, systems and intelligent applications. It is a software platform realizing data sharing, centralized control and management and interaction. The functional architecture of ICAMP is shown in Figure 12.

ICAMP should incorporate basic applications and support intelligent applications from different vendors. Basic applications should be tailored according to the specific needs of a smart hydroelectric power plant.



IEC

Figure 12 – Functional architecture of ICAMP

9.2.2 Data management

9.2.2.1 Real-time database

The real-time database acquires and stores real-time data from devices within the unit level and process level, facilitating monitoring of real-time operation status.

The real-time database is a high-speed data management system and has the advantages of fast storage, efficient query and high data compression ratio, capable of storage of massive, real-time and frequently changed data.

The real-time database should be physically distributed on multiple computer network nodes and logically belongs to an integrated management system. The database of each node collects different types and forms of on-site data. The real-time database should be redundantly configured.

9.2.2.2 Historical database

The historical database is used to store historical data, alarms, etc. The following functions should be incorporated:

- 1) It should define various basic data types, including numeric, character, date, multimedia data (like voice and graphs), and supports customized data types derived from a combination of basic data types.
- 2) It should possess the capability of data compression for storage.
- 3) With the storage capacity of massive data, it should effectively realize massive data storage and processing, such as terabytes of database storage, large objects, etc.
- 4) Logging and audit functions should be equipped for recording events and audit of data updates to facilitate comprehension of the database status and the database modification.
- 5) The historical data can be stored in milliseconds, seconds, minutes, hours, days, ten days, months, years or any other configurable period.
- 6) The data should be attached with attributes such as data source, modification identification and data quality, etc.

9.2.2.3 Model management

The modelling of a smart hydroelectric power plant should be based on models mentioned in 5.3 and should establish a unified data representation and access path. It should support supervision and control, reservoir scheduling automation, dam safety monitoring, plant condition monitoring, etc. XML language should be supported to improve the flexibility and expandability of models.

The information model is mainly based on the hierarchy of functions and components. Unified model management should be realized, through which the standard models for the whole plant can be managed via automatically or manually imported modelling files.

Model management should support information model modification, expansion, combination and association of information models. It should also support version management and query for model information of different versions.

9.2.2.4 Crossing-zone data synchronization

Data management should support data synchronization in both ways of "full contents" and "incremental contents", realizing data synchronization among control zone, non-control zone and management information zone according to application needs. The specific requirements are as follows:

Full contents: All data is synchronously transmitted at regular intervals or in time series, including real-time data, non-real-time data and text files. Functions of data transmission resumption and data compression should be incorporated.

Incremental contents: Only the data variation is recorded and synchronously transmitted.

Data transmission from the non-control zone to the management information zone should be realized via network isolation, with functions including data synchronization, alarm synchronization and data verification.

Data transmission from the management information zone to the non-control zone should be realized via network isolation, with functions including data variation and alarm synchronization of external systems (meteorological, flood control, etc.).

9.2.2.5 Data backup and recovery

Data backup should be applied for data recovery in case of database abnormality.

The query of backup and recovery logs should be provided.

The database should be backed up periodically to a specific storage media according to the backup strategy, and the backed-up database log files may be deleted. The storage media may be a hard disk, Compact Disc (CD), Redundant Arrays of Independent Disks (RAID), etc. The backup and recovery may be full or incremental. It can be for the whole database or specific tables. Strategies and parameters of data backup and recovery may be configured.

9.2.3 Basic service

9.2.3.1 Data communication

Data communication includes communication between the ICAMP and devices within the unit level, and communication between the ICAMP and intelligent applications or other systems within the plant level or group-of-plants level. All previously described variants in 5.4.4 can be applied. Data communication should meet the requirements of real-time performance and validity of the data.

Data communication protocols should refer to 5.4, and the period and data of communication should be configurable. The status of the communication link should be monitored. Communication should recover automatically after link re-connection. Logging and alarm of communication status should be embodied.

9.2.3.2 Data processing

Automatically and manually acquired data should be processed according to the data properties, realizing the functions of monitoring, modification, alarm, query, analysis, recording and compression/decompression. The following functions should be supported:

- 1) Verification of data validity.
- 2) Data processing and comprehensive calculations of various applications.
- 3) Calculation of maximum, minimum, average value, etc.
- 4) Automatic data statistics of analogue input, accumulated value, and digital input (based on a minute, hour, day, month, year, etc.).
- 5) Manual modification of value and properties of data.
- 6) Blocking of manually confirmed data.
- 7) Calculation with configurable rules.

9.2.3.3 Data access

Data access provides unified access interfaces for real-time and historical databases. It should have high performance to meet with real-time and concurrency requirements of ICAMP.

Data stored in distributed nodes or redundant nodes should be accessed correctly.

Important and key operations such as database connection and execution statements should be audited. Data security should be taken into consideration.

9.2.3.4 Message bus

Message bus connects the message sender and receiver and realizes communication between applications. It manages application registration, cancellation, message subscription/cease subscription, and message publication/ acceptance.

Message bus should identify messages and conduct routing of these messages between interaction applications.

It should support the transmission of messages between senders and receivers using different standard protocols, such as those defined in 5.4.

It can allow different data formats between senders and receivers. In that case, the message bus performs data format conversion to suit the demands of the sender and receiver.

It should support different message transmission modes, including request/reply (synchronous and asynchronous) and publication/subscription.

9.2.3.5 Graph and report service

Graph service draws graphs for monitoring and control of smart hydroelectric power plants. The graphs should automatically adapt to displays of various resolutions while they are viewed. Graph editing functions should be provided.

Report service should provide editing function, and ease for extension of various report functions, generating new reports without programming. The report function library should be provided with various calculation functions (like time function, arithmetic calculation) to meet the requirement of calculation of various reports.

Reports should be generated automatically and periodically with a configurable template, including reports of daily, monthly, annual and customized periods.

9.2.3.6 Log management

Log management should consist of the application log service, security log service and web log service.

The application log service records the operation information of various applications, which can be viewed according to different applications. For example, the application log of alarm service contains various types of alarm information. It is used for the integration and analysis of application operation information.

The security log service records information including computer start/stop, network status, user login/logout and user operation.

Web log service records the visitor's identification, browsing time and content and web traffic.

All log management services should include functions of recording, query and backup of logs.

9.2.3.7 Authority management

Authority management service should realize user/role management and comprehensive authorization control of data, menu, application, type, attribute and process.

Different access authorities should be associated with different roles. When a user is created, access authorities can be granted by selecting one or more roles.

Authority management service should support data access authority that specifies which data can be queried or modified by the user. The data access authorization identifies which plants and equipment can be accessed by the user. It should support inclusion and exclusion methods. For example, if a user has access to a certain plant, the user has access to all plant equipment by default, and certain equipment can be excluded manually. Data access authorization should support read and write authorization separately.

In addition, the service is applied to manage users, including addition, modification and deletion of users, and grant authority to the users.

Uniform authority management should be provided. If the user has already logged into a system, this function verifies whether the user shall log in again to access related sub-systems.

9.2.3.8 Task management

Task management service performs the triggering of timed tasks. Running as a background process, it continuously checks whether the timed task reaches the triggering conditions, and which node performs the timed tasks. When the conditions are satisfied, the corresponding task should be executed in the specified applications node.

The task management service should include task configuration and timed execution. The task configuration includes the addition, deletion, and modification of tasks. The configuration of each task should include:

- 1) Repeat setting, which defines whether the task is to be run repeatedly or just once.
- 2) Time setting, which defines starting time and intervals.
- 3) Execution setting, which defines whether the task is to be run automatically or not.

Timed execution is mainly to perform related tasks in a specified time.

9.2.3.9 Workflow management

Workflow management service models, schedules and supervises the step-by-step process used to perform a project activity.

Workflow management should include the following functions:

- 1) Workflow configuration: Uses graphical workflow design tools to create a new workflow, modify existing workflow and release configured workflow to corresponding personnel for execution.
- 2) Workflow engine: Mainly deals with the processes which can be started by the operator. Activity steps (nodes) are generated according to configured workflow and actual conditions. Steps are executed by the designated personnel. Different tasks are executed according to different conditions.
- 3) Workflow monitoring: Automatically records the finished work items. Operators can view the current steps and personnel, check whether the allocated time has been exceeded, decide if a reminder is needed, and terminate abnormal workflows. The administrator can query all current workflow statuses according to specific roles.

9.2.3.10 Process management

Process management should monitor and record the running status and resource allocation of processes in the ICAMP, and supports abnormal alarm and alarm recovery. In case of a certain process abnormality, it should restart the process automatically.

9.2.3.11 Geographic Information System (GIS) service

GIS service should have the function of map-browsing, layer management, real-time monitoring, map property query, iso-line/surface analysis and data maintenance, to provide visualized decision-making support for flood control and emergency command support.

9.2.3.12 Alarm service

Alarm service performs centralized alarms acquisition and notifies the corresponding personnel based on pre-defined rules.

Alarm trigger rules and alarm push methods can be configured.

The alarm trigger should be based on single or multiple conditions.

The function of alarm acknowledgement, shelving and out-of-service should be embodied.

The query of historical alarm information should be supported.

The alarm can be sent out via audio, SMS, email, etc.

9.2.3.13 Expert system service

Expert system service is used to provide analysis and decision-making support functions for intelligent applications. For example, the CBM application uses it to analyze and evaluate the condition of the primary equipment.

It should include functions of knowledge base, inference engine, interpreter and knowledge acquisition.

The knowledge base is used to store knowledge provided by the experts. The problem-solving process of the expert system is to simulate experts' thinking mode by using knowledge in the base. The knowledge base should be independent of the expert system program, which means the users can change and improve the knowledge in the base to enhance the performance of the expert system.

Based on a given condition or information, the inference engine should repeatedly match the rules in the knowledge base to acquire a new conclusion or solution. There are two modes, i.e., forward reasoning and backward reasoning.

The interpreter should be able to explain the conclusion and solution process in response to users' questions.

Through knowledge acquisition, the content of the knowledge base should be expanded and modified, and automatic learning functions should also be realized.

9.2.4 Basic applications

9.2.4.1 Supervision and control application

Deployed in the control zone, the supervision and control application should provide operators with basic real time information and commands through human-machine interfaces, related event record and report management, etc. of electromechanical equipment, including units, switchyard, common auxiliaries, dam intake, trash rack, gates, lighting, ventilation and air conditioning system, etc. Schemes for fast autonomous corrective functions should be fulfilled by devices and functions located within the plant level or a combination of functions within the plant level, group-of-plants level or off-site. Typical Remedial Action Schemes (RAS) and other functions of supervision and control application can be found in IEC 62270/IEEE Std 1819.

According to this standard, two modes of control can be selected: 1) in manual mode , the operator initiates each operation through supervision and control application; 2) in automatic mode, the operation is carried out by intelligent application such as joint control application (see description of these functions in 9.3).

9.2.4.2 Reservoir scheduling automation application

Deployed in the non-control zone, the reservoir scheduling automation application provides hydrology, power and meteorology information for economic operation intelligent application. The application conducts periodical calculations of reservoir inflow, outflow, discharge, etc., and realizes monitoring and management of generation and flood control schemes.

9.2.4.3 Electrical protection information management

Deployed in the non-control zone, the protection information management application should have the capability of monitoring and analysis of operation, action and wave recording of electrical protection devices. It should conduct configuration of settings and diagnoses of the faulty equipment and fault types, based on the action information and recording data.

9.2.4.4 Plant condition monitoring application

Deployed in the non-control zone, the plant condition monitoring application should conduct health evaluation and historical operation analysis of units, transformers and transmission lines of the hydroelectric power plant in real-time. It should provide for massive storage, long-term management and comprehensive analysis of data, reflect the variation trend of equipment conditions in graphs (distribution diagram, curves, bar charts, etc.), reports and other forms, and generate early warning and alarm in case of abnormalities.

9.2.4.5 Dam safety monitoring application

Deployed in the non-control zone, the dam safety monitoring application should provide hydraulic structure monitoring, focusing on the dam's deformation, seepage, stress and strain, temperature, etc.

9.2.4.6 Comprehensive information display

Deployed in the management information zone, the comprehensive information display application should provide a web release of information from supervision and control, plant condition monitoring, reservoir scheduling automation, dam safety monitoring, etc. The information can be displayed in graphs, reports and other forms. The application should provide a role-based layout and menu configuration, as well as configuration and management of comprehensive information.

9.2.4.7 Mobile application

Mobile application extracts and integrates information from supervision and control, plant condition monitoring, reservoir scheduling automation, dam safety monitoring, etc., providing functions of information query, data input and uploading, and noticing.

1) Information query

The query for hydrology information, project information, device state, etc., in the form of graphs, reports and Geographic Information System (GIS) should be embodied.

2) Data input and uploading

During daily patrol for important equipment or manual data collection for monitoring stations without telemetry devices, the personnel can use smart portable devices to realize data input and on-site recording.