CHAPTER-2

CONTROL SYSTEM OF HYDRAULIC ELECTRIC STATIONS

2.1 Conventional Control System with Relay Logic (Mechanical/Analogue Electronic Governor)

Control schemes are broadly classified as follows. Depending upon the method of control and location of control points, the control of unit operation is provided as follows:

a) Local Manual Control
b) Semi Automatic control
c) Automatic control

2.1.1 Local Manual (Mechanical or push button) control

In this type of control, unit auxiliaries are started manually or by electrical push buttons mounted locally. The successful operation of auxiliaries is indicated by lamps mounted at the equipment or verified by visual inspection. Any abnormal operation of these auxiliaries during running is displayed by an alarm fitted locally. Necessary electrical interlocks in the starting circuit of the turbine using relay logic may be included. The turbine is started from the governor panel. An operator at the panel adjusted the speed of the turbine and the excitation to bring the unit to ready to synchronize condition. Then he transfers the unit to control room for synchronizing and loading. Once the unit is synchronized, the adjustments of load and excitation are carried out by the control room operator. When a unit is taken out of service, the control room operator first unloaded the unit and then tripped the main circuit breaker. The stopping of the unit and its auxiliaries was performed by the operators at the machine.

This type of control is simple but requires large number of operating personnel at various floors in case of large powerhouses. Smaller lengths of control cables and lesser number of control relays are required. Such schemes are difficult to modify for converting the controls to remote/automatic control type. This type of scheme is provided in most small and mini hydro. In large hydro this was provided as a back up provision.

2.1.2 Local Control of Unit from Unit Control Board (Semi Automatic)

Generally controls of auxiliaries and the unit are brought to a centrally located control board near the turbine generator at machine floor level. This board was called Unit Control Board (UCB) or unit governor panel. In such type of stations relay logic is used and valves in cooling water, pressure oil and air supply circuits are motor operated. Cables are run from various motor starters to the UCB for start/stop operations. An operator at the UCB starts the unit auxiliaries. Their successful operation is indicated on the UCB. The necessary interlocks are included in the turbine starting circuit. Operator then starts turbine and brings it to speed no load position by adjusting the speed and excitation. Then he transfers the unit to the central control room for synchronizing and loading.

This type of control involved cable connection between UCB and various auxiliaries. The scheme enabled single operator to supervise the unit and its auxiliaries from UCB. Separate UCB is provided for each unit. Generators, transformer and bus duct protective relay panels are mounted in the central control room. Line and Bus bar protective relay panels were mounted behind the control panels in the control room if the cable lengths involved between switchyard equipment and the control rooms were small. If the distance is greater, these panels were mounted in a separate switch room at the switch yard and only necessary controls and indications are brought to the central control room.

This type of unit control still requires co-ordination of operators at two levels – one at the UCB and the other at the control room. However at later date the scheme could easily be modified for converting it for SCADA.

In modernization of control systems hard wired unit control board is still required for testing as well as a source of communication link between main and auxiliary equipment and the control board for information (signal sent to control board) and control signals (output signals leaving the control board to various
equipment) and unit control. Basically four types of signals are provided between the control board and any particular piece of equipment for computer control system.

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

2.1.3 Control of Unit from Central Control Room (Automatic Control)

Centralized control refers to a common control location from which control functions can be initiated, and from which plant operating data can be collected and displayed so as to facilitate plant operation and reduce operating staff.

In conventional system hard wire relay logic and conventional electromechanical control devices and monitoring equipment is used.

Major control and monitoring function of hydro electric plant generally consist of following.

i) Pre start checks
ii) Unit start as per unit start sequencing
iii) Unit stop as per unit stop sequencing
iv) Emergency shut down
v) Speed level (speed at no load) setting to adjust unit load
vi) Gate (or spear) limit control (built into governor)

vii) Voltage Var control
viii) Monitoring of station information e.g. sequence; circuit breaker and intake gates open or closed etc.
ix) Monitoring plant operating data e.g. real and reactive power, voltages current, turbine wicket gate/nozzle position; head water/ tailrace levels; temperature,
x) Gate limit position etc.
xi) Alarm and annunciation log sheet and reports generated from unit and plant activities manually.

In this type of control, the controls of the auxiliaries and the unit are brought to a desk/panel in the control room. This involves taking all cables from the unit and its auxiliaries to the central control room. The scheme enables operators at the central control desk to supervise and control the unit from a single controlling point. There is no problem of coordination among the operators as the responsibility of starting auxiliaries, turbines and their control on a single operator in the control room. All alarms and indications are brought to a common annunciator board in the control room. The protective relay panels of generator, transformer and busducts may be located near the unit in the machine hall and only indications may be brought to the common annunciator board. Busbar and line protective relay panel locations depends upon the distance between switchyard and the control room and arrangement may be installed as explained earlier.

The unit control from the central control room may be by sequence controller switch as in Bhakra Left Bank and Dehar Power Plant or it may be automatic with a master controller as in Bhakra Right Bank. In the former, control switch puts the unit in operation by performing the four sequence stages, that is, opening the inlet valve and starting unit auxiliaries, opening turbine gates to speed no load position, synchronizing and loading. The sequence control switch in the reverse order stops the turbine. In the latter, a single starting impulse energizes a master start relay, which starts unit auxiliaries, opens turbine gates parallel and loads the unit to a predetermined value.
2.1.4 Synchronizing

Before connecting a generator in parallel with the other machines it is necessary to prove that the incoming machine and the running system have the same frequencies and voltages and are in phase. The methods employed in hydro power stations are described below.

2.1.4.1 Manual Synchronizing

In this method incandescent lamps are connected across the respective phases of the incoming and running voltage buses. Voltage of the incoming machine is matched with the system voltage by manually adjusting the excitation of the machine. The frequency and phase angle difference are indicated by lamps. A synchroscope where a needle rotates at a speed proportional to the difference in voltage depending upon phase difference. A typical manual synchronizing panel having 2 volt meters, 2 frequency meters (incoming and running), a synchroscope and 2 lamps and synchronizing switch is shown in figure 2.1. Lamps will flicker with a frequency equal to the difference between the frequencies of incoming machine and the running system. When the phase and frequencies are matched the lamps will extinguish. This is the indication of the synchronism of the machine with the system. The breaker is then closed manually.

Manual synchronizing is simple and cheap. This requires personal supervision and judgment of the operator. This type of synchronizing is not suited for automatic or remote control of the unit. However, this has normally been provided as a standby in all power stations for use in case of failure of automatic/synchronizing equipment. In Micro hydro this method is utilized.

2.1.4.2 Automatic Synchronizing

Synchronizing equipment performs the following functions automatically.

(i) It continuously controls the terminal voltage of the incoming machine until it is almost equal to the voltage of the system to which it is to be connected.

(ii) It controls the speed of the prime mover so that the frequency difference is within the predetermined value.

(iii) It energizes the closing coil of the circuit breaker associated with the incoming machine at an instant when the phase difference between the two sources is sufficiently small and only when the conditions (i) and (ii) have been simultaneously satisfied.

Auto synchronizing equipment performs the above functions through the speed, voltage and phase matching relays. It energizes breaker closing coil at an exact time in advance of synchronism so that the time consumed by the breaker in closing is just equal to the time consumed by the generator in arriving at exact synchronism. The time for advance action of closing is adjustable in auto-synchronizing equipment.

The main disadvantages of the automatic synchronizer is that if the system is disturbed, i.e., the frequency of the system is changing due to the tripping of certain generators or due to the sudden addition of large loads, it may then take very long time to synchronize the unit with the system. Sometimes it may not be even possible to synchronize the machine. Under such conditions the manual synchronizing method could be used. This has been the practice in all large power stations.

2.1.4.3 Self Synchronizing

In this method the generator circuit breaker is closed after the unit has accelerated to approximately 95 percent of the rated speed. Field is then applied immediately after the generator breaker is closed. Earlier, this method of connecting the unit to the system was recommended for smaller units as compared to the system size for it causes disturbance in the system. However, this method was employed in Bhakra Right Bank for providing quick relief to a system when frequency of the system is falling. The method was rarely used.

The scheme for the units now employ frequency difference relay to automatically close the circuit breaker when the difference in frequencies is within the predetermined value ± 10° in automatic synchronizing system.
2.1.5 Automatic Load Control

2.1.5.1 Mechanical Governors

Automatic turbine regulation is achieved by governor speed droop settings. This involves a response of the fly balls (mechanical governor) to changes in the rotational speed. Because of the inertia of mechanical system and fly-balls, the governor does not respond immediately when the generator load is varied suddenly. There is a certain time lag (or delay) between the actual load change and the governor response. The turbine governors were able to maintain a uniform rotational speed of the generating set at all operating conditions. However, the actual speed of the turbine deviates from the rated speed within certain limits. Speed droop usually varied between zero and six percent.

2.1.5.2 Analogue Electronic Governors

Electronic governors later introduced respond not only to changes in the rotational speed, but also to accelerations during load variations. The governor responds to the maximum acceleration and start opening/closing the turbine gates to a significant extend before the change in the rotational speed of the generator. The principal advantage of such a governor is that an abrupt variation of the load causes a far smaller temporary change (temporary speed droop) in the rotational speed of the generating set than the speed sensitive regulation alone. Feedback of the actual change in servomotor function provides an integral function for limiting temporary speed droop and thus providing PID control.

In both cases frequency control is provided by speed level setting (speed at no load) manually by the operator at regular intervals, generally half an hour.

2.1.5.3 Reactive Power Control

Reactive power control is also provided by providing parallel running compensation (droop setting) in the generating sets.

2.1.6 Machine Running Supervision

Once the unit is started and synchronized with the system, the operating personnel in the control room have to perform or supervise the following three important functions of the unit.

(i) Load-frequency control
(ii) Reactive power and voltage control
(iii) Supervision of alarm and protective equipment

Functions of the above are discussed below:

2.1.6.1 Load Frequency Control

In an isolated system consisting of a generator and load, the varying demand of the load can be satisfied entirely by the governor action. The governor of the unit is set to maintain the frequency at 50 Hz by setting the speed droop indicator to zero. The machine speed will be maintained exactly at 50 Hz with varying load demands provided the amount of load is not greater than the unit’s ability to carry it.

When a unit is operating in an interconnected system it is not possible, and is indeed virtually, impossible to set all governors to respond isochronously to maintain constant frequency. In such cases unit speed droop is set at 3 to 8 percent depending on the system’s load sharing requirement. A governor set on 5 percent speed droop will cause its generator to accept 100 percent of its capacity when there is frequency droop of five percent. Depending on its regulating ability, unit can be adjusted to help maintain system frequency, which is the exact indication of the balance between supply and demand. The operator in the control room, on receipt of orders from the central load dispatch office, adjusts the speed level of the unit to assist the system to maintain frequency at 50 Hz. In the case of units fitted with automatic load-frequency control device, the speed level is adjusted from the load dispatch office itself. Automatic load frequency control is rarely employed being costly.
2.1.6.2 Reactive Power and Voltage Control

When the unit is serving isolated load, its terminal voltage is held to a schedule value by means of continuously acting automatic voltage regulator. The reactive power requirements of the load connected to it are adjusted by excitation control called power factor control. When unit is connected to a large power system, i.e. to an infinite bus, it assumes the system voltage and any change in its excitation results only in changing its kilovar loading and its power factor. Generally the unit is operated at rated kilovar load. The maximum and minimum excitation applied to the generator is dependent upon the reactive power capability of the unit. On the high side, the limitation is field and armature overheating, and on the low side the limitation is stability and leading power factors.

2.1.6.3 Supervision of Alarm and Protective equipment

The object of an alarm equipment in any power station is two fold. Firstly, it enables the duty staff to determine quickly the nature of the incipient faults. Secondly, to record transitory fault occurrences for subsequent analytical investigation. For mechanical troubles, displays are provided not only for those conditions which cause shutdown but also various non-trip conditions. In the operator’s room these are further classified as ‘urgent’ and ‘Non-urgent’ to help operators realize the urgency of the action needed. Generators are provided with necessary protection against electrical and mechanical faults. Relays have hand reset flag indicators to indicate their operation. The operator’s attention is drawn by an audible alarm on the alarm panel and by flashing light. Operators on occurrence of trouble or fault attended to it and maintained a record of the nature of the trouble and instruct maintenance staff to carry out the repair.

2.1.7 Hydraulic Control

Associated with each hydro-electric station a number of hydraulic items require control. These items may be selected from the following.

(i) Headrace storage, level indication and gate control
(ii) Tailrace level indication
(iii) Flood control including special gate operation, position indication, discharge and alarm. Flood warning stations on the upstream basin of the river are installed at Bhakra.
(iv) Intake gate control and indication
(v) Irrigation water release and discharge indication
(vi) Surge tank water level indication
(vii) River control and discharge indication for other users such as irrigation, fishery authorities, chemical works, water supply authorities etc.

Judgmental manual control of most of these items is generally under the control of project operating authority. Some indications of these is provided in the control room.

2.1.8 Large Hydro station – Conventional Control System

Indian practice for conventional control and monitoring of large hydro station system which was common up to 1990 is discussed with special reference to Dehar Power Plant having 6 vertical shaft units with Francis turbines coupled to semi umbrella generating units of 173.7 MVA each and commissioned in 1976 to 1980. The system described is as designed. Two Machine are unit connected to 245 kV single sectionalized bus and 4 units are unit connected to 420 kV double bus scheme as shown in the Single line diagram 2.1 Balancing storage of about 6 hours is provided and powerhouse designed as a frequency control station.

Entire power is fed into northern grid with provision for supplying local grid at 132 kV. The power house was commissioned from 1976 to 1980. Electro-mechanical analogue type governor and static excitation (thyristor) was provided. Entire control system was designed by conventional relay system.
2.1.8.1 Unit control

Provision for start and stop of each unit was proposed from the governor cubicle (electro hydraulic type). The local control from the governor cubicle did not include synchronising of the unit. The remote (automatic) starting and stopping of the unit was proposed in sequence through the master controller switch installed on unit control panel in the centralized control room. Provision was also proposed for the automatic starting of the unit in case system frequency drop to a preset value.

2.1.8.2 Centralised Control

Centralized control system and equipment was used to accomplish the control and monitoring function of the power plant. The control system interface with the unit control board panel located in the centralized control room. The centralized control room was proposed as common control location from which control function can be initiated and from which plant operating data can be collected and displayed so as to consolidate control functions and plant operating data at a common location in order to facilitate operation and reduce operating staff. Centralized control room proposed layout is shown in figure 2.2.

Hard wired relay logic and conventional electro-mechanical control devices and monitoring equipment were used for centralized control.

Logic for unit starting as proposed is shown in figure 2.3 and shut down logic is shown in drawings 2.4 (3 sheets).

The hardware needed for performing the above functions in the conventional, centralized hard wired control system is similar to that used for individual local unit control. Dedicated data logging load and voltage control equipment and annunciators were provided. The equipment interfaces to the unit in parallel to the local unit control with appropriate interlocks.

```
| 132kV LINE TO HIMACHAL PRADHESH |
| 132kV LINE TO BAGGI PP (FUTURE)  |
| 220kV DOUBLE CIRCUIT LINE TO GANGUWAL |
| BANK OF 3 SINGLE PHASE 250MVA 220/400kV TRANSFORMERS | 400kV LINE (FUTURE) |
| 40/36/4MVA 220/132/11kV TRANSFORMER |
| 220kV BUS 220kV BUS |
| 400kV BUS |
| BANK OF 3 SINGLE PHASE 180MVA 11/400kV TRANSFORMERS |
| BANK OF 3 SINGLE PHASE 180MVA 11/220kV TRANSFORMERS |
| 3 PHASE, 500kVA, 11/0.415kV TRANSFORMER |
| 165MW, 11kV GENERATORS |
| 3 PHASE, 500kVA, 11/0.415kV TRANSFORMER |
| 3 PHASE, 500kVA, 11/0.415kV TRANSFORMER |
| 3 PHASE, 500kVA, 11/0.415kV TRANSFORMER |
| MAIN SINGLE LINE DIAGRAM |
| DEHAR POWER PLANT |
```

Figure 2.1 (As designed)
Figure 2.2 (As designed)

Figure 2.3: Unit Start Relay Logic (As designed)
Figure 2.4: Controlled Action Shut Down (Sheet 1 of 3)

Controllable Action Shut Down

GT - Generator Transformer
AT - Auxiliary Transformer
S/D - Shut Down relay
Gen. CB - Gen. Circuit Breaker
**Figure 2.5: Emergency Shut Down**

(As designed)

- **OS** – Overspeed
- **GV** – Guide Vanes
- **PB** – Push Button
- **GCB** – Gen. Circuit Breaker
- **REF Protn.** – Restricted Earth Fault Protection

- **O/C** – Overcurrent
- **T/D** – Time Delay
- **E/F** – Earthfault
- **DIFF Protec.** – Differential Protection
- **SD** – Shut Down

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**GEN. & TURBINE URGENT MECH. AND GOV. & EXCITATION URGENT FAULTS**

- Gov. Failure 1, 2, 3, 4 & Gov. Not closed
- Mechanical Overspeed Device Operated
- Hydraulic Overspeed Device Operated
- Electrical Overspeed Device Operated
- Emergency Stop P.B. Command
- Excitation System Fault Stage – II
- Riser Earth Fault Stage – II
- G.V. Fail to Close in Preset Time
- Speed < 47 Hz & GCB Close
- Gen. Transformer Fire
- Generator Fire
- Reverse Power
- Speed Signal Failure (SSG)
- Oil Level in Gravity Tank Low
- Hot Air Okt. Temp. Very High

**GEN., GT & UAT URGENT ELECT. FAULTS**

- Gen. Trans. REF Protn. Operated
- Gen. Trans. D/A Diff. Protn. Operated
- Gen. Stat. E/F 100% Protn. Operated
- Gen. Stat. E/F 95% Protn. Operated
- Gen. Diff. Protn. Operated
ELECTRICAL SHUT DOWN

GEN., GT & UAT NON URGENT ELECT. FAULTS

NEGATIVE PHASE SEQ. D.C. STAGE - II
LOSS OF EXCITATION
OVER VOLTAGE (INST. & TIME DELAYED)
VOLTAGE CONTROLLED D.C. RELAY OPERATED
OVER/UNDER FREQUENCY PROTN. OPERATED
BACKUP IMPEDANCE PROTN. OPERATED
TRANSFORMER D/C & E/F RELAY OPERATED
AT D/C & E/F RELAY OPERATED
UAT D/C RELAY OPERATED

ELECTRICAL SHUT DOWN RELAY ENERGISED
< B6C >

GT – Generator Transformer
UAT – Unit Auxiliary Transformer
O/C – Overcurrent
E/F - Earthfault
2.1.9 Conventional Automatic Control of Small Hydro Station

Automatic Conventional control scheme for a typical small hydro power house, Kulagarh (2 x 650 kW) at Pithoragarh with mechanical wood word governors is shown in figure 2.7 to figure 2.13. The powerhouse was provided for isolated operation as well as operation in grid and made suitable for group control from a centralized control centre. Stepped control sequence was provided on the control panel. This scheme is typical of a control scheme provided for small power station with mechanical governors. The powerhouse was commissioned in 1991.

Turbine control is by 2 small fractional horse power motor for speed (level control) i.e. gate at speed no load and gate limit control. Load starting is by permanent speed droop setting. The schematic is shown in drawing 2.7 & drawing 2.8. Speed sensing was provided by special PT.

Governor oil pump control for servomotor is shown in figure 2.1.9. It may be noted that only one governor oil pump is provided (being a small unit). In normal practice two governor oil pumps are provided even in small units.

Figure 2.8: Governor control for speed adjustment (load control)
Figure 2.9 : Gate limit control
Figure 2.10: Governor oil pump control

Auto synchroising is shown in the following figure. Manual synchroising facility was also provided.
Figure 2.11: Synchronizing (manual and Automatic)

Annunciation & alarm for minor and major faults is shown in figure 2.112.
Figure 2.12: Annunciation schedule for major and minor faults
Figure 2.13 : Inlet valve control

Figure. 2.7: Kulagarh SHP – Main Single Line Diagram
(As designed)
Figure 2.8: Mechanical governor automatic unit control
Turbine control (speed adjustment)
(As designed)

Figure 2.9 Automatic Unit Control Mechanical Governor
(As designed)
Figure 2.10: Automatic Unit Control Gov. Oil Pump Control (As designed)

Figure 2.11: Automatic Unit Control Synchronising Panel
Figure 2.12.: Automatic Unit Control Annunciation Schedule
(As designed)

Figure 2.13: Automatic Unit Control
(As designed)
2.1.10 Semi Automatic Conventional Control of Grid Connected Small Hydro Station with Electronic Governor

Semi automatic conventional control (with relay logic) with electronic governor for 2 x 1800 kW turbine (Francis) is provided for Rajwakti Small Hydro Project commissioned in 2002. Single line diagram is shown in figure 2.14 and unit metering and relaying drawing is shown in figure 2.15. Entire power is fed into the grid at 66 kV. Control desk for unit operation is shown in figure 2.16 & 2.17. Semi automatic control is provided wherein the unit is brought to speed no load position by a push button. Back up manual operation is also provided. Synchronizing is manual. Push button starting sequence is described below (figure 2.16 & figure 2.17).

It may be noted that speed and voltage for grid connected small hydro power plant do not require running control. Active and reactive power control is manual.

2.1.10.1 Press “SART” Push Button – Semi Automatic Starting

Following operations will take place automatically in sequence; watch LED indications on the status display unit for status of equipment.

- OPU (Oil Pressure Unit) pump is switched ON.
- Bypass to BFV will open.
- BFV will open.
- Brake will open.
- Bypass to BFV will close.
- Guide vanes will open to opening plant load position 15%.
- Turbine will attain no-load speed of 600 rpm and guide vane position indication shall be around 4.6% for unit # 1 and 4.7% for unit # 2.

Building up of Generator Voltage

- Excitation gets ON automatically at speed ≥ 90% of the rated speed.
- Generator will build up voltage around 2.9 kV.

Taking Unit into Load Operation

- Ensure the 66 kV breaker in switchyard is in close position.
- Line up the respective 3.3 kV unit bay as per normal station practice.
- Switch synch. ON by turning the switch in clockwise direction.
- Match the m/c speed & voltage to the grid frequency and voltage through respective Raise/Lower switch and check the 12 ‘O’ clock position on synchroscope (manual synchronization).
- Close 3.3 kV unit breaker by turning breaker control switch on sync. Desk in clockwise direction. Check the breaker close indication on the status display unit.

A minimum of 250 kW load will be accepted by the machine as the base load immediately after breaker closing.

2.1.10.2 Stopping the Units

The unit can be shut down in following modes:

- Emergency
- Normal stop
**Special stop**

**Emergency Shutdown**

The unit will shutdown automatically if turbine (86FT) or generator protection (86G) operates. Under this mode of shutdown, following sequence will take place:

- 3.3 kV breaker will open.
- Guide vanes will close faster.
- Excitation system will switch OFF.
- BFV will close.
- Turbine speed will come down, brakes will be applied at 90 RPM, and unit will come to stand still.

Reset all annunciations.

The unit auxiliaries i.e., oil pressure unit (OPU) pump shall be switched ‘OFF’ automatically after 3 minutes of machine coming to standstill.

**Normal Stop**

This mode is usually activated intentionally when turbine is required to be shut down for maintenance. The command is initiated by pressing the ‘Normal stop’ push button on TACP (Turbine Actuator Control Panel).

On actuation of this command, the following sequence will be followed:

- The load on machine will gradually decrease.
- When guide vane position indication is 5%, 3.3 kV breaker opens.
- BFV will close.
- Brakes will be applied at 90 rpm.
- Machine will come to stand still.

**Special Stop**

In this mode of shutdown, the machine is brought to no load speed & is kept ready for next synchronization.

In order to activate this command, ‘Special Stop’ push button is to be pressed on TACP.

The following sequence will be followed:

- The load on machine gradually decreases.
- When guide vane position indication is about 5%, then the 3.3 kV breaker opens.
- The machine is brought to the no load speed limit.
RAJWAKTI ELECTRICAL MAIN CIRCUITS PRODUCTION (RPRO), EVACUATION (REVA) AND AUXILIARIES (RAUX)

TO 66kV GRID

800A ISOLATOR
WITH EARTHING SWITCH

PT

2000A
SF6 BREAKER

50/1A
CT

5000kVA, 3.3kV/66kV
UNIT TRANSFORMER

1200A
VCB

3.3kV BUS

630A
VCBs

1800kW

G G

200A
MCCB

3.3kV, 200A
VACUUM CIRCUIT BREAKER

100kVA, 3.3kV/433V
AUXILIARY TRANSFORMER

200A
MCCB

200A
MCCB

DG

AUXILIARIES

415V, 200A (AUX. BUSBAR)

Figure 2.14: Rajwakti SHP (2 x 1800) – Single Line Diagram

(Source: SHP Simulator AHEC)
Figure 2.15: Rajwakti SHP (2 x 1800) – Metering & Relaying Single Line Diagram  
(Source: SHP Simulator AHEC)

Figure 2.16: Rajwakti SHP (2 x 1800) – Turbine Control Panel (Control Desk)  
(Source: SHP Simulator AHEC)
2.2 MODERN CONTROL OF LARGE HYDRO POWER STATIONS - DISTRIBUTED COMPUTER CONTROL SYSTEMS

2.2.1 Introduction

Modern control system employed for large power stations is distributed computer control system with adequate redundancy as generally shown in figure 2.18. Provision for offsite control is also shown in figure.

Main controllers that is turbine governor and excitation control are controlled by microprocessor controller (PLC based). The digital modules used in the controller should belong to the same family hardware which is also being used in unit control panels. Software used in the governors generally includes PID/temporary droop control scheme for regulation; Start up and shutdown logic etc. Similarly excitation system controls are microprocessor PLC based. Function block programming language to be used should be same as in unit control panels. For details refer Para 7.13 Vol. – I for governor & Para 11.11 for excitation system.

2.2.2 Functional Capabilities

Functional capabilities generally or can be provided are summarized below:

i. Computer based automation system should permit operation of power plant, switchyard, outlet works, Inlet valves etc. from a single point (centralized control room).
ii. Local control may be provided by equipment preferably located near the generating unit. The local unit computer should be part of the equipment.

iii. Automatic unit start/stop control sequencing is part of computer based automation. Automation system should include capability to provide diagnostic information so as to isolate the problem and get the unit on line as fast as possible.

iv. Auto synchronizing is computer based. There is no objection to provide synchronizing function as internal to the automation system. Check synchronizing relay is provided for security.

v. The computer system should optimize individual unit turbine operation to enhance unit operation in respect of following:
   a) Efficiency maximization - gate position, flow, unit kW output, unit reactive power output.
   b) Minimization unit of vibration or rough running zone - gate position, unit vibration.
   c) Minimization of cavitation: Adjust Gate position, flow, Hydraulic head as per turbine manufacturers cavitation curve.
   d) Black start control - This may include starting emergency generator.

vi. Centralised Control – Individual units, switchyard, station service control, plant voltage/VAR control, water and power optimization; Forebay level control.

vii. Provide Data acquisition capabilities

viii. Provide Alarm processing and diagnostics

ix. Provide Report generation

tax. Provide Maintenance and management interface

xi. Provide Data acquisition and retrieval

xii. Provide Data access

xiii. Provide Operator simulation training

xiv. Provision of operation in stand alone or in an isolated island by frequency relays.
2.2.3 System Architecture, Communication and Databases

i. Open architecture system is followed in accordance with IEEE-1249-1996. Interface or operating standards for the following is required to be intimated and should comply with ISO/IEC 12119/IEEE 802.

- Hardware interconnectivity
- Time stamping of data,
- Communications
- Operating system
- User Interface
- Database

ii) Each of these elements should be capable of being replaced by or communicate with system elements provided by other vendors.

iii) Distributed control system is used

iv) Adequate redundancy is provided

2.2.3.1 Control Data Networks

Local area networks (LANs) are required to be configured to IEEE 802.3 (Ethernet) standard. Commerciably available software is to be used as far as possible.

2.2.3.2 Man-Machine Interface (MMI)

The operator’s station of the station controller (SCADA system) is required to have an elaborate and friendly man-machine interface. A 19” or larger monitor should be provided for the display. Provision should be made for connecting a second colour monitor in parallel. The screen display should be suitably designed to provide information in most appropriate forms such as text, tables, curves, bar charts, dynamic mimic diagrams, graphic symbols, all in colour. An event printer should be connected to PC of the SCADA system. Events should be printed out spontaneously as they arrive. Provision should be made to connect and use another printer simultaneously. Touch control screen, voice and other advanced modes of MMI are desired and preferred. The entire customization of software for MMI and report generation is required to be carried out to the satisfaction of the purchaser. A windows based operating system should be used.

Hardware

Input/output system is required to have following capabilities.

i. Portability and the exchange of I/O cards from one I/O location to another. This can reduce spare parts requirements.

ii. Availability of I/O cards to be replaced under power. This avoids the need to shutdown an entire I/O location to change one card.

iii. Sequence-of-Events (SOE) time tagging at the I/O locations; accuracy and resolution is required.

iv. Availability of I/O signal types and levels that support the field device signals are used.

v. Support of redundant field devices, capability for redundant I/O from field device to the database and operator interface are required.

vi. I/O diagnostics is required to be available at the card, e.g., card failure indicating LEDs, or through software in the system.

2.2.4 Grounding

Each equipment rack in which automation system components are located are required to be separately connected to the ground mat by a large gauge wire.
Shielded cables are used for analog signals between the transducers and the automation system. Each shield is tied to the signal common potential at the transducer end of the cable. If there are terminations or junction boxes between the transducers and automation system, each shield circuit is maintained as a separate continuous circuit through such junction or termination boxes.

2.2.5 Static Control

Equipment is required to be immune to static problems in the normal operating configuration. Anti-static carpet and proper grounding for all devices that an operator may contact are required to be provided.

2.2.6 Control and Monitoring Plant Equipment

Information and control signal for proper control and monitoring required from the following main and auxiliary/associated equipment and are provided along with the equipment in accordance with the IEEE 1010. Deviations are required to be intimated. 25% spare capacity for inputs and output are required to be provided.

The control system should receive 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. Status input is 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 provides 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.

2.2.7 Supervisory Control and Data Acquisition (SCADA) – Functions

Supervisory control and data acquisition system for control and monitoring of the plant should be provided using Man Machine Interface (MMI) & (Data Acquisition System) DAS computers. The system is intended to meet total operating functions of the plant, which are normally performed by plant operators.

The SCADA system should be complete with all primary sensors, cables, analyzers/ transmitters, monitors, system hardware/ software and peripherals etc. to monitor/ control the parameters for control, protection, annunciation, event recording for different equipments including:

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator stator and rotor winding temperatures</td>
</tr>
<tr>
<td>Lube oil temperature</td>
</tr>
<tr>
<td>Generator air gap monitoring</td>
</tr>
<tr>
<td>Status of generator coolant condition</td>
</tr>
<tr>
<td>Acoustic levels</td>
</tr>
<tr>
<td>Vibrations</td>
</tr>
<tr>
<td>Flow measurement</td>
</tr>
<tr>
<td>Turbine efficiency</td>
</tr>
<tr>
<td>Cavitation of turbine blades</td>
</tr>
<tr>
<td>Level measurement</td>
</tr>
<tr>
<td>Governor control monitoring of turbine Speed</td>
</tr>
<tr>
<td>Generator terminal voltage, current, KW, KVAR, KVA, KWH, Frequency, power factor, field voltage and field current</td>
</tr>
<tr>
<td>Annunciation for violation of permissible limits of the above parameters</td>
</tr>
<tr>
<td>Turbine bearing temperature</td>
</tr>
<tr>
<td>Guide bearing temperature</td>
</tr>
<tr>
<td>Guide bearing oil level</td>
</tr>
<tr>
<td>Guide vane bearing oil temperature</td>
</tr>
<tr>
<td>Generator bearing temperature</td>
</tr>
<tr>
<td>Generator winding temperature</td>
</tr>
</tbody>
</table>
Governor oil pumps, oil pressure indicator and low pressure switch  
Cooling water pumps, suction and discharge pressure switch/ gauge  
Inlet pressure gauge at inlet of turbine  
Vacuum gauge for draft tube pressure (Reaction Turbine)  
Level indicator for level in the forebay  
Measurement of water Flow equipment  
Annunciation

Overall philosophy of control and monitoring of the plant may be as follows:

**Without SCADA:** All Control functions for the generating units are through the electronic panels of control boards, with the associated interlocks, sequential operation and protection trip functions being met by the software programs in the processor modules. Overall monitoring may be through the indications, meters and annunciation features provided on the control boards. Station operators may take care of the data logging.

**With SCADA:** In this mode, each and every control functions provided on Unit Control Panel and Line control panel is through the MMI of SCADA system. Further, the joint control of units for overall control of active, reactive power and voltage is carried out from MMI of SCADA. Commands from SCADA are dispatched to respective unit control boards through Ethernet bus. Further, processing of commands is done by the DPUs of unit control panels through their software logic.

Automatic logging of periodical logs, event logs and alarm summaries may be achieved in the SCADA system along with overall plant monitoring through data acquisition in the form of alarms, mimics, trends, bar charts etc. Total plant operation, monitoring, logging etc. should be possible from SCADA without any need of attendance elsewhere in the plant.

2.2.8 **Description of a Typical Distributed Control System (Steppe Sequence Starting)**

The control system is built up of independent control modules in hierarchical control levels. The overall control is affected from the Operator Work Stations. The operator console assists the operator for an easy operation of power station. It also allows to print out and show on the video displays all relevant signals, events, alarms, status, status change, abnormalities, history data and plant conditions on request or immediately in case of alarm. The data is stored on hard disk. The operator console is connected to next level, namely the control boards, through a local network.

Basic manual control of drives is made possible from control boards. The local unit control board (UCB) or starter panel can be used in case of failure of control boards or for test and maintenance purposes.

The control system should be suitable for manual and automatic start-up, running & shutdown of the generating units and the station auxiliary systems.

The control should be accomplished by master control or step sequence systems to be realized using Distributed Processing Units DPUs).

In the system each unit is controlled by a unit control board for automatic start-stop sequence. In the automatic mode the unit is started and stopped by computer control or by push buttons which actuates the complete sequence with all interlocks while in the manual mode only the plant safety requirements is actuated.

The unit control should be responsible for the overall sequence of operation, for example when the machine is started or shutdown, it takes the process criteria as its input and execute a sequence program and issues commands to the drive control. It checks for the presence of all the required criteria before it issues a particular command. Also time taken for the execution of the command is monitored and an alarm or trip is generated if command execution takes more than stipulated time.

2.2.8.1 **Functional Group and Drive Control**

Control of all auxiliaries and drives pertaining to the unit is carried out. It should be possible to control either by the commands received by the sequence control or commands from push buttons mounted on the
UCB panel. All required logic and interlocks for each drive should be built up by software logic in the system.

2.2.8.2 Sequence Control

Master/Stepped sequence control performs the functions of sequential start up, shut down and/or changeover of the status of the machine. The status standstill, shut down, spin and generate. Master control type control is preferred.

2.2.8.3 Modes of Operation

The unit control is operated in three modes:

• Automatic mode
• Step by step mode
• Automatic inactive mode (manual mode)

2.2.8.4 Automatic Mode

In the automatic mode the operator gives the command only once to start the program. No further intervention is needed for normal execution. Normally the unit is operated in this mode. At each step, specified process criteria is to be checked and the program continues if the criteria is satisfied. A time monitoring of each step execution is provided and if this time is exceeded, the program stops and display the missing criteria. During the program execution if any protection operates, program execution stops and the machine brought to shut down.

2.2.8.5 Step by Step Mode

This mode is used to execute the program in steps. Every time a step is ready to be executed, the operator initiates the step through a push button command. This mode is used during commissioning and test phases. All indications of the sequence control and display of missing criteria is available in this mode. If timing of the step exceeds the set time, execution is blocked. On completion of each step, an indication for the readiness to execute the next step is available. The commands to functional group and drive control are issued during execution of the relevant steps. The drive control is also possible by operating push button command in this mode of operation.

2.2.8.6 Automatic Inactive Mode

In this mode of operation the sequencer operates as in automatic mode except that no commands for drives are issued by the sequencer. The operations are performed by the respective push buttons command. It is possible to start the drives by manual commands to the functional group or drive control from the unit control panel.

A typical stepped unit starts and stop logic was specified for Canal fall 20 MW project and is shown in following figures.

2.19 (a): Legends
2.19 (b): Main Programmes
2.19 (c): Start sequence (4 sheets)
2.19 (d): Partial Shutdown
2.19 (e): Stop Sequence (4 sheets)

2.2.8.7 Protection Functions

Protections are grouped as emergency shutdown and control action shut down as shown in figure 2.4 (3 sheets). Protection logics is derived both through software and through hard wiring. On initiation of emergency shutdown, the sequencer issues commands for tripping the generator breaker, field breaker and turbine shutdown. On initiation of control action shutdown, guide vanes are closed first and generator breaker and field breaker tripped after guide vane closing. Partial shutdown brings the unit to spin position figure 2.19 (d).
Typical Unit Start Stop Logic
(Large Power Station)

with reference to a Kaplan Generating unit (Bulb Turbine Generator)

Legends

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>END STATUS</td>
</tr>
<tr>
<td></td>
<td>&lt;MODE OF SERVICE&gt;</td>
</tr>
<tr>
<td></td>
<td>TRANSIENT STAGE</td>
</tr>
<tr>
<td></td>
<td>PROGRAMME START COMMAND</td>
</tr>
<tr>
<td></td>
<td>STEP OF SEQUENCE</td>
</tr>
<tr>
<td>&amp;</td>
<td>AND GATE</td>
</tr>
<tr>
<td>OR</td>
<td>OR GATE</td>
</tr>
<tr>
<td></td>
<td>CONTINUATION</td>
</tr>
<tr>
<td></td>
<td>SUB. PROGRAM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SD</th>
<th>Shut down</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>Stand still</td>
</tr>
<tr>
<td>SP</td>
<td>Spin generation (no load)</td>
</tr>
<tr>
<td>G</td>
<td>Generation</td>
</tr>
</tbody>
</table>

(Source: Mukerian Project AHEC)

Figure 2.19 (a): Legends
Figure 2.19 (b): Programmes and Main Program List
(Source: Mukerian Project AHEC)
Figure 2.19 (c): Start Sequence - Shut down to Stand Still – (Sheet 1 of 4)
(Source: Mukerian Project AHEC)
Figure 2.19 (c): Start Sequence - Shunt down to Stand still – (Sheet 2 of 4)
(Source: Mukerian Project AHEC)
Figure 2.19 (c): Start Sequence - Stand Still to Spin Generator (Sub Programme)
(Source: Mukerian Project AHEC)
– (Sheet 3 of 4)
Figure 2.19 (c): Start Sequence - Spin Gen. - Generation (Sub Programme)
(Sheet 4 of 4)
(Source: Mukerian Project AHEC)
Figure 2.19 (d): Generation to Spin Generator (Sub Programme) – Partial Shutdown  
(Source: Mukerian Project AHEC)
Figure 2.19 (e): Stop Sequence - Generation to Stand Still (Sub programme)
(Sheet 1 of 4)
(Source: Mukerian Project AHEC)
Figure 2.19 (e): Stop Sequence Generation to Stand Still (Sub programme)  
(Sheet 2 of 4)  
(Source: Mukerian Project AHEC)
2.2.8.8 Input /Output Modules

Input modules are used for signal acquisition from the field and convert them to bus compatible signals. Output modules are used to convert the bus compatible signals to command signals to operate output relays.

2.2.8.9 Input/Output Relays

All the outputs to the field should be through output relay module/interposing relays mounted in the panel. Input relays are used wherever the field signal is to be multiplied for meeting the requirement of annunciation etc. The output relays should be adequately rated for operating the field devices.
2.2.8.10 Processor Modules (DPU-Distributed Processing Unit)

Each processor is provided a 100% redundant processor as hot standby.

2.2.8.11 Diagnostics

Supervision and self-diagnostic features for detecting faults in the processor, power supply, I/O modules is in-built features.

2.2.8.12 Power Supply

The electronic panels of control board operate on 24 volts DC supply with uninterrupted power supply (UPS) system.

2.2.8.13 Meters and Control Switches

The required meters, control switches, Illuminated Light Push Button (ILPB)/indicating lamps and selector switches etc are provided on the control boards. Emergency trip push button (guarded with flap) for emergency tripping and push buttons for selecting targets like spin, generate shutdown, stop program, execute, auto inactive, step by step, release etc. are also provided.
2.2.8.14 Alarm and Annunciation

A microprocessor based alarm annunciation system is to be provided for trip / non-trip alarms pertaining to turbine, generator, sequencer, excitation, generator transformer etc. related to units and mounted on unit control board. Similarly a microprocessor based alarm annunciation system should be provided for trip / non-trip alarms pertaining to common auxiliaries feeders and bus coupler and mounted on common control board. A typical unit tripping and Annunciation block diagram is shown in figure 2.20.

2.2.9 Common Control Board

A common control board for the control & monitoring of common station auxiliaries, Feeders and Bus coupler is also required to be provided. The panel may consist of the required number of switches, ILPBS, relays, indicating meters etc. as required.

Following automatic and manual synchronizing equipments are generally provided on the Common Control Board.

• A dual channel auto synchronizer with voltage and frequency matching units which issues voltage adjustment and speed adjustment commands and releases breaker closing command when the frequency, voltage and phase of the generate and grid are matched within limits.
• Manual synchronizing equipment consisting of synchroscope, voltmeter and frequency meters for incoming and running bus and a check synchronizing relay is also provided.

2.2.10 Engineering Work Station (Programming & Training Console)

The programming tool included in the Engineering Station is used for accessing & modifying logic programs of the processor modules, reading the status of binary & analog signals with their addresses, simulating signals to the processor.

2.2.11 Battery and Battery Charger

Two numbers battery chargers, common battery bank and direct current distribution boards (DCDB) are provided for the stabilized power supply requirement of electronic panels of control boards. Lead acid plante/Nickel Cadmium batteries of sufficient capacity should be provided. The battery charger should be provided with its associated float and boost charger.

2.2.12 UPS System for SCADA

Two nos. UPS system having common battery and common AC Distribution Board & manual by-pass are provided for giving regulated Uninterrupted Power Supply to SCADA.

The system should be solid state type with silicon controlled rectifiers to convert mains input to DC for charging the battery. The UPS work on a 1-phase 230 volts supply.
2.2.13 Grounding System and Static Control

A separate grounding system should be provided for the plant and static control as generally shown in figure 2.21.

2.2.14 Testing

Factory Assembly and Test, Field Test should be performed as given in the typical specifications.

A training programme for the operators and maintenance personnel should be included in the procurement specifications.

2.2.15 Typical Technical Specification for computer based group control, monitoring, metering, centralized control, offsite control and data acquisition system (SCADA) for a (2 X 75 MW) main power house and offsite control for two canal based (2 x 11 MW each) hydro generating station.

2.2.15.1 General

A hydro-generating station of capacity (2 x 75 MW) and two identical hydro stations each of capacity (2 x 11 MW) are on a Canal off taking from the powerhouse tailrace at RD 1000 m and 2000 m. The powerhouses are to be interconnected to 245 kV grid sub stations as well as supply a local industrial load of 65 MW near canal powerhouse no. 2. The three powerhouses are to be supervisory controlled from main powerhouse. Main single line diagram of the main powerhouse is shown in figure 2.22 (a) and of the identical canal powerhouses in figure 2.22 (b). Interconnection with grid is shown in figure 2.23.

Specifications for Design, manufacture, testing at manufacturers works before dispatch, delivery to the site, storage till installation/commissioning, software installation, testing and commissioning of the unit and
station control system for the hydro generating station 2 x 75 MW each and two canal based hydro stations of 2 x 11 MW each with their associated auxiliaries and offsite control system from the main powerhouse.

The control system shall primarily be computer based control system, programmable logic with manual/local and centralised supervisory control suitable for centralised control from control room in each powerhouse and offsite supervisory control and data acquisition (SCADA) system for the 2 canal power houses from main power house in addition to the centralised control at each power house. Manual control and protection system panel shall also be provided. Local and centralised control configuration is shown in Dwging 2.24.

Protection to be provided is discussed in Chapter 3.

Interconnection with Regional Load Dispatch Centre shall be provided for necessary data from the offsite control station e.g. scheduled power generation, power plant output, time error bias, power frequency system bias etc.

2.15.2.2 Control Hierarchy

i. Local manual/automatic mode from hard wired control board
ii. Centralized automatic control from PLC/Computer package in the control room
iii. Off site computer control from main powerhouse for canal powerhouses

Figure 2.21: Computerised Control & Monitoring System - Grounding Scheme
(Source: Mukerian Project AHEC)
NOTES
WAVE TRAP
HV CIRCUIT BREAKER
1.
LEGEND
NOMENCLATURE
AVR ----------AUTOMATIC VOLTAGE REGULATOR
LIGHTNING ARRESTOR
COMMUNICATION LINK FOR OFFSITE CONTROL
BY CARRIER SYSTEM IS TENTATIVE.
COUPLING VOLTAGE TRANSFORMER
POTENTIAL TRANSFORMER
52 ----------HIGH VOLTAGE CIRCUIT BREAKER
FUSE
CURRENT TRANSFORMER
TRANSFORMER
EARTH
ISOLATING SWITCH
EXCITATION BREAKER WITH DISCHARGE
RESISTOR
UAT ----------UNIT AUXILIARY TRANSFORMER

72.5 KV BUS
11 KV BREAKER

52-3
METERING
SURGE
ARRESTOR
30/5
600/5 PS

THE DRAWING IS TENTATIVE ONLY
FOR TENDER PURPOSE

3.

75 MW 0.9 PF 11 kV
GENERATOR-1G1
41G
RECTIFIER
TRANSFORMER
POWER
CONVERITOR

Figure 2.22 (a): Main Powerhouse Single Line Diagram

Figure 2.22 (b): Canal Powerhouse No. 1 Single Line Diagram
Figure 2.23: Interconnection with Grid
2.2.15.3 Functional System and Scope of Work

Local Controls

1. Testing/Manual/automatic control from unit control boards at machine hall floor alongwith following.
2. Digital governor electrical control cabinet
3. Digital excitation control cabinet
5. Manual/automatic control of switchyard equipment from control room for canal power house
6. Manual/automatic control of switchyard equipment from switchyard for main power house

Centralized Control

1. Manual/automatic control of unit and common auxiliaries
2. Manual/automatic control of switchyard equipment for canal power house
3. Off site automatic control of switchyard from main powerhouse
4. Automatic control of canal powerhouses from main power house
5. Data Acquisition and Retrieval System

Scope of Work

The scope of work shall be comprehensive functional system complete in every respect including but not limited to following.

• Local Control Boards

The computerized control, monitoring and data acquisition system shall comprise of following local control boards at each of the three powerhouses.

i) Six (sets) hard wired – 2 sets for each powerhouse unit control boards (UCB) with all necessary accessories for each controlled generating unit in the machine hall floor for manual/automatic control of the unit.
ii) Three – one set for each powerhouse – local/automatic control board (LCB) for control of station and common auxiliaries located in the machine hall floor.
iii) Two – one set for each canal powerhouse – manual/automatic control Boards for switchyard protection and control in the control room.
iv) One set for main powerhouse manual/automatic control board for switchyard equipment for the main (2 x 75 MW) powerhouse with RTU for manual/automatic control in the centralized powerhouse.

• Centralised Control and Data Acquisition System (Control Room)

i) Three sets of computer based centralized operator work stations for each powerhouse with one set of TFT monitor for each computer and all necessary accessories and software.
ii) Three sets – one set for each powerhouse Data Acquisition System (DAS)/ Data Logger system comprising of suitable capacity Network attached storage system (one main & one hot standby).

• Offsite Supervisory Control of canal power houses in addition to centralized control of main powerhouse from a common desk.

i) Two sets of computer based centralized operator work stations with one set of TFT monitor for each computer and all necessary accessories and software.
ii) One (1) fixed Engineering station will all necessary accessories and software.
iii) One (1) portable engineering station with dockable arrangements, printer all necessary accessories and software with all necessary interfaces; accessories and equipment.
iv) Large Screen Display (LSD) with suitable diagonal screens and high resolutions of at least 1280x1024 pixels per block with necessary display controller shall be provided. LSD shall be connected to the
Central Control Room Network through a display controller, so as to display any combination of the control system views to be selected from any of the Operator Work Station.

v) Programming & Training Console: The Console should permit software development and operator training while providing backup hardware for use where the manual operator interface is out of service. Interlocking should be provided to permit only one console to be in control at a time.

- Manual and Automatic Synchronising Equipment
- Status Switchboards
- Annunciation and Alarm System
- Communication Link

1. Dedicated communication by Fibre optic cable system between control rooms of canal power houses to offsite control centre at main power house along with terminal equipment for control, data acquisition, local area network for distributed control and for voice communication. The fibre optic cable will be laid underground along the canal.
2. Voice communication between control rooms of each power house and (i) switchyard (ii) Centralised main power house.
3. Dedicated communication link with Regional Load Despatch Centre.

- Computer Furniture

Necessary computer furniture consisting of operating desks for Engineering stations, data storage and operator work stations with ergonomically suitable chairs etc. at the three power stations shall be provided.

- Process control networks

The communication links between the process control computers and the station control centre shall be realised by using high-speed double bus system using fibre optical cable, LAN with all necessary accessories and interfaces.

- Software

Supply of all necessary software as per the clause "Design and Construction" of this section, their license for use, and source codes for the process software that are specific for this project.

- Interfacing services and supply

Coordination, supply of associated interfaces including transducers and integration of all plant equipment and subsystems including all auxiliaries and station services with the computerized control and monitoring (SCADA) system for complete control, real-time communication and data acquisition.

- Miscellaneous items

i) One (1) set of spare parts
ii) One (1) set of tools and special instruments

Any other items not mentioned specifically but necessary for the satisfactory completion of scope of work defined above, as per accepted standard(s) / best international practices.

2.2.15.4 Applicable Standard

The system and equipment shall be designed, built, tested and installed to the latest revisions of the following applicable standards. In the event of other standards being applicable they will be compared for specific requirement and specifically approved during detailed engineering for the purpose:
### 2.2.15.5 Control and Monitoring of Plant Equipment: General Considerations

(a) Canal Power house will be designed for local/automatic control from unit control board (UCB) located in machine hall floor. Centralised automatic control from computer located in the control room in the upstream gallery and shall be designed for operation by a single operator/unattended operation.

(b) Unit Metering and Relaying as proposed is shown in drawing 2.25. This is tentative drawings. Final drawings will be prepared by tenderer and approved by the Purchaser. Protective relaying to be provided is discussed in Chapter 3.

(c) The canal power houses are proposed to be controlled by supervisory offsite control from main powerhouse control room. Accordingly provision is to be made for manual and automatic control for unit starting. Unit stopping and running control at each powerhouse with provision for supervisory offsite control and data acquisition at main powerhouse.

(d) Dependable digital controls for system control with conventional control as backup manual control are proposed.

(e) Power house units operation and loading in canal powerhouses is proposed to be based on canal water level.

(f) The Kaplan turbines proposed for the unit are directly coupled to bulb generator.

(g) Emergency conditions (power house units tripping etc.) will be taken care of by operating regulating by pass gates.

(h) A PLC based control board for manual/automatic control of unit and common auxiliaries as well as by pass gates and level control etc. shall also be located in the machine hall floor along with unit control boards.
(i) The turbines are proposed to be provided with governor with PLC based control system. The governor control panel will be located along with unit control board in the machine hall floor.

(j) The generators are proposed to be provided with static excitation with digital PLC based control system. Excitation control panels will also be located in the machine hall floor along with unit control board.

(k) A single sectionalized bus is proposed for reliability.

(l) Provision for stable operation when operating alone or in an island shall be made.

(m) Necessary sensors and actuators for the turbine, generator, transformers and other equipment have been specified along with the equipment. Any additional sensors or actuators required for the control and monitoring as detailed in this chapter or necessary shall be supplied.

(n) Open architecture system shall be followed using commercially available software to avoid obsolescence.

Detailed layout of panels in the machine hall and control room will be subject to Approval by Purchaser.

2.2.15.6 Specific Parameters and Layout Conditions

Control and Monitoring Equipment

Hard wired manual/automatic unit control board (UCB) shall be central control means and shall communicate with the unit and associated equipment and shall be designed to perform following functions.

(a) Information receipt and monitoring
(b) Start stop control sequencing – Start sequence will be with master control relay shown in figure 2.26
(c) Annunciation of alarm conditions
(d) Temperature information monitoring  
(e) Metering and instrumentation signals display  
(f) Synchronising and connecting the unit to the system  
(g) Control of real/reactive power  

Required control and monitoring of all functions of the hydroelectric power project shall be provided to the operator. The control console with conventional control devices and monitoring equipment in conjunction with a computer based data acquisition and control system (DACS), shall provide control and indication access to individual items of equipment to facilitate operation, supervision and control. Hard wired pushbutton switches shall provide for direct operator manual control of unit start-stop, breaker close (initiating automatic synchronising), breaker trip, voltage loading and gate limit raise-lower. Analog or digital panel meters and indicating lights shall continuously indicate the status of all main units, breakers, transformers, and lines. The DACS system display monitors and keyboards shall be available to operator control. The unit controls and instruments shall supplement or duplicate those on the generator switchboard, and provide the control room operator with the ability to transfer control of any selected unit or group of units to the generator switchboard in case of system trouble. The control console may also provide spillway gate control, project communications and other project equipment control functions. Panels shall have 25% spare capacity of digital and analogue inputs/output.

**Equipment Location:** Arrange the control and instrument switches and mimic bus to simulate the relative order of interconnections or physical order of the plant arrangement assisting the operator in forming a mental picture of connections. The top of the control console panel should be inclined to provide easier access to the control switches and to improve console visibility.

![Start Sequence for Generating Unit with master Control relay](image)

**Figure 2.26:** Start Sequence for Generating Unit with master Control relay
Layout and General Arrangement of Supervisory Control

The control and monitoring system shall be built up of distributed and independent control modules in hierarchical control levels. All the components and subsystems in the hierarchical control levels of the control system shall be seamlessly integrated to achieve a highly reliable power plant control system.

The overall control shall be affected from the Centralised Control Room in each powerhouse. The highest control level shall be the Operator Workstations in the Central Control Room (CCR). From the Operator Workstations, the operator shall have the possibility to perform in real-time, controls and adjustments for all the equipment of the scheme.

All the computers, peripherals, software, actuators, sensors, measuring instruments and other hardware shall be of latest state of the art at the time of supply. The control system should be built in such a way that in case of a fault in any single equipment others are not affected and system continues to function effectively.

The control system shall be designed on open architecture based on IEC standards. The control and monitoring system and the components shall be selected taking the following requirements into consideration:

• Reliability of components and subsystems,
• Availability of spares,
• Ease of maintenance,
• Service availability and adaptability for future technology developments.

Networking and communications

All the optical fibre, cabling shall be protected by suitable metal conduits as shield to protect them from moisture and micro bending. All redundant cables shall be physically routed along different paths so as to ensure higher availabilities. The networks shall be designed for 1 Gbps (Gigabit per sec.), real time and full duplex (bi-directional) communications.

All networks shall be configured to form a dual star topology with switched based Ethernet. The networks shall be designed with redundancy.

2.2.15.7 Rating and Functional Characteristics

Interoperability

The complete design of the computerized control and monitoring system shall be based on interoperability of equipment from different manufacturers and the Supplier shall be responsible for overall functional integration of the system. The control system shall be implemented on open standards based on Object oriented design.

It shall be the responsibility of the Contractor to verify and solve all interoperability issues of various components / equipment connected to the network. The Contractor shall perform a type conformance test to validate the implementation of the communication protocols.

Topology, Protocol, Redundancy and Availability

Topology is physical connection and protocol dictates how devices will communicate with each other in a network. The networks shall be configured using redundancy of communication media, servers, routers and switches, in dual star switched topology with Ethernet protocol with dual homed mesh redundancy, to achieve high operational availabilities for top order events. The system availability shall analyse and calculations shall focus on availability of the control system for the top order event: "Availability to retrieve all process data from LCBs and operate all breakers and shutdown all units". The overall system unavailability shall be computed by considering individual device unavailability in a fault tree analysis.
using MTBF (Mean Time between Failure) and MTTR (Mean Time to Repair) values of each device as supplied by its manufacturer.

**Decentralised Control**

The instrumentation and control system shall be based on the decentralized intelligence system, which means that Controllers of the corresponding system operates the logic and control functions.

The control system shall be divided into discrete functional subsystems. Each sub-system shall be controlled from its Local Control Board if the "LOCAL" position is selected. The Local Control Board of each system includes redundant power supply distribution, interfacing terminals with the process, redundant controllers and HMI. Each Local Control Board shall have provisions and interfaces for direct connection of mobile engineering stations.

The Local Control Boards' associated with switchyards 'and generating units (Unit Control Boards) shall, in addition to the above, consist of automatic and manual synchronizers.

**Computers and Peripherals**

Computers used in the control and monitoring system shall preferably be of a standardized type suitable for industrial environments and of a brand approved by the Purchaser. The signal transmission shall be via redundant fibre optic cables. All monitors shall be of SXGA resolution, flicker free TFT type with at least 20" screen size. All keyboards / functional keyboards / keypads to be supplied except those in offices and on Power House LAN shall be membrane protected. All Computers, printers and other accessories supplied shall be of robust and tropicalized type of construction so as to withstand Hydro power plant environmental conditions.

**Programmable controllers for LCBs and UCBs**

The programmable controllers / PLCs to be supplied shall be modular in architecture and microprocessor based design suitable for harsh industrial environments. All power supply cards, I/O module connections and other external interfaces shall be provided with suitable surge protection devices to protect the controllers and internal circuitry from external surges. Unless otherwise specified, the equipment shall be in compliance with IEC 61131 standard.

For each output a safe position shall be defined for cases of failure of power supply, I/O module, CPU, etc. This safe position shall be clearly defined by the Supplier and submitted to the Employer. Each controller shall have built in functions of on-line self diagnostics / watch dog features etc and shall report failures to the operators of the control system. Each I/O point of the controllers shall be supplied in standard rack-mounted I/O modules with plug-in boards. Each I/O point shall be furnished with:

- Protective network, such as surge protections, optical coupling and/or other isolating barriers,
- Filter for noise reduction,
- Test points and fault indication lamps,
- Fuse protection and fuse failure detection.

**Emergency shut down**

Emergency shutdown equipment shall be implemented though hardwired logic. Emergency shutdown shall be initiated by the monitoring and protection devices as well as by manual release of the emergency shutdown buttons to be provided in the UCB and Central Control Room. The timing "of emergency shutdown and associated closure devices shall be adjusted according to the hydraulic requirements of the system.
Metering

For monitoring the generation and transmission of power, a metering system using digital meters shall be provided for all lines and feeders, Units, Station Auxiliary Transformers and DG Sets. All measurements such as voltage, current, power, energy etc., used for monitoring, shall be provided as per drawings. All the energy meters used for measurements shall have minimum accuracy of 0.2% and shall be connected to the data acquisition system for automatic meter readings.

Time resolution of events

Resolution of dating of events for purposes of sequence of event recording shall be of 1 milisecond.

Performance Guarantee

The computerized control and monitoring (SCADA) system along with all auxiliaries and accessories shall be capable of performing intended duties under specified conditions. It is the responsibility of the Contractor to supply the equipment as per guaranteed technical particulars and shall also guarantee the reliability and performance.

Real time, full duplex data transmission rate, of at least 1 Gbps shall be provided. The availability of 1 Gbps data channel between two remote stations shall be greater than 99.99% and shall be guaranteed. The Overall control and monitoring (SCADA) system availability for top order events shall be at least be 99.98% and shall be guaranteed.

The control system shall be guaranteed against interoperability with all the power house equipment and shall comply with IEC 60870-5 series.

2.2.15.8 System Architecture, Communication and Databases

i. Open architecture system shall be followed in accordance with IEEE-1249-1996. Interface or operating standards for the following shall be intimated and should comply with ISO/IEC/IEEE std.
   Hardware interconnectivity
   Time stamping of data,
   Communications
   Operating system
   User Interface
   Database

ii. Each of these elements should be capable of being replaced by or communicate with system elements provided by other vendors.

iii. The scope of the bidder is not limited to the parts & components explicitly identified here in and shall have to provide any and all parts/components needed to meet the functional requirements laid down herein or are necessary for satisfactory operation of the plant.

Control Data Networks

Local area networks (LANs) should be configured to IEEE 802.3 (Ethernet) standard.

Commercially available software should be used as far as possible.

Man-Machine Interface (MMI)

The operator’s station of the station controller (SCADA system) shall have an elaborate and friendly man-machine interface. A 19” or larger monitor shall be provided for the display. Provision shall be made for connecting a second colour monitor in parallel. The screen displays shall be suitably designed to provide information in most appropriate forms such as text, tables, curves, bar charts, dynamic mimic diagrams,
graphic symbols, all in colour. An event printer shall be connected to PC of the SCADA system. Events shall be printed out spontaneously as they arrive. Provision shall be made to connect and use another printer simultaneously. Touch control screen, voice and other advanced modes of MMI are desired and shall be preferred. The entire customization of software for MMI and report generation shall be carried out to the satisfaction of the purchaser. A windows based operating system shall be used.

**Hardware**

Input/output system should have following capabilities.

vii. Portability and the exchange of I/O cards from one I/O location to another. This can reduce spare parts requirements.

viii. Availability of I/O cards to be replaced under power. This avoids the need to shutdown an entire I/O location to change one card.

ix. Sequence-of-Events (SOE) time tagging at the I/O locations; accuracy and resolution.

x. Availability of I/O signal types and levels that support the field device signals to be used.

xi. Support of redundant field devices, capability for redundant I/O from field device to the database and operator interface.

xii. I/O diagnostics available at the card, e.g., card failure indicating LEDs, or through software in the system.

**Grounding**

Each equipment rack in which automation system components are located shall be separately connected to the powerhouse ground mat by a large gauge wire.

Shielded cables shall be used for analog signals between the transducers and the automation system. Each shield shall be tied to the signal common potential at the transducer end of the cable. If there are terminations or junction boxes between the transducers and automation system, each shield circuit shall be maintained as a separate continuous circuit through such junction or termination boxes.

**Static Control**

Equipment shall be immune to static problems in the normal operating configuration. Anti-static carpet and proper grounding for all devices that an operator may contact shall be provided.

**2.2.15.9 Control, Monitoring and Data Acquisition System Design**

Control, Monitoring and Data Acquisition System should be provided using MMI/DAS computers complete with all primary sensors, cables, analysers/transmitters, monitors, system hardwares, softwares and peripherals to monitor/control the parameters for control. Protection, annunciation and event recording as per IEEE 1010-2006.

**General**

Information and control signal for proper control and monitoring of the required from the following main and auxiliary/associated equipment and shall be provided as tentatively detailed along with the equipment and outlined in this paragraph. Deviation will be intimated in the bid 25% spare capacity for inputs and output shall be provided.

The control system shall receive 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. Status inputs shall be 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.
Sensors to be used for the equipment are tentatively given in table 2.1.

The designed control and monitoring system shall be common state of art at the time of supply. This specification requires "that all local and remote control systems in the power house and the ancillary plant areas shall be suitable for manual and automatic start-up, running and normal and emergency shut-down of the generating units and the station auxiliary systems. Redundant Controllers of latest microprocessor based design with high processing speedy and solid-state electronic elements shall accomplish the control.

Table 2.1

<table>
<thead>
<tr>
<th>A. Generator</th>
<th>Type of Sensors</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator stator winding temperature</td>
<td>Resistance type temperature detectors (RTD) PT 100 type (Para 2.2.15.10)</td>
<td></td>
</tr>
<tr>
<td>Thrust and guide bearing temperature</td>
<td>Resistance temperature detectors (RTDs) Embedded in walls, shoes of thrust bearing and in each segment of guide bearing</td>
<td>Para 11.12 of Vol. I</td>
</tr>
<tr>
<td>Bearing oil temperature</td>
<td>Temperature detectors in each separate bearing oil reservoir</td>
<td></td>
</tr>
<tr>
<td>Bearing oil level high/low</td>
<td>Sensors for each oil reservoir high/low</td>
<td></td>
</tr>
<tr>
<td>Cooling air each cooler</td>
<td>Temperature detector at inlet and outlet</td>
<td></td>
</tr>
<tr>
<td>Rotor temperature</td>
<td>Temperature monitoring system for continuous monitoring field temperature</td>
<td>For large units only</td>
</tr>
<tr>
<td>Acoustic levels</td>
<td>Suitable noise level measurements</td>
<td>For mega units only</td>
</tr>
<tr>
<td>Vibrations</td>
<td>Microprocessor based as generally described in Para 2.2.15.10</td>
<td>For large units only</td>
</tr>
<tr>
<td>Generator air gap monitoring</td>
<td>Split phase or current unbalance CT as per specified IEEE 1010</td>
<td>For large units only</td>
</tr>
<tr>
<td>Fire detection &amp; protection system</td>
<td>Sensors as generally described in Para 5.6.6 for detection &amp; 5.6.1.3 for fire fighting</td>
<td></td>
</tr>
<tr>
<td>Thrust bearing high pressure oil system start/stop interlock</td>
<td>Pressure switches</td>
<td></td>
</tr>
<tr>
<td>Electrical measurements and protection</td>
<td>Microprocessor based transducer for interface with CTs &amp; PTs as per Para 2.2.15.10</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Excitation System</th>
<th>Type of Sensors</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static excitation system</td>
<td>Generally in accordance with IEEE 1010 And guide specification Chapter 11 of Vol. I</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Turbine</th>
<th>Type of Sensors</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine guide bearing in each segment</td>
<td>RTD for indication and recorder TSD Thermo signaling device for alarm &amp; trip</td>
<td></td>
</tr>
<tr>
<td>Turbine guide bearing oil</td>
<td>RTD for indication &amp; alarm</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Sensors in accordance with table A &amp; B of Turbine specifications in Vol. I Chapter 7</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Turbine bearing in OPU sump</td>
<td>RTD for indication &amp; alarm</td>
<td></td>
</tr>
<tr>
<td>Oil pressure in accumulator</td>
<td>Level switch</td>
<td></td>
</tr>
<tr>
<td>Turbine guide bearing level High/low</td>
<td>Level switch</td>
<td></td>
</tr>
<tr>
<td>Other sensors as considered necessary for the unit</td>
<td>As per IEEE 1010</td>
<td></td>
</tr>
</tbody>
</table>

### D. Governor

<table>
<thead>
<tr>
<th>Type of Sensors</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed indication</td>
<td>As per Para 2.2.15.10</td>
</tr>
</tbody>
</table>
| Synchronous speed, under speed & over speed | a. Electrically actuated speed relays by comparing the speed signal to reference signal  
b. Centrifugal device mounted on the turbine shaft to mechanically actuate over speed switch |
| Other speed e.g. creep detector, start/stop contacts, gate limiter limit switches etc. | As per IEEE 1010/Guide specifications of turbine in Vol. I Chapter 7 |
| Wicket gate position indication/position switches for control & indication | As per IEEE 1010/Guide specifications of turbine in Vol. I Chapter 7 |
| Governor oil pressure unit switches for oil level/pressure and sump oil temperature | As per IEEE 1010/Guide specifications of turbine in Vol. I Chapter 7 |
| Governor power supply failure, generator air brakes etc. | As per IEEE 1010/Guide specifications of turbine in Vol. I Chapter 7 |

### E. Generator Transformer

| Transducers as required | Refer specification of transformers Chapter-6 Annexure 6.2 Para 1.30 |

### F. High Voltage Circuit Breaker

| Transducers as required | Refer specifications of breakers Chapter-7 Annexure-2, Para 1.7 |

### G. Instrument Transformers

| Transducers as required | Refer protection system Chapter-3 |

### H. Auxiliary System

| Transducers as required | Refer chapter 4 & 5 |

Central control centre

The design and layout of control room shall take into consideration all ergonomic requirements associated with the control room layout as per provisions of ISO: 11064 and other international standards. The architectural finishing work, i.e., suspended ceiling, suspended floor, furniture, wall finishing required for the Central Control Room shall be designed by equipment supplier and submitted for approval for execution by civil contractor of the purchaser.

Large Screen Display (LSD)

Large Screen Display with suitable diagonal screens and high resolutions of at least 1280x1024 pixels per block with necessary display controller shall be provided. LSD shall be connected to the Central Control Room Network through a display controller, so as to display any combination of the control system views to be selected from any of the Operator Work Station.

Operator workstations

The operator consoles shall assist the operator for an easy operation and control of power station and shall allow to print out and to show on the displays, all relevant signals, events, alarms, status, status changes, abnormalities, history data and plant conditions on request or immediately in case of alarm. In the control
room two operator workstations with desks shall be provided. Each operator desk shall be equipped with two VDUs, sealed membrane covered keyboard and pointing device such as mouse / trackball, sealed membrane covered function keyboard, integrated telephone set, microphone, writing pad and workplace integrated. Each of the two monitors, attached to the workstations, shall be interfaced to be capable of displaying any of the selected plant control mimic views. All the Operator workstations shall be implemented in such a way so that each workstation shall be capable of individually controlling the entire control system even in the case of failure of all other workstations.

The configuration of each workstation shall be:

- Two VDUs each of at least 20", TFT flat screen and flicker-free,
- CPU with highest CPU clock speeds and available at the time of supply
- Minimum of 2 GBD RAM,
- CD Writer drive
- Two (2) or more - Hard Disk Drives each of at least 80GB capacity
- CD-ROM drive
- USB hub and ports
- Functional key board with all functions and provision of shortcuts for alarms
- Pointing device such as mouse or trackball.

**Engineering stations**

One Engineering Workstations with separate desks shall be provided. The Engineering Station shall be equipped with same configuration as that of Operator Workstations mentioned above. From this desk, it shall be possible to follow the control and operation and to execute trouble shooting, reprogramming, parameter and set point changes and all necessary work to support and maintain the system.

**Portable engineering stations (movable)**

Each portable engineering workstations with necessary accessories shall be provided to maintain, reprogram, check the status and test the LCB programmable controllers, loaded with all software & system configuration settings similar to engineering station necessary for the purpose, shall be included in the scope of the supply. In addition to these stations will be equipped with necessary software & ports to programme, test, data downloading & analysis for Protection relays, Governor and Digital voltage regulator described in other chapters of this document. These stations shall be installed on separate desks in the offsite control room and connected to the control room network through docking arrangements with Advanced Port.

**System Documentation**

The tenderer shall provide drawings, system overview and description, hardware/software details, technical literature, functional and hardware schemes, bill of material, parts list, interconnection diagrams, data sheets, erection/installation/commissioning procedures, instruction/operating manuals, etc. for each of the Control and Monitoring system/subsystems/equipment supplied under this package. The documentation shall include complete details of the Control and Monitoring systems/sub-systems/equipment to enable review by Purchaser during detailed engineering stage and to provide information to plant personnel for Operation and Maintenance (including quick diagnostics and trouble shooting) of these Control and Monitoring systems/sub-systems/equipments at site.

**Electronic Module/Components Details**

The tenderer shall furnish all technical details including circuit diagrams, specifications of components etc. in respect of each and every electronic card/module as employed on the various solid state as well as microprocessor based system and equipment including conventional instruments, peripherals.
2.2.15.10 Specification of Main Equipments

Temperature Monitoring Device

A microprocessor based temperature monitor equipped for serial communication with the process control computer shall be provided. It shall be equipped for processing of required number of inputs (at least 64 inputs) from type PT 100 RTDs. For the RTD's installed in the generator and turbine, decentralised input units shall be provided. These shall communicate with the temperature-monitoring unit in the UCB through a field bus (process bus). Each input shall have two adjustable binary threshold triggering devices for alarm and trip purposes. The unit shall be equipped, at least, with one digital display and corresponding selector arrangement for visual presentation of the readings at each input. High quality unit shall be provided, equipped with such features as if input circuit gets interrupted, alarm or trip shall not be triggered.

One portable temperature recorder shall be provided for each powerhouse. Provision shall be made for an easy hook up of the recorder to the monitoring device to have whichever of the 64 input readings recorded.

Vibration Monitoring Device

The vibration-monitoring device shall be microprocessor based with the capability of communication with the process control computer via serial interface. It shall be equipped with 6 channels to monitor the detectors specified in turbine/generator specifications. Each channel shall be provided with adjustable alarm and trip circuits. For local read-out of the actual vibration levels, a read-out device with selection switch for 6 channels shall form part of the device. The alarm and trip signals shall be blocked automatically during starting of unit in case this turns out to be necessary. Manual blocking facility shall be provided as well.

Speed Monitoring Device

The device as specified in turbine specification shall be installed. The sensors will be mounted on generator shaft giving output 4 to 20 ma or 1 to 5 V.

Manual / Automatic Synchronising Equipment

Provision for synchronising manually and by a dedicated automatic synchronizer unit for each powerhouse shall be made. Synchronizing check relay shall be provided.

Transducers for Electrical Measurements

A microprocessor based transducer unit with serial interface for communication with the process control computer shall be provided. The same unit shall drive all indicating instruments in the UCB. Following functions shall be provided:

a) Current in all 3 phases.
b) 6 voltages (phase to phase and phase to ground).
c) Cos-phi, MW, MVar and Hz.
d) MWh and MVarh.

Digital Status and Alarm Inputs

The controller should be capable of connecting to at least 60 contact type inputs representing digital status and alarms. All contact inputs should be sensed through optical couplers with an isolation voltage of at least 1500 Volts. The controller should accept station battery voltage level inputs. Controller input modules should be strappable for 24, 48 or 110 Volt station batteries. Controller digital input modules should also have straps to allow any contact input to cause a hardware shutdown directly to the stop relay.

DC Analog Inputs

The controller should accept 0-1ma, 0-5V, 4-20ma or 1-5V DC analog signals. The controller should be able to measure DC analog signals with as much as 5 volts common mode signal with differential inputs. The controller should provide ground straps that can be inserted on the negative lead of any input signal that should be grounded at the controller. The controller should also provide selective terminating resistors for 1ma and 20ma signals. The DC analog signals should be converted to digital signals using at minimum 12 bit
analog to digital converter in the controller with all conversion errors considered the controller should maintain an accuracy of 0.1% or better of full scale and a resolution of 1 part or less in 2000. All DC analog inputs should be protected from transient spikes and voltages with circuitry that meets the IEEE surge withstand test.

**AC current inputs**

The controller should connect directly to current transformers. The controller should accurately measure all current inputs from 0-6.25 amps. It should withstand 10 amps continuously and 50 amps for 1 second. The controller should be able to measure magnitude of the current with a true RMS to DC converter and its phase shift with respect voltage. The current measuring accuracy should be to .1% and the phase shift accuracy should be to .1 degree. The controller should induce a burden of less than .5 VA on each current transformer it connects to.

**AC voltage inputs**

The controller should connect directly to the potential transformers. The controller should accurately measure voltage inputs from 80 to 150 VAC. It should withstand up to 200 VAC continuously. The controller should be able to measure the magnitude of the voltage with a true RMS to DC converter and measure the phase shift of the voltage with respect to current. The voltage measuring accuracy should be to .1% and the phase shift accuracy should be to .1 degree. The controller should induce a burden of less than 1 VA in each potential transformer that it connects to.

**Control outputs**

The controller should provide control relays to operate the circuit breaker, voltage regulator, and other equipment. The contacts should be DPDT rated 125 VDC at 0.5 A. Two contacts should be available from the DPDT relay and either should be strappable as normally closed or normally open. An optional high-powered relay should be available that provides one normally open contact rate 150 VDC at 10A. Each relay should have an LED indicator mounted on a manual control panel to indicate the status of the relay, on or off. Next to the indicating LED should be a switch to operate the relay manually. Each switch/LED should be clearly marked as to its function.

**RTD inputs**

The controller should have provisions to connect directly to RTDs. RTD readings should be corrected for nonlinearity and readings should be accurate to + 0.25°C. The temperature range should be 0-160°C. The controller must have a 10, 100 and 120 ohms 8 input RTD module. The correct linearizing curve should be selected by configuring. The controller should be capable of reading temperatures from eight RTDs. If eight RTDs are not required, any of the RTD inputs should be able to be used as a 4-20 mA analog input. Each of the eight inputs should be assigned three alarm set points; two high alarm set points and one low alarm set point.

**Analog outputs**

The controller should output 4-20ma signals for calculated signals such as KW, KVARs, power factor, frequency, voltage, and current. The signals should be isolated outputs with 1000 common mode voltage capability. The accuracy of these outputs should be better than .25%.

**Alarm outputs (option)**

The controller should be capable of outputting contacts for alarms that it generates internally. The contact rating for these alarms should be .1 Amp. at 120 VDC. All digital inputs should be capable of meeting the surge withstand capability in accordance with IEEE 1249-1996.
**Electrical transducers**

The controller should connect directly to current transformers (CTs) and potential transformers (PTs). The controller should be capable of deriving the generator voltage (line to line and line to neutral), generator amps, generator WATTS, generator VARS, generator Power factor, generator kVA, generator frequency and bus frequency from the CTs and PTs. The controller should be configurable for open delta (line to line) or star (line to neutral) connected CTs and PTs.

**Electronic Turbine Governor**

The electronic turbine governor to be provided by the turbine manufacturer shall be installed and fully integrated in to the UCB. The turbine governor shall have a serial interface for communication with the process control computer.

**Digital Excitation Control**

Digital Excitation Control to be provided by generator manufacturer shall also be installed and fully integrated with UCB.

**Status Switchboard**

The status switchboard in each powerhouse shall contain graphic and visual indication, generator load recorders, station total megawatts and megavars recorders, and other required project data displays. The status switchboard should be located for easy observation from the control console. The status switchboard shall be a standard modular vertical rack enclosure joined together to from a freestanding, enclosed structure. A large screen shall be provided for this purpose.

Display screen of suitable size shall be provided in the main power house of site control room to monitor all three power houses.

**Annunciation and Alarm**

**Audio & Video Signals**

Annunciation system shall be providing for both audible and visual signals in the event of trouble or abnormal conditions in the main attended powerhouse. In the canal unattended power house only visual signal be provided.

a) **Audio Signals**

   Howler horns and intermittent gongs shall be used for audible signal devices. An intermittent gong shall be in the plant control room. Howler horns shall be used in the unit area and in areas where the background noise is high (e.g. in the turbine pit) or in areas remote from the unit (e.g. plant switchyard).

b) **Visual Signals**

   Visual signals shall be provided by lighted lettered window panels of the annunciator. The annunciator panel indication shall be augmented by unit trouble lamps located in a readily visible position close to the unit. The plant sequence of event recorder (SER) shall be located in the control room of each powerhouse. Separately annunciators for station service systems and switchyards shall be located on associated control panels of the station service switchgear or on the switchyard control panels.

**Annunciator**

The annunciator system shall be designed for 110 V (station DC voltage) DC system. All remote contacts used for trouble annunciation shall be electrically independent of contacts used for other purposes so annunciator circuits are separated from other DC circuits. Auxiliary relays shall be provided where
electrically independent contacts cannot otherwise be obtained. The annunciator equipment should use solid-state logic units, lighted window or LED type, designed and tested for surge withstanding capability in accordance with ANSI C37.90.1.

The switchboard and annunciator operational sequence should be manual or automatic reset sequence as listed in table 2.2

Automatic reset should be employed for the SCADA system backup. For SCADA system the design reset features of the annunciator shall be coordinated to ensure proper operation.

The generator switchboard shall be provided with annunciator alarm points for unit emergency shutdown, generator differential lockout, generator incomplete start, generator bus ground, generator over speed, generator over current, generator breaker low pressure, unit control power loss, generator CO₂/water sprinkler power off, PT fuse failure or under voltage, and head cover high water.

C. Table 2.2 Switchboard Annunciator Operational Sequence

<table>
<thead>
<tr>
<th>Field contact</th>
<th>Control pushbutton or switch</th>
<th>Alarm lights</th>
<th>Horn</th>
<th>Auxiliary or repeater contacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>--</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>Abnormal</td>
<td>--</td>
<td>Flashing</td>
<td>On</td>
<td>On</td>
</tr>
<tr>
<td>Abnormal Acknowledge or silence</td>
<td></td>
<td>On</td>
<td>Off</td>
<td>On</td>
</tr>
<tr>
<td>Normal</td>
<td>Reset</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>Normal</td>
<td>Test</td>
<td>On</td>
<td>Off</td>
<td>Off</td>
</tr>
</tbody>
</table>

The generator switchboard shall be provided with an additional annunciator for the generator step-up transformer and unit auxiliary equipment alarms, these alarm points shall be transformer differential, transformer lockout trip, transformer overheat, transformer trouble, switchgear trip, and trouble.

The switchboard shall be providing with auxiliary or repeater contacts to drive control room console remote annunciator word indicating lights.

A control console window-indicating light annunciator shall be common to all units. One unit at a time can be selected by use of the appropriate unit trouble status lighted pushbutton. Visual indication shall be provide when the unit switchboard annunciator is activated. The console window indicating lights shall be generally grouped by switchboards annunciator points and provide essential trouble status to the operator. Unit troubles shall be categorized by shutdown differential, over current, cooling water, bearing oil, unit trouble, breaker air, CO₂ discharge, control power etc.

- **Equipment racks.** Equipment racks shall be provided for mounting line relays, automatic synchronising equipment, the common and outside Annunciator chassis, auxiliary relays, communication equipment, and transfer trip equipment. The equipment racks should be standard, modular, vertical rack enclosures.

- **Cabinet Construction:** Generator switchyard panels and doors shall be 3mm thick (14 gauge) smooth select steel with angle or channel to approx. 6 mm radius: panels and doors shall be mounted on sils and supplied as ready for powerhouse installation. All switchboards shall be mounted and wired in the factory.

- **Equipment Arrangement:** the arrangement of equipment on the control switchgear, switchboard, or control console should be carefully planned to achieve simplicity of design and to replicate unit control placements familiar to the intended operating staff. Simplicity of design shall be a definite aid to operation and shall tend to reduce operating errors; therefore, the relative position of devices should be logical and uniform. Switchboard and control console design should be patterned to attain to degree of standardization in the arrangement of indicating instruments and basic control switches. Control switches shall be equipped with distinctive handles generally as shown in table 2.3. Each item of equipment should be located by consideration of its functions, its relation to other items of equipment and by its use by the operator.
Remote Terminal Units (RTU)

As per requirements, compact RTU's with an adequate protective housing shall be provided for each Unit. They shall have a modular electronic chassis with plug-in components to facilitate maintenance. These RTU’s shall receive their power supply from the power supply rack in the cubicle they communicate with, through the field bus. A separate feeder for each of the RTU's shall be provided. Each RTU shall be equipped with supporting modules such as microprocessor, memory, modem, etc. and input/output modules in the number of the type required.

Power Supplies

Each operator control station shall be equipped with redundant DC power supplies through DC batteries along with independent set of float & boost charges. Each DC battery shall be of adequate capacity and supply DC power without aid of charger for at least 4 (four) hours. Further redundant AC supply for VDU’s, printers, etc. is required (one redundant supply for the two operator control stations). For this purpose two 24 V DC/230 V AC inverters shall be provided, arranged in main stand-by configuration. A distribution panel for the 230 V AC voltage equipped with circuit breakers as required shall be included in the scope of the delivery. Power supplies shall include adequate supervisory and protective devices.

Fire Alarm

The Fire alarm and detection system shall also be monitored through Operator station shall comprise the selected alarm and indications for fire system as detailed in Chapter 5.6.

Resolution and Time Synchronisation

Fast response time of computer system is required. The resolution in the tagging of events shall be 1 milli-sec. Function shall be provided to generate accurate time Synchronisation between all computers in the system.

Bidder will intimate following:

(a) Time duration required to update a graphical display from the instant a field contact changes state.

(b) Time duration from the instant a control is activated at the operator station until the command is implemented at the field device.

(c) Overall time duration to process and log an alarm once it is received at the computer.

Methodology by which these “times” are verified must be given.

Acceptable time shall be verified at the factory acceptance test.

2.2.15.11 SCADA Functions

The system shall perform the following functions in real time.

a) Acquire data from primary sensors.
b) Process and retain data for each primary sensor.
c) Perform detailed thermal and vibration analysis.
d) Report machine performance in tabular and graphical format.
e) Trending of turbine and generator efficiencies
f) Sequence of event logging.
g) Supervisory control of auxiliaries, governing system, excitation system, circuit breakers, synchronizing and including Speed control and load control through governor/level, Automatic voltage regulation, Machine loading with active and reactive power
h) Data acquisition of water level
i) Speed control and load control through governor/level
j) Flow control: The flow control shall control the power output of the plant according to the water quantity available based on upstream and tailrace level
k) Isolated operation on a selected grid,
m) Black-start, i.e. no external power source available, but only on the emergency diesel generators
## Table-2.3 Plant control and instrument switch types

<table>
<thead>
<tr>
<th>Switch function</th>
<th>Contract type</th>
<th>No. Pos.</th>
<th>Handle type**</th>
<th>Nameplate marking***</th>
<th>Ind. lights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exciter AC voltage control</td>
<td>A</td>
<td>3</td>
<td>BPG</td>
<td>AC volt adjust</td>
<td>Lower - Raise G.R.</td>
</tr>
<tr>
<td>Excitation breaker control</td>
<td>A</td>
<td>3</td>
<td>BPG</td>
<td>Exc. Bkr.</td>
<td>Trip - Close G.R.</td>
</tr>
<tr>
<td>Exciter DC voltage adjust</td>
<td>A</td>
<td>3</td>
<td>BPG</td>
<td>DC volt adjust</td>
<td>Lower - Raise R.A.A.G</td>
</tr>
<tr>
<td>Generator breaker control</td>
<td>A</td>
<td>3</td>
<td>BPG</td>
<td>Gen PCB</td>
<td>Trip - Close G.R.</td>
</tr>
<tr>
<td>Generator start/stop control</td>
<td>A</td>
<td>3</td>
<td>BPG</td>
<td>Unit start-stop</td>
<td>Stop - Start G.R.</td>
</tr>
<tr>
<td>Emergency shutdown (main unit)</td>
<td>A</td>
<td></td>
<td>RPG</td>
<td>Emerg. shutdown</td>
<td>Pull AND Turn -</td>
</tr>
<tr>
<td>Governor gate limit control</td>
<td>A</td>
<td>3</td>
<td>BO</td>
<td>Gate limit</td>
<td>Raise - Lower -</td>
</tr>
<tr>
<td>Governor speed level control</td>
<td>A</td>
<td>3</td>
<td>BO</td>
<td>Speed adj</td>
<td>Raise - Lower -</td>
</tr>
<tr>
<td>Synchronizing (main units)</td>
<td>B</td>
<td>2</td>
<td>RBO</td>
<td>Synch</td>
<td>Off ON -</td>
</tr>
<tr>
<td>Trans. oil pump motor control</td>
<td>A</td>
<td>3</td>
<td>BPG</td>
<td>Transf oil pumps</td>
<td>Stop - Run G.R.</td>
</tr>
<tr>
<td>Ammeter switch</td>
<td>B</td>
<td>4</td>
<td>BK</td>
<td>Gen AM</td>
<td>A B C Off G.R.</td>
</tr>
<tr>
<td>Voltmeter switch</td>
<td>B</td>
<td>4</td>
<td>BK</td>
<td>Gem VM</td>
<td>Off A-B B-C C-A</td>
</tr>
</tbody>
</table>

*Type A-Momentary spring return to neutral
Type B-Maintained
**BPG –Black pistol grip
RPG- Red pistol grip
BO- Black oval
RBO- Removable black oval
BK- Black knurled

***To suit each application

- n) Metering and recording of all characteristics of the turbine and generator operation,
- o) Automatic backup of on-line process data using Network Attached Storage Devices,
- p) Perform periodic permanent backups of process data on archival storage media,
- q) Indication of normal operation of the auxiliaries that are essential for secure and reliable operation of the unit
- r) Audible and visual warning of dangerous/ faulty operating conditions of the unit and / or essential auxiliaries
- s) Audible and visual alarm and display of dangerous operation of the unit and the essential auxiliaries or faults that may initiate tripping of the circuit breaker without stopping the unit
- t) Power supply and control of essential auxiliaries of each unit,
- u) Video Mimic and indication labels on VDU,
- v) Manually operated covered push buttons for automatic safe shut down of units,
- w) Fault location: this function shall have a high accuracy. The fault location assessment shall be independent of fault resistance, load current or the supply of a data from different sources,
- x) Automatic station supply changeover
- y) Interlocking of various equipment for safe operation
- z) Predict need for shut down and maintenance of equipment.
- aa) Software shall be such that the monitoring system will take care of the transient parameters during system run-up and shut down.
- bb) Software shall be modular and upgradable.
- cc) The SCADA software should run in co-ordination with existing/proposed SCADA software for gate control operation. It can received data of Gate positions etc. from it and send generation etc. data to it
- dd) Configuration tools: Easy to use interactive configuration tools shall customize the various functionalities. The configuration tools shall provide visual presentation of the object, adaptations needed in process database, and adaptations of the communication configuration data. These tools shall provide.
Bidder shall provide suggestions relating to measurement points and sensors. If in his opinion, an enhancement in condition monitoring capability can be attained by use of additional sensors these should be provided and details indicated in the bid.

2.2.15.12 Quality Assurance

A rigorous quality assurance system shall be used in the manufacture of the system. This system shall include testing at the sub assembly and system level. Automated assembly and test equipment shall be used wherever possible to ensure consistent quality. The tenderer shall submit a complete description of his quality assurance programme. The relevant ISO certification for the control systems shall be furnished.

2.2.15.13 Standardisation

The tenderer shall ensure same make, series, and family of hardware in respect of various control and monitoring instruments/equipments in order to ensure smooth and optimal maintenance including efficient spare parts management. The tenderer shall furnish a composite list of bought out items along with proposed sub-vendors for each item.

2.2.15.14 Factory Assembly and Tests

Factory Acceptance Test – Computer Control System

Factory acceptance test shall be performed prior to shipment of the computerized equipment. The factory test shall demonstrate proper operation of all furnished software and hardware. Test procedure shall be prepared by the manufacturer and approved by the Purchaser prior to commencement of the factory test. Specific requirements for the factory test shall include but not be limited to the following: The list of test to be performed shall be submitted for approval by the Purchaser at least 60 days in advance. Factory tests will be witnessed and approved before dispatch by purchaser. Purchaser may accept type test carried out on the equipment.

i) Surge protection testing of each type of input and output cards - in accordance with IEEE Std C37.90.1-1989 or equivalent.
ii) Susceptibility to radiated electromagnetic interference – in accordance with IEEE Std C37.90.2-1998 or equivalent.
iv) Application of appropriate signals to each input point to verify their operation.
v) Running of programs adequate to test the proper operation of each output point to demonstrate that all output points revert to a specified configuration in the event of an automation system failure.
vi) Demonstration of major features of system components (CRTs, printers, disk drivers, etc.).
vii) Demonstration that data base is sized for the ultimate system and implemented for all variables.
viii) Demonstration of system performance while running all applications software during simulated worst case conditions.
ix) Demonstration of system diagnostics.
x) Testing to demonstrate proper operation of the failover process to demonstrate automatic changeover to redundant system.
xi) Demonstration of operator interface software.
xii) Demonstration of each applications software routine.

Control Switchboard – Hard Wired

Following factory tests will be on the unit control switchboard and will be witnessed by the purchaser.
1. Review front and rear elevations versus the final approved drawings. Check each item of equipment for proper location and verify the instrument/catalog number is correct per the specification.
2. Review the interior of the UCB in the same manner as the elevations. In addition, verify the lighting is adequate and grounding connections are provided.
3. Check anchor channels and cable entrances. Confirm they are in accordance with the drawings.
4. Review test certificate or witness the insulation resistance test of all wiring, current transformers, and potential transformers.
5. Check approximately 5 to 10 percent of the internal cabling. Verify that the following items conform to the drawings:
   - Cable numbers;
   - Terminal block designations;
   - Terminal designations on individual components such as control switches and lockout relay;
   - Raceway layouts; and
   - Equipment identification nameplates.
6. Activate all protective relays. Confirm that the appropriate lockout relay is energized and the correct annunciation and/or printout occurs.
7. Confirm that settings of all protective relays are in accordance with approved documents.
8. Check all annunciation points.
9. Check factory calibration of all devices possible, including electronic speed relays, current and potential transformers, and vibration monitors.
10. PLC checks:
    - Check the I/O racks for type and number of analog and digital I/O cards;
    - Check for future expansion capabilities on the I/O racks;
    - Check for surge protection provided on the I/O rack and I/O cards;
    - Identify grounding connections for the PLC and the I/O rack; determine whether chassis and logic grounds are the same or separate (this will affect the type and quantity of external surge protection required);
    - Review the PLC ladder diagram viewed on the video display terminal versus the final approved PLC software coding documentation; and
    - Verify that modem connections are provided and functional.
11. Perform the function checks listed below with the final approved schematics, PLC software coding, and control block logic diagrams in front of you. All permissive and interlocks should be provided by using the “dummy” toggle switchboard to provide these inputs.
    - Manual start/stop sequence (does not apply to redundant PLC control schemes);
    - Auto start/stop sequence;
    - Manual emergency stop sequence;
    - Automatic emergency stop sequence (usually performed by activating one of the lockout relays while in the “normal running” mode);
    - Change position of all control switches as follows (typically done while in the normal running mode);
      - Local control to remote control
      - Remote control to local control
      - Manual control to automatic control
      - Headwater level control “OFF” to “ON”
      - Headwater level control “ON” to “OFF”
      - Excitation manual control to excitation automatic control
      - Excitation automatic control to excitation manual control; and
    - Verify the performance of the automatic synchronizing circuit and the manual sync-check relay (if provided).
2.2.15.15 Field Test

General – Computer Control

The field test shall confirm that no degradation has occurred during shipment and installation. It will also be used as design verification. Test procedure shall be prepared by the manufacturer and approved by the engineer prior to commencement of the field test. The following tests are generally proposed.

a) Application of appropriate signals to each input point to verify their operation;
b) Running of programs adequate to test the proper operation of each output point;
c) Demonstration of major features of system components (CRTs, printers, disk drives, etc.);
d) Demonstration of system diagnostics;
e) Demonstration of operator interface software;
f) Demonstration of each applications software routine;
g) Demonstration of system availability.

Unit Control Switchboard (UCB) – Hard Wired

1. Verify tags on all factory-calibrated instrumentation devices.
2. Check all external interconnection wiring against the approved power house/equipment drawings, verifying the following items:
   - Cable numbers and type;
   - Terminal block designations; and
   - Raceway layouts
3. Perform point-to-point continuity and megger tests on all external cabling.
4. Calibrate all remaining instrumentation devices.
5. “Bench test” all protective relays to ensure proper settings.
6. Perform functional checks tests on all unit and station auxiliary equipment controlled from the UCB to verify proper operation.
7. Perform functional checks on unit start/stop sequences, duplicating the factory sequences. These checks should be performed first with the associated power circuits de-energized, and then with both power and control circuits energized.
8. Methodically document steps 1 through 7 to ensure that no cables, instrumentation devices, protective relays, or control systems have been overlooked.
9. Water-up the unit and perform all start/stop sequences.

2.2.15.16 Training

The supplier shall execute a training plan for the user. This plan will allow the user to become self-sufficient in all aspects of operations, software maintenance and development and hardware maintenance. Video recording may be effectively used for refresher training.

Training Plan

The training plan should include the following information on individual courses:

a) Outline;
b) Duration and scheduling;
c) Location (e.g., user site, manufacturer’s site)
d) Qualification of instructor;
e) Objectives;
f) Prerequisites;
g) Content;
h) Training material (handouts);
i) Audiovisual aids;
j) Special equipment, tools, etc;
k) Ratio of hours of classroom to hours of hands-on laboratory experience.
2.2.15.17 Documents and Drawings

Documentation should be provided that adequately describes the system such that the design can be verified. Documentation should also be provided such that it can be used to support installation, testing, system activation, hardware operations and maintenance, and software maintenance and development.

Design documentation should include follows:

a) Operator interface:
   1) Keyboard layout and operation;
   2) CRT format;
   3) Cursor control philosophy;
   4) Display call-up philosophy;
   5) User of color, flashing, inverted video, etc.;
   6) Display building

b) Functional documentation and Drawings:
   1) Outline drawings, including dimensions and arrangements;
   2) System block diagrams showing nomenclature, equipment types, model numbers and input/output provisions;
   3) Input/output lists with ranges, labels, and other related specific information.

2.2.15.18 Communication Links

i) Scope

Design, supply, delivery, Site, erection, testing and commissioning and training of personnel for Fibre optic links (buses), optional transmitters and receiver, terminals inside the powerhouses and between the powerhouses and switchyard etc. Fibre optic link between offsite control room and regional load dispatch centre.

ii) Code Standards

- ANSI/IEEE 1010 – 1987
- Relevant National / International Standards

The contractor shall furnish detailed design and calculation for approval by purchaser.

iii) Regulatory Requirement

Govt. regulatory requirement and sanctions for the communication system shall be obtained by Contractor. Necessary assistance will be provided by Purchaser.

Dedicated Communication by Fiber Optic System Cable

Dedicated communication system for SCADA, voice communication and code call paging system from power house I & II to offsite control at Main Power House shall be by Fiber optic cable. Code call facility shall be provided for paging key personnel.

Fiber optic cable

A fiber-optic cable system consisting of a terminal with multiplexing equipment, and a transmitter and receiver coupled to fiber-optic light conductors that are routed to the other terminal, which also has a receiver, transmitter, and multiplexing equipment shall be provided. Because the transmission medium is
nonmetallic, it offers the advantage of electrical isolation between terminals and immunity from electromagnetic interference.

**Special Design and layout Conditions**

The buses shall be duplicated (redundant), complete with fibre optic cables spatially separated, interface cards to transmit data and decode the same and stored in computer memory.

The bus controllers and coupling units shall ensure that the data bus system is completely duplicated so that:

One system is in operation and one in hot standby. In no circumstances should one failure lead to an outage of a complete data system. The data shall be secured in a suitable way to prevent loss of information.

If the bus selected for operation fails, the operation shall be switched over automatically to the other bus, selected for standby, and alarm shall be given.

The standby bus shall be continuously checked and in case of failure alarm shall be given.

**Repeaters**

Repeaters if needed shall be provided. Necessary equipment at sending and receiving and for Interfacing remote supervisory controller at Main Power House with SCADA. Centralized SCADA system to remote supervisory control in the control room of Power House No. I and II shall be provided by the dedicated Fiber optic couple. The design will be subject to approval by purchaser and will confirm to latest relevant standard.

**Local Area Network (LAN)**

Local area network if proposed inside the Power House for distributed control otherwise shall also connected by Fiber optic cable.

**Design and Construction**

Fibre optic cable: The cables shall be completely jelly filled to prevent moisture penetration. The fibres shall be protected in jelly filled loose tubes stranded around a central strength member to ensure optimum performance and long life. Each fibre and loose tube shall be colour coded for easy identification during splicing and termination. The outer sheath shall be marked to show fibre type and cable type at suitable intervals.

Terminal Units: Optical source safety shutoff shall be provided to prevent exposure to laser light during maintenance.

Equipment shall have sufficient test points to facilitate complete monitoring of the equipment performance without service degradation or interruption.

Re-application of lost signals at any digital level shall result in automatic resynchronization and full restoration to normal condition. All alarms shall be cleared automatically, when a system is returned to its normal condition.

**2.3 CONTROL OF SMALL HYDRO STATION – INTEGRATED GOVERNOR AND PLANT CONTROL SYSTEM**

**2.3.1 Introduction**

Major constraints in the development of economically viable small hydro have been high cost of speed control and automation with analogue governors, unit and plant control and protection systems. These systems generally required attended operation and mostly based on large capacity hydro units. This was making most of the units very costly and uneconomical to operate. The man-power as available is unskilled and further adequate supervision in remote area is not feasible. Load factors in remote areas especially for stand alone systems are very low. Many small hydro have been unstable and reliability is mostly poor.
Microprocessor can make the plant easy to operate, easier to maintain, operate more efficiently and operate more reliable. Most power plant control functions can be performed by programme in microprocessor control system. Microprocessor controller have been evolved to take care of speed control, plant control, unit automation, unit protection, data acquisition and generation scheduling at economical cost and the reliability is increased.

2.3.2 Consideration for Selecting Governor and Control System

Governor and Control systems for small hydro units especially are selected keeping in view the following:

(a) Traditional mechanical flow control governor with mechanical hydraulic devices is complex demanding maintenance and high first cost. Further performance requirements of stability and sensitivity i.e. dead band, dead time and dashpot time especially for interconnected units may not be met by mechanical governors.

(b) Electronic Digital flow control governors can take up plant control functions.

(c) Cost of speed control and automation with currently installed analog flow control governors, unit control and protection systems are high. These systems require attended operation and are mostly based on large capacity hydro units. This is making most of the units very costly and uneconomical to operate.

(d) The manpower as available is unskilled and further adequate supervision is not feasible.

(e) Analog Electronic Governors and plant controllers are also used for small hydro auto synchronizing and for remote control and monitoring of system. Experience in the successful operation of these systems in India is so far not very good.

(f) Digital generation controllers were evolved to take care of speed control, unit control and automation, unit protection, generation scheduling and have been successfully in operation for over ten years.

(g) Programmable Logic Controller (PLC) based systems are reliable and have been in operation in India.

(h) Dedicated PC based systems for complete generation control can be easily adopted for data acquisition and storage at a nominal cost and can also be adopted to Supervisory Control and data Acquisition (SCADA) system and have also been used in India.

2.3.3 Technology for Economic Small Hydro Control

2.3.3.1 General Considerations

International Standard IEC – 1116 gives the guidelines for selecting equipment for small hydro. Some of the guidelines affecting control system are given below.

i) The unit should be protected by at least one discharge closure device which in emergency would close due to lack of electrical signal. The closure should be guaranteed under any circumstances for reason of safety.

ii) Standard diameter and thickness pipes be used as penstock which can withstand 1.5 times the maximum total pressure including water hammer.

iii) The generators should be designed to withstand continuous runaway conditions.

iv) Over specification is harmful to the economy of the project.

Technology options for SHP control system are summarized in table 2.4.

2.3.3.2 Microprocessor Control

Governor and plant control, metering and protection system can be microprocessor based to provide cost effective reliability. Figure 2.27 shows power plant components which can be replaced by programmes and microprocessor control system. Microprocessor control system connects to sensing devices and actuators as
shown in figure 2.27. The programmes replace components. The reliability of each of the component that can be replaced by programming is increased. Manual back up can be provided for reliability.

2.3.3.3 Integrated Governor and Plant Control System

Following computer based systems have been installed in the country.

a) Microprocessor based controllers with specially developed software
b) PLC based controllers
c) PC based controllers

Present modern practice is to have PLC based automatic control system with manual control as backup. A common PC for Supervisory Control and data Acquisition system (SCADA) may be provided. Redundant PLC for automation as backup is not provided.

Table 2.4: Comparison of various technology options for control system, including turbine governing supervisory control and data acquisition for SHP

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Turbine Gov. and Controller Type</th>
<th>Unit size kW</th>
<th>Mode of operation</th>
<th>Suitability</th>
<th>Cost including Gov. control, protection, SCADA data Aq., Storage and Retrieval (see note-1)</th>
<th>Recommendation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mech. Flow control Gov.</td>
<td>Up to 100 kW</td>
<td>Iso. Grid</td>
<td>At high extra cost</td>
<td>Very high High without SCADA Not recommended</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grid Above 100 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Load control governor</td>
<td>Up to 100 kW</td>
<td>Iso. Grid</td>
<td>Suitable</td>
<td>Cost low (SCADA is not available) Low       Recomended up to 100 kW unit size</td>
<td></td>
<td>Digital load control governor may be developed for SCADA</td>
</tr>
<tr>
<td></td>
<td>Grid 100-500</td>
<td></td>
<td></td>
<td>At extra cost but not available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Analogue, Electronic Gov. &amp; Plant Controller</td>
<td>50-100 kW</td>
<td>Iso. Grid</td>
<td>Suitable</td>
<td>At high extra cost Very high cost</td>
<td>Not recommended</td>
<td>High to high</td>
</tr>
<tr>
<td></td>
<td>Grid Above 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>PLC integrated controller with SCADA by PC</td>
<td>SHP 100 kW to 5 MW</td>
<td>Iso. Grid</td>
<td>Suitable</td>
<td>Low Moderate Recommended</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Data Logger with PLC load controller</td>
<td>5 to 100 kW</td>
<td>Iso. Grid</td>
<td>Data not available</td>
<td>Low</td>
<td>Moderate</td>
<td>Recomended</td>
</tr>
<tr>
<td>6.</td>
<td>PC based integrated system for governing; plant control protection and metering with manual backup</td>
<td>100 kW to 25000 kW</td>
<td>Iso. Grid</td>
<td>Suitable – Indigenous system not available</td>
<td>Low</td>
<td>Medium</td>
<td>Recomended with high speed PC suitable for harsh area</td>
</tr>
</tbody>
</table>

Notes: 1. Cost normalized with main and backup SCADA system.
2. Recommended in conjunction with partial water flow control
Microprocessor controller (PLC/PC) is used to provide following unit and plant control functions.

- **Turbine Governing control & Monitoring**
- **Generator control & Monitoring**
- **Starting sequence control**
- **Auto synchronizing (if required)**
- **Automatic shut down control**
- **Emergency shut down**
- **Control of turbine generator auxiliaries**
- **Monitoring of turbine generator auxiliaries**

A dedicated controller for normal operation in isolated/interconnected operation is required. This controller can perform all the control functions of unit control e.g. starting sequence control, auxiliary control, emergency and normal shut down and governing.

In manual/maintenance control mode the controller can perform the following control functions.

- **Manual turbine gate or needle valve control**
- **Manual synchronization control**
- **Manual circuit breaker control**
- **Manual load control**
- **Manual brake control**
- **Manual normal shut down control**
- **Automatic emergency shut down**

In addition the controller can monitor all critical items that are required for safe operation.

- **Protective relay status**
- **Generator breaker status**
- **Lock out relay status**
- **Hydraulic oil high/low pressure/level**
- **Speed increaser, high oil temperature/level/flow**
- **Brake status**
- **Generator/bearing temperature**

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• Head water/tail water level
• Generator current, voltage, power-factor, kW, kVAR & kWh
• System voltage and frequency

Analogue meters may be provided as back up:

2.3.4 **Computer (PLC) based control system for SHP up to 5 MVA**

The hard wired manual unit control and computer based (PLC) automatic control system is provided in the control room. Supervisory control and data acquisition system (SCADA) if required is provided by a common Personnel Computer for all the units for Supervisory/Remote control functions in the control room.

2.3.4.1 **PLC Based System**

One PLC integrated controller per unit is provided for unit automatic control including governor control, unit control, excitation control and auxiliaries control.

Separate controllers may be provided for switchyard, common auxiliaries etc.

Remote/Supervisory control and data acquisition for all the unit may be provided by one PC.

PLC based control system with PC SCADA is shown in figure 2.28. Manual unit control facility is provided on PLC panel as back up. PLC auto/manual panel and PC SCADA system for remote/supervisory are provided in the control room. SCADA system is not provided in many powerhouses and data acquisition is manual. Supervisory control is provided by the PLC auto manual panel.

Typical PLC unit auto/manual control system with PC for supervisory control and data acquisition system was provided for Sikasar Project (2 x 3.5 MW). Auto/manual PLC panels and other control panels were provided in the control room. Supervisory control system long with printers for data acquisition were also provided in a room adjoining control room. PLCs is provided for unit auxiliary control; governor control; sequencing and synchronizing etc. Temperature monitoring and recording is by separate microprocessor based system. Single Line diagram is shown in figure 2.29. PLC controller; temperature recorder and PC SCADA system is shown in figure 2.30. General arrangement of control and protection panels is shown in figure 2.31. Start/stop and emergency shutdown sequencing is shown in figure 2.32 to figure 2.34.

![Figure 2.28: Typical Configuration for Computerized Hydro Station for SHP](image-url)
Machine level and station level is same, manual/automatic control panel is combined with unit PLC panel
Figure 2.31: General Arrangement of Control & Protection
(AHEC Project)

Figure 2.32: Start Sequence for Sikasar SHP
(AHEC Project)
Figure 2.33: Normal and Minor Fault Stop Sequence for Sikasar SHP (AHEC Project)

Figure 2.34: Emergency Stop Sequence for Sikasar SHP (AHEC Project)

Future

Figure 2.35 – System Configuration Abhor Canal SHP project (Punjab)
(SHP Simulator AHEC)
PLC integrated unit controller with PC for supervisory control data acquisition and remote control facilities for Abhor canal fall SHP with provision for remote control of 3 nearby canal fall plants is shown in Figure 2.35.

2.3.5 PC based Integrated Generation Controller

PC based integrated generation controller capable of following function was developed by M/s Digitek of USA and M/s Predeep Digitek in India for SHP.

PC based system integrated generation controller (IGC) of M/s Digitek USA for unit control, governor control and other function was provided for Sobla powerhouse (2 x 3000 kW) and is attached as figure 2.36. This is a cheaper alternative but lacks redundancy which can be provided by spare cards for each type.

- Governor speed control
- Automatic sequencing for start up and shutdown including synchronizing
- Automatic sequencing for emergency shutdown
- Data recording and reporting
- Alarm enunciators
- Full remote control and monitoring
- Control via terminal keyboard
- Water level control
- Flexible architecture
- Modular card system
- Ability to communicate with other microprocessor based equipment
- Alarm and status logging
- Data logging at user selected intervals
- Event recording
- Line protection- frequency and voltage
- Generator protection - voltage, current, reverse power, differential, loss of field

Line protection and metering was however provided by conventional meters and electromagnetic relays. Control room layout is shown in figure 2.37 and simplified start/stop scheme is shown in drawing 2.38. A typical VDT screen is shown in drawing 2.39.

Figure 2.36: Integrated generation controller (IGC) – PC based

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Figure 2.37: Control Room Layout Sobla SHP (2 x 3 MW) (As Designed)
2.3.6 Microprocessor based Generation Controllers

2.3.6.1 Generation Controller

A 8 bit microprocessor with simplified flow control governor and a fully automatic digitally controlled generation controller (level controlled turbine controller) for double regulated 500 kW Satpura units is shown in figure-2.40.

2.3.6.2 PI Dedicated Governor

Generation scheduling (reservoir level controlled) was incorporated to control generation for on-peak and off-peak time for 2 x 1000 kW power house in New Zealand by Pradeep Digitek for local manufacturers/suppliers. The controller and control scheme flow chart is shown in figure 2.41 (a) & figure 2.41 (b).

An 8-bit microprocessor was used to work as a flow control dedicated governor in semiautomatic manual mode. The governor does not require proportional valves and closing and opening pulses were given to close or open geared motor operated actuator to control nozzle (needle valve) with adjustable time between pulses. A dead band is provided based on the pulse time to achieve stability. The dead band was ±2% to 4% (48 to 52 Hz). Indian electricity rules permit ±6%. The synchronizing in this case was done manually. Provision for speed level and speed droop control was also provided.
Figure 2.40: 2 x 500 kW Controller (Satpura Project)
(As Designed in Pradeep Digitech)

Figure 2.41 (a): 2 x 1000kW Controller (Newzealand)
(As Designed in Pradeep Digitech)
2.3.7 Grid Connection for New and Existing SHP with different type of Governors

Small isolated hydro power plants were constructed in remote isolated villages and towns in hilly areas. These small hydro plants are characterized by following:

a) Development of load in these remote areas is very slow and load factors even after years of operation were low, say 20 to 30%.
b) Manpower costs for operation and maintenance are very high.
c) Spare capacity is to be provided in each power plant

Isolated operation of these powerhouses would result in high uneconomical installation and most of the power plants could not sustain even operation and maintenance costs resulting even in closure. Following measures were taken to make the attended isolated small hydros economical viable.

a) Interconnection with grid to utilize available power and reduce spare capacity
b) Remote and Group control of a cluster of nearby powerhouses to reduce operation and maintenance costs.
2.3.8 Typical Examples of Group Control and Interconnection with Grid of Small Hydro with different types of Governors

It was proposed to interconnect the four powerhouses in Pithoragarh in Uttarakhand to 33 kV existing grid substation at Dharchula. Dharchula is interconnected to the 66 kV grid substation at Pithoragargh. A single line diagram of interconnected system is at figure 2.42. The grid interconnection resulted in highly economical installation.

Different types of governors were installed for the powerhouse as given in table 2.5.

Generators were equipped with automatic voltage regulator/power factor control for the excitation system with facility for manual control.

**Table 2.5**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of powerhouse</th>
<th>Type of governor</th>
<th>Type of generator</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Sobla SHP (2 x 3000 KW)</td>
<td>Digital governor (PC based)</td>
<td>Synchronous generator</td>
<td>Excitation changed over to power factor control on grid operation</td>
</tr>
<tr>
<td>2.</td>
<td>Kulaghad powerhouse SHP (2 x 600 kW)</td>
<td>Wood word mechanical governor</td>
<td>Synchronous generator</td>
<td>Existing Excitation changed over to manual control on grid operation</td>
</tr>
<tr>
<td>3.</td>
<td>Chirkula SHP (1 x 1000 kW; 1 x 500 kW)</td>
<td>Analog electronic governor</td>
<td>Synchronous generator</td>
<td>- Do -</td>
</tr>
<tr>
<td>4.</td>
<td>Kanchavti SHP (2 x 1000 kW)</td>
<td>Analog electronic governor</td>
<td>Synchronous generator</td>
<td>- Do -</td>
</tr>
</tbody>
</table>

2.3.8.1 Monitoring and Remote Control Computerized System

Computerized monitoring and remote control system (MRC) was proposed with a capability of performing 4 primary functions.

i) Collecting information
ii) Working out decisions
iii) Issuing commands (controls) from a remote place for start stop auto synchronizing and running control.
iv) Recording of data

**Fig: 2.42: Interconnection of Power houses with Grid**
2.3.8.2 Existing Control Equipment

i) Woodward Mechanical governor automatic unit control for Kulagrah SHP is shown in figure 2.43 & figure 2.44.

ii) Analogue electronic governor control for kanchauti and Chirkila are shown in figure 2.45.

iii) PC based Digital Governor for Sobla power plant was ordered specifically for generation control. The system had provision for remote control as shown in figure 2.46.

iv) Duplicating/Replacement of conventional equipment for control & monitoring e.g. governor for turbine, Automatic voltage regulator for generators, excitation control, relays for electrical and mechanical protection and unit control boards for monitoring already installed/ordered was not considered desirable.

v) Sensors (transducers) signal processing and conditioning, equipment was proposed as follows:
   a) Input source data be obtained by connecting directly to the power plant hardware. Accordingly transducers are not required for current, voltage and frequency. Analogue signal can be taken for temperature from embedded temperature detectors and other such sensors
   b) Use computer software for analogue to digital conversion.
   c) Provide computational sub systems in the minicomputer package for calculating desired figures e.g. kW, kWh temperature etc.

vi) Remote control of intake gates, desilting tanks and power channel was not recommended because:
   a) Diversion at intake was for peak load, excess water being escaped from forebay. So that variation of load in power house is possible.
   b) Cost for such a control is high because of distance involved.
   c) Transducers installed in open and comparatively un-protected areas require physical safeguard by personnel.
   d) These locations require periodic physical inspection and preventive maintenance by Skelton staff at the unattended power station.

vii) Electrical and mechanical protection operation require emergency shut down by master relays to avoid damage to units in case of monitoring and remote control (MRC) system failure and to reduce digital outputs.

viii) Group annunciation only e.g. electrical protection operation or mechanical protection etc. is adequate at remote station as remedy of defects has to be by physical means.

ix) Unit starting and stopping (local) is possible from governor panel only. Semi automatic/automatic starting from control panel is required.

x) In case of feeder tripping at sending end the power plant may be desynchronized and any attempt at reclosing without ensuring synchronism may cause short circuits. Similarly tripping at remote ends of feeders can cause trouble if proper safe guards are not provided.
Figure 2.43  Mechanical governor automatic unit control Turbine control (speed adjustment)  
(As Designed)

Figure 2.44:  Automatic Unit Control Mechanical Governor (Woodward)  
(As Designed)
Figure: 2.45: Analogue Electronic Governor Control (As Designed)
2.3.8.3 Revised Control Scheme – Design Criteria

Local Control

Both the plants and auxiliaries was provided capability to be started locally from the individual control panels (starters, excitation panel, governor etc.). The unit and its auxiliaries to have automatic starting capability from a master switch located on the main switchboard. Manual synchronizing facility to be also provided.

Audible/visual alarms to be provided at each unattended power plant for all plant system failures, abnormal condition of level, pressure, temperature etc. Alarm signals and conditions to be properly displayed on annunciators. A push button to be provided to silence the horn and change the trouble point from flashing to steady.

Local Automatic Control

Local automatic control of each power plant to be initiated by placing the unit master control switch in the ‘local automatic’ position and placing the unit start-stop control switch in start position. Synchronizing of the unit to system is done through MRC system. The design will include manual synchronization also.

Remote Automatic Control

Remote automatic control or unattended operation of each power plant to be initiated by placing the respective unit master control switch in the “remote auto” position. The operation of these units are now
under the control of the remote operator at Dharchulla. The unit operation and control are similar to local automatic operation.

**Revised Control Scheme Description**

The generating units of Chirkilla and kanchauti power plants were proposed to be controlled from the main centralized control board in the power station with provision of remote control from Dharchulla at a distance of 25 km from Kanchauti and 35 km from Chirkilla. Suitable interlocks to be provided to safeguard the machine against inadvertent faulty operations and to ensure correct operation of all sequence when starting the machine from power station or from remote station. Control switches on generation and synchronizing panel are shown on figure 2.47.

**Normal Starting**

The normal starting of each unit was proposed locally from governor panel or automatically through a master controller switch installed on the control panel of each unit (figure 2.48). The sequences could also be operated from remote location at Dharchulla for unattended operation.

Synchronization was proposed as a separate step by auto-synchronization from supervisory panel or by manual synchronization.

Loading of generating unit was proposed in the third step by remote control of the limiter and speed level controls of the governor.

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**Figure: 2.47: Control Switches on Gen. and Synchronizing Panel (As Designed)**
Figure 2.48: Unit Starting
(As Designed)
Normal and Emergency Unit Stopping

Normal stopping was in steps. Automatic protective devices were provided to detect failure in normal operating conditions of the various equipments, secure an emergency stop of the unit whenever necessary and actuate alarms.

It was proposed that emergency stopping of the unit should occur in the following cases.

a) Electrical protection operation  
b) Mechanical protection operation  
c) Turbine speed 115%  
d) Turbine overspeed 130% (tentative figure)  
e) Governor oil pressure low

Emergency closing of turbine inlet valves was proposed in the following cases:
f) Turbine speed 130% (tentative figure)-
Proposed schematic drawing is shown in figure 2.49.

Other Controls

Inlet valve control and auto synchronizing by a dedicated auto synchronizer form remote control station and manual synchronization locally.

2.3.8.4 Hydraulic Control

Storage in the forebay tank at the heading of penstock intake is limited, it was proposed that a system of water level controls be provided based upon floats for transmission of forebay storage levels to the power plant and actuate alarms/shut down whenever the level goes beyond abnormal values.

Since the schemes were run-of-the-river schemes with no storage envisaged of any sort, it was considered that frequent adjustment of the intake for regulation will not be desirable. They should be operated for maximum/daily peak demand on the station. The excess water will spill from forebay.

2.3.9 Modern practice for control of small hydro plants (100 kW to 5000 kW)

Present modern practice is to have PLC based automatic control system with manual control as backup. A common PC for Supervisory Control and data Acquisition system (SCADA) may be provided. Redundant PLC for automation as backup is not provided. PLC can withstand harsh conditions of power house.

Most of the small hydro powerhouses in the range have the control room at the same level as the machine hall. The hard wired manual unit control and computer based (PLC) automatic control system is provided in the control room. Supervisory control and data acquisition system (SACADA) if required is provided by a common Personnel Computer for all the units for Supervisory/Remote control functions in the control room for which one additional panel (Halaipani Project) or desk at (Sikasar project) is provided.

Microprocessor controller (PLC) is used to provide following unit and plant control functions for isolated/interconnected operation.

- Turbine Governing control & Monitoring
- Generator control & Monitoring
- Starting sequence control
- Auto synchronizing (if required)
- Automatic shut down control
- Emergency shut down
- Control of turbine generator auxiliaries
- Monitoring of turbine generator auxiliaries

In manual/maintenance control mode the controller can perform the following control functions.

- Manual turbine gate or needle valve control
- Manual synchronization control
- Manual circuit breaker control
- Manual load control
- Manual brake control
- Manual normal shut down control
- Automatic emergency shut down

In addition the control system can monitor all critical items that are required for safe operation.
• Protective relay status
• Generator breaker status
• Lock out relay status
• Hydraulic oil high/low pressure/level
• Speed increaser, high oil temperature/level/flow
• Brake status
• Generator/bearing temperature
• Head water/tail water level
• Generator current, voltage, power-factor, kW, kVAR & kWh
• System voltage and frequency

Analogue meters may be provided as back up.

Halaipani Project (4 x 4 MW): Halaipani control system is a typical example. Unit control (manual/automatic) is from Turbine Auxiliary Governor Panel (TAGP) from a panel along with Manual unit control and protection panels in control room (Figure 2.50). Single line diagram is shown in figure 2.51.
Figure 2.50: Halaipani Project (4 x 4 MW) – Control and Protection
(Source: AHEC Project)

Figure 2.51: Single Line Diagram
(Source: AHEC Project)

NOTES
1. 110 VOLT DC SUPPLY SHALL BE AVAILABLE FOR
   SWITCHGEAR OPERATIONS, INDICATORS, ALARM
   ETC.
2. DRAWING IS TENTATIVE FOR TENDER PURPOSE
   ONLY
3. APPROPRIATE KNEE POINT SHALL BE CHOSEN FOR PS CLASS
   CTs
2.4 CONTROL OF MICRO HYDRO

2.4.1 Modern Digital Electronic Load Controller for Microhydro

A typical Digital Shunt Load Governors (ELC) installed on 50 kW micro hydro and developed in India is shown in Figure 2.52. These controllers are reported to be working successfully in India and abroad for many years. These Generation Controllers (load shunt governors) are Digitally controlled electronic load controllers for control including speed control of Micro Hydro power plants (up to 100 kW) by controlling the output load only.

Standard controllable loads (like water heaters) are provided along with the governor system and the load on the machine is maintained using these load in such a way so that user gets stable voltage and frequency. No major input control is required resulting in considerable saving in cost of equipment and civil works. Dummy load can be replaced by useful loads. Load controller can be designed to manage the useful load system for surplus energy. It is fool proof and suitable especially for unattended operation in remote Rural Area of developing countries by unskilled operators.

2.4.2 Advantage of Electronic Load Controller

The generator always generates the maximum power possible. The generation not immediately required is used up in secondary loads that are controlled by TRIACS. The secondary loads can be for useful purposes and the overall system efficiency can be at extremely high point. Other advantages are as follows:

i. Since the control is by digital means with speed as reference the response of the governor to changes in frequency can be faster and more accurate as compared to the mechanical governing or by electronic governing based on current / voltage as reference.

ii. Governing by control of water is complicated by the effects of water hammer. Water hammer results from having to accelerate and decelerate the moving water in the power plant and penstock in order to vary the flow through the turbine. Faster governing (for stability) can increase water hammer pressures. Water hammer induced pressure fluctuations create governing difficulties if not corrected for. Water hammer problems are reduced in large hydro-power plants by keeping the length of the pipeline as short as possible or by reducing the speed of operation of the governor (possible only if the loads change slowly enough) or by installing surge tanks to absorb the impact of flow changes. If the governing is done by load control, no quick changes are necessary.

iii. No moving parts: Mechanical governing requires relatively fast and accurate mechanical movement. These devices necessary to control water add to the turbine expense.

iv. Less expensive types of turbines having no provision for flow control of water can be used. Industrial Centrifugal pumps for example, can be applied as low cost turbines by operating them backwards but pumps do not have any inherent method for controlling water and must use load controller.

v. Little or no custom engineering is required, because the governing motion is not affected by site dependent characteristics such as length and size of the penstock. Provision of adjustable dead band and dash pot time in the field ensures stability of operation.

2.4.3 Governor Functions

Shunt load Governors can be designed to perform following jobs in a micro hydro-electric installation.

i. Stable speed control for all inflows
ii. Management of surplus energy for useful purpose.
iii. Prevent overloading of an hydro-electric plant in case of reduction in stream inflow. Shedding load at peak demand periods or during low water.
iv. Control and protection functions as described in a subsequent paragraph.
2.4.3.1 Architectural View and Hardware Details of the Digital Load Controller

The system is controlled by an 8 bit microprocessor running a real time operation system. The processor is interfaced to a Digital Input Output device giving a total of up to 24 digital Input/Outputs.

A L.E.D. / LCD display is interfaced through the input/output device. The input output device and clock timer controls the dummy load (five step loads and one variable load) through a Triacs module.

The step and variable load indications are shown through LEDs.

2.4.4 Detailed Specification

1. Processor Type : 8 bit
2. EPROM : 8 K
3. RAM : 8 K
4. Digital Input/Output Lines : 24
5. Display : Frequency (LED or LCD)
6. Power Supply : Built in from 230 V
7. Frequency input : From 230 V single phase
8. Output : 3 Phase or single phase
9. Protection : Over frequency, over voltage, under voltage, over current etc.

2.4.5 Triacs

The triacs load (variable internal load) can typically change from zero load (or vice versa) in 3 cycle (50 milliseconds) for normal frequency changes. Step load can be switched on directly by triacs (single phase) or by energising coil or Power Contactors. Operating Time of Contactors is 25 milliseconds and electrical life is of 1 million operations.

Figure 2.52: Load Controller for 50 kW Micro Hydro in Uttarakhand
(Source: As designed from Pradeep Digitech)
2.4.6 Stability

Provision of adjustable dead band and Dash pot time equivalent is necessary to ensure stability due to change of water inertia and load characteristics. Dashpot time is the adjustable time between two successive changes.

2.4.7 Parallel Operation

The units with shunt load governor can be operated in parallel amongst themselves and with grid using manual speed control (Phase control by Triac).

2.4.8 Micro Hydro Standard (AHEC) Recommendations

Micro hydro standard issued by Alternate Hydro Energy Standards specify following control for micro hydro.

<table>
<thead>
<tr>
<th>D. Description</th>
<th>Category (Installed Capacity in kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Category A (Up to 10 kW)</td>
</tr>
<tr>
<td></td>
<td>Category B (Above 10 kW and up to 50 kW)</td>
</tr>
<tr>
<td></td>
<td>Category C (Above 50 kW and up to 100 kW)</td>
</tr>
</tbody>
</table>

| Controller (Preferable/Micro processor based) | (ELC) Electronics load controller or IGC Induction Generation Controller | (ELC) Electronic Load Controller or IGC Induction Generator Controller | (ELC) Electronic Load Controller or Flow Control Governor |
| Ballast Load of Electronic Load Controller | Air heater | Water Heater | Water heater |

Notes:
1. Micro hydro for power generation category B & C should have the following provisions:
   (i) Parallel operation in local grids whenever available.
   (ii) Parallel operation with main grid whenever extended.

2. Micro hydropower generating station category B & C having more than 1 unit shall have following additional provisions:
   (i) Parallel operation between units at the station
   (ii) The Governor/Load Controller, AVR should have adequate provision for adjusting the Speed Droop and Voltage Droop for facilitating the Parallel Operation of the Units.

A typical Example is shown in figure 2.53 & figure 2.54
Figure 2.53: A Typical Metering, Relaying and Interconnection with Grid
(Source: Micro Hydro Standard – AHEC)
Figure 2.54: Ballast Load Hot Water System
(Source: Micro Hydro Standard – AHEC)

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