An American National Standard

IEEE Guide for Control of Hydroelectric Power Plants

Sponsor

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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.

The following persons were members of the Task Force when the guide was finalized and submitted for balloting:

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CLAUSE PAGE

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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.

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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.

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

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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

CONTROL CATEGORY	SUBCATEGORY	REMARKS
	Local:	Control is local at the controlled equipment or within sight of the equipment.
LOCATION	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.

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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.

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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.

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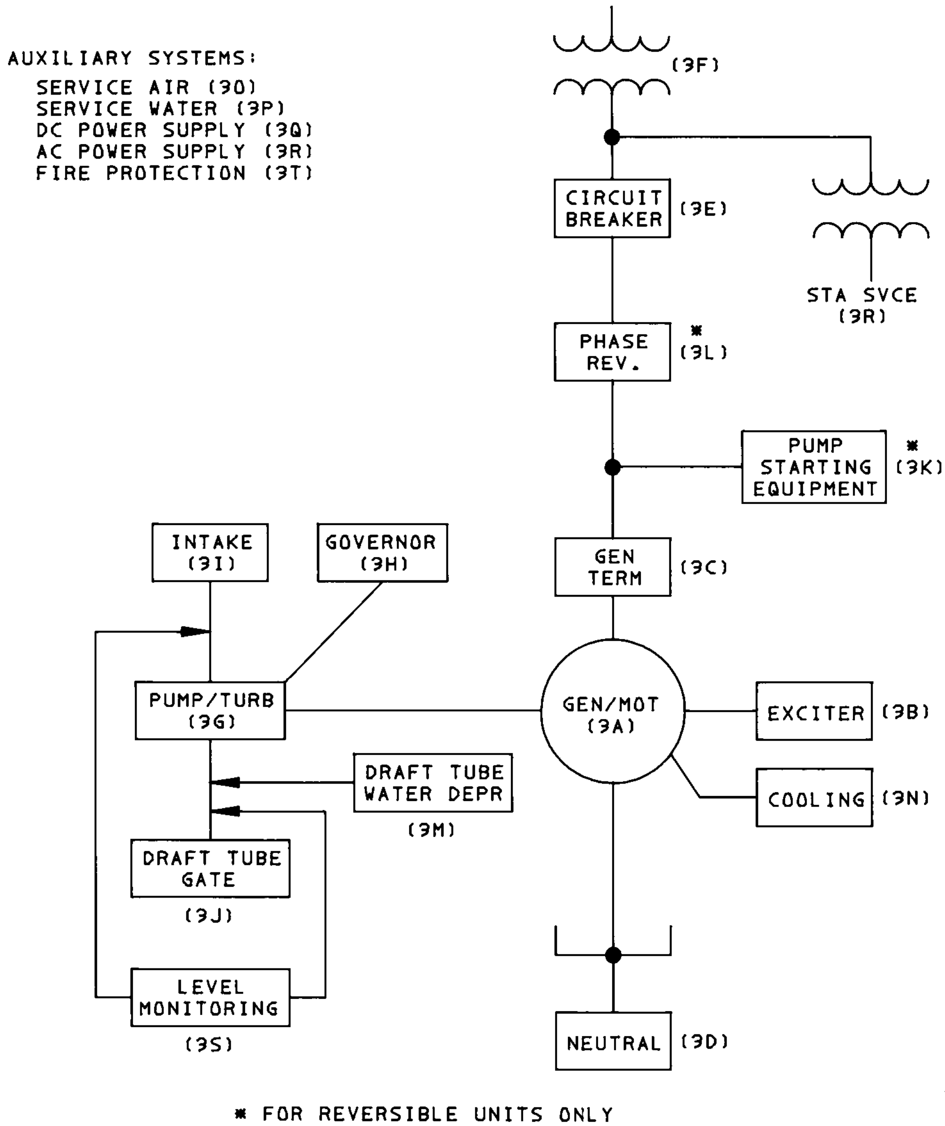

Figure 3-1 —Major Components of a Hydroelectric Unit With Reference to Descriptive Sections

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

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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.

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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.

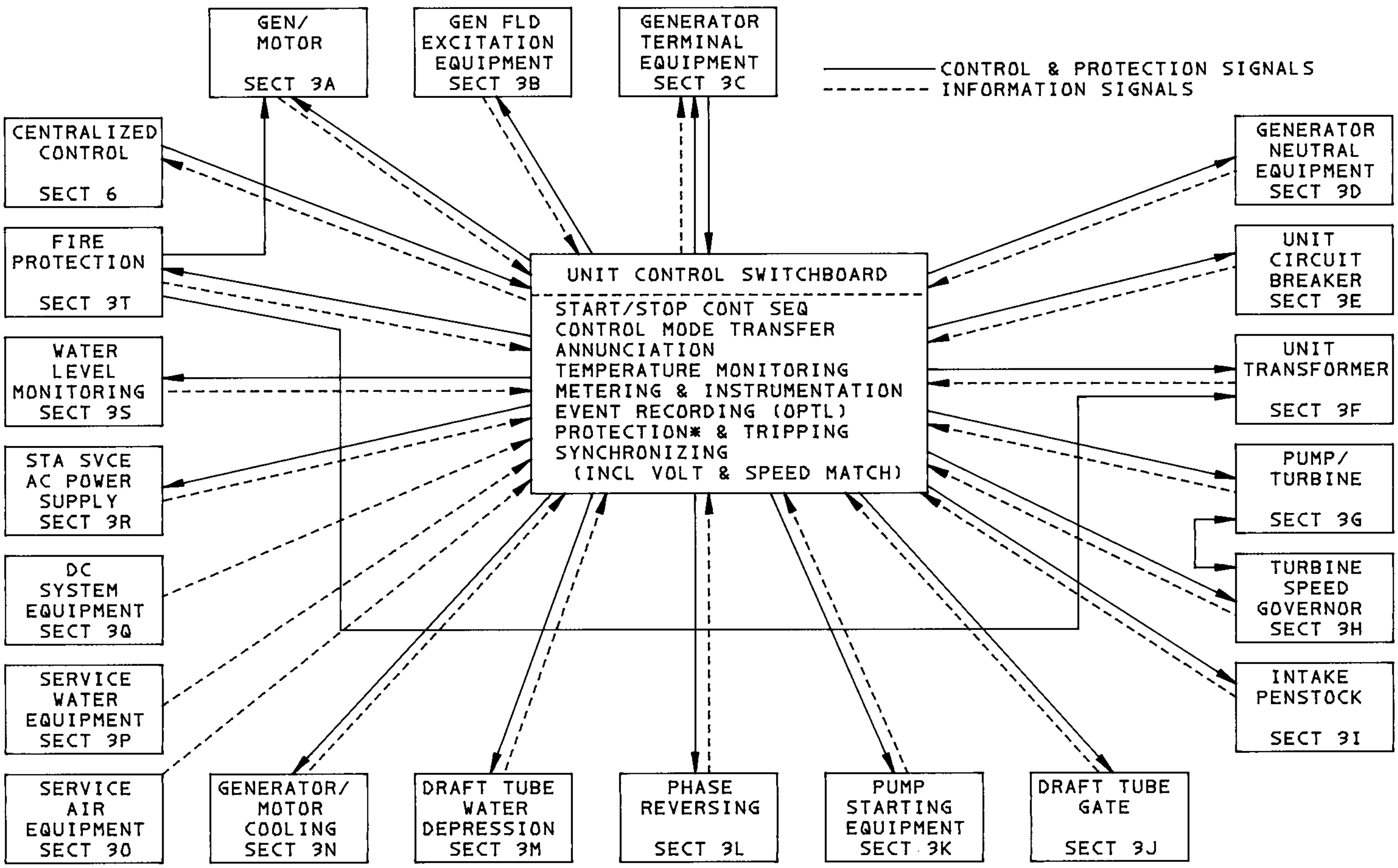

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Figure 3-2 —Controls for Large Hydroelectric Unit Basic Block Diagram Illustrating Extent of Controlled or Associated Equipment

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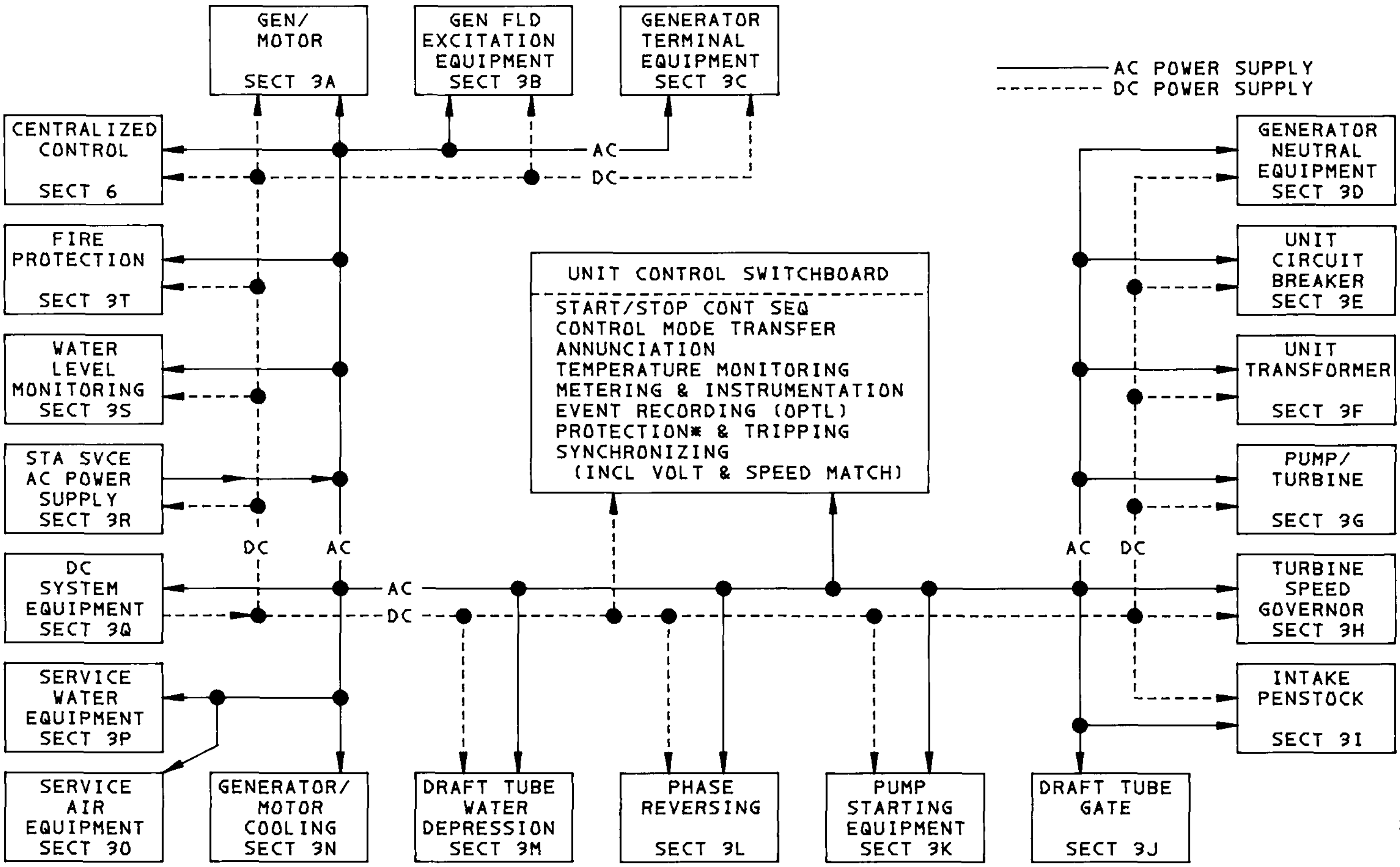

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Figure 3-3 —Controls for Large Hydroelectric Unit Basic Block Diagram Illustrating Extent of Controlled or Associated Equipment

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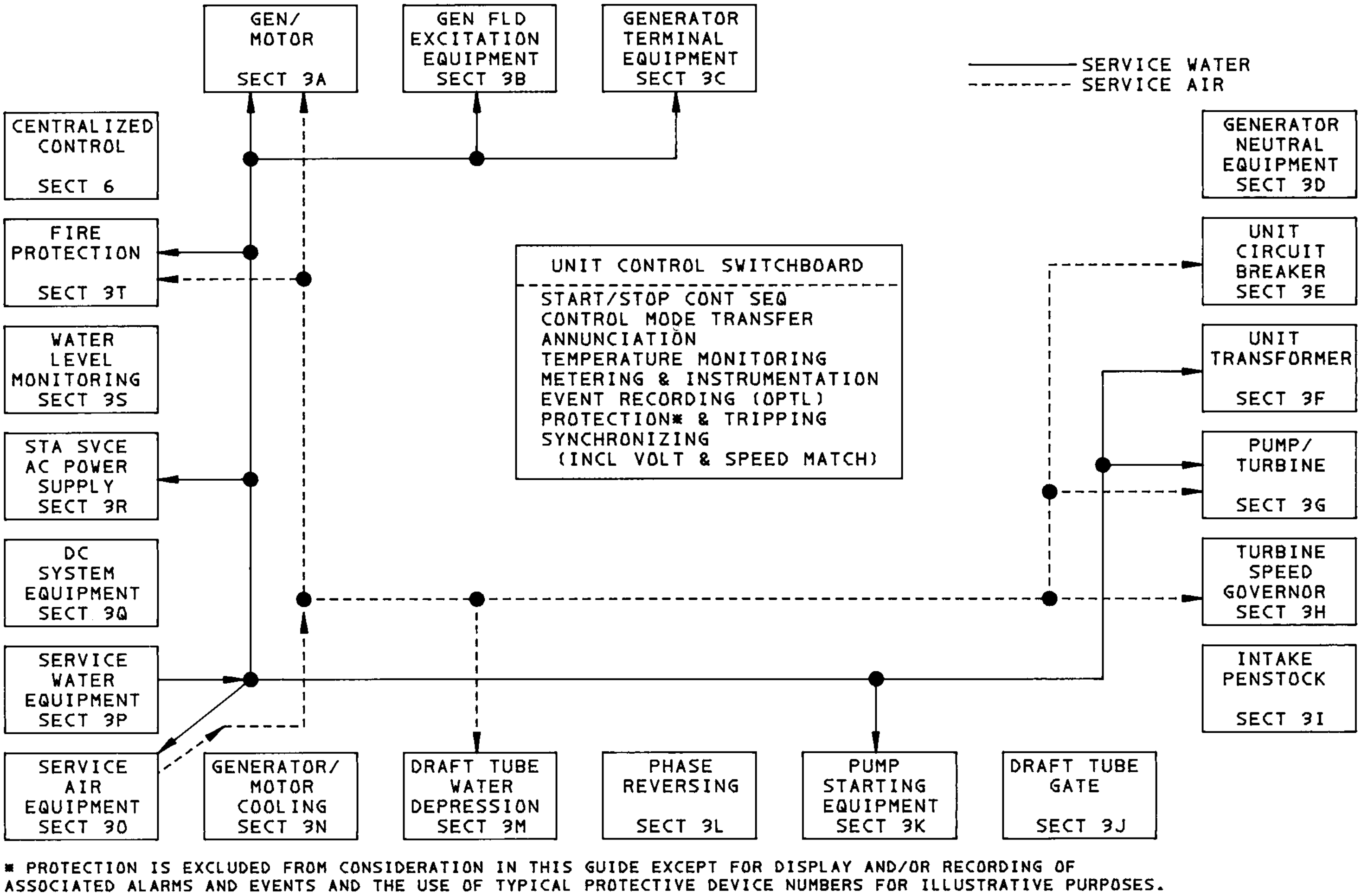

Figure 3-4 —Controls for Large Hydroelectric Unit Basic Block Diagram Illustrating Extent of Controlled or Associated Equipment

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.

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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)

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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.

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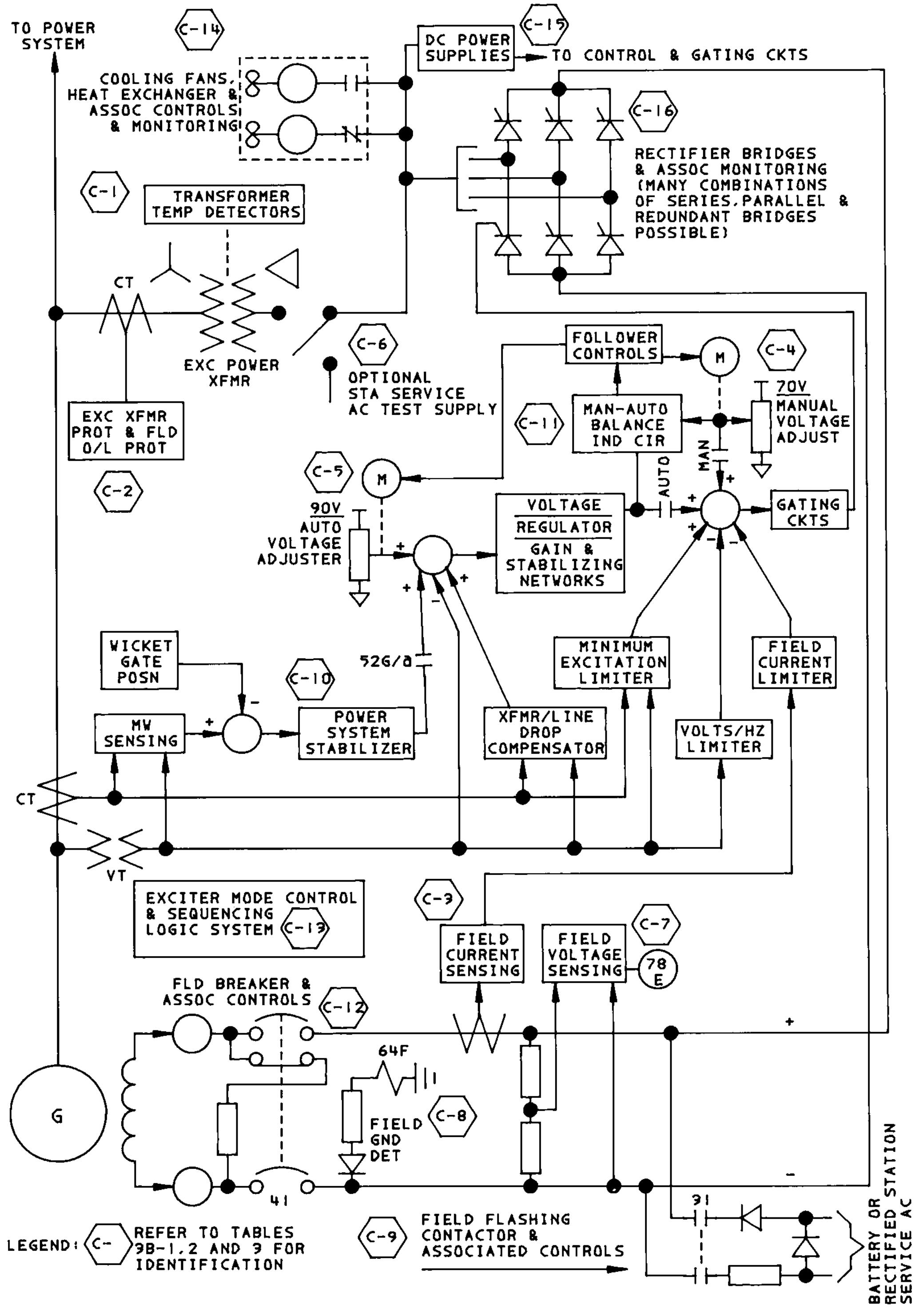

Figure 3B-1 —Typical Potential Source-Controlled Rectifier (High Initial Response Excitation System) Block Diagram

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

SIGNAL	DESCRIPTION	TYPE	ORIGINATING DEVICE AT EXCITER (REF. FIG 3B-1)	NOTES
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.

TYPE
C =Control
P =Protection Trip
A =Annunciation/Event Recording
T =Temperature Monitoring
I =Indication (analog, digital, status lamps)

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

SIGNAL	DESCRIPTION	TYPE	DESTINATION AT EXCITER (REF. FIG 3B-1)	NOTES
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.

TYPE
- C =Control
- P =Protection Trip
- A =Annunciation/Event Recording
- T =Temperature Monitoring
- I =Indication (analog, digital, status lamps)

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

DESCRIPTION	TYPE	DESTINATION AT EXCITER (REF. FIG 3B-1)	NOTES
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	

TYPE
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

SIGNAL	DESCRIPTION	TYPE	ORIGINATING DEVICE	NOTES
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.

TYPE
C =Control
P =Protection Trip
A =Annunciation/Event Recording
T =Temperature Monitoring
I =Indication (analog, digital, status lamps)

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

SIGNAL	DESCRIPTION	TYPE	NOTES
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).

TYPE
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

DESCRIPTION	TYPE	NOTES
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	

TYPE
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.)

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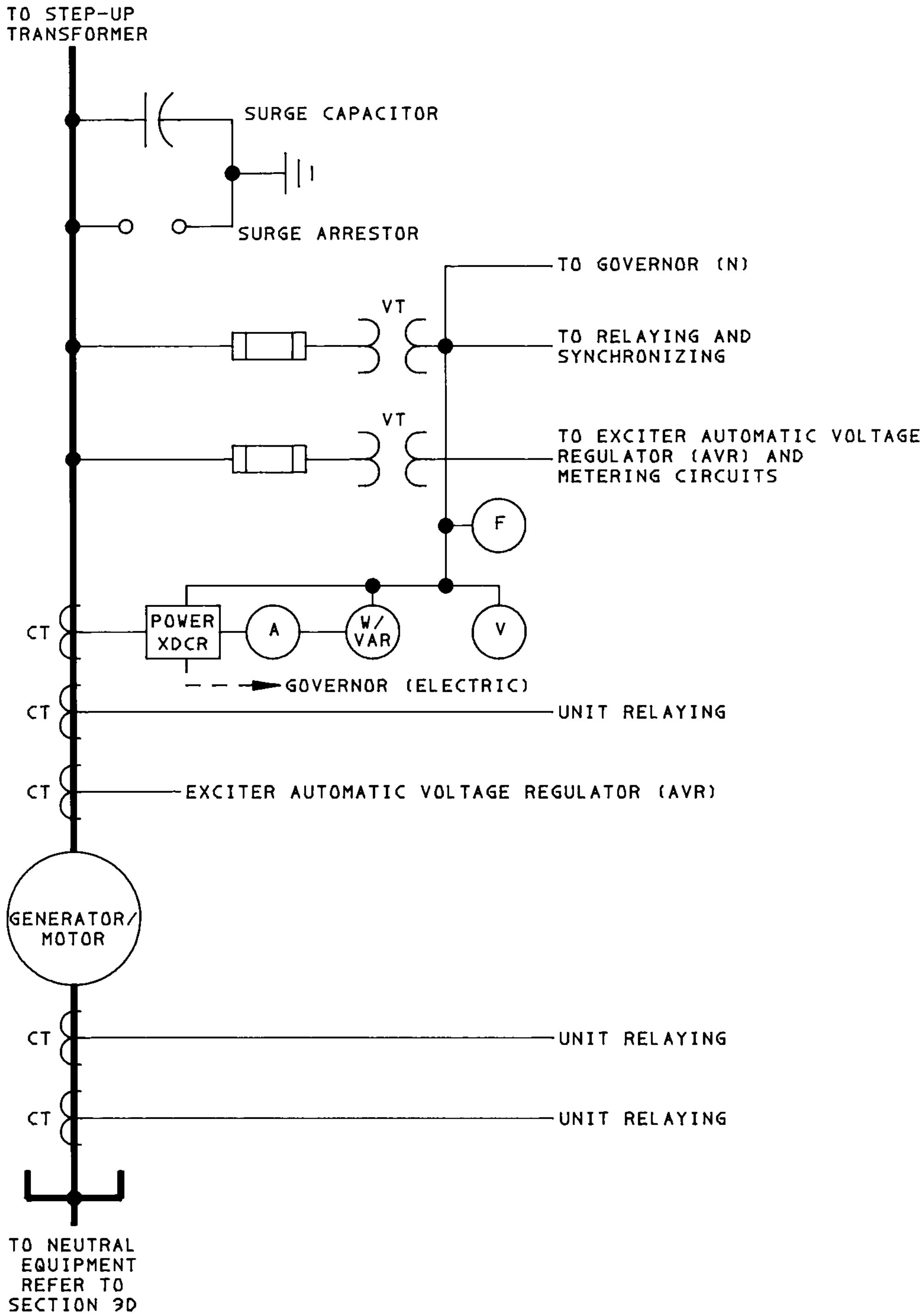

Figure 3C-1 —Typical Hydro Generator Terminal

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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.

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

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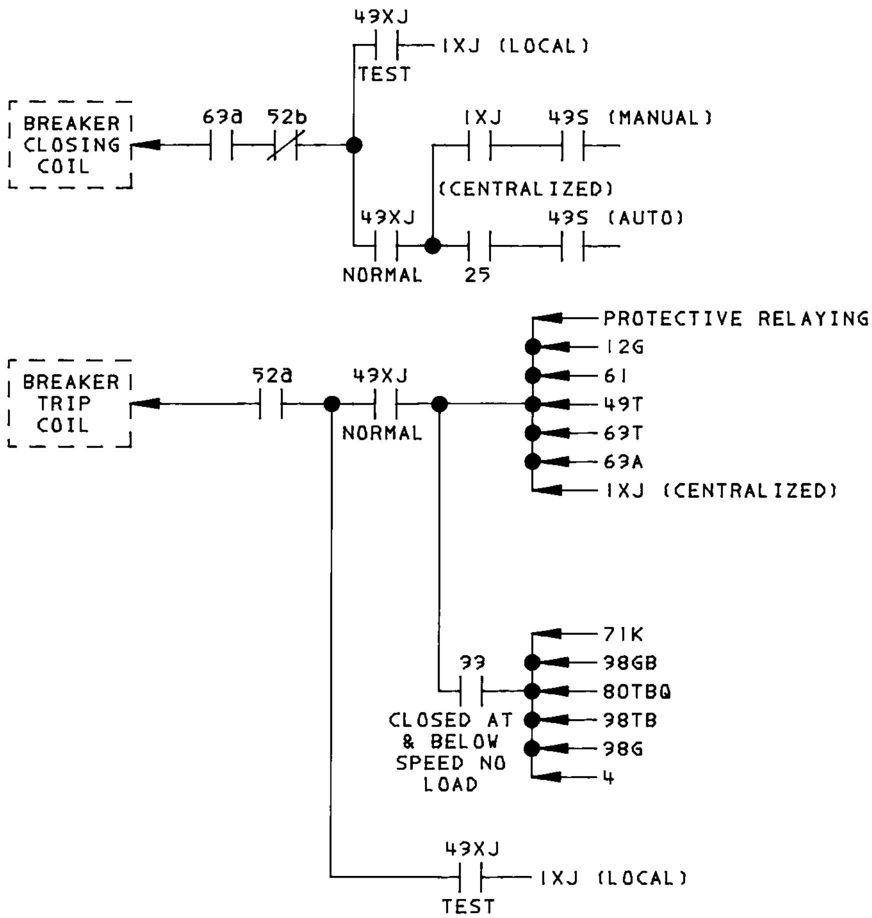

Figure 3E-1 —Typical Hydro Generator Breaker Interface Diagram

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

SIGNAL	DESCRIPTION	TYPE	NOTES
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

SIGNAL	DESCRIPTION	TYPE	NOTES
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	

TYPE
C =Control
P =Protection Trip
A =Annunciation/Event Recording
T =Temperature Monitoring
I =Indication (analog, digital, status lamps)

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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

SIGNAL	DESCRIPTION	TYPE	ORIGINATING DEVICE	NOTES
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.

TYPE
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

SIGNAL	DESCRIPTION	TYPE	NOTES
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.

TYPE
C =Control
P =Protection Trip
A =Annunciation/Event Recording
T =Temperature Monitoring
I =Indication (analog, digital, status lamps)

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

DESCRIPTION	TYPE	NOTES
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	
	TYPE 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.

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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.

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

SIGNAL	DESCRIPTION	TYPE	NOTES
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.

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

DESCRIPTION	TYPE	NOTES
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.

TYPE
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.

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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.

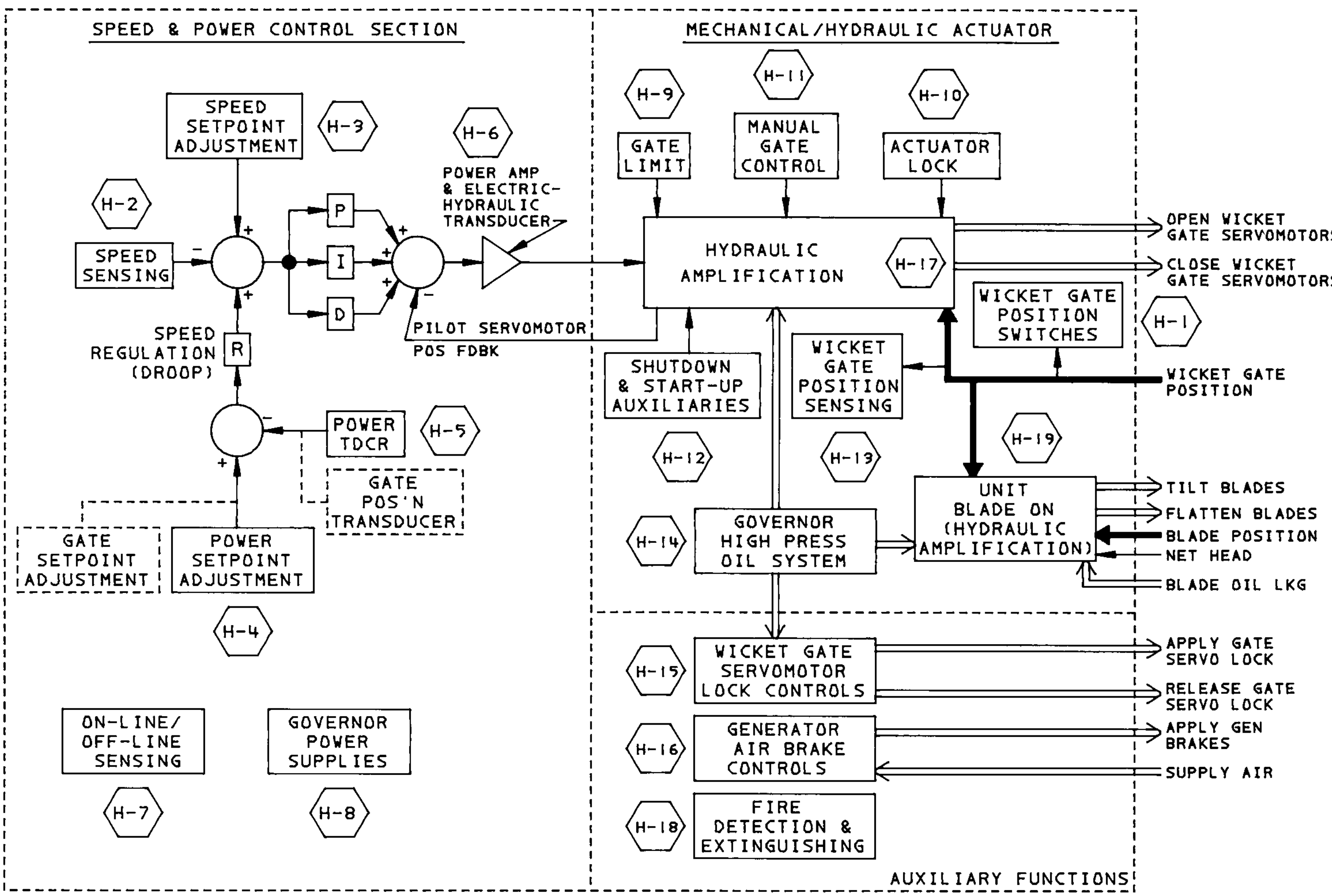

Figure 3H-1 —Typical Electric-Hydraulic Reaction Turbine Governor

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Table 3H-1 —Control and Status Data Transmitted from Governor to Unit Control Switchboard

SIGNAL	DESCRIPTION	TYPE	ORIGINATING DEVICE AT GOVERNOR (REF. FIG 3H-1)	NOTES
n	Speed indication	I	H-2	Methods of developing the speed signal include the following: —Hall-effect, eddy current, magnetic or fiber-optic sensors operated in conjunction with toothed wheels or other devices directly connected to the generator shaft (speed signal generator—SSG) —Permanent magnet generators (PMG) coupled to the generator shaft. PMG output frequency and voltage are proportional to unit speed —Voltage transformers connected to the generator output leads must be capable of operating at very low residual voltages in absence of field excitation
12-X 13-X 14-X	Overspeed, synchronous speed, and underspeed switches	C, P, I	H-2	Speed switches may be actuated mechanically by means of a positive coupling to the rotating elements of the turbine generator unit or may be actuated electrically by comparing the speed signal to a reference signal.
65SF	Speed signal failure	A, C, P	H-2	Loss of speed signal may initiate control action (that is, actuator lock) or shutdown of the unit and annunciation.
39C	Creep detector operation	A, C	H-2	Control action upon detection of shaft movement after shutdown may include any or all of the following: —Start generator thrust bearing HP oil pump —Release brakes —Start unit —Trip intake gate or draft tube gate —Alarm —Start turbine guide bearing oil pump
15FM-LS	Speed reference motor drive limit switches	C, I	H-3	Adjustable limit switches are used to pre-position the speed reference prior to starting and synchronizing the unit. “End-of-travel” limit switches are used for illumination of lamps at remote raise/lower control switches or pushbuttons.
N(ref)	Speed reference indication	I	H-3	Typically derived from a potentiometer or synchro ganged to the motor drive.
65PM-LS	Power reference motor drive limit switches	C, I	H-4	Adjustable limit switches are used to pre-position the power reference prior to starting the unit and prior to transferring from generate mode to synchronous condenser mode. “End-of-travel” limit switches are used for illumination of lamps at remote raise/lower control switches or pushbuttons.
P(ref)	Power reference indication	I	H-4	Typically derived from a potentiometer or synchro ganged to the motor drive.

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SIGNAL	DESCRIPTION	TYPE	ORIGINATING DEVICE AT GOVERNOR (REF. FIG 3H-1)	NOTES
65GL-LS	Gate limit position switches	C, I, P	H-9	Adjustable limit switches are used to position the gate limit in various automatic control and protection sequences (ref. Table II, 65GLR, 65GLL). Switches also used for "end-of-travel" indication at remote raise/ lower control switches or pushbuttons.
GL	Gate limit position indication	I	H-9	Typically derived from a potentiometer or synchro ganged to the motor drive.
33GL	Gate limit coincidence switch	A	H-9	Closes when wicket gates are opened up to the position of the gate limit. Annunciates "governor action blocked" or "blocked gate." Also used to block further raise action on speed or power reference.
63QAL or 33AL	Actuator lock applied indication	C, P, I	H-10	Actuator lock may be initiated by the following governor failures: —Power supply failure —Plugged oil filter —Loss of speed signal —Printed circuit card removal —Loss of MW transducer Typical control and protection functions involving 63QAL or 33 AL include —Tripping of unit if overspeed detected while actuator is locked —Control schemes that allow unit to be controlled remotely via the gate limit
65SS	Start-stop solenoid auxiliary contacts complete shutdown	C, I	H-12	Provides confirmation of 65SS operation.
65SNL	Partial shutdown (speed-no-load) solenoid auxiliary contacts	C, I	H-12	Provides confirmation of 65SNL operation. Used to seal in remote controls and provide remote indication.
WG	Wicket gate position indication	C, I	H-13	Typically derived from potentiometer or synchro coupled to restoring connection from wicket gate servomotor.

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SIGNAL	DESCRIPTION	TYPE	ORIGINATING DEVICE AT GOVERNOR (REF. FIG 3H-1)	NOTES
33WG	Wicket gate position switches	C, P, I	H-1	Typical uses of gate position switches for control and indication: —Generator brake application (that is, apply brakes at low speed if gates at 0%) —Synchronous condense transfer (that is, admit draft tube depression air as gates close) —Turbine gate lock (apply at 0% gate position) —Trip generator breaker as gates pass through speed-no-load position (auto-stop, protective shutdowns without overspeed) —Incomplete stop detection —Unit running detection —Initiate time delay for stopping auxiliaries —Reenergize starting relays to provide restart after momentary loss of power —Actuator lock
71QP	Governor hydraulic system pressure tank level switches	A, P	H-14	Alarms for high, low, and extreme low levels. Shutdown for extreme low level. Air admission for high level.
63Q	Governor hydraulic system pressure switches	A, P	H-14	Pump control, alarms for high, low, and extreme low pressures. Shutdown for extreme low pressure.
63AR	Governor hydraulic system air relief valve operation	A	H-14	
71QS	Governor hydraulic system sump tank level switches	A, P	H-14	Alarms for high, low, and extreme low levels. Shutdown for extreme low level.
26QS	Governor hydraulic system sump tank fluid temperature high	A	H-14	Indicative of excessive governor action.
6Q	Governor hydraulic system lag pump operation	A	H-14	Indicative of excessive governor action or pump failure.
27PS	Governor power supply failure	A, C, P	H-8	Indicates failure of input ac or dc power or failure of regulated dc power supplies. May result in application of actuator lock or unit shutdown depending upon level of power supply redundancy.
63AB	Generator air brakes applied	C, I	H-16	Indication and auto-start interlock.
63ABS	Generator air brake supply pressure low	A	H-16	
33WGL	Wicket gate automatic lock applied/released	C, I	H-15	Indicates status of the gate lock (applied on shutdown when gates at 0%).
65WGLF	Wicket gate automatic lock failure	A	H-15	Indicates that the gate lock has not been fully applied on shutdown.
65M/LS	Manual control indication	I	H-11	Provides remote indication that the governor is in manual control at the governor cubicle.

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SIGNAL	DESCRIPTION	TYPE	ORIGINATING DEVICE AT GOVERNOR (REF. FIG 3H-1)	NOTES
63QPV	Pilot valve strainer obstruction	A	H-17	
49F	Fire detection system operation/ trouble	A, P	H-18	Operation or failure of detection/ extinguishing system.
BAL	Governor balance indication	I	H-6	For electric governors, indication of electric-hydraulic transducer input voltage. Indicates degree of error between desired servomotor position computed by the electric circuits and the actual servomotor position, for effecting bumpless transfer from actuator lock to governor control.

TYPE
C =Control
P =Protection Trip
A =Annunciation/Event Recording
T =Temperature Monitoring
I =Indication (analog, digital, status lamps)

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Table 3H-2 —Control and Status Data Transmitted from Unit Control Switchboard to Governor

SIGNAL	DESCRIPTION	TYPE	DESTINATION AT GOVERNOR (REF. FIG 3H-1)	NOTES
39	Creep detector enable	C	H-2	Enables rotor creep detector after a fixed time following application of brakes on shutdown.
15FR, 15FL	Speed reference raise/lower commands	C	H-3	Typically relay or switch contact closures, routed to reversing drive motor. If power reference also provided, speed raise/lower operable only off-line. Some installations may input reference analog or digital signal rather than raise/lower commands.
65PR, 65PL	Power reference raise/lower commands	C	H-4	Typically relay contact closures, routed to reversing drive motor when unit on-line. Some installations may input reference analog or digital signal rather than raise/ lower commands.
65GLR, 65GLL	Gate limit raise/lower commands	C	H-9	Typically relay contact closures, routed to reversing drive motor. Primary function of the gate limit (GL) is to limit the maximum opening of the wicket gates under operator control to prevent overloading the unit at the prevailing head. Other control and protection applications include: —Pre-positioning GL to 0% prior to starting to permit controlled opening of the gates upon energization of the start/stop solenoid 65SS —Raising GL to turbine breakaway gate position after energization of 65SS —Generate-synchronous condenser transfer schemes —Rapid unloading of the machine during certain stop and protection shutdown sequences
65AL	Actuator lock on-off	C	H-10	Permits the actuator lock to be applied or to be reset by an operator at a location remote from the governor.

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SIGNAL	DESCRIPTION	TYPE	DESTINATION AT GOVERNOR (REF. FIG 3H-1)	NOTES
3SS	On-off command to start/stop solenoid 65SS	C, P	H-12	The start/stop solenoid 65SS typically operates as follows: —Energized to allow wicket gates to open and close under control of the electric governor, gate limit or manual gate control, that is, “energized to start and run” —Deenergized to initiate complete closure of the wicket gates at maximum rate and block subsequent opening of the gates, that is, “deenergized to stop” In some applications, 65SS may be “deenergized to start and run” and “energized to stop” although this method may not be fail-safe for loss of control voltage. Typical functions that will block start and/or initiate stop are —Unit protection operation (includes all electrical and mechanical fault detectors that initiate shutdown of the unit) —Operator-initiated stop —Generator thrust bearing high pressure oil pump failed to achieve full pressure —Turbine shaft maintenance seal on or low gland water flow —Generator brake shoes not cleared or brake air pressure not off, or both —Intake gate not fully open —Generator and turbine bearing cooling water not available —Wicket gate lock not released
3SNL	On/off command to partial shutdown (speed-no-load) solenoid	C, P	H-12	The partial shutdown solenoid 65SNL (if used) is typically deenergized to limit the opening of the wicket gates, or return them, to a position slightly above the speed-no-load position and is controlled as follows: —Energized when unit circuit breaker closes to allow generator to be loaded —Deenergized whenever unit circuit breaker trips to restore unit to near rated speed; provides backup to the electric governor —Deenergized to unload the unit for certain protection operations (that is, hot transformer)
V, I	Generator voltage and current	C	H-5	Inputs to power transducer (for governors utilizing power feedback rather than gate feedback).
52	Unit on-line	C	H-7	Generator circuit breaker auxiliary contact. Used to switch between on-line and off-line gains in compensation circuits (PID) and to switch between speed and power references.
3AB	Generator air brakes on/off command	C	H-16	Air brakes automatically applied on shutdown if wicket gates close and speed below a predetermined level.

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SIGNAL	DESCRIPTION	TYPE	DESTINATION AT GOVERNOR (REF. FIG 3H-1)	NOTES
4C	Generate to synchronous condenser transfer initiation	C	H-12	Initiates pre-positioning of governor reference setters (power, gate limit) followed by rapid closure of the wicket gates by application of closing bias to power amplifier.
71NH	Level difference between headwater and tailwater including piping losses.	C		Used for optimum turbine blade positioning and optimum pumping unit gate position.

TYPE
C =Control
P =Protection Trip
A =Annunciation/Event Recording
T =Temperature Monitoring
I =Indication (analog, digital, status lamps)

Table 3H-3 —Operating Power, Air and Water from Service Equipment to Governor

DESCRIPTION	TYPE	DESTINATION AT GOVERNOR (REF. FIG. 3H-1)	NOTES
Power supply for dc control and indication circuits	DC	H-3, H-4, H-8, H-9, H-10, H-12, H-14, H-15, H-16, H-18, H-19	One or more separate supplies depending on power distribution arrangement.
Power supply for hydraulic pressure system pumps	AC	H-14	One or more separate supplies depending on number of pumps and required redundancy.
Alternate supply for governor power supplies	AC	H-8	
Air supply for generator air brakes	A	H-16	
Air supply for hydraulic pressure system	A	H-14	
Cooling water for hydraulic fluid sump	W	H-14	(Optional)

TYPE
AC =AC Power
DC =DC Power
A =Air
W =Water

3I. Penstock/Intake Gates or Valves

The penstocks or pressure conduits are the pipes connecting the hydraulic turbines with the intake structure. The penstocks are normally fabricated of steel, but may consist of lengths of tunnels. There are no controls or instrumentation normally associated with the penstocks except piezometer taps near the connection to the turbine, or pressure/flow instrumentation sensors.

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The intake gates serve the purpose of stopping the flow of water to the turbines by closing the inlet to the penstocks. Alternate methods of stopping the flow are to have the gates at an intermediate point in the penstock or to have guard valves in the penstock just upstream from the generating unit. Inlet valves are desirable for each unit if one penstock is used for two or more turbines. Plants having intake gates or valves should have their controls interfaced with the unit's control system.

The gates are normally closed for one of two purposes—maintenance or emergency—but not during normal operation. An emergency can include a unit run-away due to such things as load rejection and failure of the wicket gates to close. It is critical that the intake be capable of closing under all flow conditions. For pumped storage installations, the intake gate should also be capable of closing under full reverse flow conditions. Tripping of the gates is initiated from the power plant by overspeed switches or other devices or by operator action. Control and trip circuits use dc power from the plant battery and stored energy systems, such as gravity or hydraulic accumulators, provide the power to close the gates. Instrumentation and alarms are usually limited to indication of fully open/fully closed position and status of the stored energy system.

3J. Draft Tube Gate

The draft tube gate provides the means to isolate the hydraulic turbine from the tailwater when the turbine is in a shutdown mode. Various types of draft tube gates are used depending upon its function.

If the purpose of the gate is to isolate the turbine just for inspection and maintenance, then the gate can be simply a "stop-log" device that is moved into place by a crane or hoist under no-flow conditions.

If the purpose of the gate is to provide isolation of the turbine during an emergency shutdown of the unit, then the gate would be motor operated or hydraulically operated and should be capable of closing under full-flow conditions.

Automatic operation of the gate is needed when the draft tube gate is used to regulate flow through the unit during the sluicing operation associated with bulb turbine units. The purpose of this mode of operation is to minimize the disturbance that an abrupt interruption of the flow of water might cause during a load rejection. During sluice operation, the generator is disconnected from the grid, and the speed of the turbine is controlled by the draft tube gate.

Typical controls for automatic operation of the gate are as follows:

1) *Unit Control Board*
   - Raise/lower control switch
   - Indicating lights for fully open/fully closed
   - Position indication showing actual position of the gate
2) *Local*
   - Raise/lower control switch
   - Mechanical device showing gate position
3) *Annunciation*
   - Failure of gate to open or close in response to an automatic signal
   - Failure of gate to maintain partial closure position during sluice operation
   - Hydraulic system trouble

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3K. Pump Starting Equipment

A pumped-storage unit is a turbine/generator that can be reversed to pump water upstream. When operating as a pump, the generator becomes a motor, which now supplies mechanical power to the turbine.

Starting the unit in the pump mode requires a means of accelerating the generator / motor in the pump direction. Regardless of how this is done, the motor is started with the gates closed and the tailwater depressed. Once the unit is at full speed and on-line, the depressing air is vented and the pump is primed. The gates are then opened and pumping begins.

Six of the most common methods of starting a motor unit are as follows:

1) *Full Voltage, Across-the-Line Starting*. With this type of starting, the unit breaker is closed, and the unit is started as an induction motor. The induction motor action is provided by amortisseur windings with special damper bars. At about 95% speed, excitation is applied and the machine becomes a synchronous motor. The acceleration time for this type of starting depends on the machine inertia and is usually on the order of one minute, or less. Because of the voltage drop on the plant's transmission system and heating of the machine windings, full voltage starting is used primarily on smaller units.
2) *Reduced Voltage, Across-the-Line Starting*. When across-the-line starting is desired and full voltage starting is not practical, reduced voltage starting should be considered. The system configuration for this method is shown in Fig 3K-1. One method is by a tap on the generator step-up transformer to feed a starting bus at one-third to one-half rated generator/ motor voltage. A breaker is provided to connect the machine to the starting bus. When the machine accelerates to about 95% speed, excitation is applied. When synchronism with the system is attained, the starting breaker is tripped and the running breaker is closed. Another method of reduced voltage starting is by connecting a series reactor during starting, and then short-circuiting it near synchronous speed.

   If the generator/ motor stator winding consists of multiple circuits, partial winding starting can be considered. This is a variation of reduced voltage starting in which one-half or less of the winding circuits are used for accelerating the machine. When the unit reaches 95% speed, excitation is applied and the remaining circuits are connected. A one-line diagram for this method is shown in Fig 3K-2.
3) *Pony Motor Starting*. A pony motor is a wound-rotor machine that is attached to the motor/generator shaft. Its rotor winding is connected to an adjustable resistor, usually a liquid rheostat, making it a variable speed device.

   The pony motor is usually fed from the plant's station service system. It is built with two or four fewer poles than the unit motor/generator, so that it can accelerate it to just above 100% rated speed for synchronizing. Since its rotor is usually directly coupled to the motor/generator shaft, a separate pony motor is required for each reversible unit. With proper switching, however, one liquid rheostat can be used on several units. A controller is provided with the liquid rheostat to adjust resistance during starting.

   A typical pony motor starting sequence begins with closing the station service breaker. The rheostat controller adjusts pony motor torque to provide linear acceleration of the unit. At approximately 95% speed, excitation is applied to the motor/generator field. The liquid rheostat control is transferred to the synchronizing controls, which adjust pony motor and unit speed for synchronization. Once the unit is paralleled, the station service supply to the pony motor is tripped. Typical acceleration time is from five to ten minutes.

   Pony motor starting is suitable for use with large motor/generator units. Pony motor size could range up to several thousand horsepower, depending upon the requirements of the unit being started. A one-line diagram for this starting method is shown in Fig 3K-3.

   The pony motor and liquid rheostat have interfaces to both the unit protection and the control system on the unit control switchboard. These are listed in Table 3K-1.
4) *Synchronous Starting*. This technique uses another generator (sometimes only a fraction of the size of the primary unit) to start the unit that is acting as a motor. The two machines are electrically connected together through a starting bus, but are isolated from the transmission system. Excitation is applied to both machines and the gates on the unit that is acting as a generator are opened. As it accelerates, the motor unit follows in synchronism. When both machines reach system frequency, the motor unit is disconnected from the starting

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bus and placed on-line. Other motor units can be started in a similar fashion with the same generator by connecting them through the starting bus. Typical starting times for this method are from three to five minutes. Figure 3K-4 shows a one-line diagram for synchronous starting.

5) *Semi-Synchronous Starting*. Sometimes referred to as reduced frequency, reduced voltage starting, the semi-synchronous starting method depends on the transfer of rotational energy from a spinning generator to the pump unit. Prior to pump starting, the generator is accelerated to about 80% of rated speed, and its wicket gates are held at a fixed position. The pump unit is tied to the generator through a starting bus. Excitation is applied to the generating unit and the pump unit starts as an induction motor with its field shorted or by using amortisseur windings. Since the generating unit's wicket gate position is fixed, it will decelerate as the pump unit accelerates. When the speed of the two units is approximately equal, excitation is applied to the pump unit to bring it into synchronism with the starting generator. The generating unit's wicket gates are then opened to accelerate both units to rated speed.
   After synchronism to the system, the generator unit may be tripped off and used to start other pump units. Typical acceleration time for the pump unit is from three to five minutes.
   Due to the manner by which this starting method works, the generator unit should have a similar flywheel effect (WK^2) to that of the pump unit. Also, the demands on the generator unit's excitation is rather high since it must maintain terminal voltage when the machine is decelerating. An individual case study is mandatory to determine the feasibility of this starting method for a particular application.
   The one-line diagram for semi-synchronous starting is similar to that for synchronous starting. Therefore, reference is again made to Fig 3K-4.
6) *Static Starting*. A static starter is a converter/inverter combination that converts station auxiliary power into a variable frequency output of sufficient magnitude to accelerate the motor unit. As in synchronous starting, the static starter is electrically connected to the unit through a bus, but isolated from the system. At the beginning of the start sequence, excitation is applied to the unit and the static starter is energized from station service. As the starter's output frequency increases, the generator/motor starts to accelerate. When the unit frequency matches the system, the starter is isolated from the unit and the unit breaker is closed. As in synchronous starting, other units can be started from the same static starter with proper switching. Figure 3K-5 illustrates the connections involved.

Dynamic braking of the machine can be accomplished by reconnecting the static starter after the unit has been tripped off the system. Circuitry inside the starter changes the direction of power flow to allow motor braking. This feature can result in greater life of the unit's mechanical brakes.

Static starting can be used on a variety of sizes of machines. Typical starting time is less than ten minutes. The interfaces from the static starter to the unit control switchboard are listed in Table 3K-2.

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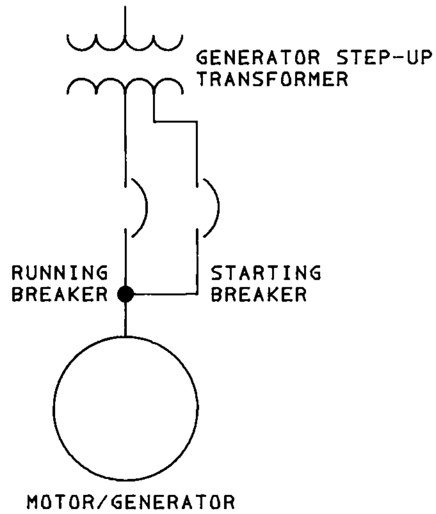

Figure 3K-1 —Reduced Voltage Starting (Phase Reversing Not Shown)

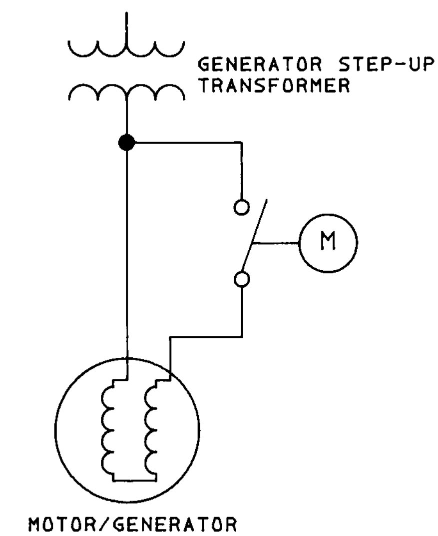

Figure 3K-2 —Part Winding Starting (Unit Breaker and Phase Reversing Not Shown)

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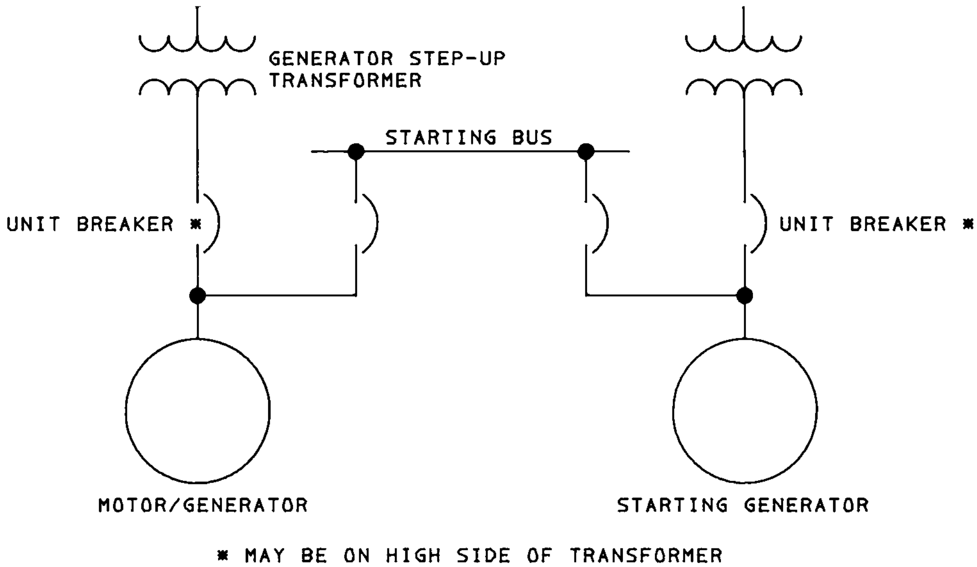

Figure 3K-3 —Pony Motor Starting * (Unit Breaker and Phase Reversing Not Shown)

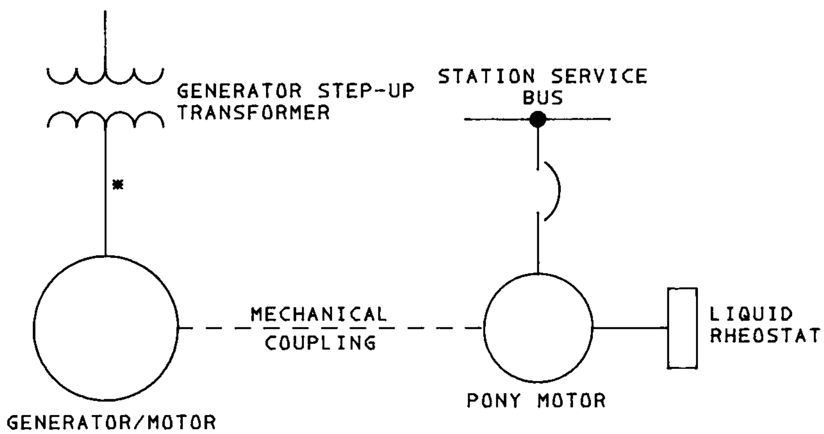

Figure 3K-4 —Synchronous Starting (Phase Reversing Not Shown)

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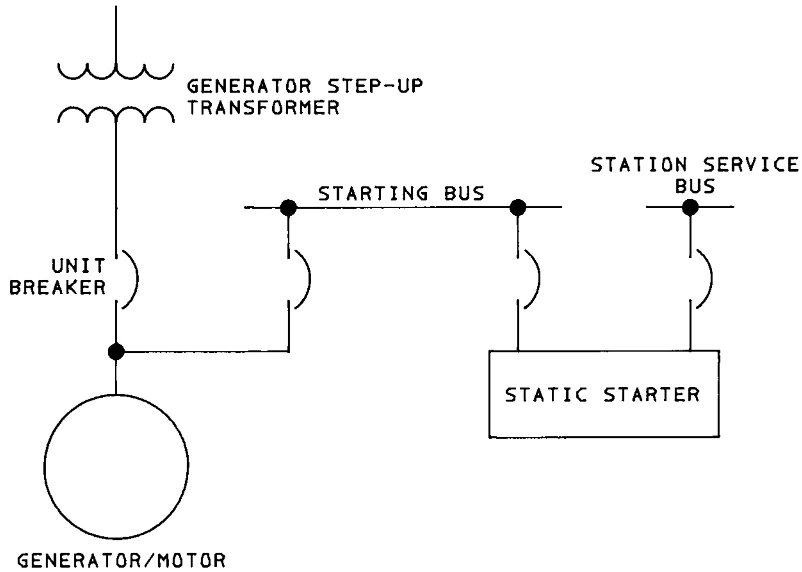

Figure 3K-5 —Static Starting (Phase Reversing Not Shown)

Table 3K-1 —Control and Status Data Transmitted from Pony Motor Unit Starting Equipment to Unit Control Switchboard

SIGNAL	DESCRIPTION	TYPE	ORIGINATING FROM: PM—PONY MOTOR LR—LIQUID RHEOSTAT	NOTES
23LR	Liquid rheostat electrolyte temperature	P	LR	Trips pony motor lockout relay.*
46PM	Pony motor phase unbalance relay	P	PM	Trips pony motor breaker.
48S-1,2	Acceleration (speed versus time) check	P	LR	Trips pony motor lockout relay.*
49PM	Pony motor stator temp	P, T	PM	Trips pony motor lockout relay.* Temperature monitoring optional.
51PM	Pony motor overcurrent relay	P	PM	Trips pony motor lockout relay.*
64PM	Pony motor rotor ground relay	P, A	PM	Alarms only or trips pony motor lockout relay*, depending on operating company practice
71LRE	Electrolyte level	A, C	LR	Alarms, and pump starting sequence prestart check.
80E	Loss of electrolyte flow	P, A	LR	Alarms; optional trip of pony motor lockout relay.*
87PM	Pony motor differential relay	P	PM	Trips pony motor lockout relay.*

TYPE
C =Control
P =Protection trip
A =Annunciation/event recording
T =Temperature monitoring

*Pony motor lockout relay trips pony motor breaker and initiates unit normal shutdown; locks out starting control sequence.

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Table 3K-2 —Control and Status Data Transmitted from Static Starting Equipment to Unit Control Switchboard

SIGNAL	DESCRIPTION	TYPE	NOTES
1	Starter ready for service	C, A	Pump mode pre-start check, alarms.
2	Start time to 5% speed exceeded	P, A	Trips static starter*, alarms.
12-105	Overspeed (105%)	P, A	Trips static starter*, alarms.
27	Incoming power to starter failure	P, A	Trips static starter*, alarms.
27PS	Internal Power supply failure	P, A	Trips static starter*, alarms.
27SV	Converter sync voltage failure	A	
33	Thyristor cubicle door open	P, A	Trips static starter*, alarms.
33RS	Phase reversing switch wrong position	P, A	Trips static starter*, alarms.
48	Start/stop sequence incomplete (time exceeded)	P, A	Trips static starter*, alarms.
49	Cooling oil high temp	P, A	Trips static starter*, alarms.
50G	Starter ground fault	P, A	Trips static starter*, alarms.
51	Starter overcurrent	P, A	Trips static starter*, alarms.
52b	Cooling system feeder breaker tripped	P, A	Trips static starter*, alarms.
59	Starter overvoltage	P, A	Trips static starter*, alarms.
63	High cooling water pressure	P, A	Trips static starter*, alarms.
80	Cooling oil low flow	P, A	Trips static starter*, alarms.
	Encoder impulse failure	A	
	Encoder plug trouble	P, A	Trips static starter*, alarms.

TYPE
C =Control
P =Protection Trip
A =Annunciation/Event Recording
T =Temperature Monitoring

*When starter trips, pump unit will shut down.

3L. Phase Reversing Equipment

Operating a pumped storage unit in the pump mode requires reversing the direction of rotation of the generator/motor unit. This is accomplished by interchanging any two of the phases with motor operated, multipole switches, or with breakers.

Usually, the simplest and most cost-effective method, especially for large units, is to use a motor operated switch. It can be either a four-pole or five-pole design, depending on whether or not it is desired to open the third phase when the switch is operated. A typical connection of a five-pole switch is shown in Fig 3L-1.

Breakers can be used for phase reversal in two ways. First, two-unit breakers can be provided with the phases interchanged in the external buswork. This connection is shown in Fig 3L-2. Interlocks must be provided to prevent

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both breakers from closing at the same time. Second, a five-pole unit breaker can provide phase reversal, as well as unit disconnection. Its connection would be similar to the motor operated switch shown in Fig 3L-1.

Phase reversal can be accomplished either on the low side or the high side of the unit step-up transformer. Several arrangements are illustrated in Fig 3L-3. The method chosen will depend on the usual constraints of cost, space, size of unit, maintainability, etc.

When specifying phase reversing equipment, major consideration should be given to the severe duty usually imposed on it by the change of modes at most pumped storage projects. Care should also be taken when applying protective relaying, especially differential and reverse power relaying, to prevent misoperation when phase rotation is reversed. High quality position switches should be purchased with the phase reversal equipment so that its position can be reliably checked prior to unit start-up.

Table 3L-1 —Control and Status Data Transmitted from Phase Reversing Equipment to the Unit Control Switchboard

SIGNAL	DESCRIPTION	TYPE	NOTES
43	Generator/Motor phase selector control switch	C	
33	Phase switch position	C	Indication on unit switchboard and input to pre-start checks.

TYPE
C =Control

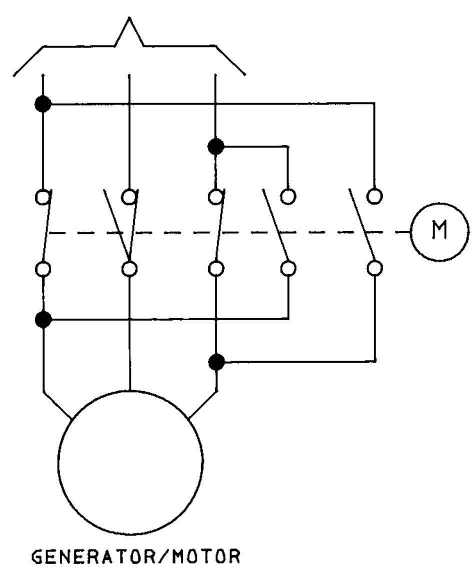

Figure 3L-1 —Phase Reversal With Five-Pole Motor-Operated Switch (Low Side Reversing Shown) to Unit Step-Up Transformer

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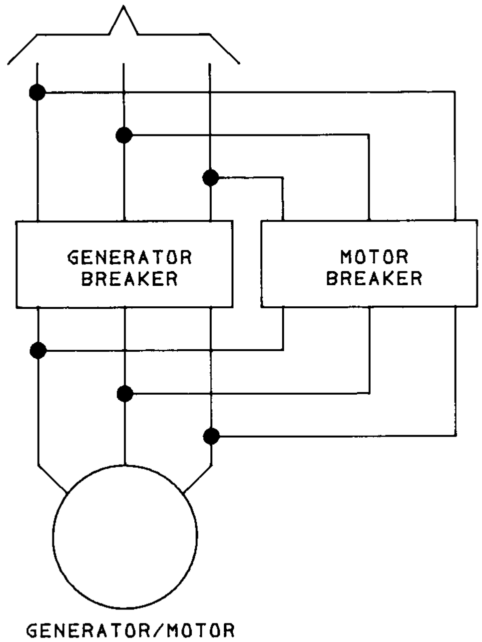

Figure 3L-2 —Phase Reversal With Two-Unit Breakers (Low Side Reversing Shown) to Unit Step-Up Transformer

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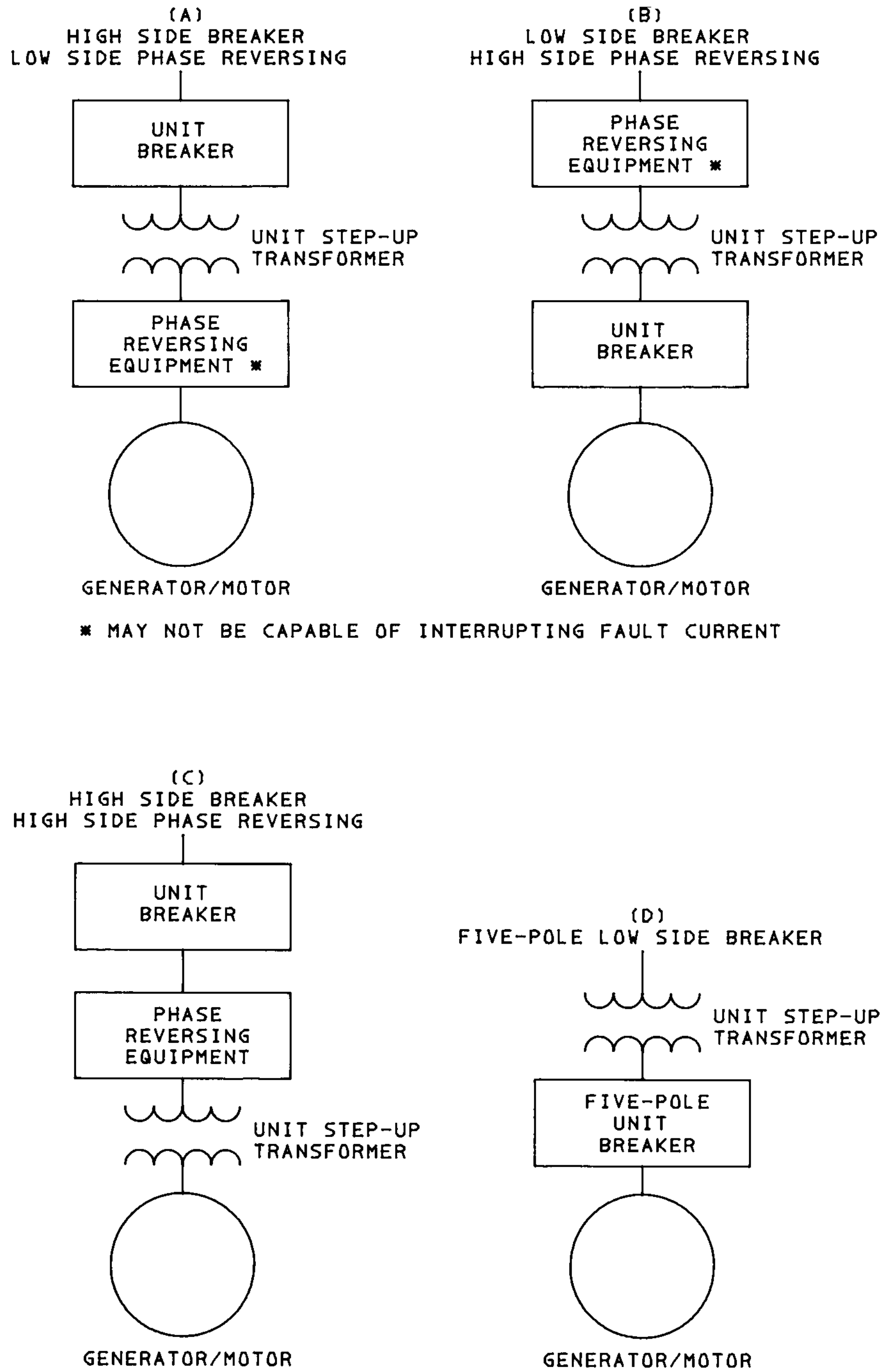

Figure 3L-3 —Phase Reversing Equipment Locations

3M. Draft Tube Water Depression System

The draft tube water depression system is utilized both in conventional hydroelectric units and in pumped storage units to depress the water below the runner of the turbine. By depressing the water below the runner, it allows the unit to be motored with minimum power consumed from the system since it is spinning in air as opposed to water. The motoring of a conventional hydroelectric unit is desired so the unit can be utilized as a synchronous condenser for electrical

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system enhancement, or for the unit to be in spinning reserve for rapid response to system needs. The motoring of a pump/turbine unit, in addition to those items for a conventional unit, is required during the acceleration of the unit in the pump direction (opposite to generator direction).

The draft tube water depression system consists of (1) a level detector located in the draft tube gallery for monitoring water level directly below the runner, (2) a depressing air system that supplies an adequate air volume at the required pressure for depressing the water to a predetermined level, and (3) solenoid operated air valves for controlling the air admitted to the turbine for depressing the water. A pressure switch often monitors the depression air system supply pressure, with alarm occurring when pressure drops to a level where full depression of a unit cannot be completed.

The operation of the system is basically as follows. The level detector senses that the water is around and above the runner and when the depressing sequence is initiated, the solenoid valves are energized to allow air into the turbine for depressing the water. Usually two solenoid valves are provided (a small and a large valve). The large valve is used to provide a rapid blow-down of the water to a preset point below the runner and the small valve is utilized to maintain the required air pressure to keep the water at that point and to compensate for any air leakage.

The sequencing of these valves for initial blow-down and make-up is totally automatic. This operation usually requires a minimum of three level set points:

Level 1—Set to sense that the water level is below the runner for motoring operation (nominal depressed level) (both large and small valves are deenergized at this level).

Level 2—Set to sense that the water level is below the runner for motoring operation but is above the nominal level and, therefore, make-up air needs to be added. (Small valve is energized.)

Level 3—Set to sense when water level is above Level 2, but still below the runner. This level is utilized to energize both the large and small valves since the make-up air is not adequate for making up the losses. An alarm is usually given at this level.

There could be a Level 4 switch added for tripping the unit if water does reach the turbine runner. Also, an extremely low-level switch could be used to alarm, indicating a depression valve has stuck open.

Associated with the depression system is the priming system, which vents the air from around the pump/turbine runner when it is desired to begin pumping. The priming system may include one or more vent valves, solenoid, or motor operated depending on the size. The system also includes a pressure switch located in the headcover that detects pressure at the runner tip as air is vented during priming. Operation of this switch indicates the runner is effectively watered and the pump is primed.

3N. Generator/ Motor Cooling

Conventional unit cooling is usually accomplished by circulating air through the unit windings and then through heat exchangers for the removal of heat. Service water is the most common cooling medium used in these heat exchangers. Instrumentation associated with conventional cooling is usually limited to fan failure, water flow, and cooling water strainer differential pressure.

A more sophisticated means of unit cooling is direct winding water cooling. This method of cooling involves circulating water through either the stator or the rotor or both windings and is used in conjunction with conventional cooling. Cooling water is circulated through hollow conductors rather than heat exchangers imbedded in the winding. Water quality is of utmost importance in this type of cooling.

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Table 3N-1 —Control and Status Data Transmitted to and from the Cooling System and Unit Control System

DESCRIPTION	TYPE	NOTES
CONVENTIONAL COOLING:		
Fan failure	A, P	Trip occurs on multiple fan failures resulting in insufficient air flow.
Raw water low flow	A	Trip is accomplished by winding temperature.
Strainer differential pressure	A	
DIRECT WINDING WATER COOLING:		
Rotating manifold high temperature	A, P, T	
Control voltage failure	A, P	
High conductivity	A, P	
Chemical filter high conductivity	A	Cleaning necessary.
Dissolved oxygen high	A	Water purification necessary.
Rotor differential pressure	A, P	Low flow back-up or manifold failure.
Stator differential pressure	A	Flow restriction.
Raw water strainer high differential pressure	A	Cleaning necessary.
Demineralized water low pressure	A	Potential pump failure.
Stator low flow	A	
Rotor low flow	A	
Raw water low flow	A	
Expansion tank high/low level	A, P	
Stator water temperature	A, P, T	
Rotor water temperature	A, P, T	
Rotor/Stator water inlet high temperature	A, P, T	Potential raw cooling water failure.
Excessive leakage	A, P	
Back-up pump start	A	Potential cooling failure.
Nitrogen pressure high/low	A	
Unit started	C	Starts demineralized water flow.
Field breaker closed	C	Starts raw water cooling of demineralized water (can be sensed as field voltage).
Unit auxiliaries started	C	Controls housing heaters.

TYPE
A =Annunciation
C =Control
P =Protective trip
T =Temperature monitoring

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A closed loop demineralized water system provides the cooling water for the winding cooling system. The demineralized water system consists of filtering equipment to maintain water purity, analyzing equipment to monitor purity, flow and pressure instrumentation, and a make-up water and leak detection system.

The demineralized water is cooled by circulating it through service water cooled heat exchangers. A normal complement of flow and differential pressure instrumentation is provided on the raw cooling water system.

In addition to the demineralized and service water systems, a rotating manifold is required on the rotor to provide the rotor demineralized water supply and return interface.

3O. Service Air

The service air system supplies compressed air for unit and general plant purposes such as for braking, air-operated tools, etc.

The source for station air is an air compressor and a storage receiver. Often a duplicate compressor and receiver set is provided for backup and to allow maintenance on one set. Both sets would connect to a common header that would have pressure switches for alarm and control. Lead-lag compressor controls would include alternators to equalize the duty on each compressor. Air compressors may require service water for cooling.

The header pressure switches perform the following as a function of detected pressure:

63ARHH	high/high	alarm
63ARNH	normal high	stop compressor
63ARNL	normal low	start lead compressor
63ARLL	low/low	start lag compressor and alarm

Compressed air for draft tube water depression, circuit breaker operation, and governor oil system make-up air is frequently supplied from similar, but separate air systems.

3P. Service Water

The service water system supplies water to the unit cooling water system, fire protection systems, and for general power-house needs. Although some filtration is provided for these purposes, additional filtration and purification would be needed for special purposes such as direct generator cooling or potable water supply.

Service water may be obtained from a penstock tap with suitable pressure reduction, or from tailwater. Service water is usually passed through a strainer for removal of silt. Often, two strainers are paralleled to permit backwashing for cleaning and for other servicing. A differential pressure switch across the strainer will alarm that backwashing is needed. The filtered water is then available for the appropriate purposes.

Unit cooling water in some cases may be supplied directly from the filtered water header, or unit cooling water pumps may be required. Usually, a motor-operated cooling water valve is provided to shut off flow to the unit when it is shut down, and a pressure switch upstream of the valve detects that correct water pressure exists. Valve position can be modulated if required to reflect actual water temperature and unit operating temperatures.

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If there are no cooling water pumps, the valve is opened at the time other auxiliary systems are started during unit startup, and closed after the unit has stopped. The cooling water pump, if supplied, is started with the other auxiliary systems, and when pressure is established on the closed valve, the valve is opened automatically. Frequently, dual pumps are provided for backup and for servicing. The pumps would have lead/lag controls, and operation of the lag pump would be initiated automatically if the pressure dropped for a preset time.

The unit cooling water header provides distribution for:

1) Generator bearing oil coolers
2) Turbine bearing oil coolers
3) Turbine packing box cooling and lubrication
4) Generator air coolers
5) Main step-up transformer oil coolers
6) Wearing ring seal water

Each unit cooler branch discharge is provided with flow switches, which operate to verify that flow has been established during unit startup for sequence interlocking, and for alarming upon sustained loss of flow. Flow to the packing box and wearing rings is monitored at its intake. Generally, the unit will not be shut down on loss of flow unless the main transformer has no self-cooled capability, or if the turbine wearing ring supply is interrupted while in a condensing mode.

Local instrumentation indicates intake water temperature and temperature of each cooler discharge. Remote instruments can be supplied, operated by vapor pressure or temperature detectors. Automatic data logging will require use of temperature detectors.

If water is required for generator or transformer fire protection or for hose connections, booster pumps connected to the filtered water header may be needed. These pumps would start automatically upon receiving an appropriate signal.

Other powerhouse requirements, such as air conditioning and service connections, are supplied from the filtered water header.

3Q. DC Power Supply

The dc power supply equipment for the power plant will normally consist of battery banks and battery chargers. A dc power distribution panel is normally used, together with subpanels as required, for distributing the dc power to the various control circuits and other loads in the plant. Instrumentation and controls are provided on the distribution panel and on the battery chargers. Alarm devices are mounted on the distribution panel, where all alarm conditions are combined into one for transmittal to the central control room.

Instrumentation will include dc volts and amperes for each battery charger and battery bank, and incoming ac volts and amperes. Protection and alarms may consist of ac and dc undervoltage, overcurrent, and battery ground. DC undervoltage is normally interlocked with the unit start circuits to prevent starting the unit without proper control power.

3R. AC Power Supply

The ac power supply equipment for the power plant can take several forms. A common one consists of one or two unit substations, depending on the number of generating units. A unit substation will contain a high-voltage section, a step-down transformer, and a low-voltage switchgear section. The high-voltage section will consist of a circuit breaker or a fused disconnecting switch and buses for connection to the generator bus, or other power source, and to the step-down transformer. The transformer will step the voltage down to the value used in the plant. The low-voltage switchgear will consist of power circuit breakers for incoming power from the transformer and for each major load. Power distribution panels and lighting panels feed power to the various loads around the plant. Instrumentation and

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controls are provided on the front of the high-voltage and low-voltage switchgear sections. Centralized instrumentation and control is usually provided; however, off-site control normally is not. Alarm devices are mounted on the unit substations, with all alarms combined into one for transmittal to the central control room.

Instrumentation will include ac volts, amperes, watts, and watthours. Protection and alarms may consist of over and undervoltages, overcurrent, differential overcurrent, sudden pressure, and over temperature.

3S. Water Level Monitoring Equipment

The headwater and tailwater surface elevations are measured very precisely for various purposes, such as reservoir level control, net head calculations, pumping unit control, spillway gate control, power generation control, minimum water release control, and gathering statistical data. The array of water level monitoring equipment is almost limitless, but a few types are most commonly used. The standard for many years and still frequently used are float-chain operated level switches and pressure transducers.

Another frequently used system, the bubbler system, measures levels by measuring the pressure required to release air bubbles from a nozzle set below the water surface. Other systems use changes in electrical conductance, electrical capacitance, ultrasonic sound reflectance, float switches, and other schemes. At those plants where the reservoir is remote from the plant, the penstock pressure is used for measuring the water level. Typical water monitoring instrumentation and alarms would be as follows:

1) Reservoir (headwater) level, an analog signal transmitted to the plant computer and to level recorders.
2) Downstream (tailwater) level, an analog signal, same as above.
3) Reservoir level switches, to give alarms if the level is above or below operating limits and to operate spillway gates if the level exceeds a set limit.
4) Downstream level switches, to give alarms if the level drops below operating limits and to operate low-level release valves if the level drops below minimum water release limits.

3T. Fire Protection

This section provides a guide for interfacing the fire protection system to the unit control system. (See Table 3T-1.)

Fire protection in a hydro station is usually automatically initiated. As a minimum, the generator and hydraulic oil equipment need fire alarm and protection systems; oil-filled transformers may also be protected. Heat and smoke detectors are put in other station areas for alarm. Station accessibility, hazard evaluation, cost of station equipment to be protected, ease of installation, and insurance requirements dictate degree of protection and actions required by the control system in other areas.

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Table 3T-1 —Fire Protection

EQUIPMENT OR AREA	TYPE OF DETECTOR	TYPICAL RESPONSE
Generator	(1) Temperature (2) Smoke (3) Differential relay trip	(1) CO_2 system (enclosed units only). Discharge CO_2, trip unit. (2) Water deluge system—Do not spray on differential relay trip. Do not use smoke detectors. Need more than one detector to operate before spraying. Some plants rotate unit with field breaker open while deluge system operates. Others require a protective relay trip plus temp alarm before deluge system operates.
Transformers	(1) Temperature (2) Protective relay trip	(1) Water deluge system—Protective relay trip should initiate only if water supply is unlimited and oil spill clean-up is considered.
Hydraulic, lubricating oil, other mechanical areas	(1) Temperature (2) Smoke	(1) Water deluge system—Bearing overtemperature protection (covered elsewhere for generators) helps prevent ignition of lubricating oil. (2) CO_2 or Halon 1301 system.
Control equipment rooms,cable spread areas, switchgear	(1) Temperature (2) Smoke (3) Heat detection cables	(1) CO_2 or Halon 1301 system.

Fire protection and alarm and control systems can add significantly to the cost of a station; therefore, it is important to consider early in the design and to involve both fire protection engineers and the insurance carrier in the design of the control system. The following applies to the design of fire alarm and protection control systems for the hydro station:

1) Fire protection or detection systems for electrical or mechanical equipment should always be interlocked to deenergize or otherwise disable the equipment. This will help to remove the source of ignition.
2) Location and type of heat detection device is important. Thermostats, heat detection cable, ionization and smoke detectors are among devices used.
3) The supply of substance used to cool or smother the fire is often limited. Even a large volume of water may be difficult to obtain in the hydro, station, due to head considerations at the fire location. Timed-flow cycling systems, which apply water, stop and measure heat, then reapply protection if necessary, may be required to conserve supply but are generally not recommended in fire protection systems. Provision for getting rid of the fire protection substance, such as water after discharge, is also a consideration.
4) Unless properly designed, false operation of fire protection systems can harm personnel and damage equipment. CO_2 and Halon 1301 systems should be alarmed or interlocked with access ways to prevent discharge if people are in an area or to delay discharge to allow people to leave the area. As an added precaution, monitoring equipment could be provided to detect gas pocketing.
5) When fires are detected, and/or a fire extinguishing system operates, an alarm should sound in the area and at the same time be transmitted to the closest manned location. As a minimum, each unit and the general station should be separately alarmed. Never include fire detection on general trouble alarm circuits.
6) Emergency power is needed to operate fire protection equipment and associated controls and alarms. Dedicated circuits from the station battery or other highly reliable power source should be used for control and alarm. Diesel or gas turbine generators can provide backup power for fire water pumps and battery chargers.

4. Control Sequencing—Generating Units

The unit control system provides operating mode selection and a means of starting and stopping a hydroelectric generator. The control system can have varying degrees of operator intervention, from a “push-one-button” automatic system to a totally manual one. Regardless of the type selected, the system should follow a certain sequence of events

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during start-up and shutdown. This section will discuss in detail the logic involved in, and the automation of, this sequence.

As shown in the block diagram (Fig 3-2), the control system has inputs from various other equipment, such as the governor, the exciter, and the automatic synchronizer. Status inputs come from control switches, level switches, pressure switches, position switches, etc, throughout the plant. The combinations of these inputs to the control system logic will provide outputs to the governor and the exciter to accelerate the unit and place it on-line. Abnormalities in the inputs should prevent the unit's start-up, or limit extended operation, if already on-line.

Regardless of the degree of automation desired, the control sequence can be divided into four parts:

1) Pre-start checks
2) Auxiliaries start
3) Unit run and load
4) Unit shutdown

4.1 Steps in the Starting Sequence

4.1.1 Pre-Start Checks

In the first step of the starting sequence, the control system verifies that various levels and pressures associated with the governor and turbine are normal and that certain breakers, switches, valves, and other devices have been properly pre-positioned. Any other restraints to unit operation, such as reservoir levels, are also checked at this time.

If these devices are arranged to provide a contact closure in their normal or permissive state, a multiple input logic "AND" gate can perform the checking operation. When the gate's output is "ON," all pre-start conditions have been satisfied and the auxiliaries start sequence can begin. The logic of the pre-start checks step is shown in Fig 4-1; a listing of typical inputs is presented in Table 4-1.

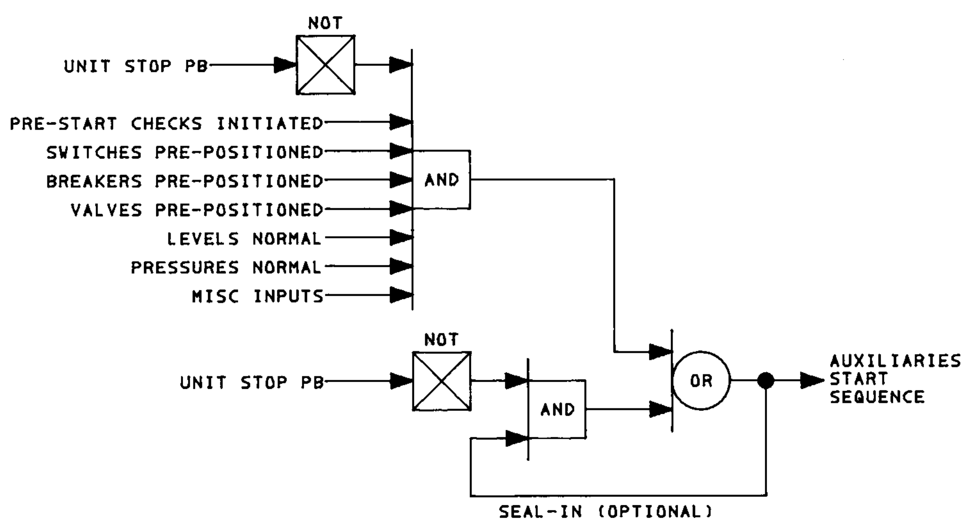

Figure 4-1—Logic Representation of Pre-Start Checks-Gen/Cond

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Table 4-1—Inputs to the Pre-Start Checks Sequence Gen/Cond Mode

INPUT	POSITION FOR STARTUP	TYPE C = CONTROL P = PROTECTION	ORIGINATING FROM: TR - TRANSFORMER GN - GENERATOR TB - TURBINE GV - GOVERNOR EX - EXCITER SB - UNIT SWITCHBOARD OT - OTHER	NOTES
Mode switch	Gen/Cond	C	SB	
Governor control switch	Gov	C	GV	
Brake control switch	Auto	C	GV	
Tailwater depressing control switch	Auto	C	SB (or OT)	
Gov. oil pump control switch	Auto	C	GV	
Grease system control switch	Auto	C	TB	
Cooling water control switch	Auto	C	OT	
Phase reversing control switch	Gen/Cond	C	SB; Reversible units only.	
Thrust bearing oil pump control switch	Auto	C	GN	
Turbine bearing oil pump control switch	Auto	C	TB	
Unit breaker	Tripped	C	OT	
Exciter supply breaker	Tripped	C	EX	
Field breaker	Tripped	C	EX If used.	
Turbine vent valve	Closed	C	TB	
Runner band drain valve	Closed	C	TB	
Air Maint. seal, below headcover	Closed	C	TB If used.	
Cooling water valve	Closed	C	OT	
Runner seal cooling water valve	Open	C	OT	
Turbine guide bearing oil level	Normal	C,P	TB	
Governor sump oil level	Normal	C,P	GV	
Governor press tank oil level	Normal	C,P	GV	
Thrust bearing oil level	Normal	C,P	GN	

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INPUT	POSITION FOR STARTUP	TYPE C = CONTROL P = PROTECTION	ORIGINATING FROM: TR - TRANSFORMER GN - GENERATOR TB - TURBINE GV - GOVERNOR EX - EXCITER SB - UNIT SWITCHBOARD OT - OTHER	NOTES
Governor oil pressure	Normal	C,P	GV	
Tailwater depressing air pressure	Normal	C	OT	
Brake air pressure	Normal	C,P	GV	
Exciter firing wave (reversible unit)	Normal	C	EX	
Lockout relays	Reset	P	SB	
Station dc volts	Normal	C	OT	
Headgate position	100% open	C	OT	
Gate locks	Locked	C	TB	
Reservoir levels	O.K. for Gen	C	OT	
Auto sync. relays	Connected to Gov. Sync. Motor	C	SB	

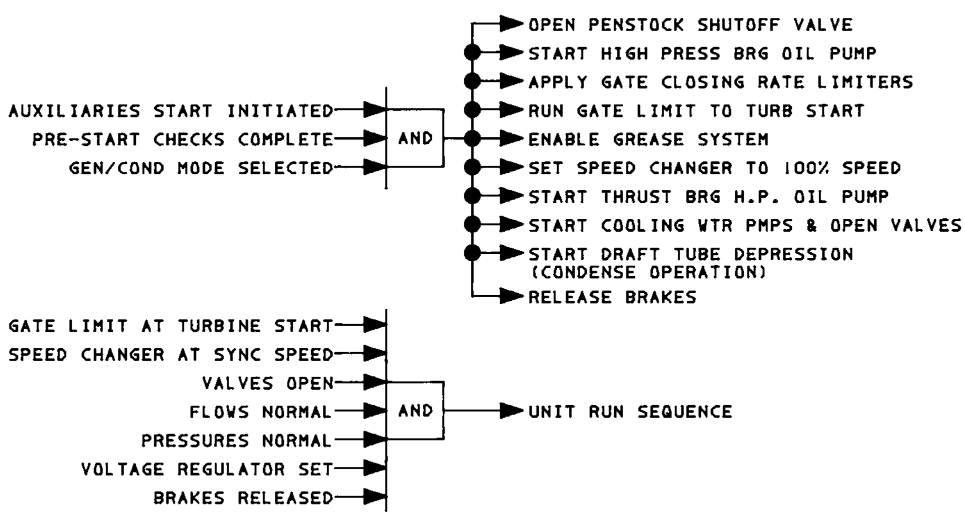

Figure 4-2—Logic Representation of Auxiliaries Start-Gen/Cond Mode

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4.1.2 Auxiliaries Start

After pre-start checks have been completed, the unit auxiliary systems (such as the cooling water pumps, the turbine grease system, and the thrust-bearing oil lift pumps) should be started, as shown in Fig 4-2. Also, at this time, the following actions should occur:

- Gate limit is set to the turbine start position
- Governor speed changer is set for synchronous speed, if not already at this point from previous shutdown
- Turbine penstock shutoff valve, if used, is opened
- Gate closing rate limiters, if used, are applied
- Exciter manual and automatic voltage regulators are driven to unit start position, if not already done from previous shutdown

The status of these items, as well as the pressures and flows associated with the unit auxiliary systems, are input to another “AND” gate. Its output is a permissive for beginning the unit run sequence. Table 4-2 lists typical inputs that are checked to verify the completion of this step.

Table 4-2—Inputs to the Auxiliaries Start Completed Sequence

INPUT	POSITION FOR STARTUP	TYPE C = CONTROL P = PROTECTION	ORIGINATING FROM: TR - TRANSFORMER GN - GENERATOR TB - TURBINE GV - GOVERNOR EX - EXCITER SB - UNIT SWITCHBOARD OT - OTHER	NOTES
Mod switch	Gen/Cond	C	SB If used.	
Gate limit	Turb. Start	C	GV	
Speed changer	100%	C	GV	
Man. voltage reg	Pre-start	C	EX	
Auto voltage reg	Pre-start	C	EX	
Thrust bearing oil press	Normal	C	GN	
Cooling water flow	Normal	C	OT	
Penstock shut-off valve	100% open	C	OT If used.	
Guide bearing oil flow	Normal	C	OT	
Brakes	Released	C	OT	

4.1.3 Unit Run

After the auxiliaries start sequence is completed, the unit run sequence begins. At this time, the following events occur:

- The gates are unlocked
- Both the complete and the partial (if used) governor shutdown solenoids are energized, allowing the gates to start opening
- Energizing the partial shutdown solenoid may be delayed until after breaker closure
- The exciter voltage regulators are enabled

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As the gates open, the unit accelerates until approximately 95% speed is attained. Then,

- The field breaker closes
- Field flashing begins
- Potential is applied to the automatic synchronizer

The synchronizer adjusts the governor speed changer to match frequency and the voltage regulator to match voltage. When this is accomplished, and any operator pre-sync interaction is performed, the synchronizer closes the unit breaker, placing the unit on-line. The operator then adjusts the governor for the desired generator output. If condenser operation is desired, the gates are closed, tailwater is depressed, and the voltage regulator is adjusted for the desired reactive power output. The logic of the unit run sequence is shown in Fig 4-3.

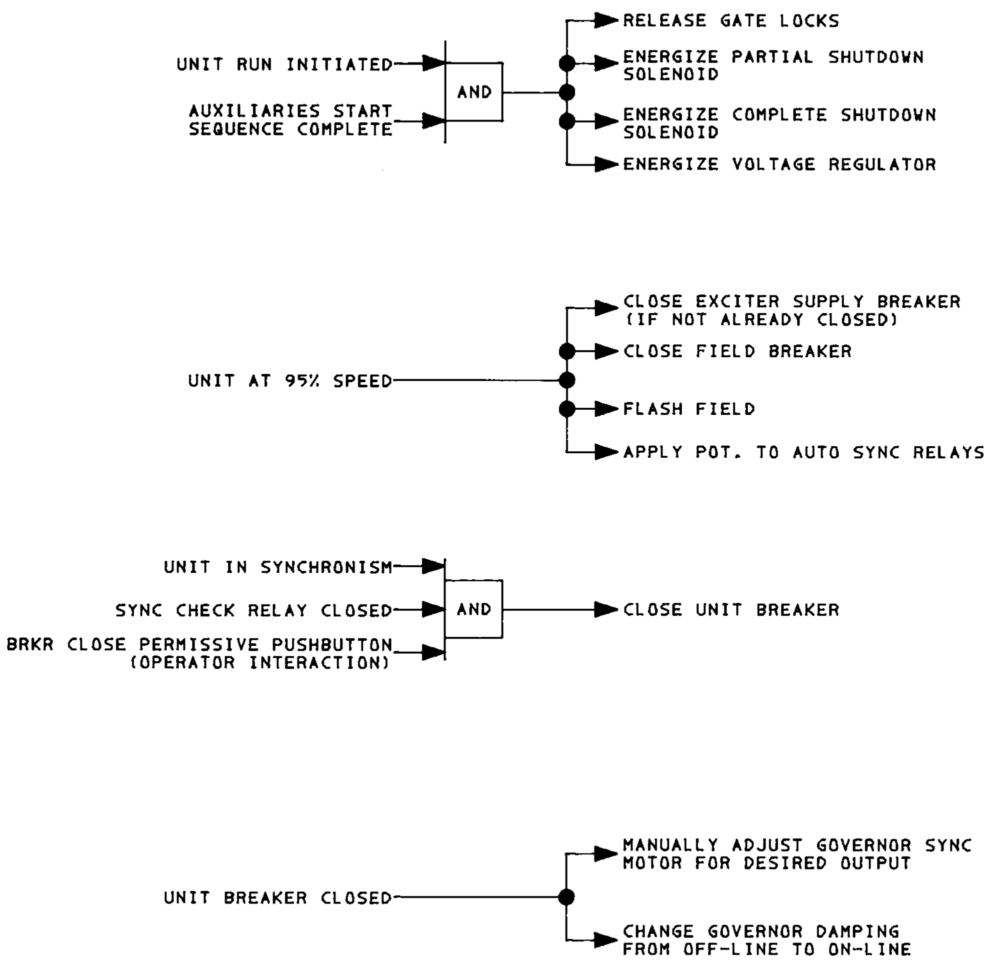

Figure 4-3—Logic Representation of Unit Run Sequence-Gen/Cond

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4.1.4 Unit Shutdown

The control system can provide three types of unit shutdown: emergency, quick, and normal. The emergency shutdown is the most rapid means of stopping the unit. An emergency shutdown lockout relay is triggered by protective relaying or the operator's emergency trip switch. The following actions occur simultaneously:

Table 4-3 (All information shown in Fig 4-3. See figure.)

- The unit breaker is tripped
- Excitation is shut down
- The governor complete and partial shutdown solenoids are deenergized, driving the gates closed
- Gate limit is run back to zero position
- The governor speed changer is driven back to the pre-start position
- The starting control sequence is disabled

As the unit speed decreases, the thrust-bearing oil lift pump is started. When the unit reaches about 30% speed, the brakes are applied until the unit is stopped. The unit auxiliary systems are shut down and the turbine penstock shutoff valve, if used, is closed. The logic for the emergency shutdown sequence is shown in Fig 4-4 and a listing of typical inputs is shown in Table 4-4.

The quick shutdown is initiated generally by mechanical problems such as low governor oil pressure and bearing high temperatures. A lockout relay may be operated by these conditions, if desired, to accomplish shutdown functions. A listing of typical inputs to the quick shutdown sequence is given in Table 4-5. A logic diagram is shown in Fig 4-5.

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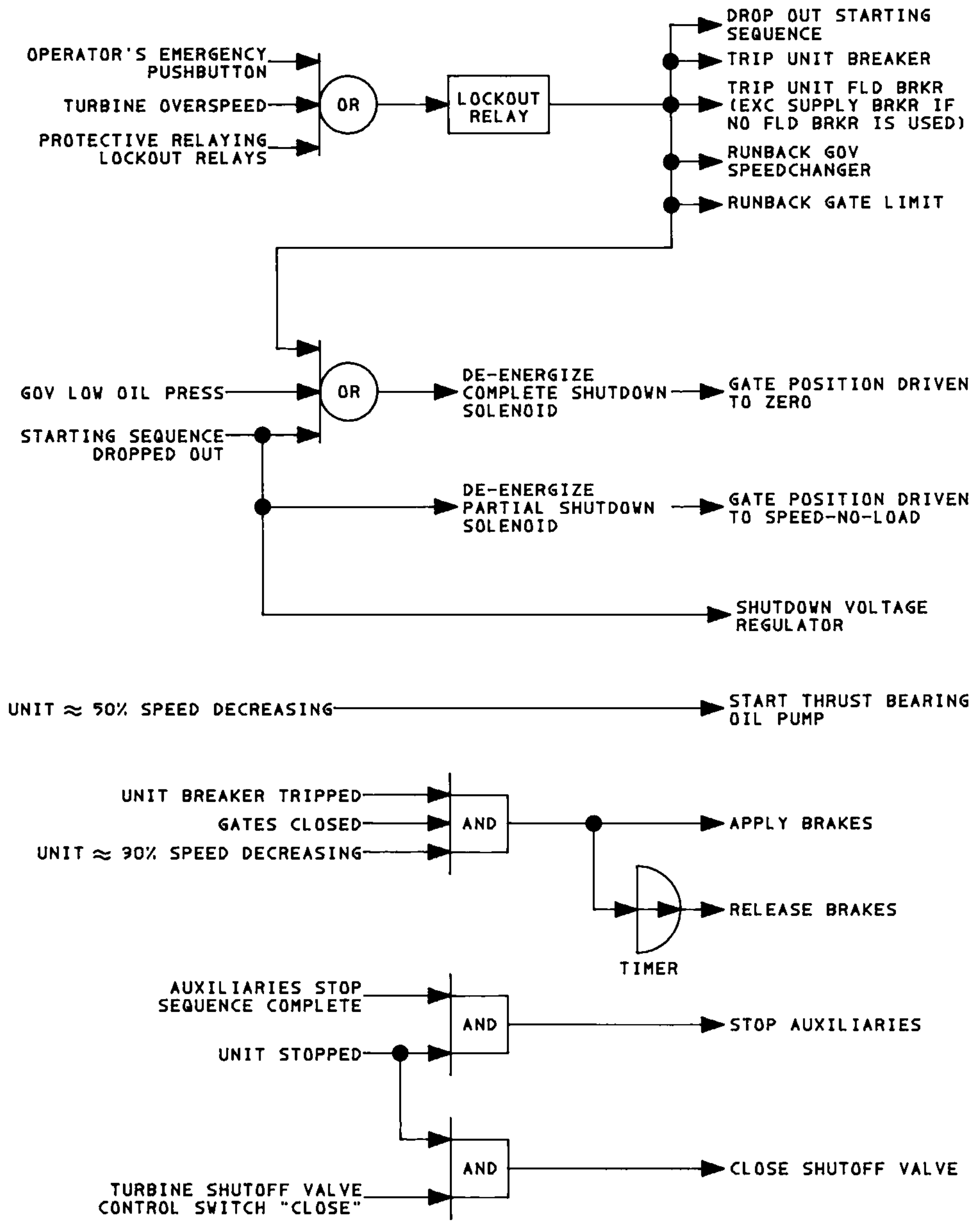

Figure 4-4—Emergency Shutdown Sequence Logic

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Table 4-4 —Inputs to the Emergency Shutdown Sequence

INPUT	TYPE C = CONTROL P = PROTECTION	ORIGINATING FROM: TR-Transformer GN-Generator TB-Turbine GV-Governor EX-Exciter SB-Unit Switchboard OT-Other	NOTES
Differential relays actuated	P	GN, TR, OT	
Overcurrent relay actuated	P	GN, TR	
Electrical disturbance detected	P	System	
CO_2 released	P	OT	
Turbine overspeed occurs	P	GV, GN	
Emergency pushbutton actuated	C	SB	

*Greater detail of the various inputs can be found in the figures and tables of Section 3..

Table 4-5 —Inputs to the Quick Shutdown Sequence

INPUT	POSITION FOR SHUTDOWN	TYPE C = CONTROL P = PROTECTION T = TEMPERATURE	ORIGINATING FROM: TR - TRANSFORMER GN - GENERATOR TB - TURBINE GV - GOVERNOR EX - EXCITER SB - UNIT SWITCHBOARD OT - OTHER	NOTES
Turb guide bearing temp	High	P,T	TB	
Shaft packing box temp	High	P,T	TB	
Runner seal temp	High	P,T	TB	
Gen thrust bearing temp	High	P,T	GN	
Gen guide bearing temp	High	P,T	GN	
Overspeed switch	Closed	P	GV	
Unit vibration	High	P	OT	
Gov press tank oil level	Hi/Low	P	GV	
Gov oil pressure	Low	P	GV	
Shaft packing box cooling water flow	Low	P	TB	

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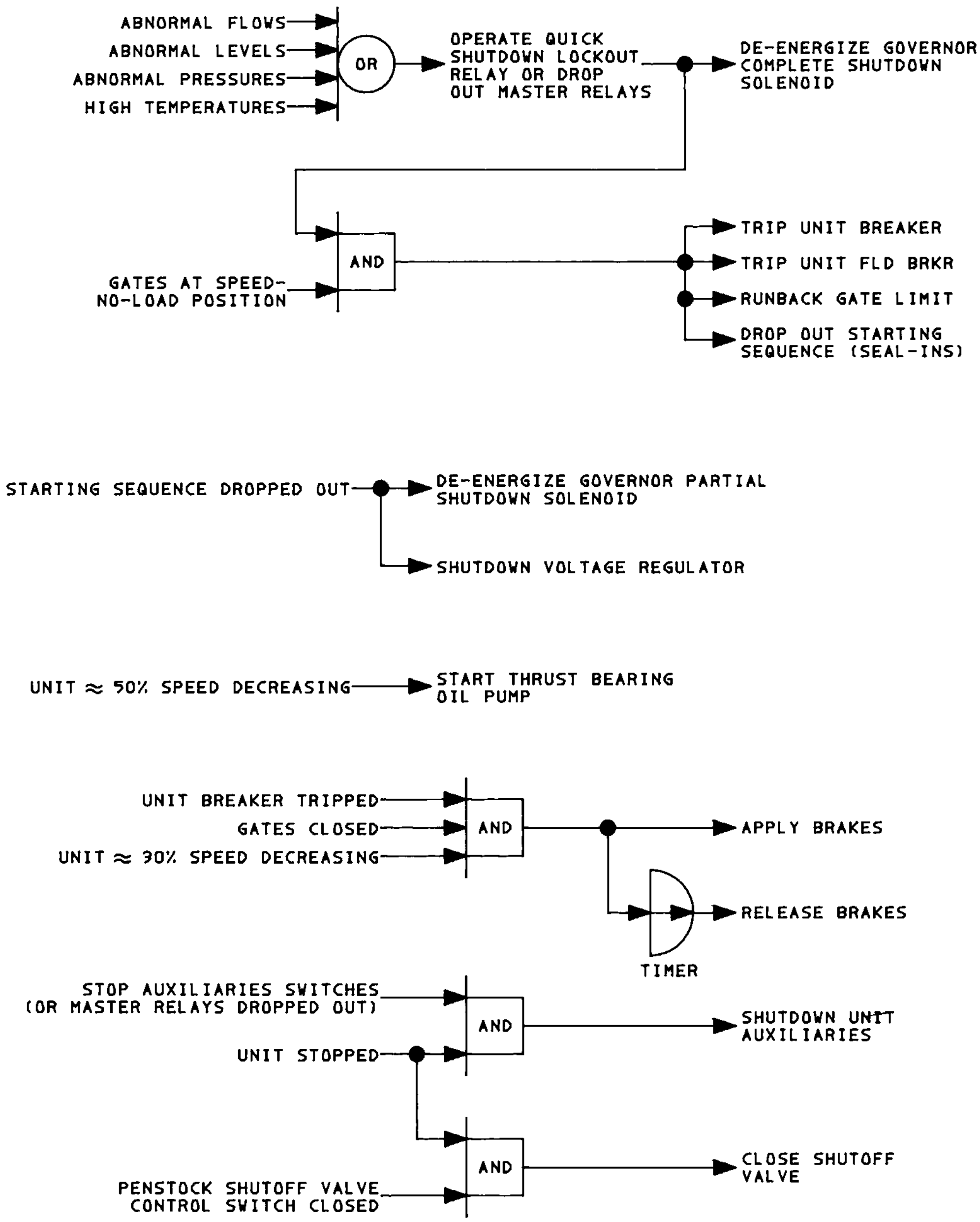

Figure 4-5—Quick Shutdown Sequence Logic

The quick shutdown is similar to the emergency shutdown in that the gates are driven closed at maximum rate by deenergizing the governor's complete shutdown solenoid. However, the unit breaker is not tripped until the speed-no-load gate position is reached, thus avoiding a load rejection trip. Also, at speed-no-load:

- Excitation is shut down
- The governor speed changer is run back to its pre-start position
- Gate limit is run back to zero position
- The starting control sequence is dropped out, deenergizing the governor partial shutdown solenoid

The thrust bearing oil pump is then started on decreasing speed and the brakes are applied. The unit auxiliary systems are shut down and the turbine penstock shutoff valve, if used, is closed.

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The normal shutdown sequence, like the quick shutdown, unloads the unit prior to tripping its breaker. The gates are closed at less than maximum rate by driving gate limit to zero position. This sequence should be used for the operator's routine unit tripping, but it is also actuated by various abnormal levels, pressures, and flows of a less critical nature.

The unit breaker is then tripped at speed-no-load gate position. The remainder of the shutdown sequence is the same as for the quick shutdown. Inputs to the normal shutdown sequence are listed in Table 4-6 and the associated logic is shown in Fig 4-6.

Table 4-6 —Inputs to the Normal Shutdown Sequence

INPUT	POSITION FOR SHUTDOWN	TYPE C = CONTROL P = PROTECTION T = TEMPERATURE	ORIGINATING FROM: TR - TRANSFORMER GN - GENERATOR TB - TURBINE GV - GOVERNOR EX - EXCITER SB - UNIT SWITCHBOARD OT - OTHER	NOTES
Gen thrust bearing temp	High High	P,T	GN	
Gen guide bearing temp	P,T	GN		
Turb packing box temp	High	P,T		
Turb guide bearing temp	High	P,T	TB	
Gov sump oil level	Low	P	GV	
Penstock shutoff valve oil level	Low Low	P	OT If used.	
Cooling water flow	P	OT		
Starting sequence dropout	Closed Closed	C	SB	
Unit stop pushbutton	C	SB		

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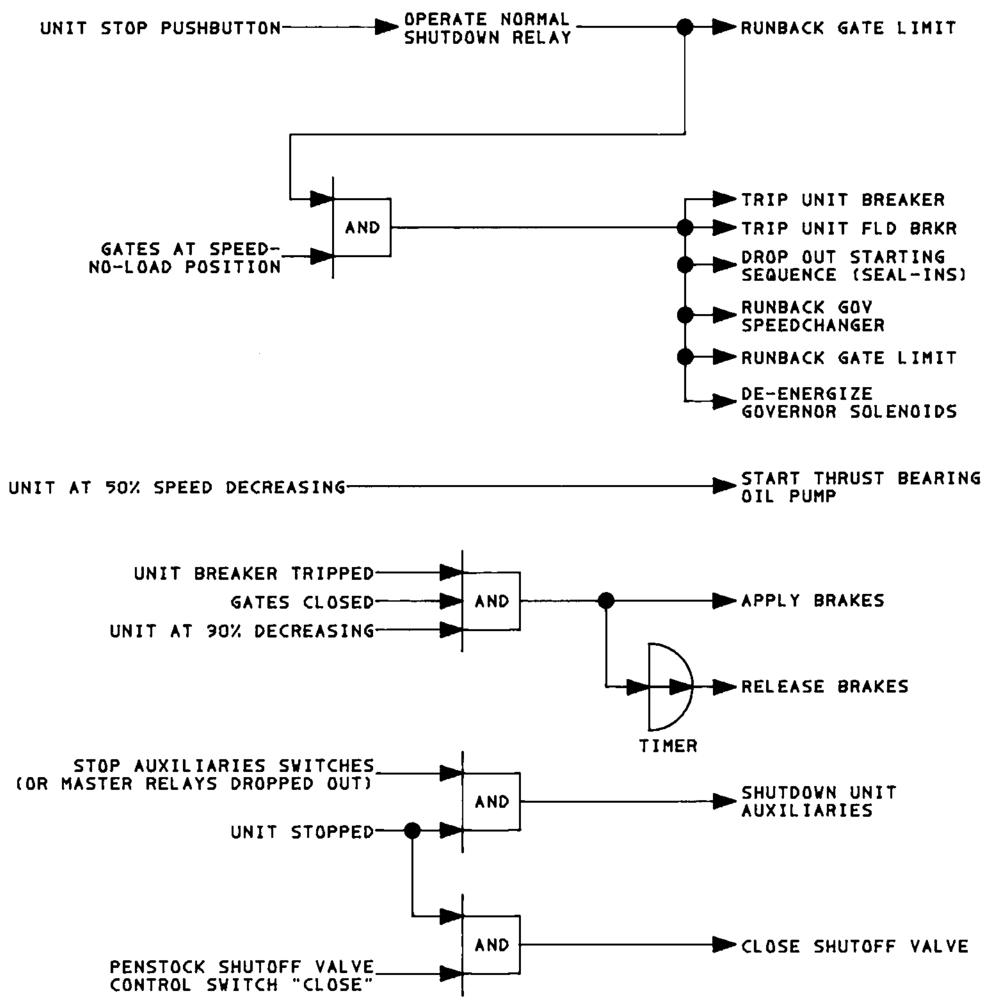

Figure 4-6—Normal Shutdown Sequence Logic

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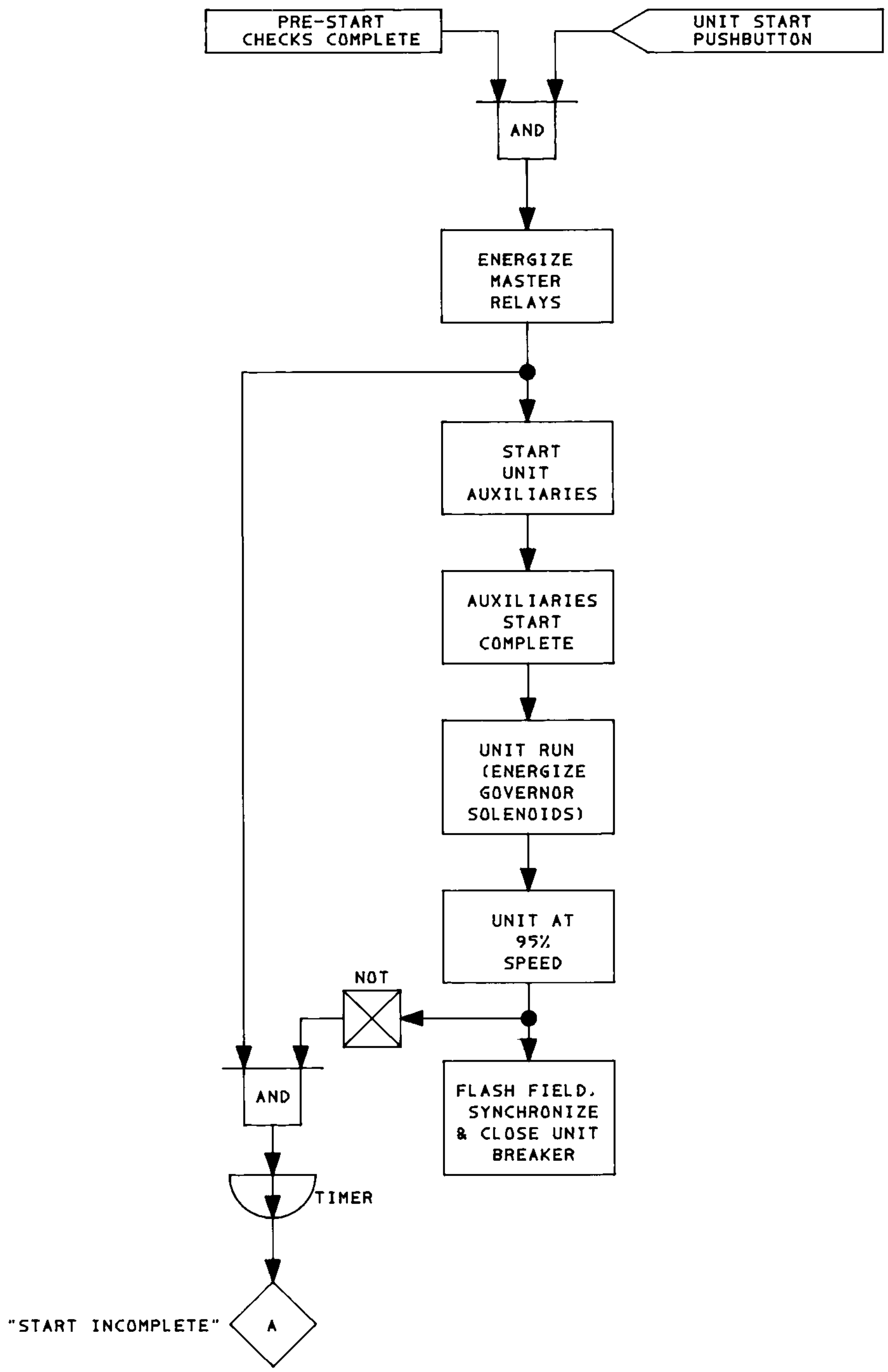

Figure 4-7—Master Relay Control System

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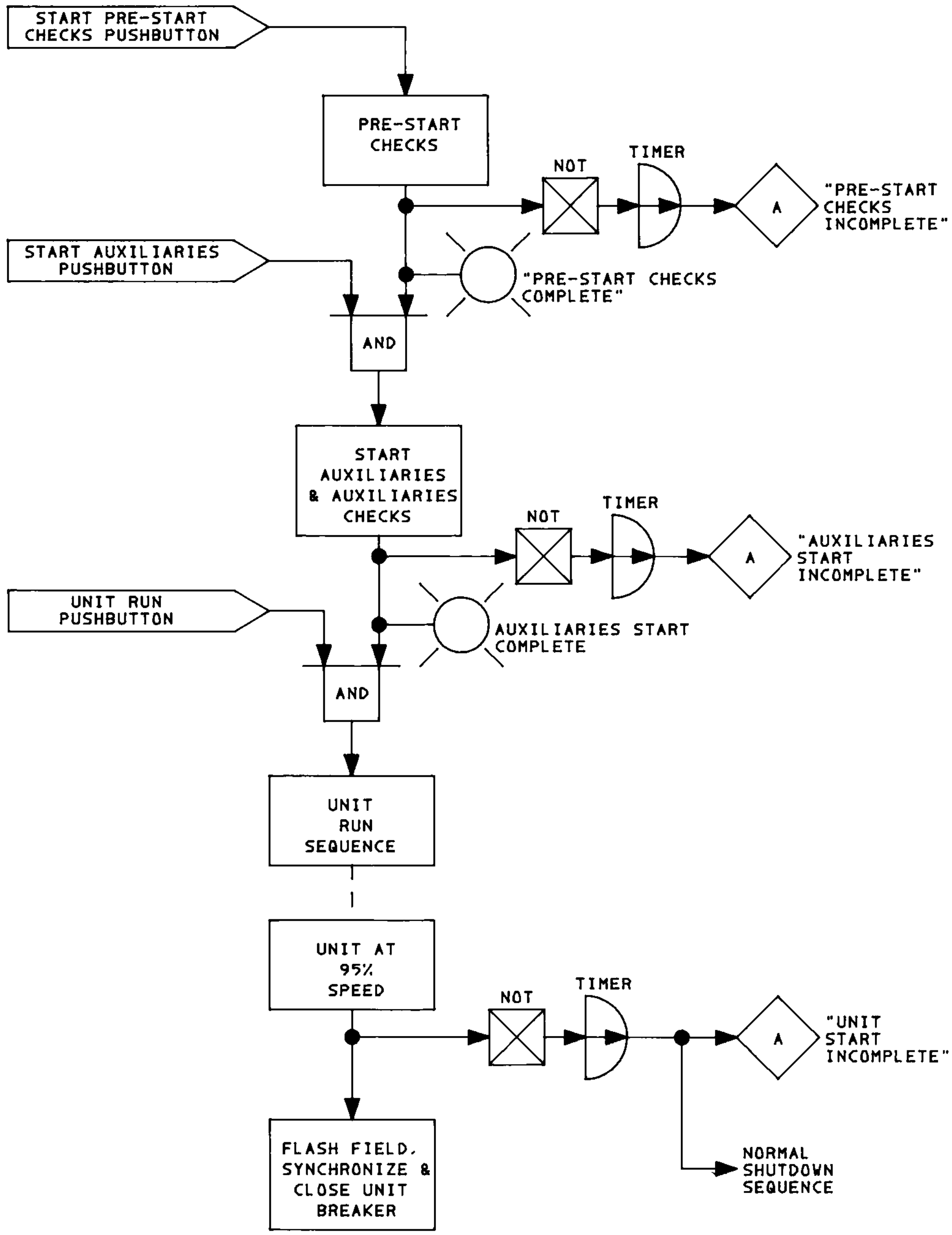

Figure 4-8—Stepped Sequence Control System

4.2 Automation of the Control System

One of the first decisions that should be made prior to designing a unit control system is how much operator intervention in the starting sequence is desired.

A fully automatic control system, commonly called the "master relay" type, operates as shown in Fig 4-7. No manual action is needed to begin pre-start checks. When pre-start conditions are met, the operator presses the unit start pushbutton, energizing the master relays. Unit auxiliaries are started and checked. The unit run sequence begins, the unit accelerates, speed and voltage are matched at the point of synchronization, and the unit is placed on-line. If the

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unit speed fails to reach 95% within a predetermined period, an alarm will indicate that the attempted start is incomplete. After a successful start, the operator adjusts the governor for the desired power output, and may adjust the voltage regulator. Even this can be automated if a fixed output is desired, or if the load curve is such that it can be programmed into the control system.

Another type of automatic system involves several operator input steps that can be performed prior to the desired starting time. This causes the system to become semi-automatic and requires more operator intervention. As shown in Fig 4-8, the sequence stops after pre-start checks. Start sequence will not begin until the operator closes a permissive switch. The sequence stops again after auxiliaries checks are completed and requires another manual contact closure before the unit run sequence begins. From this point on, the system is fully automatic. Note that timers may be added to check the progression of each step.

The unit shutdown system is similar for both types of starting systems. Shutdown is initiated by deenergizing the master sequence relays.

5. Control Sequencing—Pumped-Storage Units

The unit control system functions on a pumped-storage unit are similar to those on a conventional unit for generation as discussed in Section 4. This section discusses in particular the control sequences for "motoring" during pumping operation.

The pump control sequence can be divided into four parts:

1) Pre-start checks
2) Auxiliaries start
3) Unit run, pump prime, and pump load
4) Shutdown

5.1 Steps in the Starting Sequence

5.1.1 Pre-Start Checks

Most of the inputs to the pre-start checks sequence are the same as in the generate mode. The phase reversing switch should be placed in the motor position. If pony motor or static starting is used, there may be temperature, pressure, flow, and level switches associated with the starter that should be checked. For synchronous and semi-synchronous starting, the availability of the starting generator should be verified. The logic for the pump pre-start checks is presented in Fig 5-1 and the typical inputs are listed in Table 5-1.

5.1.2 Auxiliaries Start

Upon the completion of pump pre-start checks, the auxiliaries start sequence depresses the tailwater, drives the gate limit to zero position, and starts the thrust-bearing oil lift pump. In addition, the governor speed changer is driven "out high," since it has no speed control function in the pump mode.

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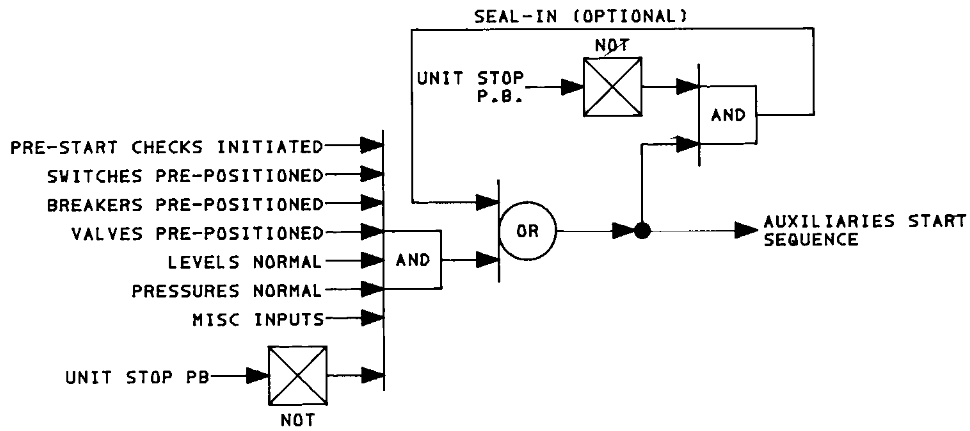

Figure 5-1—Logic Representation of Pre-Start Checks-Pump Mode

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Table 5-1—Inputs to the Pre-Start Checks Sequence Pump Mode

INPUT	POSITION FOR STARTUP	TYPE C = CONTROL P = PROTECTION	ORIGINATING FROM: TR - TRANSFORMER GN - GENERATOR TB - TURBINE GV - GOVERNOR EX - EXCITER SB - UNIT SWITCHBOARD OT - OTHER	NOTES
Mode switch	Pump	C	SB	
Governor control switch	Gov	C	GV	
Brake control switch	Auto	C	GV	
Tailwater depressing control switch	Auto	C	SB (or OT)	
Governor oil pump control switch	Auto	C	GV	
Grease system control switch	Auto	C	TB	
Cooling water control switch	Auto	C	OT	
Phase reversing switches	Pump	C	SB, OT	
Thrust bearing oil pump control switch	Auto	C	GN	
Turbine bearing oil pump control switch	Auto	C	TB	
Unit breaker	Tripped	C	OT	
Exciter supply breaker	Tripped	C	EX	
Field breaker	Tripped	C	EX	
Turbine vent valve	Closed	C	TB	
Runner band drain valve	Closed	C	TB	
Cooling water valve	Closed	C	OT	
Runner seal cooling water valve	Open	C	OT	
Turbine guide bearing oil level	Normal	C,P	TB	
Governor sump oil level	Normal	C,P	GV	
Governor press tank oil level	Normal	C,P	GV	
Thrust bearing oil level	Normal	C,P	GN	
Pump starting equipment cooling/oil/electrolyte level	Normal	C	OT	
Governor oil pressure	Normal	C,P	GV	

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INPUT	POSITION FOR STARTUP	TYPE C = CONTROL P = PROTECTION	ORIGINATING FROM: TR - TRANSFORMER GN - GENERATOR TB - TURBINE GV - GOVERNOR EX - EXCITER SB - UNIT SWITCHBOARD OT - OTHER	NOTES
Tailwater depressing air pressure	Normal	C	OT	
Brake air pressure	Normal	C,P	GV	
Pump starting equipment temp	Normal	P	OT	
Exciter firing angle	Reversed	C	EX	
Lockout relays	Reset	P	SB	
Station dc volts	Normal	C	OT	
Brakes	Released	C	GN	
Headgate position	100% open	C	OT	
Gate locks	Locked	C	TB	
Reservoir levels	O.K. for pump	C	OT	
Auto sync relays	Connected to starting eqpt	C	SB	
Starting breaker	Tripped	C	OT	

The pump starting equipment is readied at this time. For pony motor starting, the liquid rheostat is positioned for maximum resistance (minimum motor speed). The rheostat's cooling equipment is energized and proper flow is verified.

All of these processes are verified by status contact inputs to an “AND” gate, as shown in Fig 5-2. Other inputs verifying actions taken during the pre-start step are included in Table 5-2. The output of the “AND” gate is a permissive for beginning the unit run sequence.

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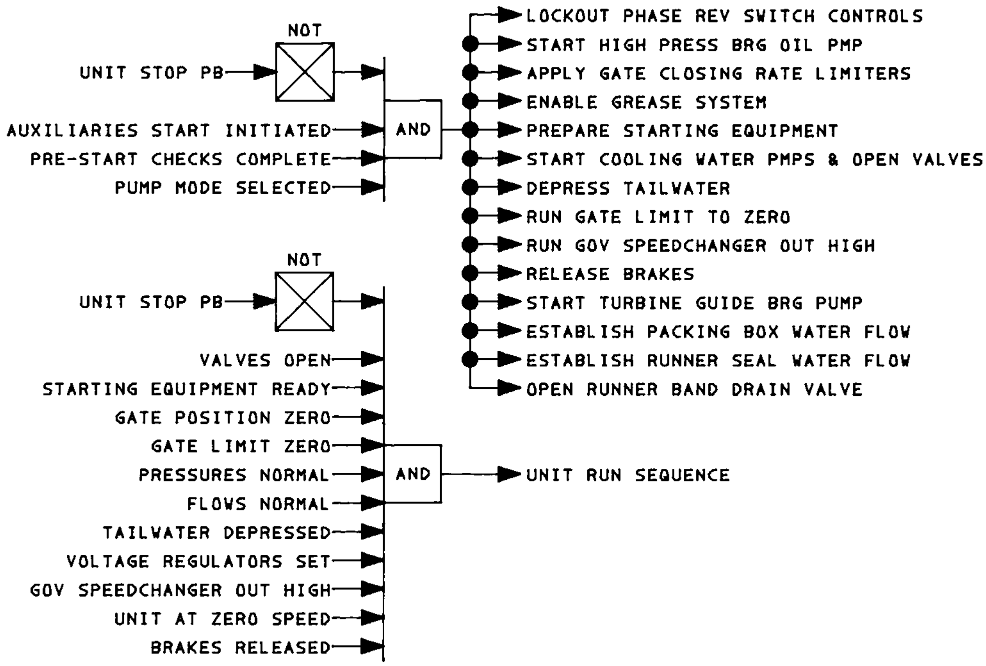

Figure 5-2—Logic Representation of Auxiliaries Start-Pump Mode

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Table 5-2—Inputs to the Auxiliaries Start Complete Sequence Pump Mode

INPUT	POSITION FOR STARTUP	TYPE C = CONTROL P = PROTECTION	ORIGINATING FROM: TR - TRANSFORMER GN - GENERATOR TB - TURBINE GV - GOVERNOR EX - EXCITER SB - UNIT SWITCHBOARD OT - OTHER	NOTES
Mode switch	Pump	C	SB	
Start auxiliary pushbutton or master relays energized	Closed	C	SB	
Gate limit	Zero	C	GV	
Speed changer	Out high	C	GV	
Gate position	Zero	C	GV	
Man voltage reg	Pre-start	C	EX	
Auto voltage reg	Pre-start	C	EX	
Thrust bearing oil pressure	Normal	C	GN	
Cooling water flow	Normal	C	OT	
Starting equipment cooling water flow	Normal	C	OT	
Tailwater level switch	Depressed	C	OT	
Penstock shutoff valve	100% open	C	OT	
Turbine guide bearing oil flow	Normal	C	TB	
Packing box water flow	Normal	C	TB	
Seal water flow	Normal	C	TB	

5.1.3 Unit Run

The unit run portion of this step brings the machine up to 100% speed in the motor direction and places it on-line and spinning in air. The sequence varies somewhat with the type of starting used.

1) *Full Voltage, Across-the-Line Starting*. The machine is started as an induction motor, which requires a specially designed amortisseur winding. At the beginning of the unit run sequence, the unit breaker is closed, which applies system power to the machine. When the unit reaches approximately synchronous speed, excitation is applied and the machine then accelerates to rated speed as a synchronous motor. This sequence is illustrated in Fig 5-3.
2) *Reduced Voltage, Across-the-Line Starting*. As in full-voltage starting, the machine is accelerated as an induction motor. At the beginning of unit run, the starting breaker is closed, applying reduced voltage to the machine. At approximately synchronous speed, excitation is applied. When synchronous speed is reached, the starting breaker is tripped and the unit breaker is closed. Partial winding starting is similar, except at near rated speed, and the remainder of the winding is connected. Figure 5-4 illustrates the logic involved.
3) *Pony Motor Starting*. The unit run sequence begins by applying power to the pony motor. Its field rheostat controller adjusts resistance to provide constant pony motor torque during the initial acceleration period. When unit speed reaches 95%, rheostat control is transferred to the synchronizing equipment. The field is flashed, establishing machine terminal voltage. When the unit is synchronized, its breaker is closed, placing it on-line. The pony motor supply breaker is tripped and the rheostat is repositioned for the next start. The unit run logic is illustrated in Fig 5-5.

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4) *Synchronous Starting*. The first step in the unit run sequence for synchronous starting is electrically connecting the starting generator to the unit motor. At this time, the starting generator's control sequence must be in the unit run mode. Excitation is applied to both machines. The gates are opened on the generator. As it accelerates, the motor unit follows. The speed of both units is brought to just above system frequency. The generator is then isolated from the motor unit, which begins coasting down to synchronous speed. When frequency is matched, the motor unit's breaker is closed. Figure 5-6 shows the logic involved.
5) *Semi-Synchronous Starting*. Prior to initiating the unit run sequence for the pump unit, the starting generator must be accelerated to about 80% of rated speed, with its excitation not applied. The unit run sequence begins with connecting the two units together through the starting bus. Excitation is applied to the starting generator, which establishes voltage on the starting bus and begins pump unit acceleration. As the starting generator decelerates and the pump unit accelerates, the two will reach approximately equal speed. At this point, which is determined by a speed matching relay, excitation is applied to the pump unit to pull it into synchronism with the generator. The wicket gates on the generator unit are then opened to accelerate both units to above synchronous speed. The starting breakers are tripped and the synchronizing equipment places the pump unit on line. The generating unit may then be used for starting another unit or tripped. Figure 5-7 illustrates the unit run logic for this starting method.
6) *Static Starting*. Since this is also a type of variable frequency starting, the unit must be isolated from the system during startup. At the beginning of the unit run sequence, the unit is electrically connected to the static starter. Excitation is applied to the machine field, the starter is enabled, and the unit begins rotating. The output frequency of the starter is increased to maintain a constant accelerating torque. Speed versus time checks in the starter will shut down the unit if acceleration does not proceed normally.

   Synchronizing may be accomplished as the unit approaches synchronous speed; alternatively, the starter may bring the unit up to just above synchronous speed. They are then isolated and the starter is shut down. When unit speed matches system frequency, the synchronizer closes the unit breaker, placing it on-line. Figure 5-8 illustrates the unit run sequence for static starting.

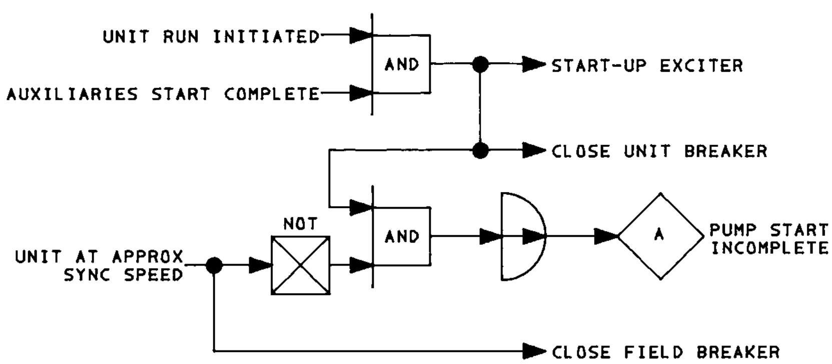

Figure 5-3—Logic Representation of Unit Run Sequence-Pump Mode—Full-Voltage Starting

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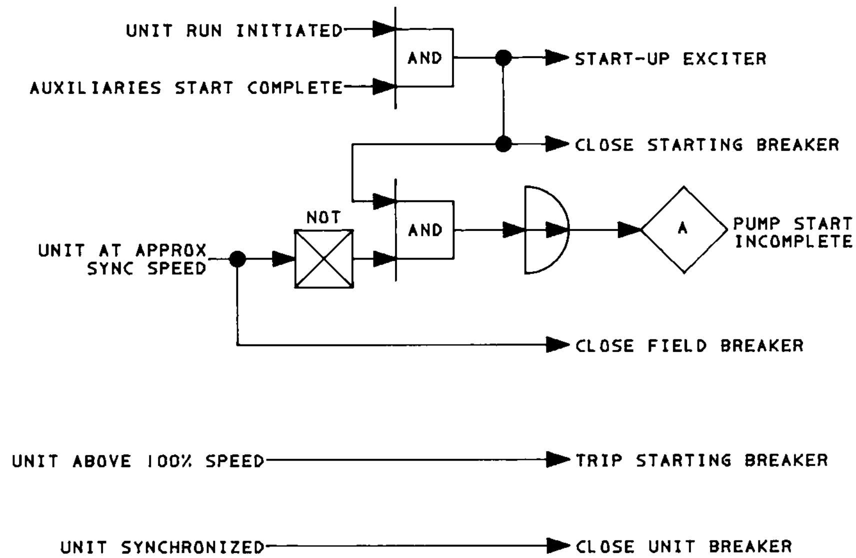

Figure 5-4—Logic Representation of Unit Run Sequence-Pump Mode—Reduced-Voltage Starting

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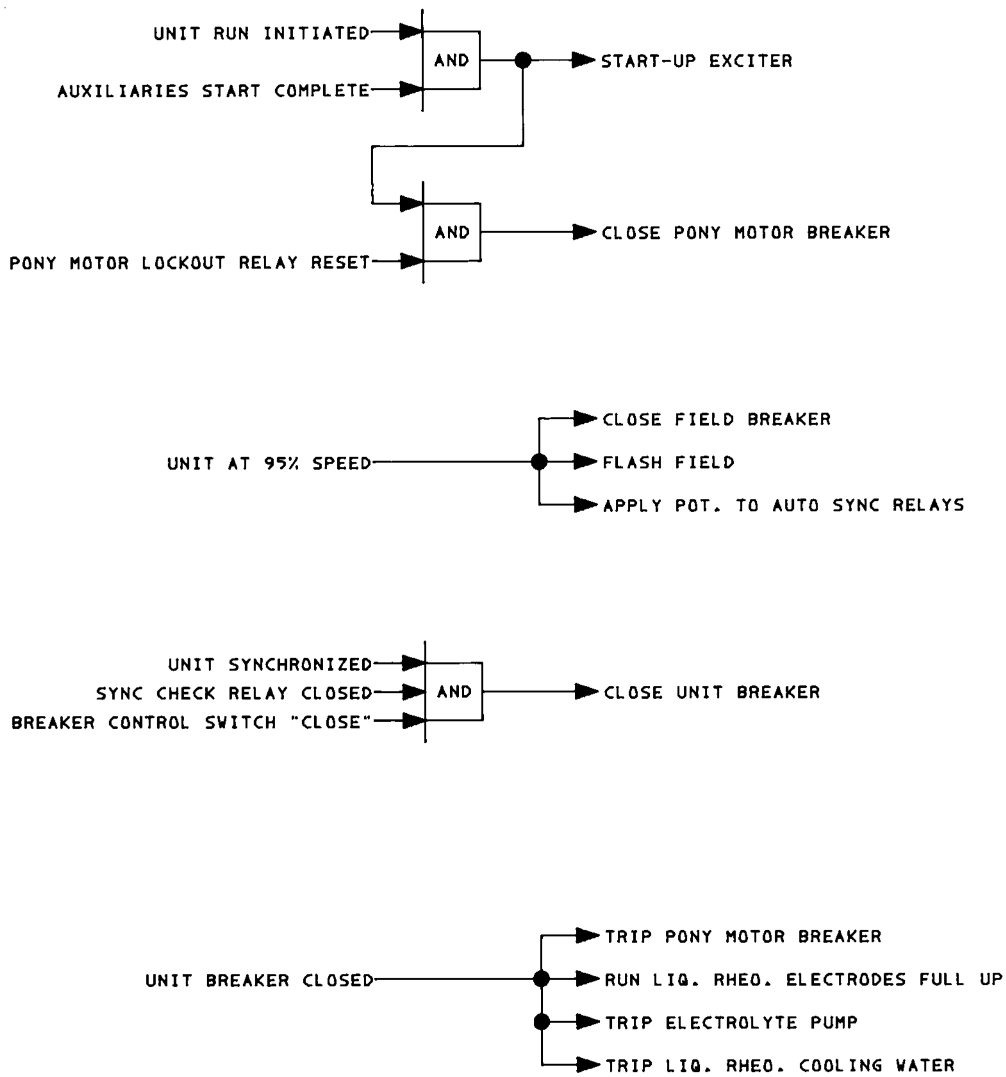

Figure 5-5—Logic Representation of Unit Run Sequence-Pump Mode—Pony Motor Start

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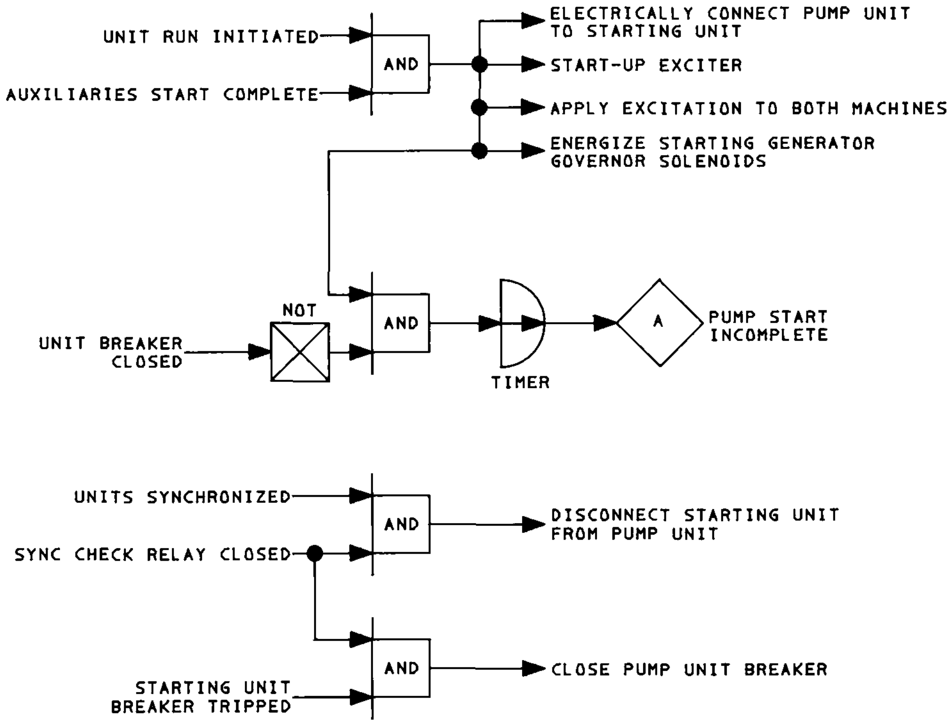

Figure 5-6—Logic Representation of Unit Run Sequence-Pump Mode—Synchronous Starting

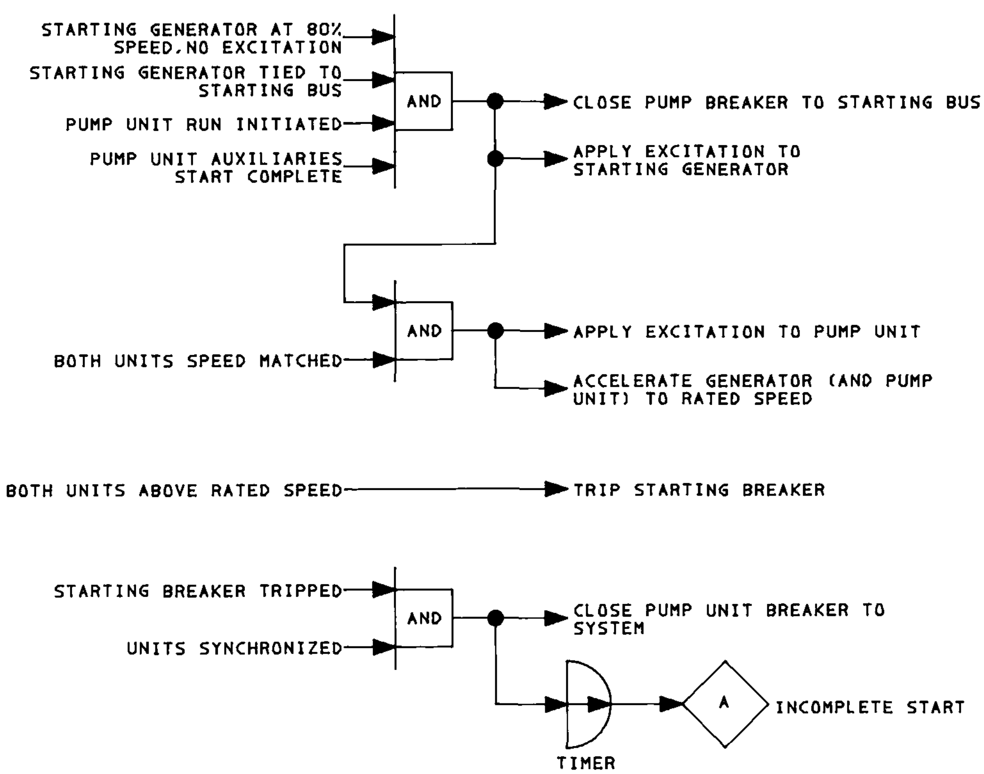

Figure 5-7—Logic Representation of Unit Run Sequence-Pump Mode—Semi-Synchronous Starting

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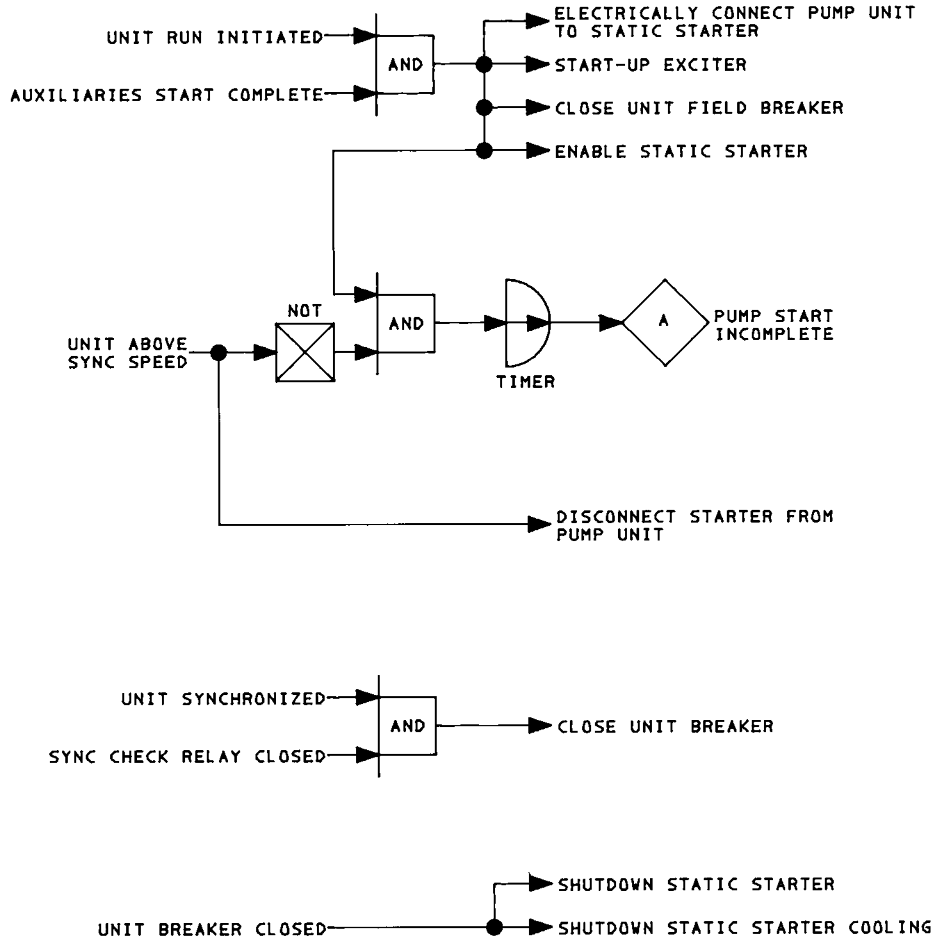

Figure 5-8—Logic Representation of Unit Run Sequence-Pump Mode—Static Starting

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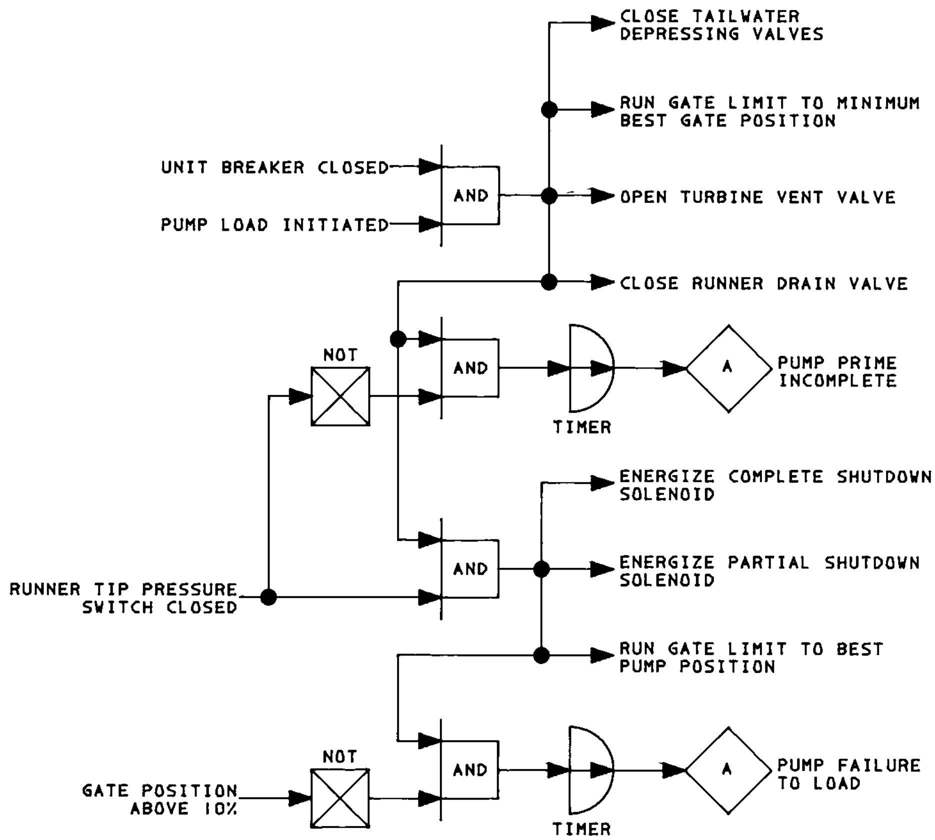

Figure 5-9—Logic Representation of Pump Priming and Unit Load Sequence-Pump Mode

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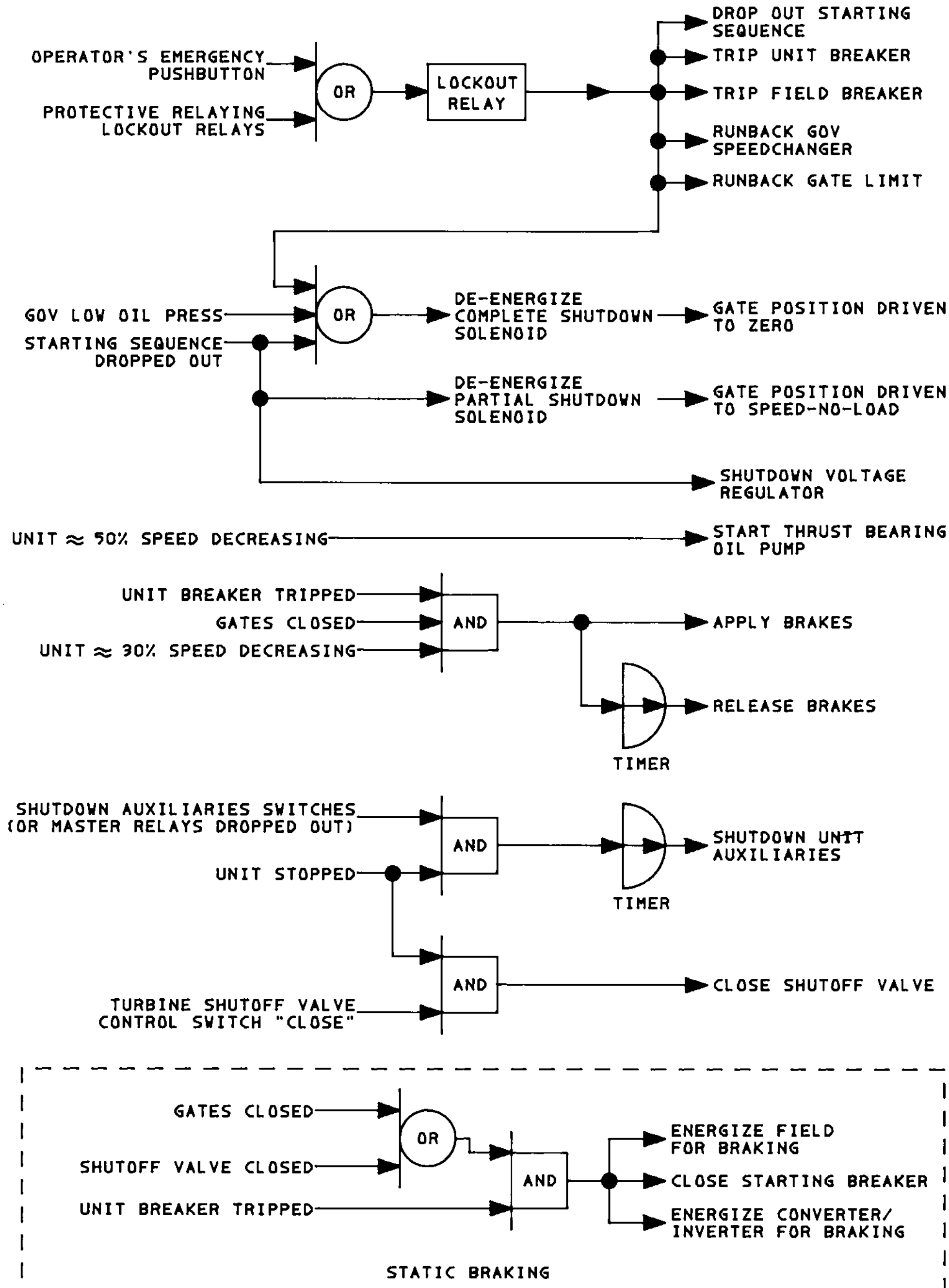

Figure 5-10—Emergency Shutdown Sequence Logic-Pump Mode

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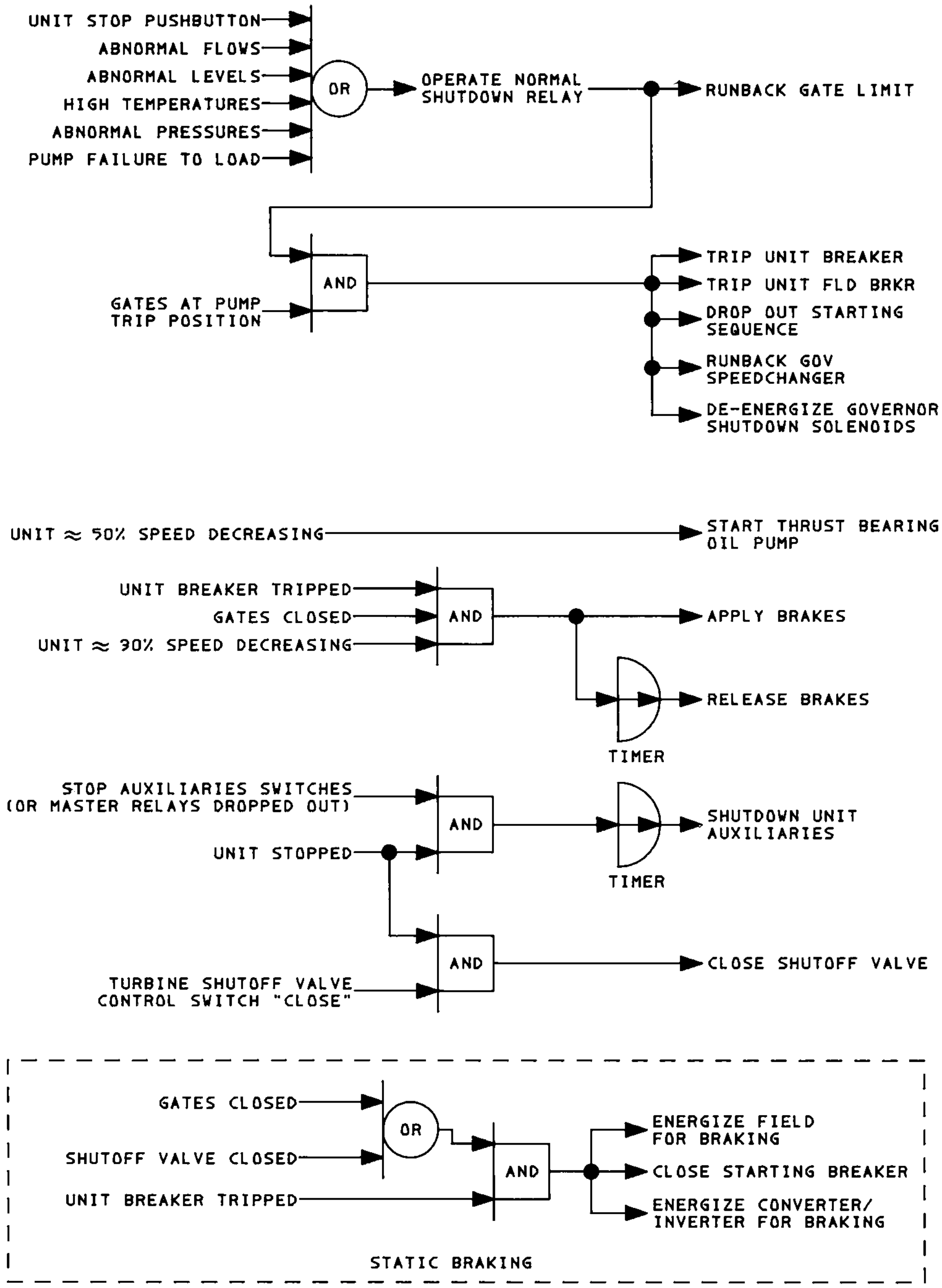

Figure 5-11—Normal Shutdown Sequence-Pump Mode

5.1.4 Pump Prime and Unit Loading

At the end of the unit run sequence, the pump/turbine is spinning in the air. The pump priming sequence is the same for all types of unit starting. It begins with closing the tailwater depression valves and opening the turbine vent valve that releases the depressing air. When the tailwater completely immerses the turbine blades, the vent valve closes. A pressure switch in the runner senses that priming is complete and the gates must be opened and the pump must be loaded immediately.

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The pump load sequence energizes the governor solenoids, allowing the gates to open. Gate limit is driven to the “most efficient pump” position. When gate position reaches this point, the loading sequence and the starting sequence are completed. During pumping operation, the optimum gate position may be automatically controlled for net head changes by the governor. If gate position does not reach 10% to 20% in a few seconds, the unit should be shut down. The logic for the priming and loading sequences are shown in Fig 5-9.

5.2 Unit Shutdown

The shutdown sequence for a pump unit is very similar to that for a conventional generator. Reference is made to the discussion of unit shutdown in the previous section. Both normal and emergency shutdown sequences are provided in the pump mode. In the unit normal shutdown sequence, the machine is unloaded prior to tripping the unit breaker by first closing the gates. Care should be taken to assure tripping the unit immediately upon gate closure. The shutdown logic diagrams are shown in Figs 5-10 and 5-11.

5.3 Control Sequence Automation

Both the “master relay” and the stepped sequence type of control systems discussed in the previous section can be applied to a pumped-storage unit. While some operator intervention may be desired, the timing involved in the pump prime and loading sequences is too critical to depend on operator control and the control systems should be fully automatic.

6. Centralized Control

This section describes centralized control systems and equipment that could be used to accomplish the control and monitoring functions of hydroelectric power plants. Such control systems normally interface with the unit control panels located near the units or in a centralized control area, and with off-site control facilities as described in Section 7.

The term "centralized control," as defined in this guide, refers to a common control location from which control functions can be initiated, and from which plant operating data can be collected and displayed.

The goal of centralized control is to consolidate control functions and plant operating data at a common location in order to facilitate plant operation and reduce operating staff.

In the past, hard-wired relay logic and conventional electro-mechanical control devices and monitoring equipment were used for centralized control. Today, computer-based systems are increasingly being used in place of/or in conjunction with hard-wired control equipment. However, the best centralized control system configuration for a particular plant is a function of the plant's characteristics such as size, number of units, and capability of operating/maintenance staff.

The major control and monitoring functions of a hydroelectric power plant may consist of the following:

1) *Unit Start*. This initiates the automatic start sequence that will start, accelerate, synchronize, and tie the unit to the system. The unit may then be loaded as desired or, optionally, it can be loaded automatically to some preset load point.
2) *Unit Stop*. The normal automatic shutdown is initiated, whereby the unit is unloaded before the circuit breaker is tripped. The unit is usually unloaded at a moderate rate.
3) *Emergency Shutdown*. Initiation of this sequence trips the circuit breaker immediately and is the usual automatic response to protective relay operation at the plant.
4) *Speed Level Control*. This control is used to raise or lower the governor speed level setting on-line, thereby adjusting unit loading.

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5) *Load Level Control*. This is also an on-line control function similar to speed level control, but it allows the operator to set a load level to be regulated automatically by a local control system, frequently built into the governor. For the computer-based system, unit load could be controlled by the computer system through an interface with the governor on the basis of the required plant load and unit participation factor. Many modes of operation such as set point control, regulating, base loaded, ramped control, manual control, and others relative to the nature of the project and operating philosophy could be applied.
6) *Voltage/Var Control*. This control adjusts the setpoint of the voltage regulator to adjust the reactive power of the machine.
7) *Joint Load/Var Control*. For a multiunit plant, the generation output and voltage/vars can be set on a plant basis by the operator or received directly from a dispatch control center and regulated automatically by plant control systems. The desired generation is then computed continuously from the plant required generation and applied to each unit. This function is applied by conventional analog type joint control system or part of a computer-based system. Accompanying this is a control function to place individual units on or off joint control. The joint control, or in a broader sense computer-based automatic unit control, generally releases the operator from continuous monitoring and control of the plant for optimal operation.
8) *Monitoring of Status Information*. Status information allows the operator to be aware of unit and plant conditions. The following are samples of status information:
   - Readiness for automatic start
   - Automatic start sequence initiated
   - Automatic stop sequence initiated
   - Unit on or off joint or automatic control
   - Unit on or off dispatch center control
   - Unit circuit breaker open or closed
   - Intake gate open or closed
   - Mode of operation
9) *Monitoring of Analog Measurements*. These data are presented to the operator to provide information required for monitoring and control of the power plant and include
   - Unit and plant real and reactive power
   - Unit voltage and current
   - Turbine wicket gate and/or blade or nozzle position
   - Headwater and tailwater levels
   - Various temperature readings
   - Gate limit position
10) *Alarms*. These advise the operator of abnormal conditions. Examples of alarms are as follows:
   - Major troubles
   - Minor troubles
   - Protective relay operations
   - Initiation of emergency or other protective type shutdown sequences
   - Troubles in unit equipment including generator/turbine, governor, exciter, transformer, controls, etc
   - Plant troubles such as fire, flood, security, station service systems, etc
11) *Report Generation*. Logs and reports are generated from unit and plant activities. At computer based systems, events and operator actions including other logs and reports are processed by a computer system and printed out on printers. A disturbance file can be provided to store selected real-time values and a history file can generally store a given set of hourly information for subsequent generation of hourly, daily, weekly, and monthly reports.
12) *Trending*. A plant control system can include video trending or conventional chart recorders.
13) *Sequence-of-Events Recording*. This is used for recording and correlating event information related to and occurring prior to, during, and after disturbances to plant operation. Each event is time tagged and logged in sequential order. Time resolution in the range of 1–2 ms is normal. This function can be integrated in the computer-based control system or stand-alone equipment can be used.

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6.1 Control System Hardware Requirements

6.1.1 Conventional Control Systems

The hardware needed for performing the above functions in a conventional, centralized hard-wired control system is generally similar to that used for individual local unit control. This consists of equipment such as control panels with discrete control, alarm, and indication devices, dedicated data logging, load and voltage control equipment, and annunciators. This equipment interfaces to the units in parallel to the local unit control or through the local unit control board control circuits with appropriate interlocks.

6.1.2 Computer-Based Control Systems

Computer system hardware needed to perform the above functions generally falls into the category of minicomputers or mainframes because of the speed, memory size, and flexibility needed to run the complex real-time control software and to store and manipulate data. Where the cost is justified, the system may employ redundant computers for reliability and serviceability reasons.

The computer system interfaces to the plant and to the conventional control system via *I/O* (input/output) interface equipment suitable for operation in the sometimes harsh power plant environment. This interface may be in parallel to the hard-wired control system (in other words, directly connected to the unit hardware via an RTU) and may operate into some of the conventional hard-wired control circuits.

The computer system must be configured to have the appropriate amount and type of memory for the software to be used, as well as all needed permanent data storage devices, display generators, and printers.

The computer system operator interface consists of consoles equipped with VDU's (video display units) and operator control hardware (keyboard, light pen, etc), which provide operator indication and control of all plant activities. Where the cost is justified, it may be desirable to furnish a programming and training console that permits software development and operator training while providing backup hardware for use when the normal operator interface is out of service. Interlocking should be provided to permit only one console to be in control at a time.

All system hardware and software should be designed keeping in mind what part, if any, it will play in the off-site control discussed in Section 7..

Special consideration must be given to the design of the computer system power supply, grounding, and shielding in view of the harsh power plant environment and generally sensitive nature of computer equipment.

Software development and purchase must be considered early in the design so that the hardware will be compatible and the software will perform the desired control.

7. Off-Site Control

This section treats the control, status, alarm, and data requirements for off-site control of a hydroelectric unit. It assumes the remote location is sufficiently distant to discourage hardwired, point-by-point control and that multiplexed supervisory control communications techniques are required.

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7.1 Control

The following are typical control functions that are provided at an off-site location. These functions are described in Section 6..

1) Unit start
2) Unit stop
3) Emergency shutdown
4) Speed level control
5) Load level control
6) Voltage and var control
7) Joint load and var control

7.2 Status

Status information allows the operator to be aware of unit and plant conditions of a normal nature. The following are status items usually provided:

1) Readiness for off-site control
2) Automatic start sequence initiated
3) Automatic stop sequence initiated
4) Unit on or off joint control
5) Unit circuit breaker open or closed
6) Intake gate open or closed
7) Mode of operation

7.3 Alarm

Alarm information advises the operator of abnormal conditions.

1) *Protective Relay Operation*. Separate indication of generator and transformer differential relay operation is usual.
2) *Emergency or Other Protective Type Shut-down Sequence Initiation*.
3) *Troubles in Unit Equipment*. Turbine and generator, governor, exciter, transformer, controls.
4) *Plant Troubles*. Fire, flood, security, station service system.

7.4 Data

Data are presented to the operator to provide information required for control and monitoring, and generally include:

1) Unit real and reactive power
2) Unit voltage and current
3) Turbine wicket gate or blade or nozzle position
4) Unit speed
5) Headwater and tailwater levels

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8. Trends

It is difficult to discuss control system trends in specific detail because control design is site-dependent. What would be considered suitable for a smaller single unit plant might be considered outmoded for a larger multiple unit plant. The main factors influencing control philosophy and current control designs is the continuing trend to reduce operating costs by reducing operating staff. Historically, control has evolved from schemes that require much operator intervention to ones that are less operator dependent.

Plants that were controlled entirely on-site are now being included in larger area control schemes. Here several plants are controlled and monitored off-site from a single control location.

Another factor influencing control design is the availability of more complex equipment for plant control and monitoring. Sophisticated equipment that has been used for other forms of power generation is becoming commonplace in the larger hydroelectric systems. Water use optimization, electrical system stability, and plant system response is driving design toward sophisticated electronic equipment that gives the speed of response needed. This equipment brings with it an increase in the training level of the maintenance personnel.

Advances in electronics are bringing costs down and reliability up to where programmable controllers, microcomputers, minicomputers, and large computer-based systems are common-place in hydroelectric plants. It is anticipated that this trend will continue in the years ahead.

In summary, current trends show the traditional philosophy of single-plant control giving way to more efficient multiple plant area control. The control systems are becoming more complex and incorporating more electronic circuitry in order to reduce operating costs. Advances in electronics are allowing the use of more sophisticated control systems and equipment. Hard-wired control and monitoring-based systems are being augmented by this new equipment.

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Annex A
(Informative)

(This Appendix is not a part of ANSI/IEEE Std 1010-1987, IEEE Guide for Control of Hydroelectric Power Plants, but is included for information only.)

In 1981, a questionnaire was sent to 175 utilities owning and/or operating hydroelectric plants in order to determine current control practices in the industry. A copy of the questionnaire and a tabulation of the results is included in this Appendix.

The results of the questionnaire were tabulated into four groups:

Group	Number of Plants	Size of Units
1	19	0–30 MW
2	23	30–75 MW
3	27	Larger than 75 MW
4	17	Pumped storage units

The following is a summary of some of the control aspects of these plants:

• Type of Operation	
Designed for manned operation	43
Designed for unmanned operation	42
• Turbine-Generator Start-Up and Shutdown Logic Done By:	
Electromechanical relays	77
Other	17
• CRT's Used for Control or Display	
Located in-plant	17
Located off-site	34
None used	38
• Location of Unit Controls	
Local to units	52
In a main control room	75
In an off-site control center	60
From a CRT keyboard or display screen	15

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Questionnaire Sample

Questionnaire on Control Systems for Hydroelectric Power Plants

Preface. Response to this questionnaire will be used by an IEEE Power Engineering Society Working Group for the preparation of a paper on control systems for hydroelectric power plants. Please complete as many questionnaires as needed to cover your control philosophy for new, or the modernization of the following:

Pumped storage plants
Conventional hydro plants
Large versus small plants (your own definition)
Manned versus unmanned plants

YOUR RESPONSE SHOULD REFLECT YOUR PRESENT PHILOSOPHY CONCERNING PLANT CONTROL AND MONITORING FOR MANNED AND UNMANNED PUMPED STORAGE AND CONVENTIONAL HYDRO PLANTS.

I. PLANT CHARACTERISTICS

PLANT NAME ____

LOCATION ____

PLANT STATUS:

____ In operation ____ In construction ____ In design ____ Being modernized

TYPE OF PLANT

____ Pumped storage ____ Conventional hydro ____ Peaking

____ Run-of-river ____ Other (please describe) ____________________

____

____

____

____

NUMBER OF UNITS __________

TYPE OF UNIT

____ Horizontal ____ Vertical ____ Bulb ____ Tube ____ Inclined

SIZE OF UNITS _______ MVA _______ P.F. _______ Voltage

OPERATION

____ Manned (maintenance personnel and operators)

____ Unmanned (maintenance personnel and no operators)

TYPE OF GENERATOR

____ Thrust bearing above ____ Thrust bearing below ____ Guide bearing above

____ Guide bearing below

TYPE OF TURBINE

____ Francis ____ Impulse ____ Fixed blade propeller ____ Adjustable blade propeller

TYPE OF GOVERNOR

____ Mechanical-hydraulic ____ Electric-hydraulic

TYPE OF EXCITATION SYSTEM

____ Brushless ____ Brush-type static ____ Brush-type rotating

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II. PLANT EQUIPMENT AND OPERATING PHILOSOPHY

1. (A) Is in-plant unit start-up/shutdown control sequencing done with relay logic? Yes _____ No _____
   (B) Is in-plant unit start-up/shutdown control sequencing done with computers ____, microprocessor-based control systems ____, interposing logic systems ____, or programmable controllers ____?
   (C) Is the equipment in (B) backed up by electromechanical relay systems? Yes _____ No _____
2. If joint load control of the units is used, is the equipment part of
   (A) Governor system ____
   (B) Plant control system ____
       1. plant computer ____
       2. dedicated solid-state system ____
   (C) Dispatch center ____
   (D) Other (please describe) ______________________________
   ____
3. If joint VAR control of the units is used, is the equipment part of
   (A) Excitation system ____
   (B) Plant control system ____
       1. plant computer ____
       2. dedicated solid-state system ____
   (C) Dispatch center ____
   (D) Other (please describe) ______________________________
   ____
4. Are in-plant CRT displays used for the following:
   (A) Graphics of electrical systems showing circuit breaker positions, disconnect switch positions, etc
   Yes _____ No _____
   (B) Graphics of fluid systems showing pumps, valves, etc
   Yes _____ No _____
   (C) Display of unit and plant operating data such as alarms, temperatures, etc
   Yes _____ No _____
   (D) Are the graphic displays used for control
   Yes _____ No _____
5. Are remote CRT displays used for the following:
   (A) Graphics of electrical systems showing circuit breaker positions, disconnect switch positions, etc
   Yes _____ No _____
   (B) Graphics of fluid systems showing pumps, valves, etc
   Yes _____ No _____
   (C) Display of unit and plant operating data such as alarms, temperatures, etc
   Yes _____ No _____
   (D) Are the graphic displays used for control
   Yes _____ No _____
6. Is multiplexing used for the following:
   (A) Control circuits Yes _____ No _____
   (B) Alarm circuits Yes _____ No _____
   (C) Indication circuits (on-off, open-close, etc) Yes _____ No _____
   (D) Metering (watts, volts, etc) Yes _____ No _____

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(E) Protection circuits Yes _____ No _____
(F) Instrumentation (temperature, pressure, etc) Yes _____ No _____

7. To what extent is this plant controllable from the following:

	Full	Partial	None
(A) Control panels located near the units	____	________	_____
(B) Control panels located in a main control room	____	________	_____
(C) CRT system	____	________	_____
(D) Remote dispatch center	____	________	_____
(E) Other (please describe)	____	________	_____

8. Are generator protective relays located
(A) Near the units Yes _____ No _____
(B) In the main control room Yes _____ No _____
(C) In an electrical equipment room Yes _____ No _____
(D) Other (please describe)____

9. Are main transformer, station service, transmission line protective relays located:
(A) Near/on the associated equipment Yes _____ No _____
(B) In the main control room Yes _____ No _____
(C) In an electrical equipment room Yes _____ No _____
(D) Other (please describe) ____

10. For protective relays located near the associated equipment, have you experienced any problems resulting from vibration, humidity, dust, etc?
Yes _____ No _____
If yes, please describe the problem ____

11. Is a <u>sequence of events</u> recorder used? Yes _____ No _____
How many points are connected to the recorder ____
Number of points per unit ____
Number of points for balance of plant ____
What is its resolution (milliseconds) ____

12. What method is used for generator synchronizing?
(A) Manual ____________
(B) One automatic synchronizer for all units ____________
(C) One automatic synchronizer for each unit ____________
(D) Other (please describe) ____________

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Do you normally include a synch check relay in the breaker closing circuit in the Manual Mode ____ Automatic Mode ____ Both Modes ____ Neither Mode ____

Is voltage matching as well as speed matching used when synchronizing?
Yes _____ No _____

13. What action is taken when generator overcurrent relays operate?
    (A) Complete unit shutdown ____
    (B) Generator breaker trip only ____

14. Annunciation
    (A) How many annunciator windows are used per unit? Approx.________
    (B) How many annunciator windows are used for the rest of the plant? Approx.________
    (C) Are unit alarms displayed near the units? Approx.________
    (D) How many unit alarms are also displayed in the main control room?
        All unit alarms ____
        One common alarm per unit ____
        Other (please describe) ____
        ____
        ____
    (E) Where are plant alarms (main transformers, station service system, station sump, etc) displayed?
        (1) Main control room ____
        (2) Near associated equipment ____
        (3) Other (please describe) ____
        ____
        ____
    (F) How many alarm points are transmitted to an off-site location? ____________

15. What type of plant operating data is transmitted to an off-site location:
    ____ Unit Megawatts ____ Unit Megavars ____ Generator Volts
    ____ Generator Amps ____ Excitation Voltage ____ Excitation Amps
    ____ Wicket Gate Position ____ Blade Position ____ Generator Stator Temp ____ Bearing Temps ____ Others (please list)
    ______________ ______________ ______________ ______________
    ______________ ______________ ______________ ______________

16. What type of communication link is used between the plant and remote locations?
    (A) Microwave ____
    (B) Fiber optics ____
    (C) Telephone line ____
    (D) Carrier ____
    (E) Other (please describe) ____
    ____
    ____

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17. Does this plant have "black start" capability? Yes______ No______
    If yes, please describe including time reference for restarting. __________

____
____
____
____

18. Is unit creep detection equipment used? Yes______ No______
    (B) What action is taken if unit creep is detected?
        Start the unit ____
        Alarm only ____
        Apply brakes ____
        Close draft tube gate ____
        Close intake gate ____
        Start injection oil pumps ____

19. (A) What type of braking is used?
        Intermittent ____ Continuous ____ None ____
    (B) At what percent speed are the brakes applied for a normal shutdown? ____
    (C) At what percent speed are the brakes applied for an emergency shutdown? ____

20. What type of generator fire protection is used?

____
____

How is this system initiated?

____
____

III. FUTURE CONSIDERATIONS

1. What do you like least about the plant control equipment or operating philosophy?

____
____
____
____
____

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2. What would you do differently for a future plant of similar type and size?

3. What do you believe is the trend for hydroelectric power plant control systems?

Name of Respondent:

Title:

Company Address:

Telephone No.:

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Questionnaire Results
Plants With Units 0–30 MW Number of Plants Surveyed—19

		NUMBER OF UNITS IN THE PLANT			
	INFORMATION	**1**	**2**	**3**	**≥4**
1.	Manned Operation	1		1	3
	Unmanned Operation	9	3		2
2.	TYPE OF TURBINE				
	Francis	4	2		4
	Fixed Blade Propeller	1		1	1
	Pelton	5			
	Adjustable Blade Propeller		1		
	Kaplan				
	Pump				
3.	TYPE OF GOVERNOR				
	Mechanical-Hydraulic	4	1	1	3
	Electric-Hydraulic	5	2		1
	None	1			1
	Electronic-Hydraulic				
4.	TYPE OF EXCITATION SYSTEM				
	Brushless	2			
	Brush-Type Rotating	4	1	1	3
	Brush-Type Static	2	1		2
	Static				
	Induction Gen W/Cap	1	1		
	No Response	1			
5.	TURBINE-GENERATOR START-UP/ SHUTDOWN LOGIC CIRCUIT DONE BY:				
	Electromechanical Relays	9	2	1	5
	Solid-State Equipment		1		
	Computer				1
	Microprocessor-Based				
	No Response				
6.	CRT'S USED FOR CONTROL OR DISPLAY				
	In-Plant		1		1
	Off-Site	5	2	1	1

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	INFORMATION	NUMBER OF UNITS IN THE PLANT 1	2	3	≥4
	None Used	5			3
7.	UNIT LOCATION OF CONTROLS				
	Local to Units	5	2		3
	Main Control Room	9	2	1	3
	Off-Site Control Center	7	2	1	4
	CRT Keyboard or Display Screen	5	1		
	No Response				1
8.	SEQUENCE OF EVENT RECORDER PER UNIT				
	0–100	10	3	1	5
	>100				

	INFORMATION	PUMPED STORAGE NUMBER OF UNITS IN THE PLANT 1	2	3	≥4
	BALANCE OF PLANT				
	0–100 >100	10	3	1	5
9.	METHOD OF SYNCHRONIZING				
	Manual	3			1
	Automatic Synch For Each Unit	1	2	1	1
	Automatic Synch For All Units	6			3
	Other	2	2		1
10.	SYNCHRONIZING CHECK RELAY USED IN THE CKT BKR CLOSING CKT				
	Manual Mode	3	1		
	Automatic Mode	2		1	3
	Both Modes				
	Neither Modes	3	1		1
	No Response	2	1		1
11.	VOLTAGE MATCHING AS WELL AS SPEED MATCHING USED WHEN SYNCHRONIZING				
	Yes	7	2	1	3
	No	1			2
	No Response	2	1		

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	INFORMATION	PUMPED STORAGE NUMBER OF UNITS IN THE PLANT			
		1	2	3	≥4
12.	ANNUNCIATOR WINDOWS PER TURBINE				
	0–15	1	1	1	3
	16–30	8	2		1
	31–100	1			1
	≥101				
13.	ANNUNCIATOR WINDOWS FOR BALANCE OF PLANT				
	0–25	9	1	1	4
	26–50	1	2		
	51–100				
	≥101				1
14.	ALARM POINT TRANSMITTED TO OFF-SITE LOCATION				
	0–15	10	2	1	3
	16–30		1		
	31–100				
	≥101				2
15.	PLANT OPERATING DATA POINTS TRANSMITTED TO OFF-SITE LOCATIONS				
	0–10	10	3	1	5
	11–20				
	21–50				
	>50				
16	TYPE OF COMMUNICATION LINK TO OFF-SITE LOCATION				
	Microwave	4		1	2
	Telephone Line	7	1	1	
	Fiber Optics				
	Carrier	1	1		2
	Radio				1
	Other				
	None		1		

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Plants With Units 30–75 MW Number of Plants Surveyed—23

		NUMBER OF UNITS IN THE PLANT			
	INFORMATION	**1**	**2**	**3**	**≥4**
1.	Manned Operation	3		3	5
	Unmanned Operation	1	7	1	3
2.	TYPE OF TURBINE				
	Francis	2	5	1	5
	Fixed Blade Propeller	2	1	3	2
	Pelton		1		1
	Adjustable Blade Propeller				
	Kaplan				
	Pump				
3.	TYPE OF GOVERNOR				
	Mechanical-Hydraulic	4	7	4	6
	Electric-Hydraulic				2
	No Response				
	Electronic-Hydraulic				
4.	TYPE OF EXCITATION SYSTEM				
	Brushless		1		
	Brush-Type Rotating	3	5	4	7
	Brush-Type Static	1	1		
	Static				
	Induction Gen W/Cap				
	No Response				1
5.	TURBINE-GENERATOR START-UP/ SHUTDOWN LOGIC CIRCUIT DONE BY:				
	Electromechanical Relays	4	7	4	6
	Solid-State Equipment				
	Computer		2		
	Microprocessor-Based				
	No Response				
6.	CRT'S USED FOR CONTROL OR DISPLAY				
	In-Plant				1

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		NUMBER OF UNITS IN THE PLANT			
	INFORMATION	**1**	**2**	**3**	**≥4**
	Off-Site	3	3	3	2
	None Used	1	4	1	5
7.	UNIT LOCATION OF CONTROLS				
	Local to Units		3	2	5
	Main Control Room	4	6	4	7
	Off-Site Control Center	4	7	4	5
	CRT Keyboard or Display Screen		1		
8.	SEQUENCE OF EVENT RECORDER PER UNIT				
	0–100	4	5	4	8
	>100		2		

		0–30 MW NUMBER OF UNITS IN THE PLANT			
	INFORMATION	**1**	**2**	**3**	**≥4**
	BALANCE OF PLANT				
	0–100	4	5	4	8
	>100		2		
9.	METHOD OF SYNCHRONIZING				
	Manual		1	1	3
	Automatic Synch For Each Unit		1		
	Automatic Synch For All Units	3	7	4	7
	Other				
10.	SYNCHRONIZING CHECK RELAY USED IN THE CKT BKR CLOSING CKT				
	Manual Mode				
	Automatic Mode	3	5	4	7
	Both Modes		1		
	Neither Modes	1	1		1
11.	VOLTAGE MATCHING AS WELL AS SPEED MATCHING USED WHEN SYNCHRONIZING				
	Yes	3	5	4	7
	No	1	2		1
12.	ANNUNCIATOR WINDOWS PER TURBINE				

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		0–30 MW NUMBER OF UNITS IN THE PLANT			
	INFORMATION	**1**	**2**	**3**	**≥4**
	0–15		1	3	2
	16–30	2	4	1	4
	31–100	2	2		2
	≥101				
13.	ANNUNCIATOR WINDOWS FOR BALANCE OF PLANT				
	0–25	3	2	2	3
	26–50	1	5	2	3
	51–100				1
	>101				1
14.	ALARM POINT TRANSMITTED TO OFF-SITE LOCATION				
	0–15	3	2	2	7
	16–30				1
	31–100	1	5		
	≥101			2	
15.	PLANT OPERATING DATA POINTS TRANSMITTED TO OFF-SITE LOCATIONS				
	0–10	4	5	4	8
	11–20		2		
	21–50				
	>50				
16.	TYPE OF COMMUNICATION LINK TO OFF-SITE LOCATION				
	Microwave	5	3	4	6
	Telephone Line	2	3	3	4
	Fiber Optics				
	Carrier		2		2
	Radio	1			1
	Other				

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Plants With Units > 75 MW Number of Plants Surveyed—27

	INFORMATION	NUMBER OF UNITS IN THE PLANT 1	2	3	≥4
1.	Manned Operation		2	2	11
	Unmanned Operation	3	5		4
2.	TYPE OF TURBINE				
	Francis	3	7	1	12
	Fixed Blade Propeller			1	1
	Pelton	1			1
	Adjustable Blade Propeller				
	Kaplan				1
	Pump				
3.	TYPE OF GOVERNOR				
	Mechanical-Hydraulic	2	5	1	5
	Electric-Hydraulic	1	2		9
	No Response			1	
	Electronic-Hydraulic				1
4.	TYPE OF EXCITATION SYSTEM				
	Brushless			1	1
	Brush-Type Rotating	1	5	1	7
	Brush-Type Static	2	2		6
	Static				1
5.	TURBINE-GENERATOR START-UP/ SHUTDOWN LOGIC CIRCUIT DONE BY:				
	Electromechanical Relays	3	7	1	13
	Solid-State Equipment				2
	Computer		2		6
	Microprocessor-Based				1
	No Response				
6.	CRT'S USED FOR CONTROL OR DISPLAY				
	In-Plant				8
	Off-Site	1	4	2	2
	None Used	2	3		5
7.	UNIT LOCATION OF CONTROLS				

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INFORMATION	**NUMBER OF UNITS IN THE PLANT** 1	2	3	≥4
Local to Units	1	5	1	12
Main Control Room	2	7	2	14
Off-Site Control Center	3	6	2	10
CRT Keyboard or Display Screen	1	1		1
8. SEQUENCE OF EVENT RECORDER PER UNIT				
0–100	3	6	2	13
>100		1		2
BALANCE OF PLANT				
0–100	3	7	2	11
>100				4

INFORMATION	**30–75 MW NUMBER OF UNITS IN THE PLANT** 1	2	3	≥4
9. METHOD OF SYNCHRONIZING				
Manual	1	3		8
Automatic Synch For Each Unit		2	1	4
Automatic Synch For All Units	3	4	1	10
Other		1		1
10. SYNCHRONIZING CHECK RELAY USED IN THE CKT BKR CLOSING CKT				
Manual Mode				1
Automatic Mode	1	5	1	3
Both Modes	1	2	1	8
Neither Modes	1			3
11. VOLTAGE MATCHING AS WELL AS SPEED MATCHING USED WHEN SYNCHRONIZING				
Yes	2	6	2	12
No	1	1		3
12. ANNUNCIATOR WINDOWS PER TURBINE				
0–15		1	1	1
16–30		2	1	3
31–100	2	4		11

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	INFORMATION	30–75 MW NUMBER OF UNITS IN THE PLANT 1	2	3	≥4
	>101	1			
13.	ANNUNCIATOR WINDOWS FOR BALANCE OF PLANT				
	0–25		3	2	4
	26–50	1	3		2
	51–100	2	1		3
	≥101				6
14.	ALARM POINT TRANSMITTED TO OFF-SITE LOCATION				
	0–15	1	2	2	12
	16–30				
	31–100	2	4		2
	≥101		1		1
15.	PLANT OPERATING DATA POINTS TRANSMITTED TO OFF-SITE LOCATIONS				
	0–10	3	6	2	13
	11–20		1		2
	21–50				
	≥50				
16.	TYPE OF COMMUNICATION LINK TO OFF-SITE LOCATION				
	Microwave	2	7	2	11
	Telephone Line	1	2	1	6
	Fiber Optics				1
	Carrier			1	6
	Radio				2
	Other				

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Plants With Units 12.5–425 MVA Pumped Storage Plants Number of Plants Surveyed—17

		NUMBER OF UNITS IN THE PLANT			
	INFORMATION	**1**	**2**	**3**	**≥4**
1.	Manned Operation	2	1	1	8
	Unmanned Operation	1	1		2
	No Response	1			
2.	TYPE OF TURBINE				
	Francis	2	1	1	7
	Fixed Blade Propeller				1
	Pelton				
	Adjustable Blade Propeller		1		1
	Kaplan				
	No Response	1			
	Pump	1			
3.	TYPE OF GOVERNOR				
	Mechanical-Hydraulic	2	2		4
	Electric-Hydraulic	1		1	4
	None				
	No Response	1			2
4.	TYPE OF EXCITATION SYSTEM				
	Brushless				
	Brush-Type Rotating		2	1	6
	Brush-Type Static	3			3
	Static				
	No Response	1			1
5.	TURBINE-GENERATOR START-UP/ SHUTDOWN LOGIC CIRCUIT DONE BY:				
	Electromechanical Relays	3	2	1	9
	Solid-State Equipment	1			
	Computer				2
	Microprocessor-Based				
	No Response				

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	INFORMATION	NUMBER OF UNITS IN THE PLANT 1	2	3	≥4
	Manual				1
6.	CRT'S USED FOR CONTROL OR DISPLAY				
	In-Plant	2			4
	Off-Site	1			4
	None Used	2	2	1	4
7.	UNIT LOCATION OF CONTROLS				
	Local to Units	2	2	1	8
	Main Control Room	4	1		9
	Off-Site Control Center	4	1	1	9
	CRT Keyboard or Display Screen	2			3

	INFORMATION	> 75 MW NUMBER OF UNITS IN THE PLANT 1	2	3	≥4
8.	SEQUENCE OF EVENT RECORDER PER UNIT				
	0–100	4	2		9
	> 100			1	1
	BALANCE OF PLANT				
	0–100	4	2	1	8
	> 100				2
9.	METHOD OF SYNCHRONIZING				
	Manual	1	1		4
	Automatic Synch For Each Unit	4	1	1	1
	Automatic Synch For All Units	1			7
	Other		1		
10.	SYNCHRONIZING CHECK RELAY USED IN THE CKT BKR CLOSING CKT				
	Manual Mode				
	Automatic Mode				9
	Both Modes	1	1		1
	Neither Modes	2		1	
	No Response	1	1		

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	INFORMATION	> 75 MW NUMBER OF UNITS IN THE PLANT 1	2	3	≥4
11.	VOLTAGE MATCHING AS WELL AS SPEED MATCHING USED WHEN SYNCHRONIZING				
	Yes	4	1	1	8
	No				2
	No Response		1		
12.	ANNUNCIATOR WINDOWS PER TURBINE				
	0–15		1		1
	16–30				
	31–100	3	1	1	9
	> 100	1			
13.	ANNUNCIATOR WINDOWS FOR BALANCE OF PLANT				
	0–25	2	1	1	3
	26–50		1		
	51–100	1			2
	> 100	1			4
14.	ALARM POINT TRANSMITTED TO OFF-SITE LOCATION				
	0–15	3	2		3
	16–30				2
	31–100			1	1
	> 100	1			
	No Response				4
15.	PLANT OPERATING DATA POINTS TRANSMITTED TO OFF-SITE LOCATIONS				
	0–10	4	2	1	8
	11–20				1
	21–50				
	> 50				
16.	TYPE OF COMMUNICATION LINK TO OFF-SITE LOCATION				
	Microwave	3	1		4
	Telephone Line	1	1	1	5
	Carrier	1	1		1
	No Response				2

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