

IEEE Guide for Computer-Based Control for Hydroelectric Power Plant Automation

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Abstract: The application, design concepts, and implementation of computer-based control systems for hydroelectric power plant automation is addressed. Functional capabilities, performance requirements, interface requirements, hardware considerations, and operator training are discussed. Recommendations for system testing and acceptance are provided, and case studies of actual computer-based control applications are presented.

Keywords: alarm processing, automatic generation control, automatic voltage control, computer-based automation, closed-loop control, data acquisition, hydroelectric, power plant, network bus configurations, system architecture, system performance

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Introduction

(This introduction is not part of IEEE Std 1249-1996, IEEE Guide for Computer-Based Control for Hydroelectric Power Plant Automation.)

Automation of hydroelectric generating plants has been a known technology for many years. Due to the relative simplicity of the control logic for hydroelectric power plants, the application of computer-based control has lagged, compared to other types of generating stations, such as fossil. Now that computer-based control can be implemented for comparable costs as relay-based logic and can incorporate additional features, it is being applied in hydroelectric power stations worldwide, both in new installations and in the rehabilitation of older plants.

The guide is directed to the practicing engineer who has some familiarity with computer-based control systems. The authors have attempted to make the document a comprehensive guide to the application of such systems to hydroelectric plants. It begins with a discussion of computer-based control system functional capabilities, pursues data acquisition, alarm processing, report generation, and operator training, as well as various system architecture and network bus configurations. System performance and testing are discussed, and finally, four case studies of actual computer-based hydroelectric control applications are presented.

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IEEE Guide for Computer-Based Control for Hydroelectric Power Plant Automation

1. Overview

1.1 Scope

This guide addresses the application, design concepts, and implementation of computer-based control systems for hydroelectric plant automation. It addresses functional capabilities, performance requirements, interface requirements, hardware considerations, and operator training. It includes recommendations for system testing and acceptance. Finally, case studies of actual computer-based automatic control applications are presented.

The automation of control and data logging functions has relieved the plant operator of these tasks, allowing the operator more time to concentrate on other duties. In many cases, the plant's operating costs can be significantly reduced by automation (primarily via staff reduction) while still maintaining a high level of unit control reliability.

Automatic control systems for hydroelectric units based on electromechanical relay logic have been in general use for a number of years and, in fact, were considered standard practice for the industry. Within the last decade, microprocessor-based controllers have become available that are suitable for operation in a power plant environment. These computer-based systems have been applied for data logging, alarm monitoring, and unit and plant control. Advantages of computer-based control include use of graphical user interfaces, the incorporation of sequence of events and trending into the control system, the incorporation of artificial intelligence and expert system capabilities, and reduced plant life cycle cost.

1.2 Purpose

This guide is directed to the practicing engineer who has some familiarity with computer-based control systems and who is designing or implementing hydroelectric unit or plant control systems, either in a new project or as a retrofit to an existing one. This guide assumes that the control system logic has already been defined; therefore, its development is not covered. For information on control sequence logic, the reader is directed to the IEEE guides for control of hydroelectric power plants listed in Clause 2. of this guide.

2. References

ANSI C63.4-1992, Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz–40 GHz.¹

IEEE Std 100-1996, The IEEE Standard Dictionary of Electrical and Electronics Terms.²

IEEE Std 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations (ANSI).

IEEE Std 610-1990, IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries (ANSI).

IEEE Std 1010-1987 (Reaff 1992), IEEE Guide for Control of Hydroelectric Power Plants (ANSI).

IEEE Std 1020-1988 (Reaff 1994), IEEE Guide for Control of Small Hydroelectric Power Plants. (ANSI)

IEEE Std 1046-1991 (Reaff 1996), IEEE Guide for Distributed Digital Control and Monitoring for Power Plants (ANSI).

IEEE Std 1147-1991 (Reaff 1996), IEEE Guide for the Rehabilitation of Hydroelectric Power Plants (ANSI)

IEEE Std C37.1-1994, IEEE Standard Definition, Specification, and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automation Control (ANSI).

IEEE Std C37.90.1-1989 (Reaff 1994), IEEE Standard for Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (ANSI).

IEEE Std C37.90.2-1987, IEEE Trial Use Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers (ANSI).

IEEE P1379 (Draft 5, September 1996), IEEE Trial Use Recommended Practice for Data Communications Between Intelligent Electronic Devices and Remote Terminal Units in a Substation.³

IISA/SAMA PMC 31.1-1978, Electromagnetic Susceptibility of Process Control Instrumentation.⁴

ISO/IEC 8802-3: 1996 (ANSI/IEEE Std 802.3, 1996 Edition) Information technology—Telecommunications and information exchange between systems—local and Metropolitan Area Networks—Specific requirements—Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications.⁵

IEEE Std ISO/IEC 8802-4; 1990 [ANSI/IEEE 802.4-1990 (Reaff 1995)], Information processing systems—local area networks—Part 4: Token-passing bus access method and physical layer specifications.

IEEE Std ISO/IEC 8802-4; 1990 [ANSI/IEEE 802.4-1990 (Reaff 1995)], Information processing systems—local area networks—Part 4: Token-passing bus access method and physical layer specifications.

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²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Po. Box 1331, Piscataway, NJ 08855-1331, USA.

³This IEEE standards project was not approved by the IEEE Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.

⁴This document is available from the Instrument Society of America, 67 Alexander Drive, Research Triangle Park, NC 27709.

⁵ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

ISO/IEC 8802-5: 1995 (ANSI/IEEE Std 802.5, 1995 Edition), Information technology-Telecommunications and information exchange between systems—local and Metropolitan Area Networks—Specific requirements—Part 5: Token ring access method and physical layer specification.

3. Definitions

The definitions provided here reflect common industry usage as related to automation of hydroelectric power plants, and may not in all instances be in accordance with IEEE Std 100-1996, or IEEE Std 610-1990, or other applicable standards. For more rigorous definitions, or for definitions not covered herein, the reader is referred to the appropriate IEEE standards.

3.1 analog-to-digital (a/d) conversion: Production of a digital output corresponding to the value of an analog input quantity.

3.2 automatic control: An arrangement of electrical controls that provides for switching or controlling, or both, of equipment in a specific sequence and under predetermined conditions without operator intervention.

3.3 automatic generation control (AGC): The capability to regulate the power output of selectable units in response to total power plant output, tie-line power flow, and power system frequency.

3.4 automatic voltage control (AVC): The capability to regulate a specific power system voltage, via adjustment of unit excitation within the limits of unit terminal voltage and VAR capability.

3.5 automation hierarchy: The design and implementation of automation functions in a multilevel structure, such as local level, group level, unit level, etc.

3.6 availability: The ratio of uptime (system functional) to uptime plus downtime (system not functional).

3.7 backplane: A circuit board with connectors or sockets that provides a standardized method of transferring signals between plug-in circuit cards.

3.8 bridge: A device that allows two networks of the same or similar technology to communicate.

3.9 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).

3.10 closed loop control: A type of automatic control in which control actions are based on signals fed back from the controlled equipment or system. For example, a plant control system can control the power output of a multi-unit hydroelectric power plant by monitoring the total plant megawatt value and, in response, by controlling the turbine governors of each unit, change the plant power output to meet system needs.

3.11 computer-based automation: The use of computer components, such as logic controllers, sequence controllers, modulating controllers, and processors in order 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.

3.12 control hierarchy: A system organization incorporating multiple levels of control responsibility.

3.13 control philosophy: The total concept on which a power plant control system is based.

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

3.15 database: The collection of stored data regarding the process variables and processing procedures.

3.16 data bus: A control network technology in which data stations share one single communication system medium. Messages propagate over the entire medium and are received by all data stations simultaneously.

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

3.18 digital-to-analog (d/a) conversion: Production of an analog signal whose magnitude is proportional to the value of a digital input.

3.19 distributed processing: A design in which data is processed in multiple processors. Processing functions could be shared by the processors throughout the control system.

3.20 event: A discrete change of state (status) of a system or device.

3.21 expert system: Computer programs that embody judgmental and experimental knowledge about an application. Expert systems are able to reach decisions from new, uncertain and incomplete information with a specified degree of certainty. Expert system abilities include; making logical inferences under unforeseen conditions; using subjective and formal knowledge; explaining the procedures used to reach a conclusion; growing in effectiveness as embedded expertise is expanded and modified.

3.22 firmware: Hardware used for the nonvolatile storage of instructions or data that can be read only by the computer. Stored information is not alterable by any computer program.

3.23 gateway: A device that allows two networks of differing technology to communicate.

3.24 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.

3.25 logic: (control or relay logic) Predetermined sequence of operation of relays and other control devices.

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

3.27 mean-time-between-failure (MTBF): The time interval (hours) that may be expected between failures of an operating equipment.

3.28 mean-time-to-repair (MTTR): The time interval (hours) that may be expected to return a failed equipment to proper operation.

3.29 modem: A modulator/demodulator device that converts serial binary digital data to and from the signal form appropriate for an analog communication channel.

3.30 monitoring: A means of providing automatic performance supervision and alarming of the status of the process to personnel and control programs.

3.31 offsite control: Controls that are not resident at the plant (e.g., at a switchyard, another plant, etc.).

3.32 open loop control: A form of control without feedback.

3.33 proportional integral derivative (PID) [control system]: Control action in which the output is proportional to a linear combination of the input, the time integral of input, and the time rate of change of input. Commonly used in hydroelectric applications for the control of a generator's real power, reactive power, or flow.

3.34 pixel: In image processing, the smallest element of a digital image that can be assigned a gray level.

3.35 programmable logic controller (PLC): Solid state control system with programming capability that performs functions similar to a relay logic system.

3.36 protocol: A structured data format required to initiate and maintain communication.

3.37 relay, interposing: A device that enables the energy in a high-power circuit to be switched by a low-power control signal.

3.38 remote control: Control of a device from a distant point.

3.39 reliability: The characteristic of an item or system expressed by the probability that it will perform a required mission under stated conditions for a stated mission time.

3.40 response time: The elapsed time between the moment when a signal is originated in an input device until the moment the corresponding processed signal is made available to the output device(s), under defined system loading conditions.

3.41 resistance temperature detector (RTD): A resistor for which the electrical resistivity is a known function of the temperature.

3.42 scan (interrogation): The process by which a data acquisition system sequentially interrogates remote stations for data at a specific frequency.

3.43 scan cycle: The time in seconds required to obtain a collection of data (for example, all data from one controller, all data from all controllers, and all data of a particular type from all controllers).

3.44 serial communication: A method of transmitting information between devices by sending digital data serially over a single communication channel.

3.45 sequential control: A mode of control in which the control actions are executed consecutively.

3.46 supervisory control and data acquisition (SCADA): A system operating with coded signals over communication channels so as to provide control of remote equipment and to acquire information about the status of the remote equipment for display or for recording functions.

3.47 user interface: A functional system used specifically to interface the computer-based control system to the operator, maintenance personnel, engineer, etc.

4. Functional capabilities

4.1 General

Computer-based automation has enhanced hydroelectric power plant operation and maintenance activities. Many activities previously accomplished by plant personnel can now be performed more accurately, safely, and consistently by computer-based automation systems. Also, new tasks are within the capabilities of computer-based systems.

Power plant operators have long been responsible for manually performing control and data acquisition tasks. Relay logic type automatic control systems were, for many years, the only automated control assistance for operations staff. These systems were limited to unit control sequencing (start/stop) and were not easily changed, once installed. The quality of data acquisition has been subject to the limitations of available staff and human error.

Computer-based control and data acquisition systems have made major changes in the way these tasks are carried out. Power plant operator expertise has been supplemented in many plants by the computer, which can assist with unit start/stop sequencing and data logging; in other plants, the computer has replaced the operator altogether by performing these tasks. The online diagnostic, corrective, and protective capabilities of these computer systems continue to be developed.

Computer-based automation systems now allow plant owners to operate and maintain their plants in ways not possible before. Control algorithms based on criteria such as efficiency, automatic generation control, and voltage control allow more cost effective and safe operation of plants and interconnected power systems. It is now possible to acquire and process more data than in the past, so generated reports can keep operators and maintenance staff apprised of the total plant condition. Maintenance activities are enhanced by the computer's ability to isolate problems, describe trends, and keep maintenance records.

Computer-based automation systems also permit operation of the power plant, switchyard, and outlet works (spillway gates, bypass gates and valves, fishways, fish ladders, etc.) from a single control point that can be local, centralized, or offsite. This one-point control has many advantages, including reduced operations staff, consistent operating procedures, and the capability to have all control and data available for reference during normal and abnormal conditions.

Subclauses 4.2–4.11 outline the functional capabilities of hydroelectric plant computer-based automation systems.

4.2 Control capabilities

4.2.1 Control hierarchy

A general hierarchy of control for hydroelectric power plants is defined in IEEE Std 1010-1987.⁶ The combination of computer-based and noncomputer-based equipment utilized for unit, plant, and system control should be arranged in accordance with Table 1.

Table 1—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.
	OffSite	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	Operation staff is not normally available at the project site.

and automatic control. At the other extreme, the computer-based equipment may handle only automatic unit sequences and data acquisition, with all other functions, such as local manual control, handled by noncomputer-based equipment.

Manual controls are used during testing, and maintenance, and as a backup to the automatic control equipment. Generally, manual controls are installed adjacent to the devices being controlled, such as pumps, compressors, valves, and motor control centers. Transfer of control to higher levels is accomplished by means of local-remote transfer switches installed at the equipment. Often, capability to operate individual items of equipment is also provided at the unit switchboard while in the local-manual mode. If this capability is designed to backup the computer-based equipment, then additional interposing relays and other devices will be required. Alternately, with the high reliability of modern computer equipment, local-manual operation from the unit switchboard may be incorporated into the computer controls, thereby reducing control complexity. In this case, direct manual operation will still be possible at the equipment location. Further backup control considerations are described in 8.2.

For severe faults that require high-speed tripping of a unit, separate protective equipment is included in the unit control system. This protective equipment comprises relay-based, solid-state, or microprocessor-based protection for electrical and mechanical equipment and trip logic. These high-speed protective functions are generally not incorporated into the computer-based systems used for control.

Figure 1 illustrates the arrangement of control locations, typical functions at each location, and typical interchange of control and operating information. Local control, centralized control, and offsite control functions are described in 4.2.2–4.2.4.

⁶Information on references can be found in clause 2..

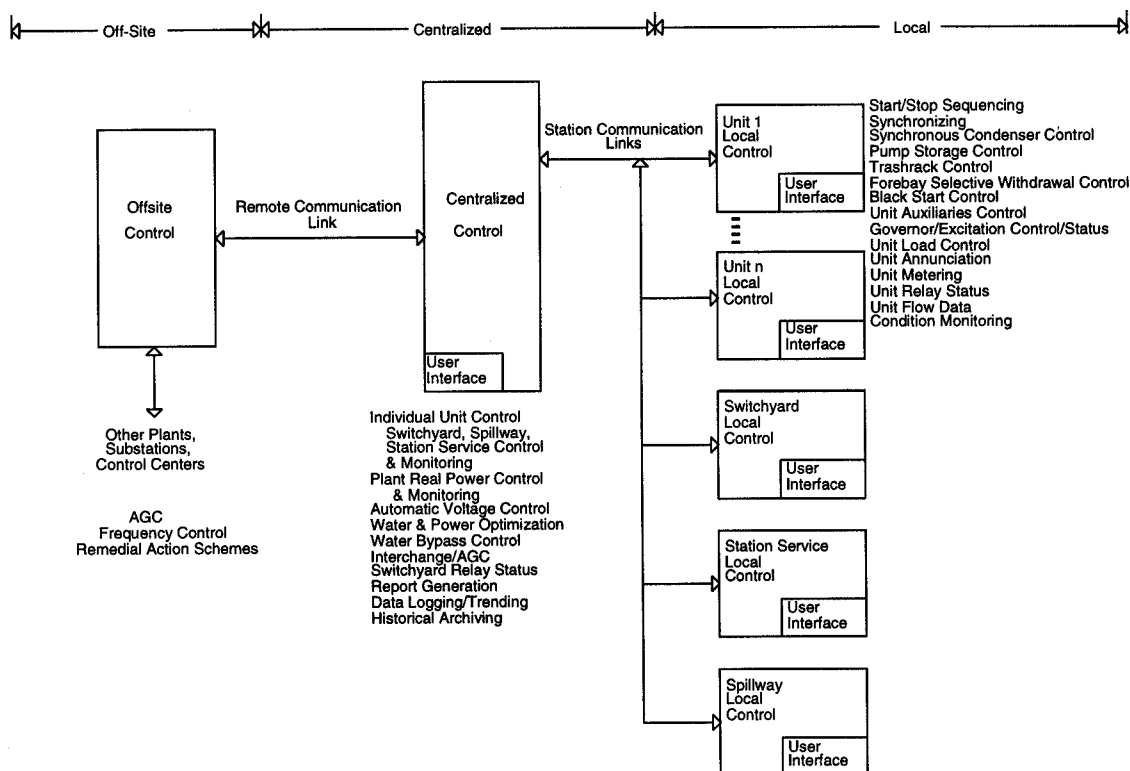


Figure 1 — Relationship of local, centralized, and offsite control

4.2.2 Local control

Local control can be provided by equipment located near the generating unit itself. The local unit computer is part of this equipment and backup manual control may be desired depending on the operator's design philosophy. Where there are multiple units in a plant, one computer is typically allocated to each unit. The local unit computer interfaces to higher level plant or offsite computers exchanging control signals and data without the need for additional wiring. Figure 2 illustrates the local control configuration.

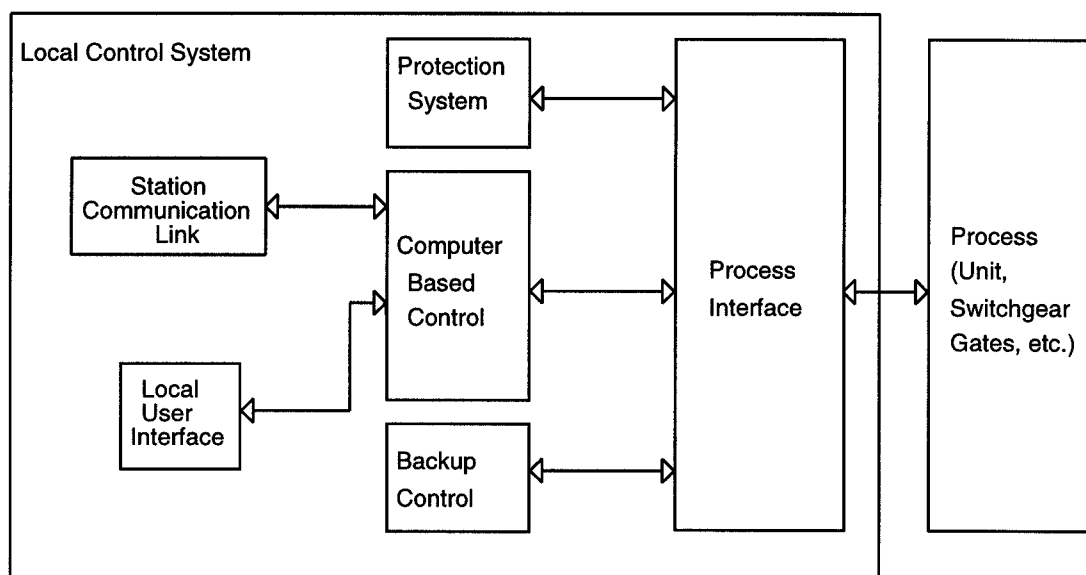


Figure 2—Local control configuration

4.2.2.1 Start/stop sequencing

One of the most obvious uses for computer-based automation in power plants is for automating unit start/stop control sequencing. Older designs that use electromechanical relay-based start/stop sequential logic are being replaced with modern computer automation systems. The computer is programmed to completely start or stop the unit when directed by higher level control or by the operator. The computer system controls the generator's electrical and electrical/mechanical auxiliary systems to start or stop the unit. Inputs to the computer are unit and plant status points that are constantly monitored for change during the sequence. The computer can continuously monitor and display more status information than an operator can assimilate so that control actions, such as abort sequences, can be initiated immediately, without operator reaction time. Because the computer is programmable, modifications to the sequence control can be made relatively simply, even after the plant is operational. Computer-based start/stop sequencing is cost-effective, reliable, and easy to maintain, compared to older electromechanical relay systems. Some owners of hydroelectric plants may not be comfortable with full computer automation of the start/stop sequencing. In these cases, the start/stop sequencing can be made more conservative by containing breakpoints in the sequencing to allow for operator intervention or permissive action.

The computer system can also monitor the control sequence and provide troubleshooting information identifying where in the sequence a failure occurred. The computer can then pause in the sequencing to suggest operator intervention or to implement the corrective action. This diagnostic capability can speed up the process of correcting the problem and returning the unit to service. Systems with very high-resolution time stamping can provide sequence-of-events recording that can be used to augment and analyze the protective and control relay actions.

One of the most important features is the automation system's capability to provide diagnostic information in the event something fails to operate during the start sequence. This information can be used to isolate the problem and get the unit online as fast as possible.

Examples of some of the equipment controlled and monitored during the start/stop sequence are as follows:

- a) Intake gate or inlet valve;
- b) Governor hydraulic oil system;
- c) Gate limit position;
- d) Gate position;
- e) High pressure oil system for the thrust bearing;
- f) Mechanical brakes;
- g) Cooling water system;
- h) Excitation equipment;
- i) Unit speed;
- j) Protective relaying status;
- k) Unit alarms;
- l) Unit breaker status.

4.2.2.2 Synchronizing

Synchronizing has traditionally been performed either manually or by a dedicated automatic synchronizer unit. Today, automatic synchronizers use computer technology to optimize their performance.

In some cases, the synchronizing function is performed by the plant computer-based automation system. Synchronizing is a critical function that requires accurate and reliable monitoring of voltage magnitude, frequency, and phase angle. Not all systems can provide the synchronizing function as part of the computer-based automation system. The advantages of the synchronizing function being internal to the automation system include less plant wiring, less maintenance, reduced installation costs, and much better diagnostic capabilities. For security, a synchrocheck relay is typically used as a permissive for the circuit breaker close.

4.2.2.3 Synchronous condenser mode

Hydroelectric generating units are often used in synchronous condenser mode where real power output is negative (the unit is running as a motor) while the unit is online and excited. One reason for this is to provide reactive power control, as described below. Synchronous condenser mode is generally dispatched according to prevailing power flow conditions, but can be regulated automatically by the computer-based control system to achieve optimal real and reactive power capability and maximum transmission utilization.

In cases where a turbine is located below the tailwater level and runs as a synchronous condenser, the water is expelled from the runner area by compressed air to reduce power losses and turbine wear and tear. The computer-based automation system can control the auxiliary devices and monitor the generator during this mode of operation. For example, the automation system can override the reverse power relay during this mode of operation.

Another purpose of synchronous condenser operation is to provide readily available, real-power spinning reserve dictated by power system operating requirements. Computer-based control schemes can be useful in efficiently and automatically performing this mode of operation.

4.2.2.4 Pumped storage control

The computer-based automation system can provide the complete control necessary for a unit to operate in pumping or generating mode. The system can control the switchgear and related equipment necessary to run the unit in either mode. Some basic features easy to implement in a computer-based control system include providing a run time summary of units in the pump mode, providing an automatic restart timer feature in the event the unit fails to start properly, and determining which unit should be started to balance the run time between multiple units. All these features can be implemented at the power plant level and would involve control of the units directly or through unit controllers based on the configuration of the automation system. The main advantages of using a computer-based

system to control the pumped storage mode of operation includes easy maintenance, easy modifications, and available diagnostic information.

4.2.2.5 Turbine operation optimization

There are numerous possibilities for optimizing individual unit turbine operation through the application of custom software algorithms. Depending on the parameters monitored and control sequences needed to achieve the operating mode, algorithms can be created to enhance unit operation.

Typical algorithms and monitored parameters are as follows:

- a) *Efficiency maximization.* Head water level, tail water, gate position, blade position (Kaplan turbines), flow, unit kW output, unit reactive power output.
- b) *Minimization of unit vibration or rough running zones.* Gate position, blade position, unit vibration.
- c) *Minimization of cavitation.* Gate position, blade position, flow, hydraulic head (head water level, tail water level) turbine manufacturer's cavitation curves (or scroll case sound level).

4.2.2.6 Trashrack control

The computer-based automation system can be used to monitor the water level differential between the water level on the outside and the inside of the trashrack and to use this information to operate automatic trashrack cleaning equipment. The information provides operations personnel with appropriate data about the condition of the water flow through the trashrack to allow them to make informed decisions. One of the most important functions that the system can provide is the ability to automatically lower the flow through a unit by decreasing the generated power whenever the trashrack differential exceeds a predetermined value. In this way, the automation system can be used to ensure that the trashrack equipment is not damaged.

4.2.2.7 Forebay selective withdrawal control

Environmental regulations often prescribe an optimal temperature for downstream flow to assist local fisheries. In installations where a large impoundment exists, it is often possible to draw either bypass flow or unit flow from different temperature levels of the reservoir using slide gates or other water level selection equipment. Slide gates, for example, are positioned at various heights along the intake structure, which allow water to be drawn from various levels in the reservoir. Computer algorithms can be written to monitor downstream river temperature and to control that variable to a predetermined set point. This is accomplished by monitoring temperatures at reservoir elevations and varying the flow mix to achieve the desired downstream temperature. Slide gate control can also be helpful in regulating the amount of dissolved oxygen in the downstream flow.

4.2.2.8 Black start control

Hydroelectric powerplants play a critical role in helping reestablish power systems after a major outage. Such outages can leave the plant isolated from the system with no generators running and, therefore, no station service power. Black start capability (i.e., starting the plant without normal station service power) for restoring the plant, and ultimately the power system, is vital. Computer-based automation systems can play a role in accomplishing this black start. The computer system can be activated manually or automatically in such conditions to begin a black start control sequence. Automatically, the system can monitor plant and system conditions, start units, and restore station service power. Subsequently, the entire plant can be brought back to full operation and the power system can be restored.

The capability to start a unit under black start conditions is usually a function of the physical devices in the powerplant rather than the automation system. An auxiliary power system, such as an emergency generator or station batteries, must be available to provide power to the unit's auxiliary systems in the powerplant to ensure a black start will be successful.

Hydraulic and pneumatic systems must be operational for the automation system to provide black start capabilities. The advantages of black starting under computer-based automation are similar to those found in a normal start condition.

4.2.3 Centralized control

Centralized control refers to a common control location from which plant functions can be initiated and plant operating information can be collected and displayed. The purpose of centralized control is to consolidate control and monitoring at a common location in order to facilitate efficient plant operation and to carry out control functions best handled at the plant level. An important example of efficiency derived from centralized control is the economy of minimizing the number of operating staff required during attended operation of the facility. Centralized control also provides a link between the offsite control facilities and the in-plant facilities. The following clauses describe typical functions provided by the centralized control system.

4.2.3.1 Control of individual units

A number of the functions available at the unit local control system may be made available at the centralized control location. The extent of duplication between centralized and local control functions will depend on the operating philosophy of the utility or owner and the capability of the plant data network. Typical unit control functions able to be initiated at the centralized control location are as follows:

- a) Automatic start and synchronization;
- b) Automatic stop;
- c) Emergency shutdown;
- d) Speed setpoint;
- e) Power setpoint;
- f) Voltage and reactive power set point.

4.2.3.2 Switchyard, spillway, and station service control

A number of the functions at the switchyard, spillway, and station service local control systems may be made available at the centralized control location. Again, the extent of duplication with local control is an operational decision. Typical functions provided at the centralized location are as follows:

- a) Circuit breaker open/close synchronization;
- b) Disconnect switch open/close;
- c) Transformer tap changer control;
- d) Spillway gate open/close;
- e) Plant real-power control.

The computer system can be used to maintain the plant or individual unit power output based on different operating criteria. If a plant or unit is to maintain a predetermined power level it can be essentially block-loaded by the computer, and power output will be very accurately maintained at that level regardless of other variables, such as head changes.

Similarly, a plant or unit can be tied to a certain discrete demand and be assigned the task of exactly satisfying that demand in order to allow other units to be block-loaded. When this swing unit trips offline, it is necessary for one or more of the remaining units to transfer from the block-load mode to the swing unit mode to pick up the variable load. Computer-based control systems can automate this control scheme.

A joint power control scheme is often employed in which the desired plant power output is allocated equally among the individual units selected for joint power control. In this case, the plant control scheme includes functions for unit selection, balancing of individual unit power setpoints, control of joint power setpoint, and frequency bias (regulation).

4.2.3.3 Plant voltage/var control

Plant voltage and corresponding plant var output may be controlled by dispatch of individual unit voltage setpoints or by means of a joint voltage control scheme. The joint voltage control system maintains a desired high voltage bus or line voltage by allocating var generation among individual units selected for joint voltage control. The joint voltage control system may include functions for unit selection, control of joint voltage setpoint, and transformer tap position or line drop compensation.

4.2.3.4 Water and power optimization

As maximum utilization of the water resource becomes more and more important to power producers, power plant operators are striving to optimize water usage and power production. Automated water resource management, such as scheduled water releases for minimum water flow and fish water needs, is an excellent application for the computer control system. Accurate, timely, and recorded release information is retrievable through an automated system.

It is also possible to optimize the use of water for given power requirements by computer-based unit, plant, or system efficiency algorithms. For example, knowing the individual generator, turbine, and penstock efficiencies and the hydraulic head and flow, the onsite computer can direct the optimal loading of the units to meet the overall plant load requirement while achieving the best possible plant efficiency. As the hydraulic head changes, operating efficiencies will change and it may be necessary for the computer to reallocate unit load to maintain best achievable overall plant efficiency while satisfying the total demand.

4.2.3.5 Water bypass control

Minimum downstream water flows are often dictated by irrigation and environmental requirements. Water release through bypass mechanisms can be done automatically and more efficiently through the computer. Accurate, real-time control of valves and gates to provide exact flows based on current head and other conditions is possible rather than relying on simple open or closed control.

4.2.4 Offsite control

Offsite control refers to plant control activity from one or more control centers remotely located from the hydroelectric plant. Plant operations performed from such centers are usually one component of an integrated power dispatch and system operation strategy. Personnel at the offsite control location are normally responsible for operating several powerplants and substations, and will probably interface with other control centers (regional, power distribution system, or other power producers).

Some of the system control functions that are generally performed by offsite control centers are:

- a) Periodic megawatt (MW) and megavar (MVar) adjustments to maintain power system operation in accordance with requirements and criteria established by coordinating bodies (e.g., regional reliability councils);
- b) Maintain generation reserves in accordance with criteria established by coordinating bodies to assure power system stability;
- c) Energy interchange scheduling;
- d) Automatic Generation Control, including time error control and frequency control (these require coordination with other control areas with which the system may be interconnected);
- e) Hourly load forecast;
- f) Transmission line loading (system power flow);
- g) Power sales control adjustments.

The interconnection of power systems, and the need to control generation and power flow throughout such systems, has led to the design and installation of networks of hierarchical computer-based control schemes that allow system dispatchers to direct power generation at many plants. The computer-based automation systems at individual

hydroelectric plants are often integral parts of these power system-wide computer-based control systems used for interconnected power system operation.

When considering automation of hydroelectric plants, it is important to determine how the proposed computer-based plant control system will interact with the offsite power system control computers. Since specific control capabilities can be programmed into computers at various levels in a hierarchical control scheme, an overall philosophy of system control must be established first. The control capabilities and data requirements for the local plant computer can then be defined.

Subclauses 4.2.4.1–4.2.4.4 describe typical functions performed by offsite control systems that impact the control requirements of the hydroelectric powerplant.

4.2.4.1 Control of individual generator sets and selection of centralized control functions

A number of the control functions implemented in the local control system at the hydroelectric plant are made available to, or usable by, the control system at the offsite location. The number and type of plant control functions available at the offsite system will depend on the power system operating philosophy, agreements among power system and plant operating agencies, and the amount and quality of plant and system data available to the offsite control system. Individual and centralized unit control functions available for use by the offsite control system may include those listed in clauses 4.2.3.1 and 4.2.3.3–4.2.3.5.

4.2.4.2 Switchyard, spillway, and station service control

The control functions available at the offsite location will be similar to those listed in clause 4.2.3.2.

4.2.4.3 Automatic generation control (AGC)

Computer-based AGC, normally executed at one control center in a regional power system, provides the capability to regulate the real power output (megawatt) of selected generators or power plants in real-time. Megawatt setpoints are periodically adjusted by the AGC system to meet requirements for correcting the area control error (ACE), and other constraints.

For the regional control center to be able to allocate a plant's share of the ACE [station control error (SCE)] in a correct and timely manner, the center's control computer must receive data from the plant. Inputs to the algorithm that calculates the ACE include: Tie-line power flows; scheduled power generation; power plant outputs; time error bias; power system frequency bias. The amount of the ACE assigned to each individual plant (SCE) as a desired change in generation level depends on the plant's assigned level of participation in ACE correction. Plant participation in turn depends on the plant's share of system generation, capability to vary generation, water availability, constraints on changing plant discharge and forebay and tailwater elevations, among other factors.

The amount and type of data and the frequency of update must be established early in the design cycle of the plant control system, and becomes an important design parameter. It is usually critical that generation change allocations to the plant do not violate environmental or equipment limit constraints. A well-designed plant control system will not allow control actions that will result in such violations; however, lack of plant control response has the undesirable effect of slowing needed generation changes, and of causing reallocation of changes to other plants in the center's control area. Such reallocations may upset plant generation scheduling and water use planning at all plants affected.

Power setpoint signals are transmitted to selected power plants either as a plant scheduled generation, or individual unit scheduled generation, depending on the utility's practice, or the operating agreement between plant operator and system control center operator if they are owned or controlled by different entities.

Operator interfaces to the plant control system are provided so that individual units may be placed on AGC operation, or removed from AGC operation and placed on local control.

4.2.4.4 Remedial action schemes (RAS)

A number of remedial action schemes are provided in modern power systems, normally controlled from offsite area control centers. Typical schemes include the following:

- a) Automatic generation shedding based on transmission line configuration (for transient stability);
- b) Automatic generation shedding to help correct large-scale system overfrequency;
- c) Voltage transient boost capability for dynamic stability;
- d) Braking resistor application for transient stability;
- e) Load shedding to help correct system underfrequency.

To implement these schemes, various signals will be transmitted between the offsite area control center and the plant for arming and triggering corrective action schemes. The update and response time of the plant control computer system are critical and must be carefully considered in implementing remedial action schemes.

4.2.4.5 Data integrity

Reliable power plant data is important to system operation. If even one plant reports erroneous generation, operation of the whole power system is affected by the error until the problem is identified and faulty data corrected, either by the temporary expedients of manual override or substitution of an alternate data source.

The designer of the plant control system must assess the reliability requirements, including the impact that faulty data will have on operation of both the local control system and the offsite control system. The plant control systems should be capable of dealing with failures that impact plant and power system generation.

4.3 Data acquisition capabilities

Hydroelectric plant computers can enhance the acquisition of data from the equipment and systems at the facility. The availability and flexibility of modern computer input hardware and data acquisition software make the collection and manipulation of large amounts of plant data possible.

Data can be acquired directly from plant devices such as transducers and contacts, but given the communication capabilities of computer-based equipment such as dataloggers, sequence-of-events recorders, and digital fault recorders, the plant computer can, if a common protocol is available, acquire data directly from these intermediate data collection systems. This data can be displayed for operator's use, used in the computer control logic, uploaded to higher level control computers, or stored for future report generation.

4.3.1 Analog

Analog signals can be monitored at fixed intervals by the system for control purposes. For the purpose of data acquisition, the number of samples per unit of time is usually configured according to the parameter being monitored. Some critical quantities such as bearing temperature, hydraulic pressures, or vibration may be sampled more frequently than quantities that do not have the potential for rapid change, such as water level. Trending displays of selected analog quantities is a powerful capability of the computer system.

Several methods of collecting data from analog signal inputs are as follows:

- a) *Constant interval.* Data is stored at a constant time interval.
- b) *Report by exception.* The quantity is constantly monitored, and while the variable remains within certain limits, infrequent reporting of data takes place. When the quantity is out of range, data is reported at predetermined intervals until a steady-state condition exists.
- c) *Variable interval monitoring triggered by event occurrence.* This method monitors and stores signal values at a rate that changes as the result of an event. If no unusual event occurs, older data is overwritten by new data and constant interval storage takes place. Upon initiation of an event, the data collection rate will be increased to provide extremely fine time resolution and all data points stored for future review. This method is very useful for troubleshooting and research into equipment characteristics, but could require extensive memory.

In all cases of analog monitoring, limits can be assigned to each parameter to alarm, shut down, or initiate some other action when a value is out of range. Limits can be absolute, or may include a rate of change of the variable. The computer system has a high degree of flexibility in the recording, alarming, and processing of analog data.

4.3.2 Discrete

Most automation systems offer sequence of events recording for discrete (on/off) status inputs. Ideally, the system should provide time stamping in sufficient resolution to provide the information required to analyze the proper operation of the high speed equipment used in modern powerplants. Computer systems with this sequence-of-events capability are often preferred because they eliminate a stand-alone sequence-of-events recorder and all of the associated additional duplicate wiring and maintenance. Discrete events, alarms, and status points can be time-tagged and saved in a database for future analysis. Examples of discrete status inputs are as follows:

- a) Event points such as relay operation, unit shutdown, or operator action;
- b) Alarm points such as low pressures, high temperatures;
- c) Status points such as breaker position, control switch position.

4.3.3 Fire detection data

Modern design and operating philosophies for hydroelectric plants include increased emphasis on fire detection. The data acquisition capabilities of computers are very useful for monitoring plant fire detection systems, providing the ability to acquire fire detection data, filter it through software, and provide plant personnel with knowledge-based courses of action. In addition, fire protection control actions such as closing doors and shutting down ventilation fans can be initiated by the computer. Since fire regulations vary and can require separate fire protection control, local regulations should be checked prior to inclusion in the plant computer system.

4.3.4 Plant security data

Plant security is becoming more important to owners working to minimize vandalism, unauthorized entry, and the effects of natural events that might jeopardize the safe and proper operation of the facility. Security information displayed at centralized operators' stations makes it easier and safer for plant personnel to respond to security breaches. For unattended plants, the transmittal to offsite locations of such security information is used to dispatch personnel to investigate the cause. The computer on site also can be programmed to control responses to the security breach, such as turning on lights or alarms, or activating cameras.

4.4 Alarm processing and diagnostics

Accumulating large amounts of plant status and alarm data is not very useful unless the information can be processed in such a way to enhance operation and maintenance activities. The capabilities of the computer can be used to sort, select, prioritize, interpret, and display information in ways that were not possible before.

Modern power plants are designed to provide status and alarm indication of virtually all electrical and electrical/mechanical systems in the plant. This massive amount of information can be overwhelming, and even counterproductive, if it is not processed and presented properly. When major plant problems occur, multiple alarms are inevitable.

Knowledge-based programs can filter alarms for the operator and even interpret alarm groupings to identify the probable event that generated them. Expert system programming can assist plant operations and maintenance personnel in the location and solution of problems.