

SECTION – I

CONTROL AND PROTECTIONS

CHAPTER –1

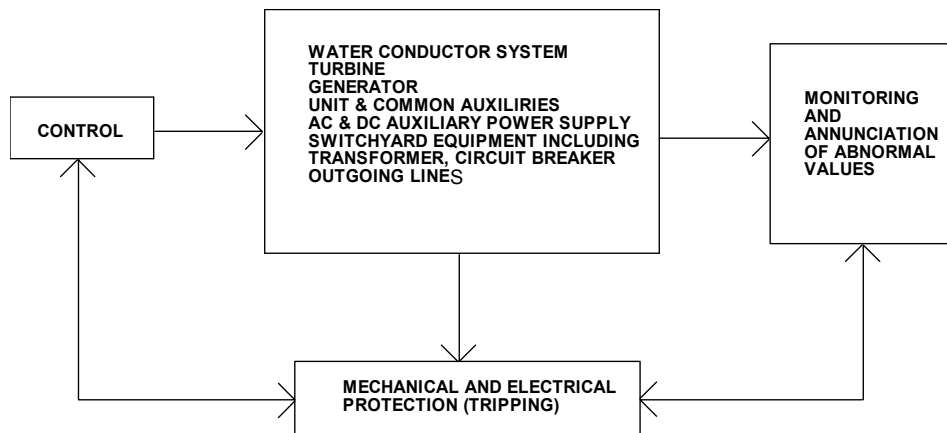
CONTROL AND PROTECTION GENERAL CONSIDERATIONS, TECHNOLOGY DEVELOPMENT (Reviewed by Dr. R. Thapar)

1.1 Control System

The main control and automation system in a hydroelectric power plant are associated with start and stop sequence for the unit and optimum running control of power (real and reactive), voltage and frequency. Data acquisition and retrieval is used to cover such operations as relaying plant operating status, instantaneous system efficiency, or monthly plant factor, to the operators and managers. Type of control equipment and levels of control to be applied to a hydro plant are affected by such factors as number, size and type of turbine and generator. The control and monitoring equipment for a hydro power plant include control circuits/logic, control devices, indication, instrumentation, protection and annunciation at the main control board and at the unit control board for generation, conversion and transmission operation, grid interconnected operation of hydro stations including small hydro stations. These features are necessary to provide operators with the facilities required for the control and supervision of the station's major and auxiliary equipment. In the design of these features consideration must be given to the size and importance of the station with respect to other stations in the power system, location of the main control room with respect to the equipments to be controlled and all other station features which influence the control system. The control system of a power station plays an important role in the station's rendering reliable service; this function should be kept in mind in the design of all control features.

Basic control functions in a modern hydro-electric station requires all equipment (generating unit, auxiliaries, switchyard equipment and hydraulic control e.g. spill way gates etc.) to be connected to the plant control system by electrically actuated element for automatic control, protection and monitoring.

Basic functions of control and protection are as per following flow chart.



1.1.1 Standards and Codes

- Hydroelectric power plant automation – Guide for computer based control IEC 62270 – 2004
- IEEE Guide for Control of Small Hydroelectric Plants, “ANSI/IEEE Standard 1020, American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE).
- “IEEE Guide for Control of Hydroelectric Power plants,” ANSI/IEEE Standard 1010, ANSI/IEEE, 1991.8
- IEEE Guide for Computer Based Control for Hydro Electric Power Plant Automation – IEEE std. 1249 – 1996.
- IEEE std. 1046 – IEEE application guide for distributed digital control and monitoring of power station
- IEC Electro-Mechanical equipment guide for small hydro – Electric Installation – IEC: 61116 – 1992
- IEEE guide for generator protection - ANSI/ IEEE std C 37.102:1987
- (R1980) IEEE guide for protective relaying of utility - ANSI/ IEEE std C 37.95 : 1974

- IEEE standard electrical power systems device function numbers - ANSI/ IEEE std C 372-1987
- IEEE recommended practice for protection and coordination of industrial and commercial power systems - ANSI/ IEEE std 242:1996
- IEEE guide for generator ground protection - IEEE std. C 37101
- Alternate Hydro Energy Centre IIT Roorkee - Micro Hydro Quality Standards - 2005

1.2 Methods of Control

Local, centralized and offsite modes of operation and supervision as per IEC 62270 and IEEE 1010 as recognized by industry is given in table 1.1. Details of control interface for plant equipment as per modern Indian practice are discussed and control system is designed in accordance with standards specified in Para 1.1.

Table 1.1 – Summary of control hierarchy for hydroelectric power plants

Control category	Sub Category	Remarks	Modern India Practice
Location	Local	Control is local at the controlled equipment or within sight of the equipment	Provided in all plants as backup facility
	Centralized	Control is remote from the controlled equipment, but within the plant	Centralized control is provided in most hydro stations
	Offsite	Control location is remote from the project	Not very common
Mode	Manual	Each operation needs a separate and discrete initiation; could be applicable to any of the three locations.	Provided as back up
	Automatic	Several operations are precipitated by a single initiation; could be applicable to any of the three locations	Most common
Operation (supervision)	Attended	Operator is available at all times to initiate control action	
	Unattended	Operation staff is not normally available at the project site	

1.3 Major Controllers for Component of Hydro Electric Plant

Although machines differ widely in physical appearance, there are comparatively few basic types of turbine and main controls described below which are common to all. Major components of a hydro electric plant for control are given in Figure 1.1.

The elements to be controlled in hydro power stations are intake gates, main inlet valve, turbine, governor, the lubrication system, the excitation of the generator, main circuit breakers. Each of these elements has a particular function in the overall operation. The intake gate and main inlet valve render the plant inoperative and conserve water during shutdown period of the plant. The turbine gates under the control of the governor admit water in the runner in proportion to the load requirements of the turbine. The lubrication system establishes a lubricating film on the bearings during starting and maintains it during operation and circulates the lubricant so that it can be cooled. The voltage regulator controls the excitation of the generator in keeping with the voltage requirements and demand for reactive power output of the generator. The generator field circuit breaker provides a means of field interruptions during faults and thereby minimizing damage to the generator and the other equipments. The generator line circuit breaker serves to connect the generator to the grid system after the generator has been started. It also disconnects the generator from the system prior to shutdown or following an electrical fault.

1.3.1 Intake

Penstock gates at the intakes and inlet valves adjacent to the turbine are provided for following purposes.

- a) Emergency shutdown of unit
- b) Prevent leakage in turbine wicket gates/needle valve when turbine is shut down
- c) Dewatering for maintenance of turbine

When a tunnel and pipeline connect the reservoir to the turbines, an additional valve may be provided at the junction of the tunnel and the pipe line if the latter is long, and either this valve or the intake gate is arranged for remote closure in an emergency.

Main inlet valves at the turbines are either butterfly valve type or spherical type depending upon the head at the turbine inlet. All types of valve incorporate arrangements for slow filing of turbine casing by crack opening or by special bypasses. Main inlet valves are generally opened by oil servomotor. The opening motion of the main inlet valve is preferably interlocked so as to open the valve only when balanced water head pressure is established on both sides of the valve.

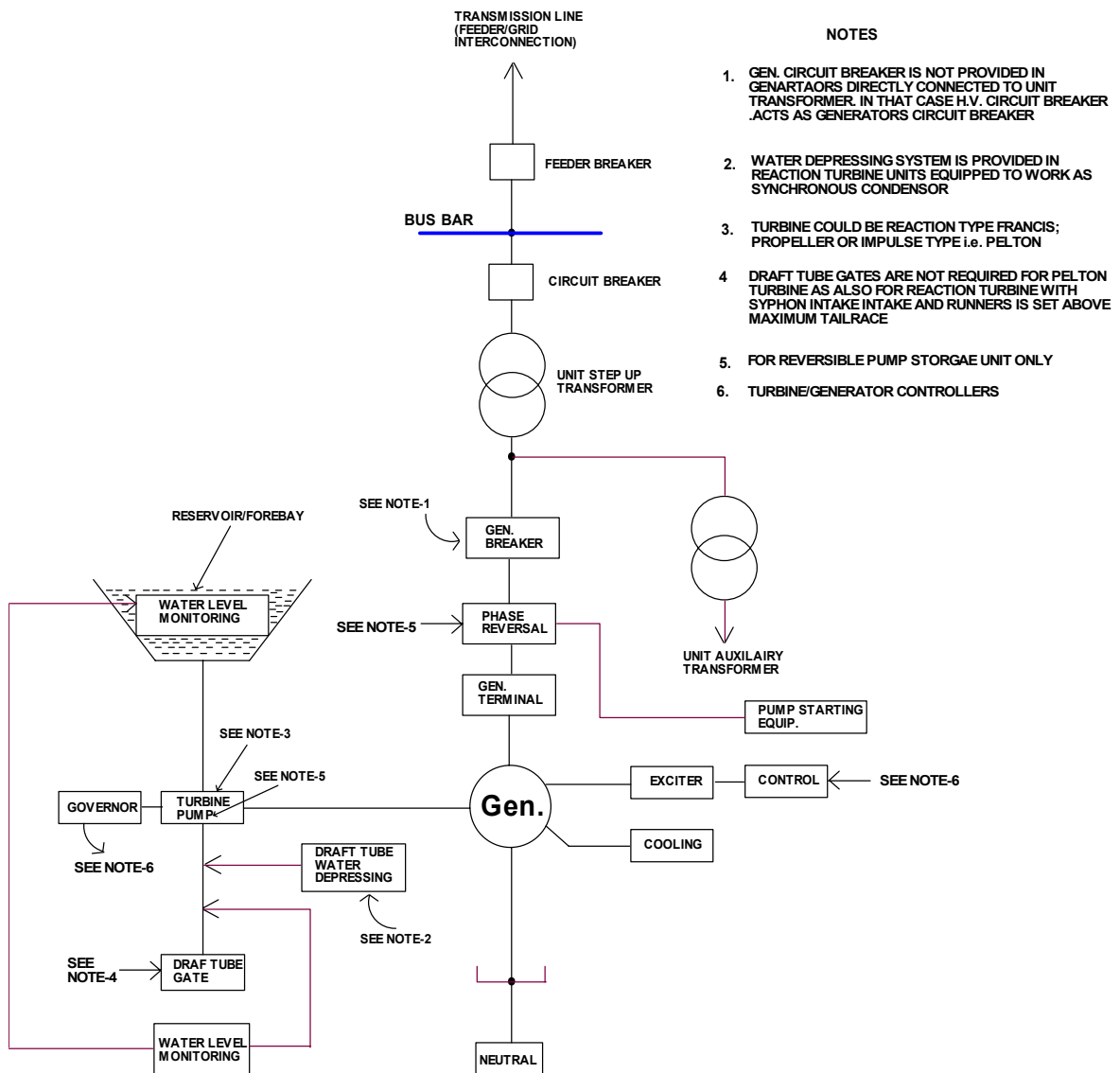


Figure. 1.1 Major Controllers and Components for Control of Hydro Electric Plant

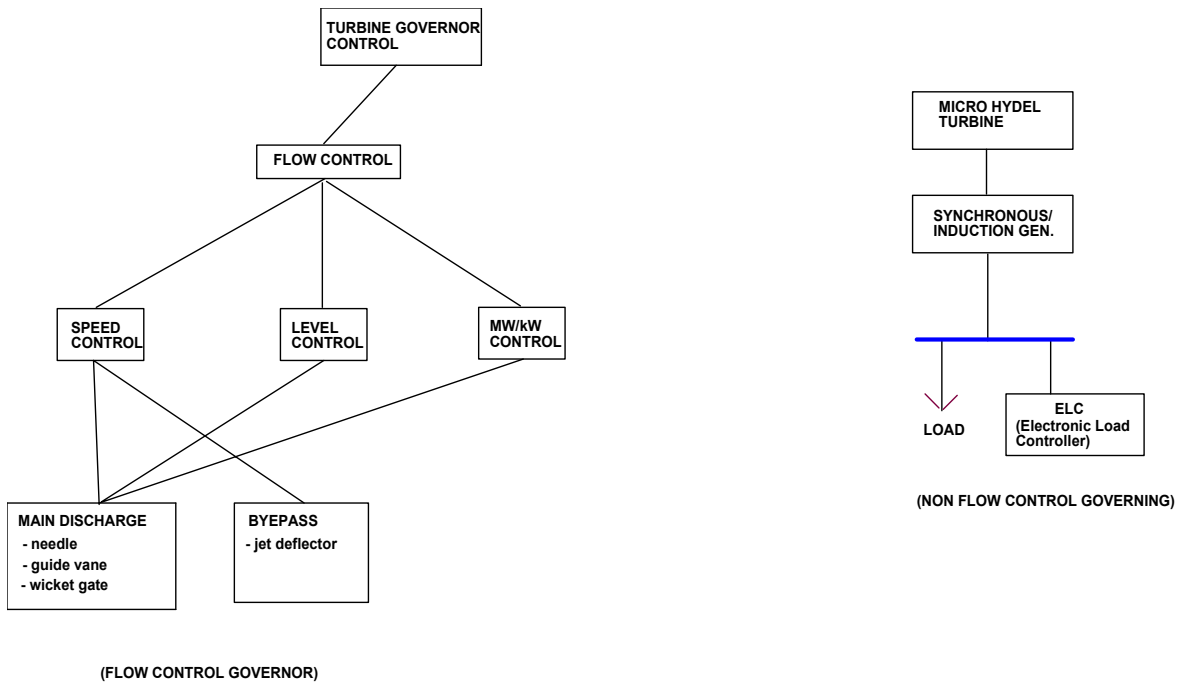


Figure. 1.2 Schematic Overview of Turbine Control

1.3.2 Turbine and Governing System

Governors are discussed in volume -1. Main controllers are governing systems. Control and data signals required are typically given in table and turbine specification (Vol. I) for proper operation and monitoring.

1.3.3 Generator and Excitation System

Generators are discussed in volume -1. Main controllers are excitation systems. Control and data signals required are typically given in table 2.1 and generator specification (Vol. I) for proper operation and monitoring.

1.3.4 Step up Transformers

These are discussed in Chapter-6. Control and data signals required are typically given in Para 1.39 (Annexure 6.2) of chapter 6 for proper control.

1.3.5 Generator Breakers

These are discussed in Chapter -7. Signals required for control are generally opening of the circuit breaker during emergency stopping initiated by electrical mechanical protection and over speed device. Control and data signals required are typically given in Para 1.7 (Annexure 7.2) of chapter 7 for proper operation and monitoring.

1.3.6 Auxiliary Systems

These are discussed in chapter 4 & 5. Control of auxiliary systems for unit starting, unit stopping and running control is required. Necessary signals are required. . Control and data signals are required for proper operation and monitoring.

1.4 Technology - Control System

1.4.1 Conventional Control System

Upto 1990s, conventional control system was almost universally used. In this system control of a hydro plant's generating units was typically performed from governor panel or unit control switchboard. If the

plant had multiple units, a centralized control board was provided. The unit control board and centralized control board using relay logic contained iron vane meters, hardwired control switches, and hundreds of auxiliary relays to perform the unit start/stop and other control operations. All the necessary sensors and controls required to operate the unit or units were hardwired to the unit control board and/ or centralized control board, allowing operator to control the entire station from one location. Stepped sequence control system was mostly followed. Large hydro stations mostly had operators at two levels i.e. governor gallery and centralized control room. Offsite supervisory control was by hardwires and not successful. Data acquisition was manual. Modernization of the conventional control system using digital control technology is now being undertaken.

1.4.2 Modern Control System

Modern systems permit control of the entire plant from a single location. Modern control rooms utilize the far more cost-effective supervisory control and data acquisition (SCADA) systems (including programmable logic controllers (PLCs) and distributed computer control systems with graphic display screens to implement a vast array of control schemes. The SCADA control scheme also provides flexibility in control, alarming, sequence of events recording, and remote communication that was not possible with the hardwired control systems. Data acquisition, storage and retrieval is provided by the computer.

The main control and automation system in a hydroelectric power plant are associated with following:

- i) Turbine governor for speed control (frequency) optimum running control for real power generation and dynamic stability.
- ii) Generator excitation control for voltage reactive power control and transient stability of the interconnected grid systems.
- iii) Plant automation to cover such operation as start, stop, synchronizing and running control of the unit.
- iv) Supervisory control including off site control and centralized control.
- v) Data acquisition and retrieval is used to cover such operations as relaying plant operating status, instantaneous system efficiency, or monthly plant factor, for the operators and managers.

Microprocessor based digital governing and excitation control system provided in modern systems is detailed in Volume-1. Integration of the Plant automation, data acquisition and supervisory control including offsite control for various elements to be controlled for large, small and micro hydro is brought out.

The control and monitoring equipment for a hydro power plant include control circuits/logic, control devices, indication, instrumentation, protection and annunciation at the main control board and at the unit control board for generation, conversion and transmission operation including grid interconnected operation of hydro stations. These features are necessary to provide operators with the facilities required for the control and supervision of the station's major and auxiliary equipment. In the design of these features consideration must be given to the size and importance of the station with respect to other stations in the power system, location of the main control room with respect to the equipments to be controlled and all other station features which influence the control system.

Modern practice for control of hydroelectric plants is based on the combination of computer based and non-computer based equipment utilized for unit, plant and system control.

1.4.3 Modern Control of Power Station

Modern control system employed for large power stations is distributed computer control system with adequate redundancy.

Modern control of small hydro up to 5 MW is mostly PLC based integrated governor and plant control systems.

Micro hydro modern control is micro processor based non flow control electronic load controller.

1.5 Protection System

1.5.1 General

Hydro turbine-generators are protected against mechanical, electrical, hydraulic and thermal damage that may occur as a result of abnormal conditions in the plant or in the grid system to which the plant is electrically connected.

The abnormal operating conditions that may arise should be detected automatically and corrective action taken in a timely fashion to minimize the impact. Relays (utilizing electrical quantities), temperature sensors, pressure or liquid level sensors, and mechanical contacts operated by centrifugal force, etc., may be utilized in the detection of abnormal conditions. These devices in turn operate other electrical and mechanical devices to isolate the equipment from the system.

Programmable controllers provided for unit control also perform some of the desired protective functions.

Operating problems with the turbine, generator, or associated auxiliary equipment require an orderly shutdown of the affected unit while the remaining generating units (if more than one is in the plant) continue to operate. Alarm indicators are used to advise operating personnel of the changed operating conditions.

Loss of individual items of auxiliary equipment may or may not be critical to the overall operation of the plant, depending upon the extent of redundancy provided in the auxiliary systems. Many auxiliary equipment problems may necessitate loss of generation until the abnormal conditions has been determined and corrected by operating or maintenance staff.

The type and extent of the protection provided will depend upon many considerations, some of which are:

- (1) The capacity, number, and type of units in the plant;
- (2) The type of power system;
- (3) Grid Interconnection requirement
- (4) The owner's dependence on the plant for power;
- (5) Manufacturer's recommendations;
- (6) Equipment capabilities; and
- (7) Control location and extent of monitoring.

Overall, though, the design of the protective systems and equipment is intended to detect abnormal conditions quickly and isolate the affected equipment as rapidly as possible, so as to minimize the extent of damage and yet retain the maximum amount of equipment in service.

Small hydroelectric power plants generally contain less complex systems than large stations, and therefore tend to require less protective equipment. On the other hand, the very small stations should be typically unattended and under automatic control, and frequently have little control and data monitoring at an off-site location. This greater isolation tends to increase the protection demands of the smaller plants.

An inherent part of the power plant protection is the design of the automatic controls to recognize and act on abnormal conditions or control failures during startup. Plant equipment mechanical troubles are a part of the control system. Trouble in power system components say generator, power transformer etc. require electrical relay protection system integrated with the control system.

Plant Mechanical Equipment Troubles for Generators and turbines are:

Excessive vibration, Bearing problems, Over speed, Insufficient water flow, Shear pin failure, Grease system failure and Stator winding high temperature etc.

Hydraulic Control System Troubles may be:

Low accumulator oil level, Low accumulator pressure and Electrical, electronic or hydraulic malfunctions within the governing or gate positioning system

Water Passage Equipment are:

Failure of head gate or inlet valve, Head gate inoperative, Trash rack blockage and Water level control malfunction

1.5.2 Mechanical Protection System

Mechanical protection of the power plant equipment is assigned to the plant control system which provides signals for monitoring alarm and protection.

1.5.3 Electrical Protection System

Forced outage due to faults in power system components e.g. generator, unit and station auxiliaries, generating unit transformer, bus bars, substation and transmission lines affect reliability of power supply. Increasing spare capacity margins and arranging alternative circuits to supply loads are provided to take care of such failures. For minimum isolation following a break down the system is divided into zones controlled by switchgear in association with protective gears. Switchgear is designed to interrupt normal and fault current. Protection gear must recognize an abnormal condition and operate to secure its removal with the minimum disturbance to normal system operation. Protective gear defines all equipment necessary for recognizing; locating and initiating the removal of a fault or abnormal condition from the power system and includes a relay or group of relays and accessories to isolate electrical installation (machine, transformer etc.) or to activate a signal. Accessories are current and voltage transformers, shunts, d. c. and a. c. wiring and auxiliary devices necessary to secure successful operation. For safety and reliability modern practice is to provide separate relay protective system duly integrated with plant control system. Electrical protection system as part of digital control system (PC) has not been successful so far.

1.6 Protective Relay Technology

Protective relay technology has changed significantly in recent years. Induction disk relays for each individual protective function were normally used. Individual solid-state static relays for protective function were introduced in the decade 1980-1990 and IS: 3231-1965 was accordingly revised in 1987. Microprocessor based multi function relays are now being introduced. Advantage claimed for these relays are as follows:

- i) Self-monitoring of operating status on continuing basis and to alarm when to function.
- ii) Multiple protective functions in one relay reduces panel space and wiring
- iii) Self calibration by software programming
- iv) Programmable set point by software programming

Microprocessor relaying is gaining acceptance among both utilities and consumers. The relay functions are the same as those in electromechanical and solid-state electronic relaying, but microprocessor relays have features that provide added benefits. Microprocessor relays may have some disadvantages, however, so that there are additional considerations when these are applied to the hydroelectric station.

The benefits of microprocessor relays include the ability to combine relay functions into economical unit. Where an electromechanical over current relay may be only a single phase device, a microprocessor relay will often include three phases and a neutral. It could also include reclosing, directional elements, over/under voltage, and over/under frequency. Outgoing transmission line relay could combine multiple zone phase and ground distance elements, over current fault-detectors, pilot scheme logic, and reclosing. An electromechanical scheme will normally consist of individual relays for each zone of phase and ground protection, separate fault-detectors, and additional relaying for pilot scheme logic. Similarly, a microprocessor transformer relay might combine differential and over current protection and a generator relay could include differential, over current, negative, sequence, frequency, voltage, stator ground, and other protective functions. These same devices can include non relaying functions such as metering, event

recording, and oscillography. All of these functions are contained in an enclosure that requires less space than the combination of relays and other devices they duplicate.

A microprocessor relay has self-monitoring diagnostic that provide continuous status of relay availability and reduces the need for periodic maintenance. If a relay fails, it is typically replaced rather than repaired. Because these relays have multiple features, functions, increased setting ranges, and increased flexibility, it permits stocking of fewer spares.

Microprocessor relay also have communication capability that allows for remote integration of meter and event data and fault oscillography. This also permits relay setting from a remote location. The relays have low power consumption and low CT and VT burdens. They also increase the flexibility of CT connections. For instance, microprocessor transformer differential relays can compensate internally for ratio mismatch and the phase shift associated with delta-wye connections.

All of these features have economic benefits in addition to the lower initial costs and potentially reduced maintenance costs that microprocessor relays have when compared to individual conventional relays.

1.7 Considerations for Application of Digital Control and Protection System

1.7.1 Digital Control and Protection System

Solid state digital control and protection system is fast replacing hard wired control and electro-mechanical relaying systems in hydro stations. These systems working on 4 to 5 volts with respect to ground are susceptible to damage/malfunction from induced voltage from switching surges, rise of ground grid voltage on ground faults and lightning surges etc. and require appropriate measures for control and protection.

Computer control SCADA (Supervisory Control and Data Acquisition)/protection system receive signals from equipment to be controlled and give output signals to actuators for control/protection action.

Isolation of the digital system for protection and control is very important to avoid damage. A design that provides complete isolation from the high frequency surges is vital to maximize plants on line availability.

Standards addressing these problems for the control and protection equipment have been issued by IEC and other standards organization and mentioned at appropriate places.

Programmable logic controller (PLC) input/output racks used in hydro plants have been used in industry for quite some time and hardened for use in harsh environment of the hydro plants. PLCs input/output racks and solid state components are designed to withstand the surges and stray voltage. Isolation is by optically coupling I/O racks and cards so as to provide isolation and withstand surge voltage capability.

These systems are vulnerable to damage from transient surges especially in EHV and UHV systems, due to switching and lightning.

There are IEC/IEEE standards for surge protection and acceptable installation procedures which are mentioned at appropriate places.

Grounding: Ground grid voltage rise on ground faults especial as HV outgoing feeders may affect functioning earth is connected to main ground grid. Separate earth systems are used.

1.7.2 Main disadvantages and advantages for application of digital protection in hydroelectric station

- i) **Control Power:** The operating energy for most electromechanical relays is obtained from the measured currents and/or voltages, but most microprocessor relays require a source of control power.
- ii) **Multi Protective Functions:** Digital relays provide multiple protective functions in one relay. In contrast, older relay system required an individual relay for each protective function. Consequently, multifunction digital relays reduce panel space and wiring costs while providing equivalent protection. Multifunction feature can result in a loss of redundancy. For instance, the failure of a single-phase over current relay is backed up by the remaining phase and neutral relays. In a microprocessor scheme, the phase and neutral elements are frequently combined in one package and a single failure can disable the protection.

iii) **Self Test Function:** microprocessor-based digital relays have provisions for continuous self monitoring of their own operating status. Any potential malfunction will be identified and communicated to the control system. The self monitoring feature eliminates the possibility of a non functioning relay in the plant protective relay system. In previous protective relay systems, a non functional induction disk or solid state relay would not normally be discovered until the next maintenance test of the protective relay system.

The self-monitoring capability of these relays is only effective if the alarm output can be communicated to a manned location such as a control center. Also, the remote communication ability assumes there is a communication channel available to the relay.

iv) **Communication:** The digital relay uses a digital communication scheme which allows the relay to communicate directly with the plant control system. The digital relays are provided with serial data ports based on established protocols, which should be compatible with the DACS (Data Acquisition & Control System) /PLC communication protocol used at the plant.

The communication capability of microprocessor relays in hydroelectric stations interconnection with grid can benefit both the power plant operating and power receiving grid authority from the communication capability. In particular, the recorded history of events can be very useful in analyzing relay operations after a fault. However, for both to communicate directly with the relay will require special considerations. Both the utility and the consumer may be required to purchase software license for the communication software if that software is propriety. Also, they will both need to maintain the same versions of the software. The communication settings, such as modem baud rate, will have to be mutually agreed on. Some relays have security passwords, which restrict access. There may be one password to permit read only access to meter and event records and a different password to make changes. Although both parties may have read only access, ideally only one party should have the necessary access to make setting changes.

v) **Self Calibration:** Digital relays are provided with a self-calibration routine, which can be initiated by selecting the relay calibration mode in the relay's soft ware programming.

vi) **Programmable Logic:** Previous relay systems required “experienced” protective relay engineers to calculate the set points for each individual relay, define the zones of protection for each primary and back-up relay, and perform a coordination analysis to confirm that the operation times of the various protective relays did not conflict. The digital relay uses a PC based System software program which provides detailed instructions and recommended setpoints for each protective relay function based upon system characteristics.

vii) **Event Recording:** The digital relays can store selected wave forms on an oscillograph record. The numbers of cycles that can be stored differ with the manufacturer. This record will show the condition of each of the selected waveforms before and after the protective relay has operated. This additional information is valuable in determining the cause of the protective relay trip.

viii) **Other Considerations**

- Microprocessor transformer package that has both differential and over current relaying provide less redundancy than a scheme comprising separate relays. The self-diagnostics ability of the microprocessor relay, and its ability to communicate failure alarms, mitigates some of the loss of redundancy. It may also be economical to use multiple microprocessor relay.
- Microprocessor relays require more engineering in the application and setting of the relay though less work in the panel design and wiring. The increased relay setting flexibility is accompanied by an increase in setting complexity that requires proper care to avoid setting errors.
- Some relays have experienced numerous software upgrades in a short period of time.
- Microprocessor relays have relatively shorter product life cycles because of the rapid advance in technology. As a result, a specific microprocessor relay model may only be available for a relatively short period of time. As a failure may require replacement rather than repair, it may not be possible to use an exact replacement, which may require more engineering and installation work. Although less frequent testing may be required, when it is, it requires a higher level of training for the technician and more test equipment than is normally used with electromechanical relays in order to obtain the full benefit of all the features of the microprocessor relay.

1.7.3 Modern Indian Practice













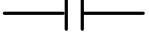








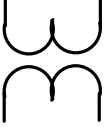
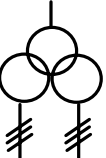




Emerging modern practice in India is to provide suitable digital protection for generators, transformers and two terminal lines on a single card from separate instrument transformers in addition to conventional relay protection for mega and large hydro units as back up to each other so that blind spot of one system are covered.

In case of small hydro limited back up protection by conventional static relays are provided.

1.8 Power and Control System Single Line and Schematic and Detailed Wiring Drawings

1.8.1 Graphic Symbols

Single line diagrams representing 3 phase by single line are generally made as a starting point in designing protection systems for hydro plants i.e. generators; transformers; circuit breakers etc. Graphic symbols used to represent various elements are generally as per IS: 2032. Some generally used graphic symbols are given below. In case some other symbols are used same are specified on the drawing.

ALTERNATING CURRENT, GENERAL SYMBOL		FUSE	
POSITIVE POLARITY		VOLTMETER	
NEGATIVE POLARITY		AMMETER	
WINDING, DELTA		WATTMETER	
WINDING, STAR		VARMETER	
WINDING		POWER FACTOR METER	
CAPACITANCE, CAPACITOR		INDICATING INSTRUMENT/RELAY (GENERAL SYMBOL)	
EARTH		RECORDING INSTRUMENT (GENERAL SYMBOL)	
FAULT		INTEGRATING METER	
GENERATOR		CURRENT TRANSFORMER	
TRANSFORMER		VOLTAGE TRANSFORMER	
3-PHASE TRANSFORMER WITH THREE SEPERATE WINDINGS-STAR-STAR-DELTA		NORMALLY OPEN AUX. CONTACT	
SWITCH		NORMALLY CLOSED AUX. CONTACT	
CIRCUIT BREAKER			

1.8.2 Device Numbers

Relays and protection devices used in schematic drawings are classified by device function members used in generating station, substation generally according to IEEE C37.2-1991. The use of prefixes and suffixes provide a more specific definition of the function. Commonly used device numbers in India are as follows. For deviations specific mention is made in the drawings. It is general practice in India to mention device numbers on the drawings.

5	-	Stopping device
12	-	Over speed or over frequency relay
14	-	Under speed or under frequency relay
21	-	Distance relay
23	-	Temperature control device
25	-	Synchronizing or synchronizing check device
26	-	Apparatus thermal device
27	-	A. C. under voltage or NO voltage relay
30	-	Annunciation relay
32	-	Reverse Power flow relay
37	-	Under current or under power relay
38	-	Bearing protective device
40	-	Field Failure relay
41	-	Field circuit breaker
46	-	Reverse phase or phase balance current relay
47	-	Phase sequence or phase balance voltage relay
50	-	Instantaneous over current relay
51	-	AC time over current relay
52	-	AC Circuit breaker
55	-	Power Factor relay
56	-	Field application relay
59	-	Over voltage relay
62	-	Time-delay stopping or opening relay
63	-	Pressure switch
64	-	Ground fault relay
65	-	Governor
67	-	AC directional over current relay
68	-	Blocking relay
71	-	Level switch
72	-	DC circuit breaker
76	-	DC over current relay
79	-	AC reclosing device
81	-	Frequency relay
85	-	Carrier or plot wire receive relay
86	-	Lock out relay
87	-	Differential protective (current) relay
89	-	Line switch

1.8.3 Suffix Letter

C	-	Closing relay/contactor
CS	-	Control switch
PB	-	Push button
U	-	“UP” position switch relay
X	-	Auxiliary relay
Y	-	Auxiliary relay
Z	-	Auxiliary relay
A	-	Air/amperes
C	-	Current
F	-	Frequency/flow/fault
J	-	Differential
L	-	Level/liquid
P	-	Power/pressure
PF	-	Power factor
Q	-	Oil
S	-	Speed
T	-	Temperature
V	-	Voltage
VAR	-	Reactive power
VB	-	Vibration
W	-	Water/watts

1.8.4 Schematic Drawings

Three line diagrams based on the single line diagram are made. Detailed wiring diagrams showing the terminal nos. are made by the supplier of equipment for actual laying of cables etc.

REFERENCES

- Technology recommended under UNDP-GEF Project for Himalayan range SHP project. These recommendations were made by AHEC (Alternate Hydro Energy Centre) as Indian consultant based on specific recommendations of M/s Mead and Hunt – US consultant; M/s MHPG Group of European Consultants; World Literature review and local experience.
- UNDP/world bank recommendation for cost effective irrigation based Mini Hydro Schemes in India under Energy Sector Management Assistance programme (ESMAP) by standardization of designs and equipment.
- “Economic Computer Controls for Low Head Hydro” by R. Thapar and D.A. Perrault; WATERPOWER’85, U.S.A.
- Thapar, Rakesh, et.al, “Microprocessor Controller for a small Hydroelectric System”, I.E.E. October, 1986.
- “Microcomputer Based Control and Monitoring Systems”; DIGITEK INC. 11807, North Creek Pkwy, So. Bothell, WA 98011 U.S.A. – Technical Literature.
- “Small Hydro-Electric – Technology for Economic Development” by O.D. Thapar, Presented in Eleventh National Convention of Electrical Engineers and Seminar on Environmental Friendly Electric Power Generation- Nov. 1995, Roorkee.
- Report on study and design and development of Model SHP based self sustained projects - E & M Equipment standardization and cost reduction Vol. III (a) prepared by Alternate Hydro energy Centre, IIT Roorkee for Power finance corporation Ltd. – 2002.
- Design of a large number of SHP projects for different states and organization.
- Art & science of protective relaying 1956 by MASON, CR