

An American National Standard

IEEE Guide for Control of Hydroelectric Power Plants

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of the
IEEE Power Engineering Society**

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Foreword

(This Foreword is not a part of ANSI/IEEE Std 1010-1987, IEEE Guide for Control of Hydroelectric Power Plants.)

This document is a guide for the North American hydroelectric power industry for the control of large hydroelectric power plants. The document was prepared by a task force of the Working Group on Hydro Plant Controls of the Hydroelectric Power Subcommittee of the IEEE Power Generation Committee.

The Group was formed at the 1980 IEEE Winter Power Meeting to investigate the current use and possible application of modern control equipment in hydroelectric plants. Modern control equipment includes microprocessor-based equipment such as distributed control systems and programmable controllers.

A questionnaire was prepared and sent to utilities owning and/or operating hydroelectric plants to determine current practices in the industry. The results of the questionnaire are given in the Appendix of this guide.

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 that are controlled in a hydroelectric plant.

Members of the Task Force represent a cross section of the hydroelectric industry, including power plant owners, designers, and equipment manufacturers.

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IEEE Guide for Control of Hydroelectric Power Plants

1. Scope and Introduction

1.1 Scope

This document 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, requirements for centralized and off-site control, and trends in control systems. Where specific values are given to control parameters, they should be considered as typical.

This document does not include 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, high-voltage switchyards, and navigational and flood control facilities.

This document is directed toward practicing engineers in the field of power plant design that have a basic knowledge of hydroelectric facilities.

1.2 Introduction

The main control systems in a hydroelectric power plant (hydro plant) are associated with the start and stop sequences for the unit, and for control of real power, voltage, and frequency.

The type of control equipment and levels of control to be applied to a hydro plant are affected by such factors as the number, size, and type of turbine and generator, whether the plant is for generation only or for pumped storage, the type of auxiliary systems, and whether or not the plant is designed for unattended operation.

Pumped-storage plants add to the complexity of the controls with separate control systems for the generating and pumping modes. Additional control equipment is needed for the starting equipment and the phase reversing of the main leads in the pumping mode.

Hydro plants may include automatic control systems operated from an off-site location. This type of operation requires the use of supervisory control and data acquisition (SCADA) equipment and a communication link between the powerhouse and the remote control point.

At power plants using variable pitch turbine blades, controls are provided to automatically adjust the turbine blades and the wicket gates to provide the most efficient output of the plant. To this end, control and measuring systems monitor such quantities as hydraulic head, wicket gate position, and plant output.

The following is a brief description of the other sections in the guide:

Section 2., Control Hierarchy, discusses various categories that affect the levels of control for a plant. The categories discussed are location, mode, and supervision.

Section 3., Requirements for Control and Monitoring of Plant Equipment, includes block diagrams and descriptions of the control and monitoring requirements for major plant systems and equipment.

Section 4., Control Sequencing—Generating Units, includes logic diagrams and control descriptions for the control of generating units.

Section 5., Control Sequencing—Pumped-Storage Units, includes logic diagrams and control descriptions for the control of pumped-storage units.

Section 6., Centralized Control, discusses the type of control equipment that can be used to interface with the equipment described in Section 3.

1.3 References

The following publications shall be used in conjunction with this guide:

[1] ANSI C50.10-1977, American National Standard General Requirements for Synchronous Machines.¹

[2] ANSI/IEEE C37.101-1985, IEEE Guide for Generator Ground Protection.²

[3] ANSI/IEEE C62.92-1987, IEEE Guide for the Application of Neutral Grounding in Electric Utility Systems: Part 1.—Introduction.

Section 7., Off-Site Control, discusses the type of control and information that is needed to operate a hydro plant from an off-site location.

Section 8., Trends, discusses the trends in hydro plant control that the working group is presently observing, and that it believes will take place in the future.

¹ANSI publications are available from the Sales Department of the American National Standards Institute, 1430 Broadway, New York, NY 10018.

²ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Institute of Electrical and Electronics Engineers, Service Center, Piscataway, NJ 08854-1331.

2. Control Hierarchy

2.1 General

The control of a power plant or the equipment in the plant can be defined by identifying a type of control from each of three categories. The three categories of control are location, mode, and supervision. The resulting definition will fall into a general control hierarchy for hydroelectric plants. The terms used to describe this control are recognized throughout the industry but common understanding varies; therefore, the terms are defined herein.

Table 2-1—Summary of Control Hierarchy for Hydroelectric Power Plants

<u>CONTROL CATEGORY</u>	<u>SUBCATEGORY</u>	<u>REMARKS</u>
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.

2.2 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 either local, centralized, or off-site.

2.2.1 Local

This term 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 switchboard/governor control station. The unit switchboard 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.

2.2.2 Centralized

This 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 or could be paralleled with the unit switchboard. The full complement of controls available locally need not be present at the centralized area.

2.2.3 Off-Site

This control location is one that is not resident to the plant. It could be located at the switchyard, another plant, or some other remote structure. The term remote should not be confused to be synonymous with 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.

2.3 Control Modes

The second category of control that can be defined is the mode of control. Two types of control modes exist for this category, manual and automatic.

2.3.1 Manual

This is the most basic control mode. It is characterized by the type of controls found local to the devices being controlled, such as pumps, compressors, valves, and motor control centers. The full complement of controls and indication exist here. Each operation needs a separate and discrete initiation. This type of 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.

2.3.2 Automatic

This is a level above the basic control mode. It is characterized by the more sophisticated type of controls found in centralized or off-site locations. It can also be utilized in local operations. 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 would be initiated by a single operator instruction. The equipment to accomplish this ranges from simple relay logic to large computer-based supervisory control and data acquisition systems. Load dispatch and automatic generation control would be an example of the latter.

2.4 Control Supervision

After the location and mode of control is 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 related to the plant supervision. The greater the degree of sophistication in the controls, the greater the distance between the equipment being controlled and the control location. As the main point of control moves from the equipment to an off-site locale, the need for staffing/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.

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:

- 1) *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.

- 2) *Off-Site Monitored Control*—All of the controls for the plant are local. A minimum 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.

2.5 Summary

The practice is to describe a control system by location and then mode. It can then be modified by defining the type of supervision. Since the staffing of a plant varies within the industry, it is difficult to define this 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 unit 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. To complete the scenario, the plant may be unattended except for routine maintenance visits

A 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 and the most sophisticated. Starting from the lowest (most basic) echelon in the hierarchy and working to the highest (most sophisticated), we find

- 1) Local manual
- 2) Local automatic
- 3) Centralized manual
- 4) Centralized automatic
- 5) Off-site manual
- 6) Off-site automatic

It should be kept in mind that the above combinations can further be modified/described by appending either attended or unattended to them.

3. Control and Monitoring of Plant Equipment

3.1 General

The control system receives input signals from main equipment such as the turbine or the generator, and from various other accessory equipment, such as the governor, exciter, and automatic synchronizer. Refer to Fig 3-1 for the major components of a hydroelectric unit. Status inputs are obtained from control switches and level and function switches indicative of pressure, position, etc, throughout the plant. The proper combination of these inputs to the control system logic will provide outputs to the governor, the exciter, and other equipment to start or shutdown the unit. Any abnormalities in the inputs must prevent the unit's startup, or if already on-line, provide an alarm or initiate its shutdown.

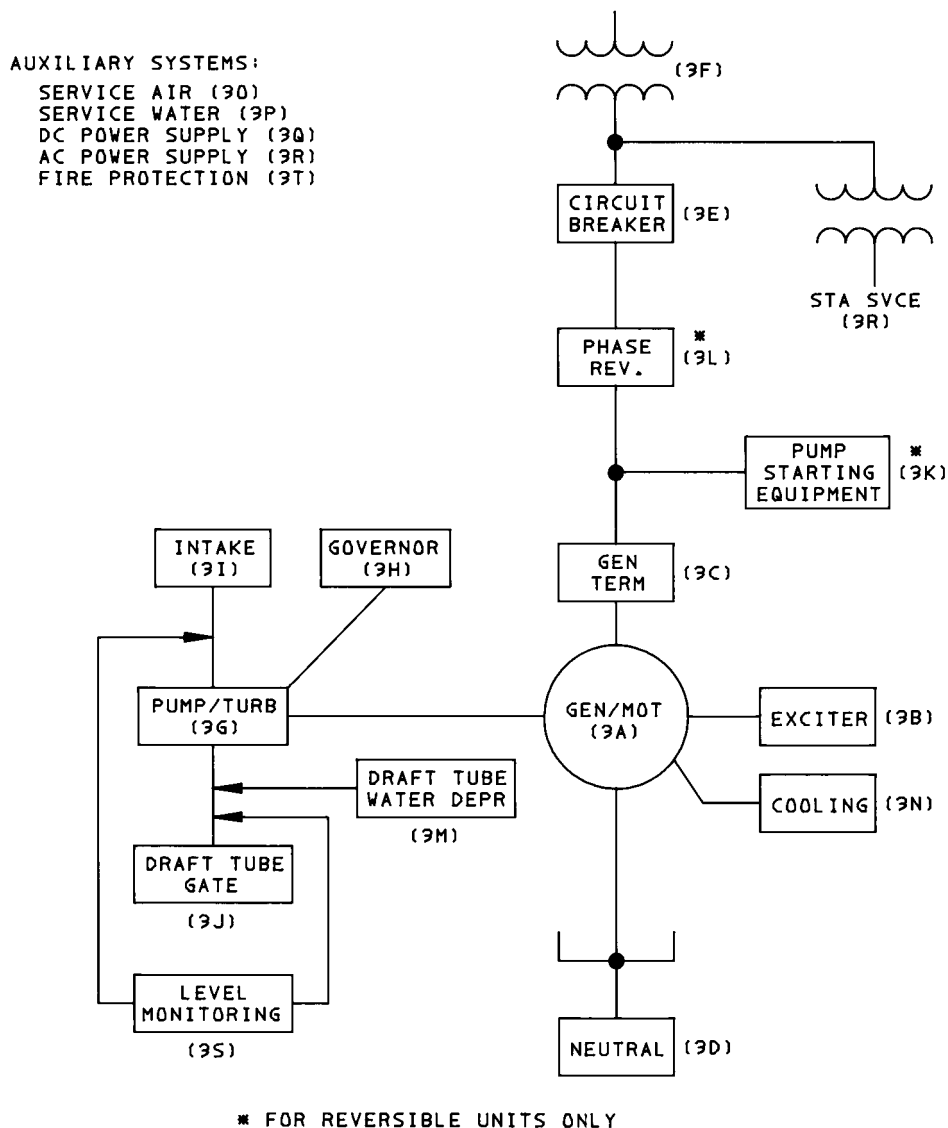


Figure 3-1 — Major Components of a Hydroelectric Unit With Reference to Descriptive Sections

The controls for a large reaction-type hydroelectric unit are shown in Figs 3-2, 3-3, and 3-4, basic block diagrams illustrating the extent of control and monitoring of the main and associated equipment. For multiple unit sites, each unit may be equipped with a control switchboard located physically close to the individual units and a centralized control panel located in the control room. For a plant with only one unit, the unit control switchboard may be located at the control room.

This guide is not intended to cover the protection of the unit, although the protective devices could be housed in cabinets or on panels adjacent to the control panels.

The unit switchboards should be designed to perform the following functions:

- 1) Information receipt and monitoring
- 2) Start/stop control sequencing
- 3) Annunciation of alarm conditions
- 4) Temperature information monitoring

- 5) Metering and instrumentation signals display
- 6) Event recording, when required
- 7) Synchronizing and connecting the unit to the system
- 8) Control of real/reactive power

The unit control switchboard is the central control means and communicates with the unit and associated equipment through hard wire or multiplexing, if warranted.

3.2 Information and Control Signals

Basically, there are four types of signals that may be provided between the control board and any particular piece of equipment.

- 1) Analog inputs to transmit variable signals from the CTs, PTs, resistance temperature detectors (RTDs), thermocouples, pressure, flow, level, vibration, or other transducers.
- 2) Digital inputs (typically contact closures) to provide status, or digitized values of variable quantities from the equipment.
- 3) Digital outputs to send command signals (ON and OFF) from the control board to the equipment.
- 4) Analog outputs to transmit variable signals from the control board to equipment such as the governor, voltage regulator, etc.

The communication links between the control board and the equipment should be adequate to transmit information and control signals. Information signals are those signals sent to the control board. Control signals are the outputs leaving the control board to various equipment.

Information signals to the control board will come from the following:

- 1) Generator neutral and terminal equipment
- 2) Head water and tailwater level equipment
- 3) Penstock
- 4) Turbine

Information and control signals will be needed between the control board and each of the following:

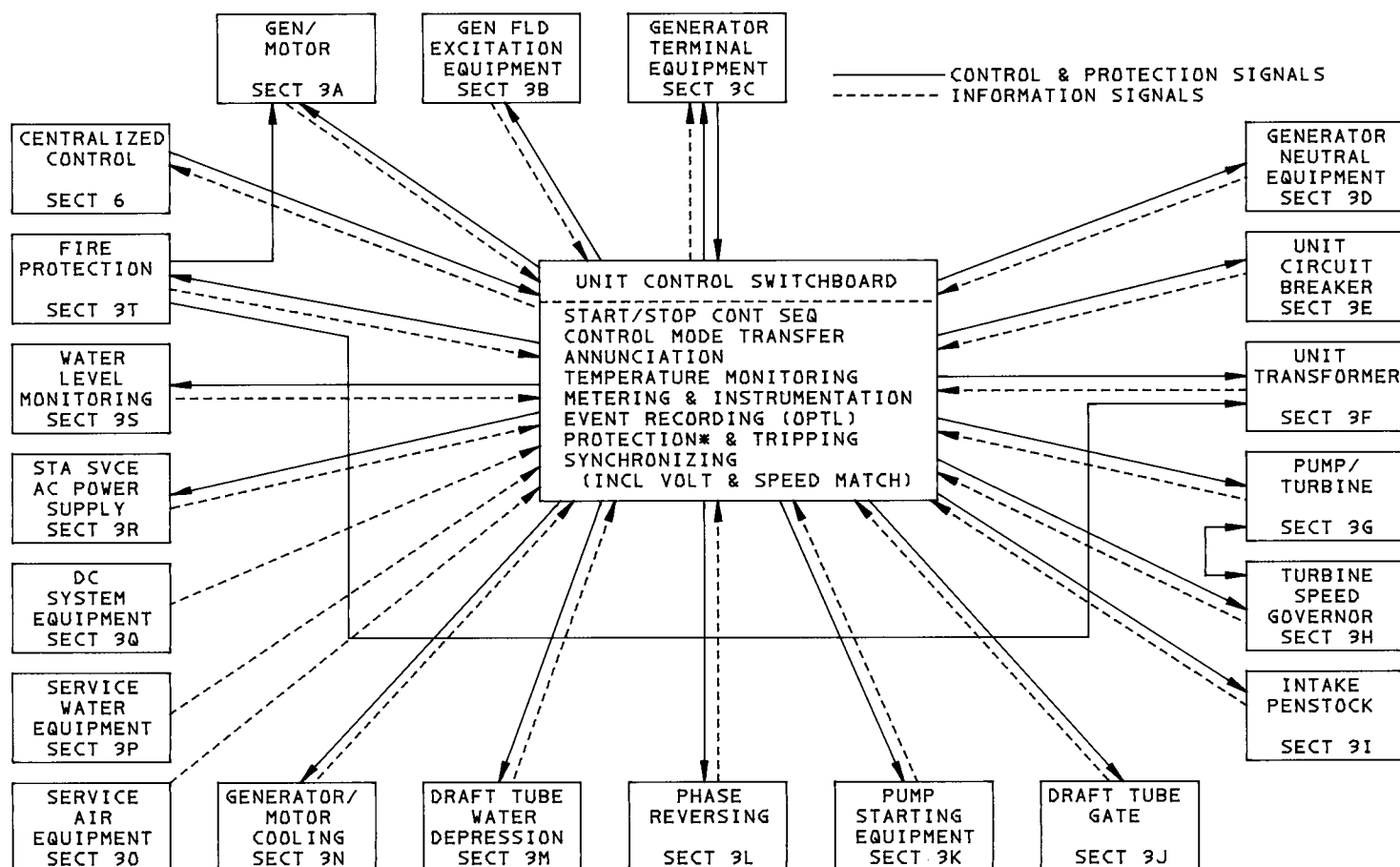
- 1) Unit transformer
- 2) Circuit breaker and switches
- 3) Generator
- 4) Intake gate (and / or inlet valve) and draft tube gate
- 5) Turbine speed governor
- 6) Generator excitation system
- 7) Synchronous condenser equipment
- 8) Auxiliary equipment

Additionally, Figs 3-2, 3-3, and 3-4 show the interconnection of the following auxiliary equipment:

- 1) Fire protection
- 2) AC power supply
- 3) DC power supply
- 4) Service water
- 5) Service air

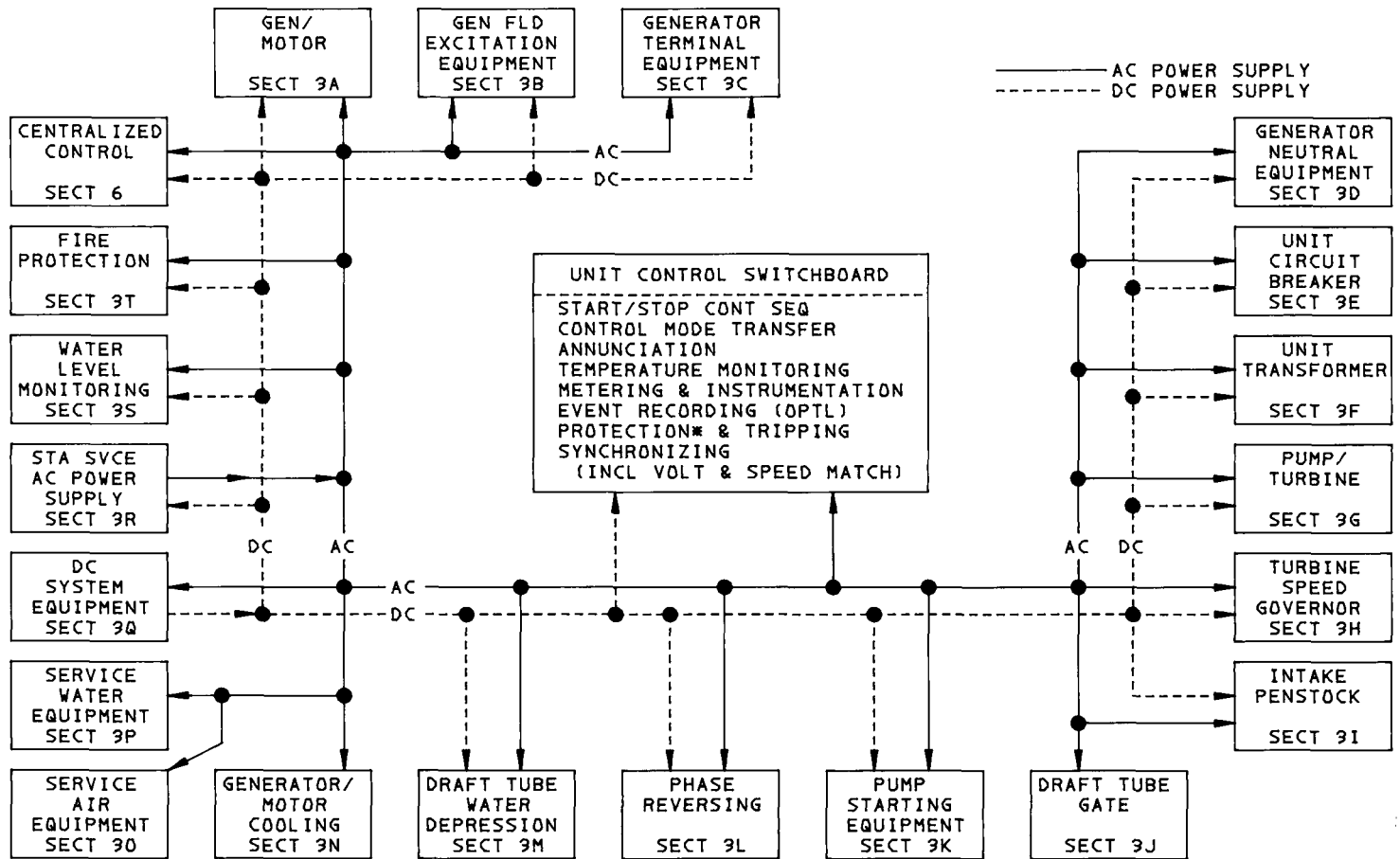
The above equipment blocks represent auxiliary service equipment needed for the proper operation of the generating plant. Abnormal conditions of this equipment will be alarmed.

The information and control signals to be interchanged between each piece of equipment represented in the block diagrams and the control board are given in detail in the following sections.



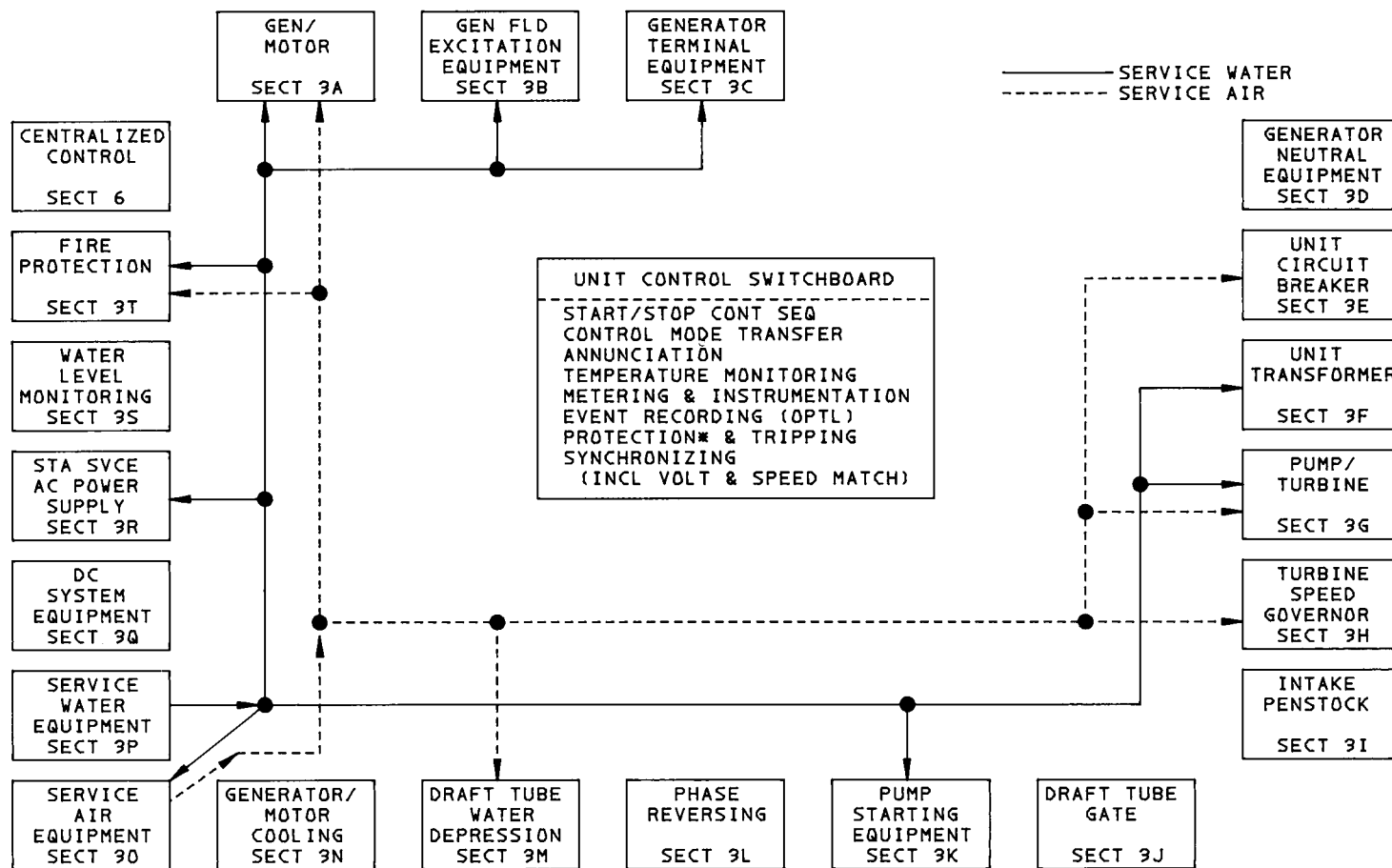
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Figure 3-2 —Controls for Large Hydroelectric Unit Basic Block Diagram Illustrating Extent of Controlled or Associated Equipment



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Figure 3-3 — Controls for Large Hydroelectric Unit Basic Block Diagram Illustrating Extent of Controlled or Associated Equipment



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Figure 3-4 — Controls for Large Hydroelectric Unit Basic Block Diagram Illustrating Extent of Controlled or Associated Equipment

3A. Generator/Motor

This section provides a guide for interfacing a typical generator/motor to the unit control system. The description is based on the use of a synchronous generator/motor with thrust bearing and one or more guide bearings.

Interface points between the generator / motor and the unit control switchboard are shown in Tables 3A-1 and 3A-2. Connections between the generator/ motor and the station service equipment are shown in Table 3A-3.

Table 3A-1 —Control and Status Data Transmitted from Generator/Motor to Unit Control Switchboard

SIGNAL	DESCRIPTION	TYPE	NOTES
26GS	Stator winding temperature	T, A, P	Temperature detectors (typically 12) embedded in stator winding in accordance with ANSI C50.10-1977 [1]. 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, equipped with direct reading visual indicator.
71QBL	Bearing oil level low	A	One sensor for each separate oil reservoir, 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	Eddy current probes installed in 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.
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. Backtrips 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.
CT-SP	Split phase or current unbalance current transformer	P, I	Double window split phase CT's 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 current transformers	P, I	Furnished in quantities and ratings compatible with the metering and primary/standby protection requirements.
33CW or 80CW	Cooling water valve position Cooling water flow	C, I	Start interlock and status indication.
			TYPE C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)

Table 3A-2 — Control and Status Data Transmitted from Unit Control Switchboard to Generator/Motor

SIGNAL	DESCRIPTION	TYPE	NOTES
2THS	Thrust bearing high pressure oil pump start/stop command	C	Start pump prior to starting unit. Confirmation of pump starting via 63QTH (Table 3A-1).
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 (Table 3A-1).
20FGS	Fire extinguishing system operate command	C, P	Open valve upon detection of fault + excessive heat. Confirmation of valve operation via 63FG (Table 3A-1).
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 on-line.
TYPE C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)			

Table 3A-3 — Operating Power, Air and Water from Service Equipment to Generator/Motor

DESCRIPTION	TYPE	NOTES
Power supply for thrust bearing high-pressure oil pump	AC	May be fed alternatively from dc source.
Power supply for dc control circuits	DC	For uninterruptible systems such as air cooler temperature control system, fire protection.
Air supply for brakes and rotor jacking system	A	Control valve may be located in governor cubicle.
Water supply for fire extinguishing system	W	May also be atomized.
Power supply for generator housing space heaters	AC	Thermostatically controlled, for reducing condensation on windings when generator is shut down.
Water supply for generator air coolers and bearing oil coolers	W	
Air supply for operating discharge and inlet air louvers	A	
Power supply for CO ₂ fire extinguishing system	DC	
Power supply for generator lube oil system	AC	May be fed alternatively from dc source.
TYPE AC =AC Power DC =DC Power A =Air W =Water		

3B. Generator Field Excitation Equipment

This section provides a guide for interfacing the excitation system to the unit control system. The description is based on the use of a potential source—controlled rectifier—high initial response (PS-CR-HIR) excitation system. This is the most common type of excitation system presently being specified for large generators.

A typical PS-CR-HIR excitation system is shown in Fig 3B-1. Interface points between the excitation system and the unit control switchboard and between the excitation system and the station service equipment are detailed in Tables 3B-1, 3B-2, and 3B-3.

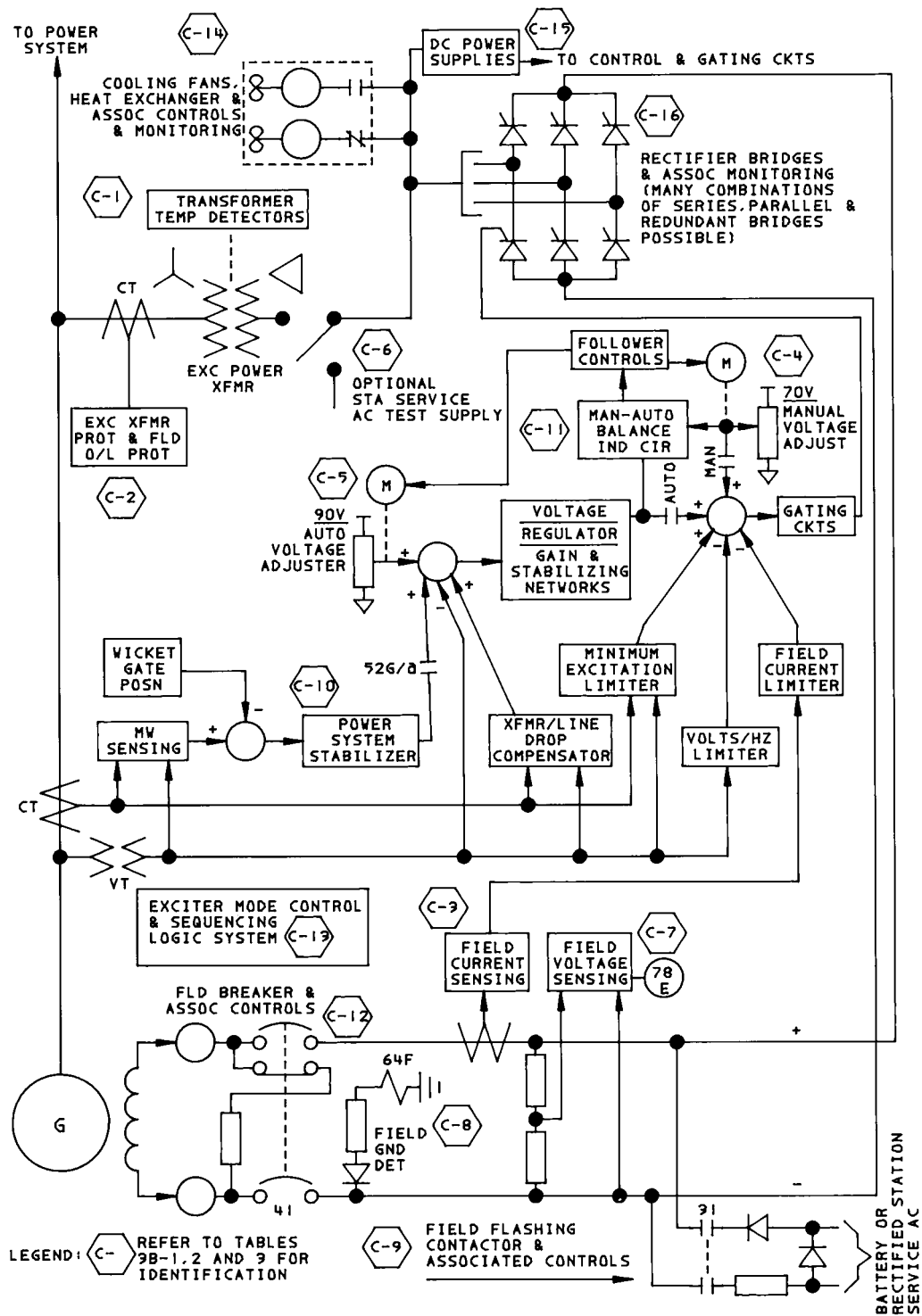


Figure 3B-1 — Typical Potential Source-Controlled Rectifier (High Initial Response Excitation System) Block Diagram

Table 3B-1 — Control and Status Data Transmitted from Excitation System to Unit Control Switchboard

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>ORIGINATING DEVICE AT EXCITER (REF. FIG 3B-1)</u>	<u>NOTES</u>
51ET	Exciter transformer o/c protection	P	C-2	
49GF	Field overload protection	P or A	C-2 or C-3	Set to coordinate with field winding thermal characteristic.
If	Field current indication	I	C-3	Transduced from DCCT (saturable reactor).
Vf	Field voltage indication	I	C-7	
64F	Field ground detection	P or A	C-8	
27FF	Failure of preferred field flashing source	A	C-9	Provision of this alarm assumes 2 sources provided, AC and DC. AC should be preferred source to minimize chance of backfeeding field voltage onto battery if blocking diode fails. Automatic transfer to alternate source on failure of preferred source.
41/a, 41/b	Field breaker position	C, I	C-12	
31/a, 31/b	Field flashing contactor position	I	C-9	
48E	Exciter start sequence incomplete	P, A	C-13	Set to operate after normal time required for field flash source to build terminal voltage to level sufficient for exciter gating to commence.
78E	Pole slip protection	P	C-7	
63F-1	Cooling fan failure—Stage 1	A	C-14	Failure of redundant fan(s).
63F-2	Cooling fan failure—Stage 2	P	C-14	
27PS	DC power supply failure	P or A	C-15	Trip or alarm depending on level of power supply redundancy.
26ET-1	Exciter transformer over temperature—Stage 1	A	C-1	Indicating unit with dial contacts typical.
26ET-2	Exciter transformer over temperature—Stage 2	P	C-1	
58-1	Rectifier failure—Stage 1	A	C-16	Thyristor fuse, conduction, or gating failure.
58-2	Rectifier failure—Stage 2	P	C-16	
49HE	Heat exchanger failure	A	C-14	Various heat exchanger arrangements are possible; eg, once-through, closed system, etc.
26RTD	Exciter transformer temperature indication	I	C-1	Temperature detectors. Quantity variable depending on number of secondary windings and whether transformer is 3 phase or 3 × 1 phase.
70V	Manual voltage adjuster with position indication	I	C-4	Signal generated by potentiometer coupled to 70V motor drive.
70V/LS1,2	70V End-of-travel indication	I	C-4	Signal generated by limit switches coupled to 70V motor drive.
90V	Auto voltage adjuster with position indication	I	C-5	Same as 70V.
90V/LS1,2	90V End-of-travel indication	I	C-5	Same as 70V/LS1,2.
70V/LS3	70V Preset position	C	C-4	Interlock in start sequence.
90V/LS3	90V Preset position	C	C-5	Interlock in start sequence.
89LS	Station service ac test supply switch position	I	C-6	Optional.
MAN-AUTO Balance	Indication of mismatch between auto voltage regulator output and manual voltage setpoint	I	C-11	To ensure bumpless transfer from AUTO to MAN and MAN to AUTO.
<u>TYPE</u> C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)				

Table 3B-2 — Control and Status Data Transmitted from Unit Control Switchboard to Excitation System

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>DESTINATION AT EXCITER (REF. FIG 3B-1)</u>	<u>NOTES</u>
41 protective trips	Field breaker tripping from generator	P	C-12	
41 control trips	Field breaker tripping from manual control and unit shutdown sequence logic	C	C-12	
41 close	Field breaker closing from manual control and unit start sequence logic	C	C-12	
1E	Exciter start	C	C-9, C-13	Close contact to initiate field flashing at 95% speed during auto start or under manual control.
1E	Exciter de-excite	C	C-13	Open contact to initiate phaseback below 95% speed, unit separated from system.
83VT	Voltage transformer potential supervision	C	C-13	Transfer exciter from auto voltage control to manual control.
43VM	Close contact to transfer exciter to manual voltage control	C	C-13	
43VA	Close contact to transfer exciter to auto voltage regulator control	C	C-13	
70V run-back logic	Run 70V to preset position in preparation for unit starting	C	C-4	
90V run-back logic	Run 90V to preset position in preparation for unit starting	C	C-5	
70V raise	Raise manual voltage adjuster	C	C-4	
70V lower	Lower manual voltage adjuster	C	C-4	
90V raise	Raise auto voltage adjuster	C	C-5	
90V lower	Lower auto voltage adjuster	C	C-5	
52G/a	Generator CB auxiliary switch	C	C-10, C-13	De-excite control, disable power system stabilizer off-line.
Wicket gate position	Analog signal representing wicket gate position	C	C-10	Used to develop accelerating power input to PSS if required.
<u>TYPE</u> C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)				

Table 3B-3 —Operating Power, Air and Water from Service Equipment to Excitation System

<u>DESCRIPTION</u>	<u>TYPE</u>	<u>DESTINATION AT EXCITER (REF. FIG 3B-1)</u>	<u>NOTES</u>
Station service ac test supply	AC	C-6	Used for exciter testing and emergency operation if exciter transformer out of service (optional).
Battery-fed field flashing source	DC	C-9	
Station service field flashing source	AC	C-9	AC preferred source. Auto transfer to dc if ac not available.
Cooling water supply for heat exchanger	W	C-14	
<u>TYPE</u> AC =AC Power DC =DC Power A =Air W =Water			

3C. Generator Terminal Equipment

This section provides a guide for interfacing the information obtained from the generator terminals to the unit control system. (See Tables 3C-1, 3C-2, and 3C-3.)

Table 3C-1 —Control and Status Data Transmitted from Generator Terminal Equipment to Unit Control Switchboard

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>ORIGINATING DEVICE</u>	<u>NOTES</u>
CT	Current signal for relaying and metering		CT	
VT	Voltage signal for relaying and metering		VT	
A	Current indication	I	CT	
F	Frequency indication	I	VT	
V	Voltage indication	I	VT	
W/VAR	Metering	I, A	CT & VT	Analog signals for indication and/or recording.
AVR	Voltage signal for automatic voltage regulator (AVR)	C	VT	Analog signal from a VT.
63	Pressure relay in the closed-loop forced air cooled isolated phase bus duct, if used	A, P	Bus-duct	
49	Thermal device to service air or bus temperature	A, T	Bus	Temperature detector embedded in the hottest location of the phase. It could back up pressure differential devices (trip optional).
N	Governor speed sensing	C	VT	
XDCR	Power transducer	C	CT & VT	Unit power input to electric governor.
<u>TYPE</u> C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)				

Table 3C-2 — Control and Status Data Transmitted from Unit Control Switchboard to Generator Terminal Equipment

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>NOTES</u>
20	Fire extinguishing system command	C, P	Deluge valve open upon differential operation and high temperature detection.
80	Forced air bus duct cooling control start/stop	C	External controls to start/stop forced air cooling are associated with the generator breaker (closed/open) and generator connected to the system (ON/OFF).
<u>TYPE</u> C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)			

Table 3C-3 — Operating Power, Air and Water from Service Equipment to Generator Terminal Equipment

<u>DESCRIPTION</u>	<u>TYPE</u>	<u>NOTES</u>
Power supply from dc control circuits	DC	For uninterruptible systems such as fire protection.
Power supply for forced air bus duct circulation system	AC	
Water supply for fire extinguishing system and forced air cooling	W	
<u>TYPE</u> AC =AC Power DC =DC Power A =Air W =Water		

The major part of this information is standard practice and should be considered common for any generator terminals. However, some specific units may need additional or different information (signals) to be transmitted depending on the type of equipment that is used. (Refer to Fig 3C-1.)

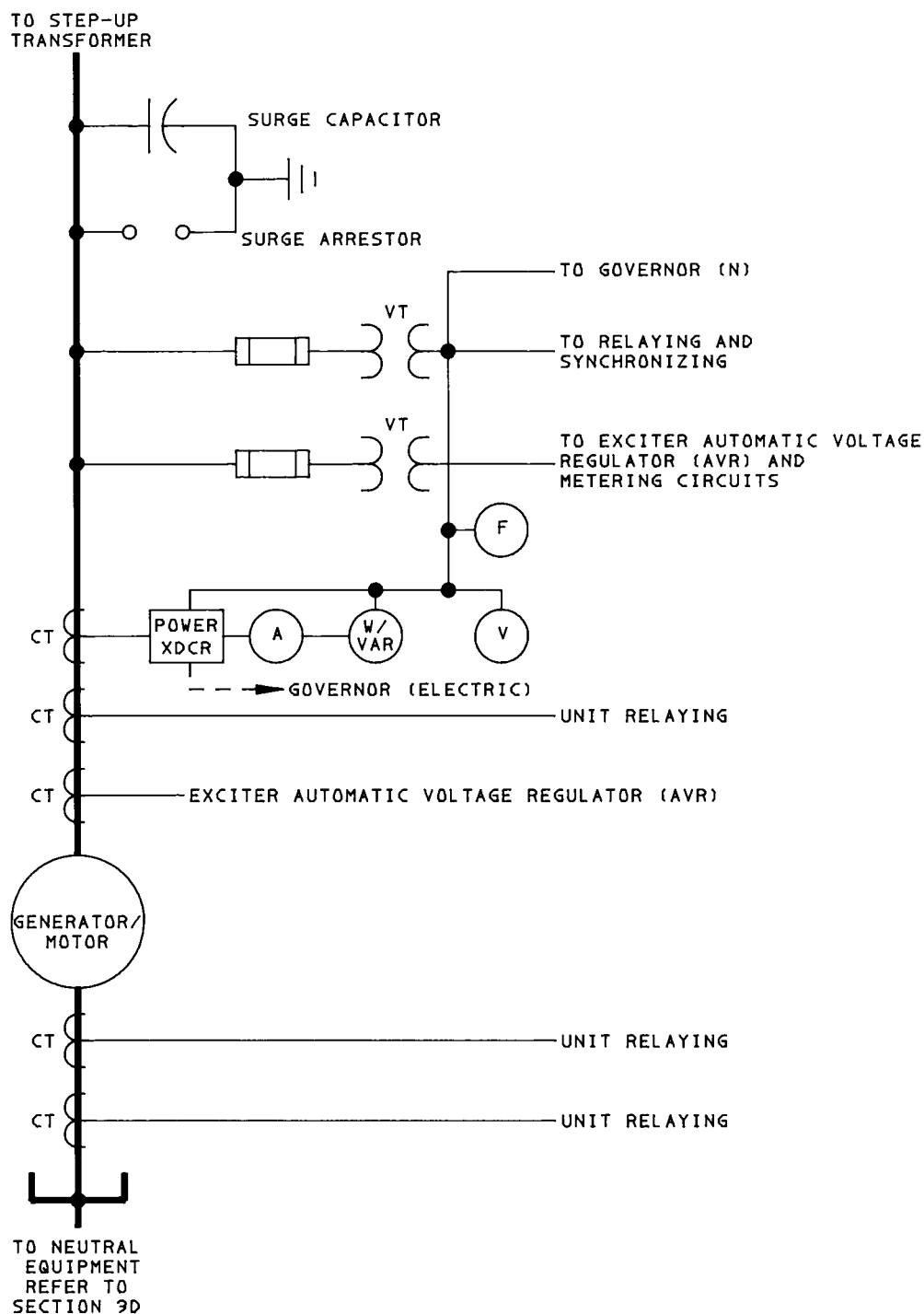


Figure 3C-1 — Typical Hydro Generator Terminal

3D. Generator Neutral Equipment

The generator neutral equipment needed for the various methods of neutral grounding is determined by the amount of phase-to-ground fault current that is allowed to flow. Due to the relatively low zero sequence impedance in most synchronous machines, a phase-to-ground fault results in much higher winding current than a 3-phase fault. Therefore, a neutral impedance should be provided to limit this current and the resulting damage to the generator under these conditions.

When static starting systems are used for pumped storage units, a capacitive grounding system may be needed in addition to conventional grounding to limit circulating dc ground current.

Neutral impedance to ground can be provided by the following methods:

- 1) Distribution transformer with resistor grounded
- 2) Neutral resistor grounded
- 3) Ground fault neutralizer grounded
- 4) Grounding transformer with resistor grounded

The application of these methods is affected by the electrical configuration of the station, the number of generators, the number and switching of the main voltage bus, and the owner's protection philosophy.

Approved grounding methods are covered in detail in ANSI/IEEE C62.92-1987 [3]³.

ANSI/IEEE C37.101-1985 [2] will also aid in the application of relays and relaying schemes for the protection of synchronous generators for single phase-to-ground faults in the stator winding. The various protective schemes as well as alternative methods of protection for the most commonly used generator connections and grounding practices are covered.

3E. Unit Generator Breaker Equipment

This section provides a guide for interfacing the generator breaker control to the unit control and protection system.

A typical, large hydro generator station to a generator breaker interface is shown in Fig 3E-1. Interface points between the generator breaker equipment and the unit control switchboard are detailed in Table 3E-1 and Table 3E-2.

³The numbers in brackets correspond to those of the references listed in 1.3.

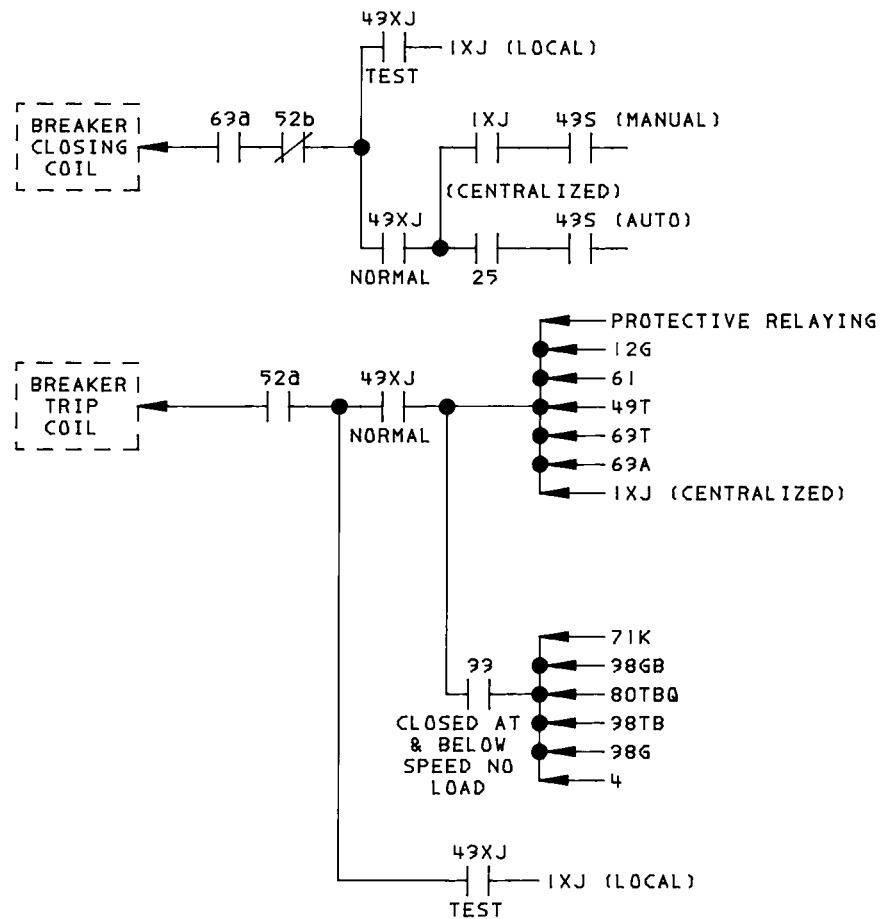


Figure 3E-1 — Typical Hydro Generator Breaker Interface Diagram

Table 3E-1 — Signals Transmitted from Plant Equipment to Generator Breaker

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>NOTES</u>
4	Unit control master relays	C	Normal shutdown.
1XJ	Breaker control switch, trip/close	C	
12G	Generator overspeed	P	
25	Synchronizing equipment	C	
33	Wicket gate position switch	C	Permissive switch.
38GB	Generator bearing temperature	P	
38TB	Turbine bearing temperature	P	
43XJ	Breaker test switch	C	
49T	Step-up transformer overtemperature	P	
63T	Step-up transformer sudden pressure	P	
71K	Kaplan low oil	P	
80TBQ	Turbine bearing oil	P	
38G	Generator winding temperature	P	
43S	Unit synchronizing selector switch	C	Permissive switch.

Table 3E-2 — Signals Transmitted from Generator Breaker to Unit Control Switchboard

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>NOTES</u>
52a, b	Breaker open-close	C, I	
27CB	Generator breaker loss of dc control power	A	
61	Generator breaker pole failure	P, A	Trip to isolate breaker.
63a	Breaker air pressure switch	C	Permissive switch.
63A	Generator breaker low air pressure	P, A	
<u>TYPE</u> C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)			

3F. Unit Step-Up Transformer

This section provides a guide for interfacing the information between the unit step-up transformer and the unit control switchboard. (See Tables 3F-1, 3F-2, and 3F-3.)

Table 3F-1 — Control and Status Data Transmitted from Transformer to Unit Control Switchboard

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>ORIGINATING DEVICE</u>	<u>NOTES</u>
CT	Current signal for relaying and metering	A, P, I	CT	
71G	Gas accumulation detection	A	Transformer Tank	Event recording (optional).
63G	Gas pressure device	A, P	Transformer Tank	Event recording.
63Q	Main tank sudden pressure relief device	A, P	Transformer Tank	Hand reset contact (local). Event recording.
63T	Main tank over pressure switch	A, P	Transformer Tank	Trip generator breaker.
49-1W 49-2W	Transformer winding temperature thermal device in each separate winding	A, T, P	Transformer Winding	Temperature detectors embedded in each separate winding for first stage temperature control. RTDs are in each winding because of the possibility of unbalanced loading.
26Q	Top oil temperature indicator	A, T	Transformer Tank	Dial type oil temperature indicator at the transformer. First stage annunciation, tripping optional. Second stage tripping.
71QC	Conservator tank oil level indicator	A	Transformer Tank	Dial type indicator with maximum and minimum indicating levels. Tripping optional.
<u>TYPE</u> C =Control P =Protection Trip A =Annunciation / Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)				

Table 3F-2 — Control and Status Data Transmitted from Unit Control Switchboard to Transformer

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>NOTES</u>
20	Fire extinguishing system command	C, P	Actuated upon differential relay operation or sudden pressure relief device. Fire detection sensors shut off the transformer fan and pumps.
<u>TYPE</u> C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)			

Table 3F-3 — Operating Power, Air and Water from Service Equipment to Transformer

<u>DESCRIPTION</u>	<u>TYPE</u>	<u>NOTES</u>
Power supply for DC control circuits	DC	For uninterruptible systems such as fire protection.
Power supply for fans, pumps, ac control circuits	AC	For FA, FOA transformers. If an FOW transformer is used, additional information and control signals may be needed, such as monitoring of the pressure difference between the oil and water systems.
Water supply for fire extinguishing system	W	
Water supply for cooling	W	
	<u>TYPE</u> AC =AC Power DC =DC Power A =Air W =Water	

The major part of this information is standard practice and should be considered common for any step-up unit transformer. However, some specific units may need additional or different information (signals) to be transmitted depending on the type of equipment that is used.

The description is based on the assumption that tap changer position indication would normally not be provided at any location remote from the transformer site.

3G. Turbine and Pump/Turbine

This section provides a guide for interfacing a typical turbine or pump/turbine to the unit control system.

propeller, diagonal flow propeller, Kaplan, and Deriaz turbines.

Impulse turbines are controlled by moving the needles into and out of the nozzles to throttle flow and by deflecting the water with deflectors during rapid load changes. Reaction turbines are controlled by adjusting the wicket gates to throttle flow. In addition to wicket gate control, blade angle is adjusted on Kaplan and Deriaz turbines to maximize efficiency and to limit overspeed.

Reversible pump/turbines are usually Francis-type, although axial and diagonal flow turbines have been used. Flow control for pump/turbines is identical to conventional turbines of similar type. Due to the similarities between turbines and pump/turbines, only the control and auxiliary systems for turbines will be discussed.

Servomotors can be coupled directly to each individual gate or needle, or a common servo-motor system can be coupled to a regulating ring that is coupled to the gates. A single servomotor is generally used to position the blades.

Auxiliary systems associated with turbines and pump/turbines include shear pin failure systems, wicket gate greasing systems, bearing

Modern turbines can be separated into two broad classifications: impulse turbines and reaction turbines. Impulse turbines are commonly referred to as Pelton turbines. The reaction turbine classification includes Francis, axial flow cooling and lubrication systems, shaft seal or packing systems, turbine runner seal systems (wearing rings), and runner band drain valve.

Interface points between the controlled equipment and the unit control switchboard are shown in Tables 3G-1 and 3G-2. Connections between the controlled equipment and the station service equipment are shown in Table 3G-3.

Table 3G-1 — Control and Status Data Transmitted from Turbine and Pump-Turbine to Unit Control Switchboard

SIGNAL	DESCRIPTION	TYPE	NOTES
38TG	Turbine guide bearing temperature	T, A, P, I	Temperature detectors. Provision for mounting sensors in all segments.
38QTG	Turbine guide bearing oil temperature	T, A, P, I	Temperature detectors in bearing oil reservoir.
71QTGH	Turbine guide bearing oil level high	A	Sensor in bearing oil reservoir, with direct reading visual indicator.
71QTGL	Turbine guide bearing oil level low	A	Sensor in bearing oil reservoir, with direct reading visual indicator.
39TV	Bearing/shaft vibration detector	A, P	Vibration probes installed in guide-bearing segments at 90 degrees to each other, for detection of equipment defects and rough load zone operation. Used in conjunction with probes on generator guide bearing.
26RS	Upper runner seal temperature	T, A	Temperature detectors for sensing excessive temperature due to inadequate cooling water flow.
33SP	Wicket gate shear pin failure	A, P	Reaction turbines only.
80WB	Bearing cooling water low flow	A, P	Pump failure, obstructed piping or pipe rupture.
80WS	Shaft seal water low flow	A, P	Conditional trip during condensing operation or pump starting.
80WTS	Turbine seal water low flow	A, P	Conditional trip during condensing operation or pump starting.
71WTH	Turbine pit water level high	A, C	Senses excessive water level in turbine pit due to plugged drains or major seal failure. One contact operates submersible pump.
63AMS	Turbine shaft air maintenance seal applied	A, P	Contact blocks unit startup and initiates shutdown when seal applied.
SCWP	Spiral case water pressure	I	Direct reading or transducer-operated gauge.
DTWP	Draft tube water pressure-vacuum	I	Direct reading or transducer-operated gauge.
48TG	Turbine greasing system failure	A	Alarm if lubrication cycle not completed.
74TG	Turbine greasing system low voltage	A	Detects failure of power supply to solenoid valve used to control greasing cycle.
73DTH	Draft tube water level high	A	Initiated if draft tube water level increases excessively during the synchronous condenser mode. Indicative of problems in air system or excessive wicket gate leakage.
71DTEH	Draft tube water level extremely high	C, A	Transfers unit from synchronous condenser to generate mode.
48SC	Synchronous condenser incomplete sequence	C, A	Transfers unit from synchronous condenser mode to generate mode if draft tube water level is not fully depressed within a set time from initiation of the sequence.
	Gate/needle position	C	Feedback to the governor control system.
	Blade position	C	Feedback to the governor control system (Kaplan and Deriaz turbines only).
	Deflector position	C	Feedback to the governor control system (Pelton turbines only).
		TYPE	
		C =Control	
		P =Protection Trip	
		A =Annunciation/Event Recording	
		T =Temperature Monitoring	
		I =Indication (analog, digital, status lamps)	

NOTE — Wicket gate automatic lock functions are described in Section 3H.

Table 3G-2 —Control and Status Data Transmitted from Unit Control Switchboard to Turbine and Pump-Turbine

<u>SIGNAL</u>	<u>DESCRIPTION</u>	<u>TYPE</u>	<u>NOTES</u>
1GS	Turbine grease system start/stop	C	Enables grease system when unit is running.
4SC	Synchronous condenser sequence start/stop	C	Upon energization, wicket gate closure is initiated, compressed air is admitted to the draft tube to depress the water level and cooling water is applied to the runner seals. Upon de-energization, wicket gates are opened, depression air valves and running seal cooling water valves are closed.
4RA	Atmospheric or compressed air admission under runner	C	Used on some Francis turbines to reduce rough operation over a selected range of wicket gate positions. Control signal will initiate opening or closing of a solenoid valve.
1TL	Turbine lube oil system start/stop	C	Enables turbine lubrication prior to unit run.
20RBD	Runner band drain valve	C	Releases water trapped in turbine runner during water depression.
<u>TYPE</u> C =Control P =Protection Trip A =Annunciation/Event Recording T =Temperature Monitoring I =Indication (analog, digital, status lamps)			

NOTE — Wicket gate automatic lock functions are described in Section 3H.

Table 3G-3 —Operating Power, Air and Water from Service Equipment to Turbine and Pump-Turbine

<u>DESCRIPTION</u>	<u>TYPE</u>	<u>NOTES</u>
Power supply for control and protection devices	DC	
Power supply for turbine pit water pump	AC	
Air supply for shaft maintenance seal, greasing system, air admission under runner, draft tube water level depression system for synchronous condenser mode and pump starting, shear pin failure	A	
Water supply for bearing oil coolers and turbine seals	W	
Power supply for turbine lube oil system	AC	May be alternately fed from dc.
<u>TYPE</u> AC =AC Power DC =DC Power A =Air W =Water		

3H. Governor

This section provides a guide for interfacing the governor with the unit control system.

Typical mechanical, hydraulic, and pneumatic interfaces between the governor and a reaction turbine and between the governor and the generator/motor are shown in Fig 3H-1. Interfaces for an impulse turbine are similar, except control is by needle valve and deflectors. Electrical protection, control, alarm, and indication interfaces between the governor and the unit control switchboard are developed in Tables 3H-1 and 3H-2. Table 3H-3 describes the operating power, air, and water connections between the station service equipment and the governor.

Figure 3H-1 represents a typical electric-mechanical PID (proportional, integral, derivative) governor. Other variations include electric-mechanical PI (temporary droop) governors and mechanical PI governors. The detailed descriptions in this section assume the governor utilizes power feedback with separate power and speed reference adjustments. Variations include wicket gate feedback with speed reference adjustment only, wicket gate feedback with gate and speed reference adjustments and power feedback with speed reference adjustment only.

In some applications, the speed/power control section and the actuator may be installed in separate locations. Auxiliary functions represented in blocks H-14 and H-15 are commonly located in the actuator but are sometimes located in other equipment.

Some installations may utilize an electrical restoring connection in which case gate position switches and position transmitters located in block H-13 should be mounted near the wicket gate servomotors or regulating ring. In any case, failure of the mechanical or electrical restoring connection should cause the gates to close automatically.

With reference to block H-19, unit blade control, net head and wicket gate position are inputs to an electronic or mechanical three-dimensional cam that outputs blade position. Alternatively, the net head signal may be replaced with forebay and tailrace level signals. Several blade cams could also be supplied for manual selection based on current net head. Backup manually adjustable net head signals are optional. Sustained blade oil leakage typically operates a blade oil pressure cutoff and unit shutdown after a time delay.

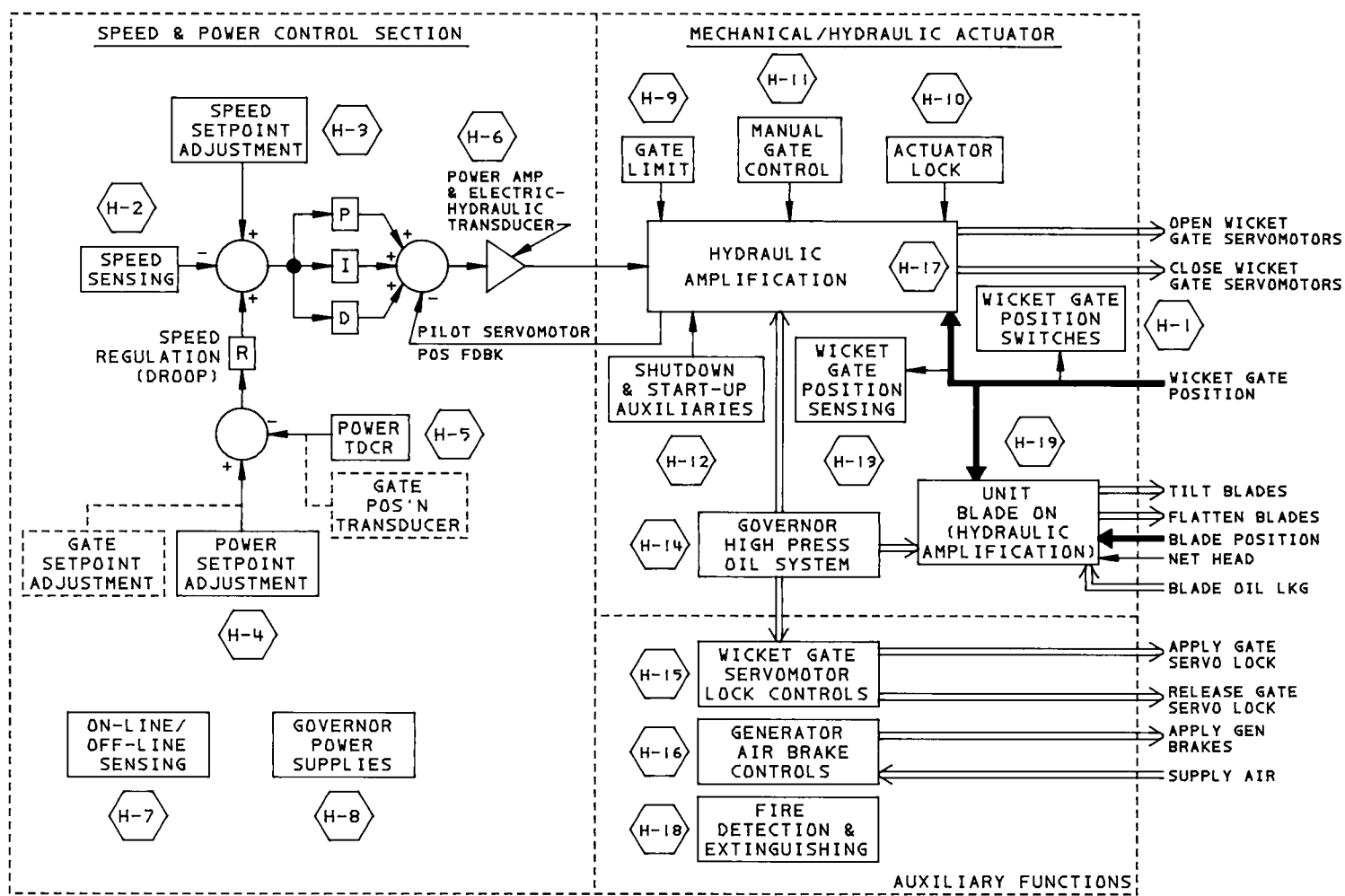


Figure 3H-1 — Typical Electric-Hydraulic Reaction Turbine Governor