



IEEE Guide for Control of Hydroelectric Power Plants

IEEE Power Engineering Society

Sponsored by the
IEEE Energy Development and Power Generation Committee

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IEEE Guide for Control of Hydroelectric Power Plants

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IEEE Energy Development and Power Generation Committee
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Abstract: This guide serves as a reference document for practicing engineers in the hydroelectric industry. It documents prevailing industry practices in hydroelectric power plant control system logic, control system configurations, and control modes. It describes the control and monitoring requirements for equipment and systems associated with conventional and pumped-storage hydroelectric plants. It includes typical methods of local and remote control, details of the control interfaces for plant equipment, and requirements for centralized and off-site control.

Keywords: automation, control systems, hydroelectric, unit controls

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Introduction

This introduction is not part of IEEE Std 1010-2006, IEEE Guide for Control of Hydroelectric Power Plants.

This document is a guide for the power industry for use in the design and understanding of control systems for hydroelectric power plants. The guide was prepared by the Working Group on Control of Hydroelectric Power Plants of the Hydroelectric Power Subcommittee of the IEEE Energy Development and Power Generation Committee of the IEEE Power Engineering Society (PES).

This guide was originally issued in 1988. Its origin was a direct result of efforts during the 1980s by the Working Group to investigate and document prevalent industry practices for controlling hydroelectric power plants in conjunction with associated application of systems and equipment for implementing these practices.

Since preparation of the 1988 guide, significant changes in control equipment and system technologies, coupled with their application, have occurred. Additionally, ongoing restructuring of the utility industry has imposed new criteria for plant availability and for optimizing a plant's operational costs and power production, in turn increasing the complexity of the control, supervisory, and monitoring functions of the plant control system. The purpose of this revision is to address these new requirements and to harmonize guidelines contained in this document with a subsequently issued companion document IEEE Std 1249TM.^a

This guide is intended to be used as a reference document for practicing engineers in the hydroelectric industry. Although termed a *guide*, it is basically a tutorial document that provides information on the various equipment and systems being controlled in a hydroelectric plant.

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IEEE Guide for Control of Hydroelectric Power Plants

1. Overview

This document serves as a guide for the power industry by providing information on prevailing industry practices for the control of hydroelectric power plants. The guide discusses basic requirements and characteristics of hydroelectric power plant control systems, including architecture, reliability, redundancy, control level, location, and control modes. By its nature, this control is local to the hydro plant and generating units. For a complete perspective, centralized and off-site control and their specific requirements for hydroelectric plants are reviewed.

Requirements for control and monitoring of plant equipment are discussed, accompanied by block diagrams and detailed descriptions of the control and monitoring of major plant systems and equipment. Control of hydroelectric generating units is described with logic diagrams to show the flow and sequence of the control. This is done for the predominant types of conventional generating units as well as pumped-storage units.

1.1 Scope

This guide describes the control and monitoring requirements for equipment and systems associated with conventional and pumped-storage hydroelectric plants. It includes typical methods of local and remote control, details of the control interfaces for plant equipment, and requirements for centralized and off-site control. Where specific values are given for control parameters, they should be considered as typical.

This document does not address civil and structural details of hydroelectric power plants unless required for the understanding of certain control and monitoring functions. Also excluded is a detailed discussion of protective relaying systems, high-voltage switchyards, and navigational and flood control facilities associated with a hydroelectric plant.

Hydroelectric applications of variable frequency operation and high-voltage generation are not covered in this guide due to the specialized nature of these applications.

1.2 Purpose

This guide serves as a reference document for practicing engineers in the hydroelectric industry. It documents prevailing industry practices in hydroelectric power plant control system logic, control system configurations, and control modes. Implementation of the concepts described in this guide is covered in companion IEEE guides for control of hydroelectric power plants listed in Clause 2.

2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI C50.10, American National Standard for Rotating Electrical Machinery—Synchronous Machines.¹

IEC 60545:1976 (Rev 1.0), Guide for Commissioning, Operation, and Maintenance of Hydraulic Turbines.²

IEC 61116:1992, Electromechanical Equipment Guide for Small Hydroelectric Installations.

IEEE Std 421.1TM, IEEE Standard Definitions for Excitation Systems for Synchronous Machines.^{3, 4}

IEEE Std 421.4TM, IEEE Guide for the Preparation of Excitation System Specifications.

IEEE Std 1020TM, IEEE Guide for Control of Small Hydroelectric Power Plants.

IEEE Std 1046TM, IEEE Application Guide for Distributed Digital Control and Monitoring for Power Plants.⁵

IEEE Std 1248TM, IEEE Guide for Commissioning of Electrical Systems in Hydroelectric Power Plants.

IEEE Std 1249TM, IEEE Guide for Computer-Based Control for Hydroelectric Power Plant Automation.

IEEE Std C37.101TM, IEEE Guide for Generator Ground Protection.

IEEE Std C50.12TM, IEEE Standard for Salient-pole 50 Hz and 60 Hz Synchronous Generators and Generator/motors for Hydraulic Turbine Applications Rated 5 MVA and above.

3. Definitions

For the purpose of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B2]⁶ should be referenced for terms not defined in this clause.

3.1 automatic control: An arrangement of controls that provide for switching or controlling, or both, of equipment in a specific sequence and under predetermined conditions without operator intervention after initiation.

3.2 centralized control: A control location one step removed from local control; remote from the equipment or generating unit, but still within the confines of the plant (e.g., controls located in a plant control room).

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⁵IEEE Std 1046-1991 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

⁶The numbers in brackets correspond to those of the bibliography in Annex A.

3.3 computer-based automation: The use of computer components, such as logic controllers, sequence controllers, modulating controllers, and processors to bring plant equipment into operation, optimize operation in a steady-state condition, and shut down the equipment in the proper sequence under safe operating conditions.

3.4 control hierarchy: A systematic organization incorporating multiple levels of control responsibility.

3.5 control mode: A specific category of controlling a power plant.

3.6 control philosophy: The overall conceptual layout on which a power plant control system is based.

3.7 data acquisition systems: A system that receives data from one or more remote points. Data may be transported in either analog or digital form.

3.8 device (apparatus): An operating element such as a relay, contactor, circuit breaker, sensor, or switch used to perform a given function in the operation of electrical equipment.

3.9 local control: For auxiliary equipment, controls that are located at the equipment itself or within sight of the equipment. For a generating station, the controls that are located on the unit switchboard-governor control station.

3.10 logic (control logic): Predetermined sequence of operation of control devices.

3.11 manual control: Control in which the system or main device, whether direct or power-aided in operation, is directly controlled by an operator.

3.12 off-site control: Controls that are not resident at the plant (e.g., at a switchyard, another plant).

3.13 programmable logic controller (PLC): Digital control system with programming capability that performs functions similar to a relay logic system

4. Control system configuration

4.1 Introduction

Control system configurations for hydroelectric power plants have gone through an evolutionary development as advances in control system technology, new operating strategies for power plants, and increasing requirements for information on plant performance imposed new criteria on the plant control system. To develop basic concepts on control system configuration this clause addresses the following:

- a) Hydroelectric power plant control system evolution
- b) Basic control system concepts
- c) Basic control functions
- d) System architecture

4.2 Hydroelectric power plant control system evolution

Traditionally, control systems in a hydroelectric power plant (hydroelectric plant) are associated with the start and stop sequences for the unit, and for control of the unit's power, voltage, and frequency. With evolution of the utility industry, operation of a hydroelectric plant in today's environment requires power plant control systems with capabilities beyond those provided by the earlier traditional systems.

Historically, the architecture, complexity and functionality of a hydroelectric plant control-system was determined by the following:

- a) Number, size, and type of turbine-generator unit
- b) Type of plant (i.e., conventional or pumped-storage)
- c) Type of plant auxiliary systems
- d) Nature of operation (i.e., attended or unattended)

These criteria become more complicated when additional capabilities dictated by new power plant operating criteria are imposed on the plant control system (whether new or existing).

Examples of present day “non-traditional” control criteria include pumped-storage plants that add to the complexity of the controls with requirements for control systems capable of handling generating, pumping, and synchronous condensing modes of operation associated with these plants. Pumped-storage plants also require additional control equipment for starting equipment and phase reversing of the main leads in the pumping mode. Conventional and pumped-storage plants may also have operational requirements dictating a capability of “black starting” (i.e., starting the plant without the need for external power), adding another degree of complexity to the control system. Hydroelectric plants may include automatic control systems operated from an off-site location. This type of operation requires the use of supervisory control and a reliable communication link between the powerhouse and the off-site control point.

The bulk of the existing hydroelectric power plant inventory has been in service for many years. Control systems at older plants may have gone through several evolutions or changes in control philosophy and strategy. Consequently, the controls at an existing plant may be a mixture of manual and automatic systems, and hardware implementation a mixture of electromechanical relay logic and microprocessor-based digital logic control systems.

4.3 Basic control concepts

4.3.1 Control system basic design

4.3.1.1 General

An explanation of a basic control system is presented to help the reader to better understand this guide. The simplest form of control is known as *open-loop control*. The controller issues an action to the apparatus being controlled. No direct feedback is provided from the apparatus to the controller. Figure 1 illustrates this concept. There are few true open-loop control systems.

A much more common basic control system is closed-loop control. In this scheme, the controlled apparatus feeds data back to the controller, usually an error signal. The controller uses the error signal to modify the control action. In many cases, the error signal is visual, such as an operator observing a dial or gauge. A simple example of a closed-loop control scheme is shown in Figure 2.

4.3.1.2 Hydroelectric powerhouse control system scheme

For hydroelectric powerhouse control systems, it is convenient to portray the components of the control system in a vertically arrayed scheme. A typical array is shown in Figure 3.

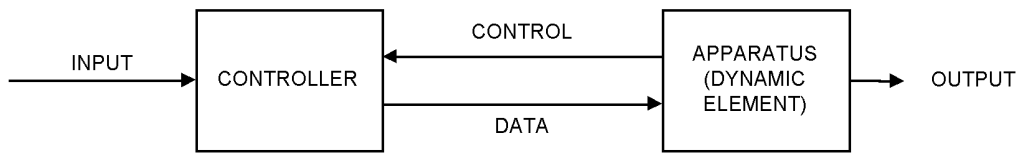


Figure 1—Open-loop control system

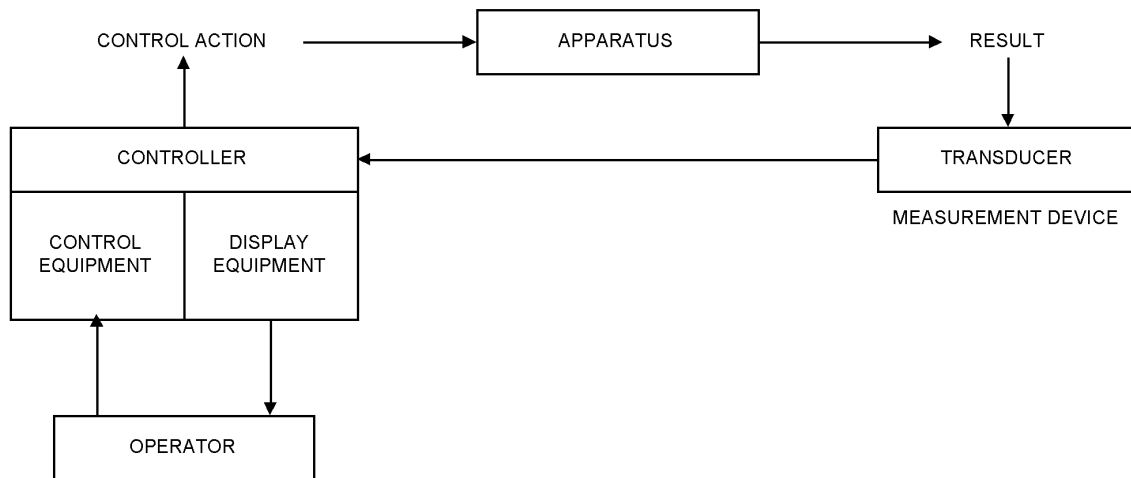


Figure 2—Closed-loop control system

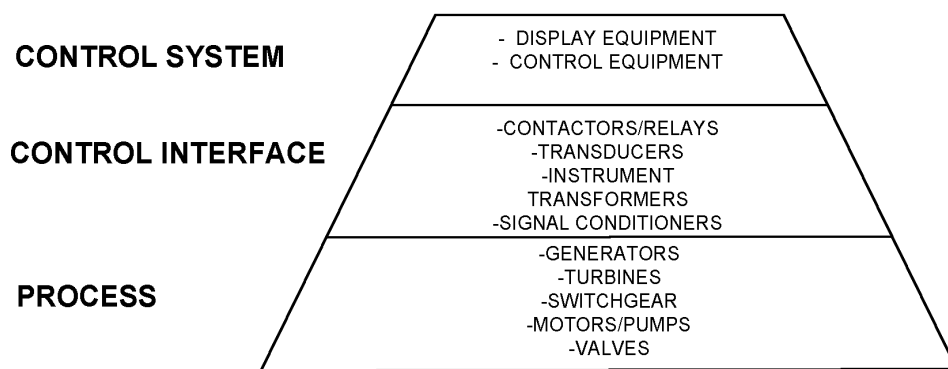


Figure 3—Control system vertical array

4.3.1.2.1 Process level

The lowest level of the vertical control scheme is the process being controlled. This includes the exciter, the hydraulic turbine, switchgear, pumps, valves, or other auxiliary powerhouse equipment.

4.3.1.2.2 Control interface level

The next level is the control interface equipment necessary to send control signals to the apparatus from the controlling equipment and for the apparatus to transmit data back to the controlling equipment. Auxiliary contacts of motor starters, relays, instrument transformers, signal conditioners, transducers, or other such equipment are typical examples of control interface equipment devices.

4.3.1.2.3 Control system level

The highest level is the controlling system that initiates the control signals and receives the data transmitted from the apparatus' control interface equipment. This level also includes appropriate human machine interfaces.

4.3.1.3 Typical hydroelectric powerhouse control system

Frequently, a generating unit's start, stop, reactive power, and active power are controlled by an operator working through a human-machine interface (HMI) to a control system. Figure 4 illustrates a typical HMI for a control system.

A typical scheme illustrating a vertical array controlling a powerhouse is shown in Figure 5. Multiple apparatus exist in this example. Though shown in Figure 5 as being on the same level, the apparatus may actually be nested and exist on several different levels.

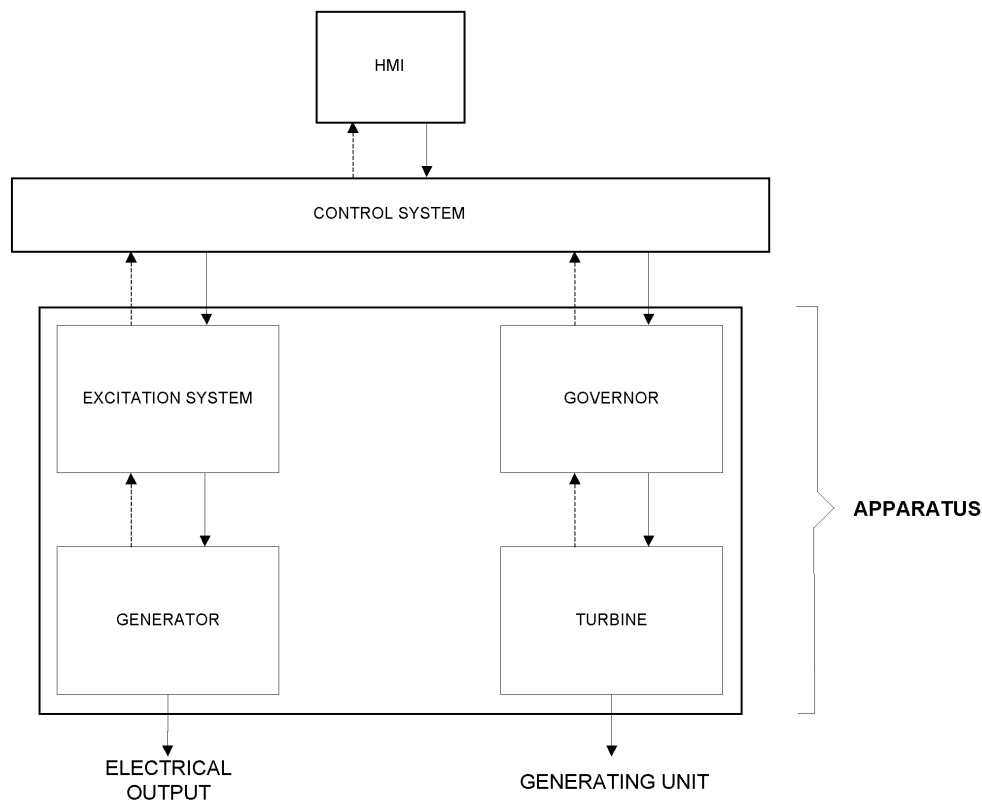


Figure 4—Typical HMI system interface

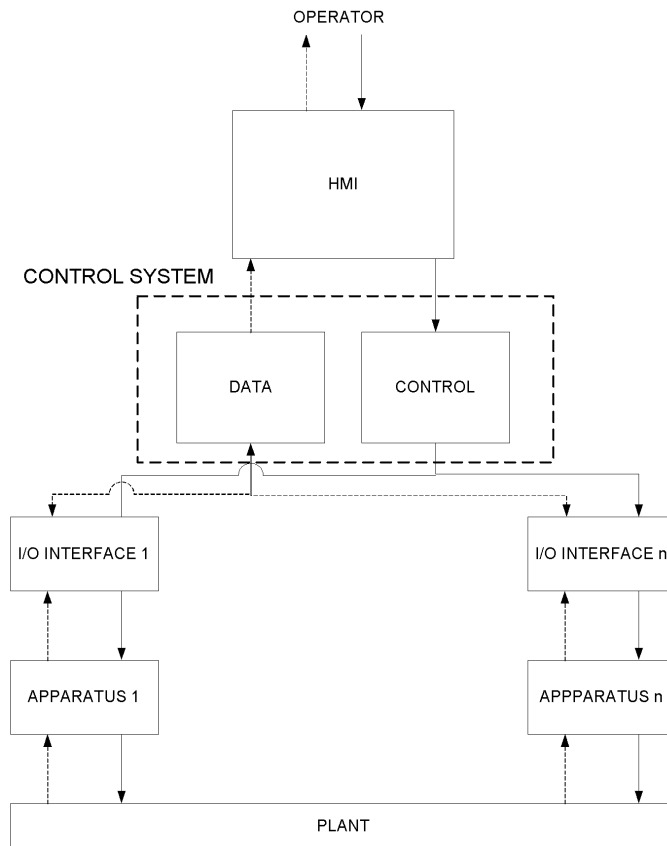


Figure 5—Typical control system arrangement

A hydroelectric turbine-generator is usually thought of as a generating “unit” but is comprised of several apparatus at different levels. The electrical generator is the device that produces the electricity, but the excitation system controls the voltage and reactive power. The prime mover for the generator is the hydraulic turbine that is controlled by the hydraulic governor. The governor controls the active power output of the unit.

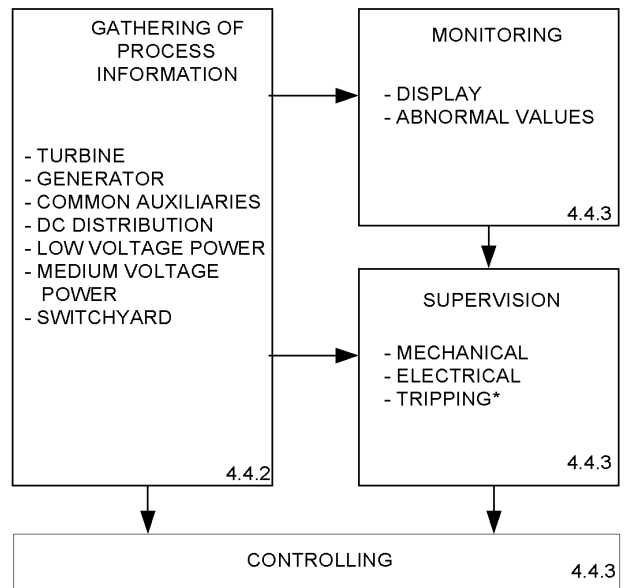
4.4 Basic control functions

4.4.1 General

In a modern hydroelectric power station, almost all apparatus is connected with the plant’s control system to allow operation in either manual or automatic mode. Most of the major apparatus (e.g., exciter, turbine, spillway gates) is equipped with electrically actuated control elements allowing it to work automatically. Many hydroelectric plants are controlled from off-site locations, and the automatic control systems facilitate unattended plant operation. Regardless of the type of plant operation, the following functions are common to all hydroelectric control systems:

- a) Gathering of process information
- b) Controlling the process
- c) Protecting and supervising the process
- d) Monitoring of process information

Figure 6 illustrates basic functions of a typical hydroelectric power plant control system.



*PROTECTION MAY OR MAY NOT BE PART OF THE CONTROL COMPUTER SYSTEM.

Figure 6—Functions of typical hydroelectric plant control system

4.4.2 Gathering of process information

Gathering and presentation of process information is an essential function of the control process. Process information can be gathered continuously or periodically and can consist of control parameters, status information, or feedback signals. For data gathered periodically, the sampling rate is dependent on the dynamics of the respective process signal.

Presentation of process information can be visual, recorded, audible, or a combination of all. Visual information formats include strip-chart recorders, analog and digital indicating instruments, video display units (VDU), lamp indicators or liquid crystal display (LCD) panels. Audible output is usually associated with a bell, gong, or tone alerting the operator to an alarm condition or message.

4.4.3 Controlling the process

The process information gathered serves two purposes. First, it is used by the automatic control system to perform appropriate control actions. Second, it allows the operator to operate the plant in a safe, reliable, secure, and economical manner. This requires ensuring the operator has the ability to start, stop, load, unload, and monitor the generating units and to control the plant's auxiliary systems including switchyards, water control structures, and other ancillary features associated with the project.

4.4.4 Protecting and supervising the process

4.4.4.1 General

The protection system is divided into two subcategories: the electrical protection system and the mechanical protection system. Electrical protection systems cover protection for major plant electrical apparatus and essential electrical auxiliary systems (e.g., generators, step-up transformers, station service electrical systems). Mechanical protection is usually confined to a generating unit's hydraulic turbine, generator, and major plant mechanical systems (e.g., turbine draft tube air depression system).

4.4.4.2 Electrical protection system

For safety and reliability, prevailing and recommended practice is to separate protective systems from control systems. Protective systems have progressed from systems comprised of specific-purpose electromechanical relays, to specific-purpose electronic analog relays, to contemporary multipurpose digital relays. Protective systems at many existing plants may be a mixture of all three relay types. Tripping commands from the protective relay system should bypass the automatic control system and operate directly on the shutdown circuits of the turbine and generator. In addition, they provide initiating signals for shutdown of related unit auxiliary systems. They also provide alarm signals to the plant annunciator or event recorder.

Multifunction digital relays, in addition to providing the same types of signals and initiating commands as discrete relay systems, may have serial or bus interface systems allowing connection to automatic control systems. These contemporary relays can provide time stamping, relay parameter setting, data trending, and other features such as diagnostics. Integration of the protective system with plant control systems is covered in succeeding subclauses.

4.4.4.3 Mechanical protection

Protection of “non-electrical” apparatus and systems in the plant are normally assigned to the plant control system. The control system generally provides tripping signals required for input to the plant protection system should any of the protected non-electrical systems or apparatus require removal from service.

4.4.4.4 Supervisory process

The supervisory process involves comparing plant and equipment operating values against limits. Typically, the control process monitors the four limit values shown in Table 1.

The supervisory process may also involve monitoring equipment status as well as limits. Whether equipment is on or off, or open or closed, may be incorporated into the supervisory process with consequential control actions. For instance, sequences like pump controls may be monitored to ensure safe and prudent functioning of the system. Another basic concept of the supervisory process is to have redundancy in the monitoring elements. Figure 7 illustrates the concept with a simple temperature monitoring system.

Table 1—Limit value monitoring

Monitored value	Control action
Too low	Trip
Low	Alarm
High	Alarm
Too high	Trip

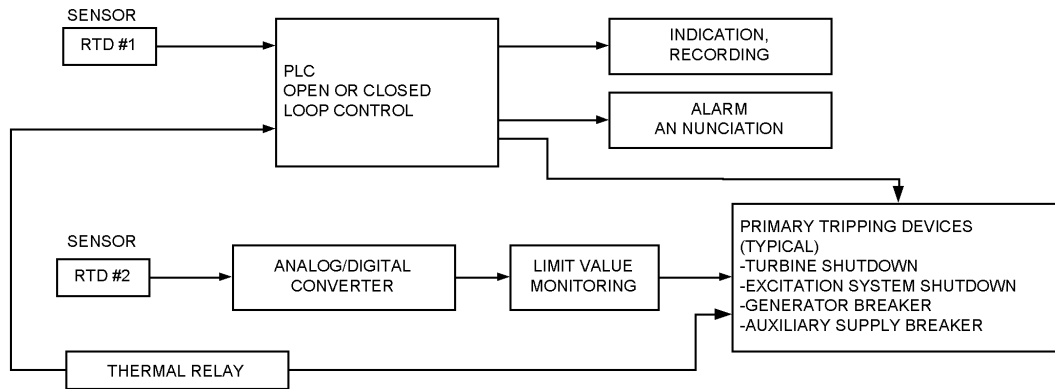


Figure 7—Redundancy in temperature monitoring system

Resistance temperature detector (RTD) #1 is connected to the control system, which performs control functions and monitors the limit values and provides alarm signals if a limit value is reached. Typical means for implementing this process is either through RTD recorders with alarm contacts (traditional) or as a function of a microprocessor-based programmable logic controller (PLC) (contemporary). RTD #2 in this example provides a tripping signal to the protection systems independent of the PLC. A third electromechanical device (e.g., thermal relay) backs up RTD #2 by also providing a tripping signal. Alternative means for providing such redundancy through automation systems are covered in companion guide IEEE Std 1249.⁷

4.4.5 Monitoring process

Instrumented values can be monitored using display devices at their respective control boards (e.g., turbine governor actuator cabinet, unit control board) or at a plant control switchboard. Analog and digital instrumentation, VDUs, and other devices mentioned in 4.4.2 are typical of the monitoring equipment. Some display units also permit manual unit control via touch screen.

4.5 System architecture

This guide describes hydroelectric power plant control system configuration in terms of a hierarchical, vertically arrayed control structure, which has been used in the industry through the years. This approach conforms to the control system logic developed in succeeding clauses. This approach may differ in the terminology, application, and technical issues from the contemporary automated control system described in IEEE Std 1249. However, this does not invalidate the application of the standard to existing systems or rehabilitation of existing systems. The two systems can coexist at the same hydroelectric project. For an in-depth discussion of architecture issues such as reliability, control system configuration, configuration trade-offs, and system capabilities as applied to hydroelectric automation systems, refer to companion document IEEE Std 1249.

4.5.1 General

The control system of a hydroelectric power plant can be defined by identifying three categories of control: location, control mode, and mode of operation. How these categories are assembled for a specific control system defines where it is in the general control hierarchy for hydroelectric power plants.

⁷Information on references can be found in Clause 2.

Hydroelectric industry practice is to describe control system configuration in terms of a hierarchical, vertically arrayed structure with the simplest and most basic controls at the lowest level in the array and the most sophisticated (and most remote) controls at the highest level. Industry practice is to describe a control system configuration by location and then mode. It can then be modified by defining the type of supervision (mode of operation). Since the staffing of a plant varies within the industry, it is difficult to define the supervision aspect generically. All combinations of location and mode are legitimate and more than one combination can exist at a plant. For example, a multiple unit plant can have local manual controls at the unit auxiliaries and the control switchboard. It can have a control room that would have both centralized manual and centralized automatic controls. It may even have equipment at the plant that would allow the capability of off-site automatic controls. The plant may also be unattended except for routine maintenance visits.

A general hierarchy of control can, therefore, be developed, going from those controls closest to the equipment and the least complex to the controls located off-site that are the most sophisticated. Typically, the lowest level control has priority. Starting from the lowest (most basic) level in the hierarchy and working to the highest (most sophisticated), the levels are as follows:

- a) Local manual
- b) Local automatic
- c) Centralized manual
- d) Centralized automatic
- e) Off-site manual
- f) Off-site automatic

A summary of this hierarchy is shown in Table 2. The preceding combinations can further be modified by appending either *attended* or *unattended* to them.

Table 2—Summary of control hierarchy for hydroelectric power plants

Control category	Subcategory	Remarks
Location	Local	Control is local at the controlled equipment or within sight of the equipment.
	Centralized	Control is remote from the controlled equipment, but within the plant.
	Off-site	Control location is remote from the project.
Mode	Manual	Each operation needs a separate and discrete initiation; could be applicable to any of the three locations.
	Automatic	Several operations are precipitated by a single initiation; could be applicable to any of the three locations.
Operation (supervision)	Attended	Operator is available at all times to initiate control action.
	Unattended	Operating staff is not normally available at the project site.

4.5.2 Control locations

The first category, *location*, is used to define where the controls are placed in relation to the equipment being controlled. More than one location of control can exist for a single piece of equipment, and the complement of equipment controls available at each location can vary. Location is defined as being local, centralized, or off-site.

4.5.2.1 Local

Local has a dual meaning and can be used with respect to the control's relation to either the generating unit or the auxiliary equipment. If local is being used in reference to the auxiliary equipment, it refers to the controls that are located at the equipment itself or within sight of the equipment. If local is being used in reference to the generating unit, it refers to the unit control system interface-governor control panel. The unit system may have controls that are not within sight of the auxiliaries being controlled, but usage of the term *local* in this respect is understood throughout the industry. Local control is synonymous with the most basic controls in the plant.

4.5.2.2 Centralized

Centralized denotes a control location that is one step further removed from local. It is removed from the equipment or generating unit and yet still within the confines of the plant. An example would be where controls for multiple units are brought to a control room within the powerhouse. The controls could be brought directly from the auxiliaries to the central location or could be incorporated with the unit-plant control system. The full complement of controls available locally need not be present at the centralized area.

4.5.2.3 Off-site

An *off-site* control location is one that is external to the plant. It could be located at the switchyard, at another plant, or at some other remote location. The term *remote* should not be confused with the term *off-site*. Remote can be understood to pertain to a control location distant from the actual equipment but still on-site. This type of control is characterized by a greater degree of sophistication in the controls themselves.

4.5.3 Control modes

After location, the second category of control that can be defined is the *mode* of control. Two types of control modes exist: manual and automatic.

4.5.3.1 Manual

Manual is the most basic control mode. It is characterized by the type of controls installed near or with the devices being controlled, such as pumps, compressors, valves, and motor control centers. The full complement of controls and indication may exist here, but it is more common to only provide a minimal control. Each operation needs a separate and discrete initiation. Manual control can be found in all three sublevels of the location category. It is more predominant in the local area but can be found in off-site systems of control such as control of high voltage power circuit breakers and high-voltage disconnect switches associated with the plant switchyard. Manual control finds use in commissioning, maintenance, or operational training procedures.

4.5.3.2 Automatic

Automatic is a level above the basic control mode. It is characterized by more sophisticated type of controls installed at both local and centralized locations. Automatic control is recognized by several operations being started or, consequently, precipitated by a single initiation. Examples can be found from the sequencing of unit auxiliaries for an automatic unit start, to the loading and balancing of multiple units in a plant. Both examples are initiated by a single operator command. The equipment to accomplish this ranges from simple relay logic to fully computerized automation systems. Automatic load dispatch and automatic generation control are examples of applications associated with fully computerized automation systems.

4.5.4 Control operation (supervision)

After the location and mode of control are defined, the manner in which the plant is supervised or staffed should be recognized. Though this aspect is not commonly addressed in industry-recognized labels for plant control, the equipment selection and its degree of automation is influenced by plant supervision. As the main point of control moves from the equipment to an off-site locale, the need for staffing and supervision at the lower levels of control diminishes. Supervision can, therefore, be described relative to the plant as either attended or unattended.

Attended. The plant is staffed 24 hours a day. The operator is available to perform control actions either locally or at a centralized area. Operators may staff the control location full time or may be roving throughout the plant or a local group of plants.

Unattended. The plant is not staffed for the full 24 hours a day. An operator may be present for a single shift or make a routine visit to the project. With the exception of small hydro, the policy throughout the industry is to have some form of supervision or monitoring at a given plant. If the plant's on-site control is defined as unattended, then it is implied that the supervision-monitoring is performed off-site. Unattended operation is represented by two predominant examples:

- a) *Off-site supervisory control.* Here, control of the remote plant exists for all essential operations and a full complement of indications for the remote plant are brought to the off-site control location. Occasional visits by operation and maintenance people are made to ensure plant security.
- b) *Off-site monitored control.* All of the controls for the plant are local. A representation of plant indication is brought to an off-site location where full attendance exists. The capability exists at the off-site location to dispatch an operator to the plant if conditions warrant. Routine maintenance visitations can also be made to the plant.

5. Control and monitoring of plant equipment

5.1 General

The control system receives input signals from main equipment such as the turbine, generator, governor, exciter, and auxiliary systems, such as motor control centers and the automatic synchronizer. Refer to Figure 8 for the major components of a hydroelectric unit. The control system receives status inputs from control, level, pressure, and other auxiliary switches, and analog inputs from transducers and other sensors. The control system provides outputs to start, operate or shut down the unit. Abnormal conditions indicated by the inputs should prevent the unit's start-up, or if already online, provide an alarm or initiate its shutdown or other protective measures.

Block diagrams illustrating controls for a large reaction-type hydroelectric unit are shown in Figure 9. For multiple unit sites, each unit should be equipped with a control interface located physically close to the individual units. A centralized control panel may be located in a control room. This guide is not intended to cover unit protection although the protective devices could be housed in cabinets or on panels associated with unit controls.

The unit control system interface should be designed to perform the following functions:

- a) Data gathering and monitoring
- b) Start-stop control sequencing
- c) Annunciation of alarm conditions
- d) Temperature monitoring
- e) Metering and instrumentation

- f) Event recording, when required
- g) Synchronizing and connecting the unit to the system
- h) Control of real and reactive power

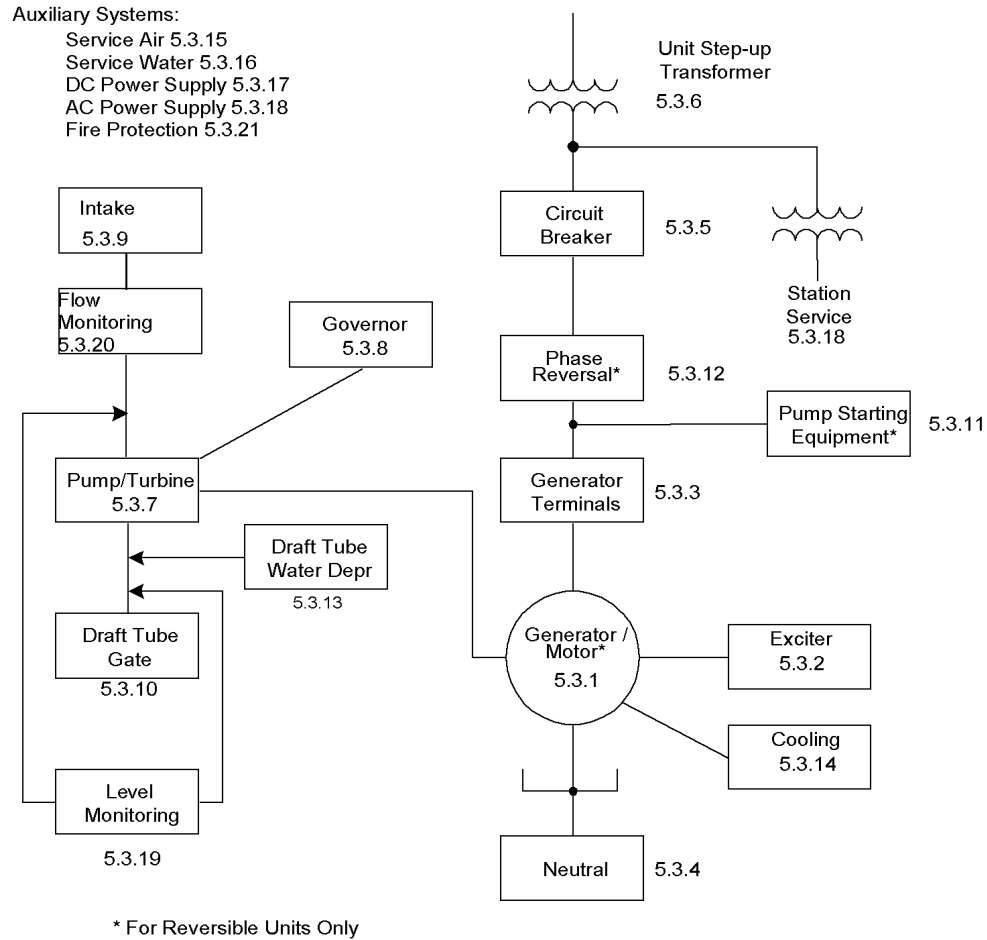


Figure 8—Major components of a hydroelectric unit with reference to descriptive subclauses

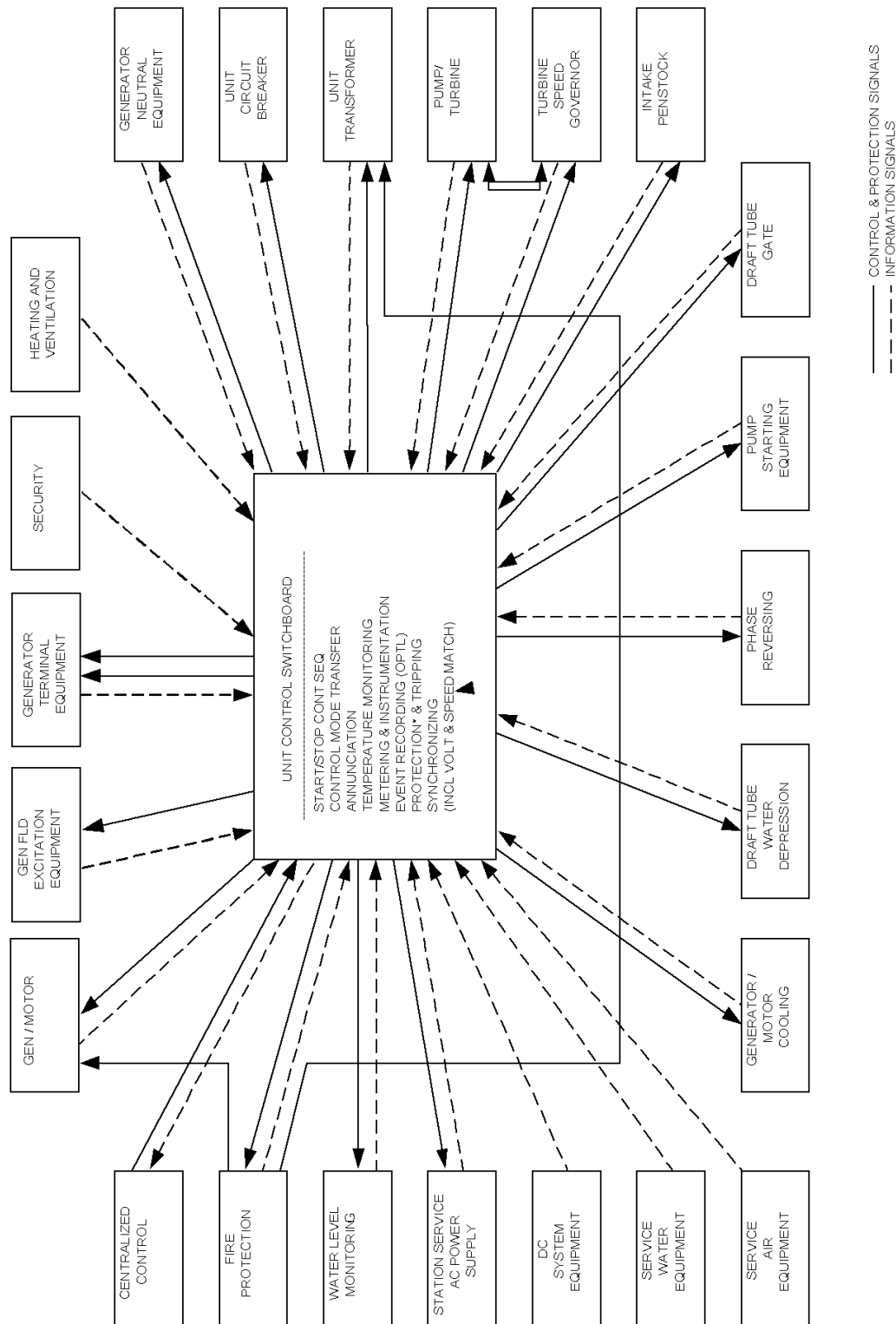


Figure 9—Controls for large hydroelectric unit—basic block diagram illustrating extent of controlled or associated equipment

5.2 Information and control signals

5.2.1 General

There are four types of signals that may be provided between the control board and any particular piece of equipment, as follows:

- a) Analog inputs to transmit variable signals from the current transformers (CTs), voltage transformers (VTs), RTDs, thermocouples, pressure, flow, level, vibration, or other transducers.
- b) Digital inputs (typically contact closures) to provide status or digitized values of variable quantities from the equipment.
- c) Digital outputs to send command signals from the control board to the equipment.
- d) Analog outputs to transmit variable signals from the control board to equipment, such as the governor, voltage regulator, etc.

5.2.2 Communications with control board

The communication links between the control board and the equipment should be adequate to transmit information and control signals. Data and control signals will be needed between the control board and each of the following unit equipment:

- a) Generator neutral and terminal equipment
- b) Headwater and tailwater level equipment
- c) Water passage facilities (shut-off or bypass valves, gates, etc.)
- d) Turbine or pump-turbine
- e) Unit transformer
- f) Circuit breaker and switches
- g) Generator-motor
- h) Intake gate (and/or inlet valve) and draft tube gate
- i) Turbine speed governor
- j) Generator excitation system
- k) Synchronous condenser equipment

5.2.3 Communications with auxiliary equipment

Data and control signals will be needed between the control board and auxiliary systems and equipment. Figure 9 shows the interconnection of the following auxiliary equipment:

- a) Fire protection
- b) AC power supply
- c) DC power supply
- d) Service water
- e) Service air

5.3 Control system interfaces

The following subclauses describe the characteristics of interfaces to the major equipment and systems.

5.3.1 Generator-motor

This subclause provides a guide for interfacing a typical generator-motor to the unit control system. The description is based on a vertical synchronous generator-motor with thrust bearing and one or more guide bearings. Horizontal and inclined axis units are similar with different bearing arrangements.

Interface points between the generator-motor and the unit control system are shown in Table 3 and Table 4. Connections between the generator-motor and the station service equipment are shown in Table 5.

Signal designators shown in the tables and figures are in common practice.

Table 3—Control and status data transmitted from generator-motor to unit control system

Signal	Description	Type ^a	Notes
26GS	Stator winding temperature	T, A, P	Temperature detectors (typically 12) embedded in stator winding. Two hottest RTDs connected to thermal overload relay 49G.
38THT	Thrust bearing temperature	T, A, P	Temperature detectors embedded in wells in the shoes or segments with provision for interchanging sensors between segments.
38GT	Guide bearing temperature	T, A, P	Temperature detectors. Provision for mounting sensors in all segments.
38QB	Bearing oil temperature	T, A, P	Temperature detectors in each separate bearing oil reservoir.
26AO	Air cooler outlet air temperature	T, A	Temperature detectors. (Quantity dependent on number of coolers and desired level of coverage.)
26AI	Air cooler inlet air temperature	T, A	Temperature detectors. (Quantity dependent on number of coolers and desired level of coverage.)
26GF	Generator field temperature	T, A, P	Temperature monitoring system for continuously monitoring field temperature.
71QBH	Bearing oil level high	A	One sensor for each separate oil reservoir often equipped with direct reading visual indicator.
71QBL	Bearing oil level low	A	One sensor for each separate oil reservoir often equipped with direct reading visual indicator.
38QW	Bearing water contamination detector	A	One sensor in each separate oil reservoir, for detection of water buildup or emulsified oil.
39V	Bearing-shaft vibration detector	A, P	Detectors installed near the guide-bearing segments at 90 degrees to each other, for detection of equipment defects and rough zone operation. Used in conjunction with probes on turbine guide bearing.
63QTH	Thrust bearing high-pressure oil system start interlock-failure alarm	C, A, I	Pressure switch provides confirmation that the oil pump motor has established sufficient pressure to allow the start sequence to proceed. Used also to generate alarm if pressure fails to establish after pump is commanded to start.
CPD	Combustion products detectors	A	Several ionization detectors located in air cooler outlet air stream and in other areas of the generator housing.

Table 3—Control and status data transmitted from generator-motor to unit control system (*continued*)

Signal	Description	Type ^a	Notes
26G	Temperature detectors for fire protection system	P, C, A	Fixed temperature or rate-of-rise of temperature or both; detectors mounted in stator end turn area. Used to initiate fire extinguishing system in conjunction with fault detecting equipment.
63FG	Fire extinguishing system operation	P, A	Pressure switches installed downstream of actuating valve. Back trips generator protection. May also be used to generate an extinguishing system failure alarm if system is initiated but pressure fails to establish within a fixed time.
33AB	Air brake position indication	C, I	Start interlock indicating all brake shoes have cleared runner plate.
33CW or 80CW	Cooling water valve position	C, I	Position, pressure, or flow switch provides confirmation that cooling water is available to coolers. Start interlock and status indication.
CT-SP	Split phase or current unbalance CT	P, I	Double window split phase CTs or single window CT in each parallel circuit for protection against bar-bar faults within a parallel circuit or parallel-parallel faults in one phase. Split phase currents can also be monitored to determine changes in the air gap profile.
CT-G	Neutral end and terminal end CT	P, I	Furnished in quantities and ratings compatible with the metering and primary-standby protection requirements.

^aType: C = control; P = protection trip; A = annunciation—event recording; T = temperature monitoring; I = indication (analog, digital, status lamps).

Table 4—Control and status data transmitted from unit control system to generator-motor

Signal	Description	Type ^a	Notes
2THS	Thrust bearing high-pressure oil pump start-stop command	C	Start pump prior to starting unit. Confirmation of pump starting via 63QTH.
20CWS	Generator cooling water system start-stop command	C	Open valve or start pump prior to starting unit. Confirmation of water flow via 33CW or 80CW.
20FGS	Fire extinguishing system operate command	C, P	Open valve upon detection of fault and excessive heat. Confirmation of valve operation via 63FG.
20AL	Air louver operate command	C, P	Close discharge and inlet air louvers in generator housing in event of a fire.
1GL	Generator lube oil system start-stop command	C	Enables generator lubrication prior to unit run.
1CF	Cooling fan start-stop command	C	When forced air cooling is used for the generator.
1SH	Unit housing heaters on-off	C	Turned off when unit is online.

^aType: C = control; P = protection trip.