CHAPTER - 4

DESIGN AND ENGINEERING PHILOSOPHY FOR ELECTRO-MECHANICAL WORKS OF HYDRO POWER PROJECTS – BEST PRACTICES & BENCH MARKING

> ***"The best practices in design and engineering philosophy of hydro power projects involve various considerations at different levels of project implementation such as selection of generating unit, selection and development of turbines, choice of generators, reactor power capability, excitation system, electrical auxiliaries, mechanical auxiliaries, control and protection, ventilation and air-conditioning etc. The chapter also provides a highly informative table of national and international benchmark practices in this field."***

4. GENERATING UNIT – SIZE SELECTION

Selection of unit-size is dictated by the techno-economic considerations (hydraulic data, effective head, flow rate, type of purchase, especially pumped storage schemes, availability for peaking etc.) and transport limitations. Space constraints for underground power house cavity also limit the maximum unit-size to be selected for the prevalent hydrological condition. However, within these constraints, attempts shall be made to choose the layout & unit size so as to get benefits of economy due to size.

Hydro generators of more than 700 MW unit capacity are already in operation in the world. The highest capacity so far in India is 250 MW in Koyna St.-IV, Tehri & Nathpa Jakhari HE Projects. Although, the increased unit sizes reduce the cost per kw, floor space / kw & weight of the machine, the size of the Hydro generating units is dictated by various considerations, which are taken into view while deciding the unit size. The various aspects are:

4.1.1 Design considerations

With the use of improved cooling & improvement in insulation & magnetic steel technology for Hydro generators, higher rating machines with lower weight ratio have been developed. Besides there is a significant improvement in the capability of the machines to withstand high run away speed.

4.1.2 Transport Limitations

Site location determines the limitations regarding the weight, height, length & width of any package that can be safely transported to the site. In terms of weight limitation, strength of bridges etc. on the way has to be critically examined before taking up the decision regarding Unit size.

Baira Siul HEP-180 MW (H.P.)

With the developments in metallurgy, superior insulation materials & new methods of cooling, fast response digital governing & excitation systems, improvement in manufacturing techniques & methods of erection, assembly at site is gradually over coming the limitations imposed by Transport conditions. Split type large capacity power transformers, split runners & forged welded shafts are some of the latest developments which could help in overcoming the logistical limitations involved in the transportation of these equipments.

4.1.3 Manufacturing considerations

Hydro generators are generally tailor made to site conditions & the manufacturer has to examine the availability of sizes, variety & complexity of various machine tools, implements & facilities.

4.1.4 Effect of Weight & Dimensions on civil works

The internal dimensions of the machine hall, width & height are determined in accordance with the weight & size of the largest assembly. Foundation construction depends upon the weight & size of the machine.

4.1.5 Effect of size on system operation

- Load dispatching & economic loading angle
- Stability consideration

4.2 TURBINE & MAIN INLET VALVE

4.2.1 Selection of Turbine

The selection of turbine is of prime importance to get best operating efficiencies and optimum civil works cost. The operation and maintenance cost are also important considerations.

The possible combination of head and capacity, even when speeds are restricted by synchronous speed are so numerous that identical units can hardly be used at more than one site.

The hydro projects being site specific, as such the use of standard or off the shelf units may not be possible. Thus for the selection of turbine, a detailed case study is carried out by considering the various parameters/ conditions. The selection of type of turbine is made based on the "Head" and output. The broad classification is given below:-

- Low head (upto 60 mtrs.) – Kaplan Turbine.
- Medium head (30 to 600 mtrs) – Francis Turbine.
- High head (more than 300 mtrs) – Pelton Turbine.

The above classification based on head is only a broad guide line and there is a large overlapping zone, for which the following aspects can be considered for the selection of a hydro turbine:-

- Head variation
- Civil costs
- In flow variation i.e. part load operation
- Maintenance
- Efficiency

4.2.2 Development of Turbine with Improved Efficiency

New design of turbine runners can increase the efficiency of older plants by about 2 per cent. Computer programmes help in accurately analyzing deformation and stresses of structural components. Computer studies provide more reliable and faster identification and quantification of losses to improve efficiency.

4.2.3 Turbine Efficiency

The hydro turbines are expected to operate over a wide range of output. It is advisable to specify weighted average efficiency based on the computed efficiencies at various outputs. The weighting factors should be selected corresponding to the average annual time (in percent) that the units are expected to be operated at a particular output. Due to improved design of turbine, the weighted average efficiency obtainable for Reaction turbine is more than 95% and for Impulse turbine more than 92%.

4.2.4 Design Head

Design head (h_d) is the net head at which peak efficiency of turbine is desired. This head must be so selected that the maximum and minimum heads are not beyond the permissible operating range of the turbine. Design head determines the basic dimensions of the turbine. Design head (h_d) is calculated approximately by the following equation: -

(h_d) : Minimum net head +2/3 (Maximum net head - Minimum net head)

4.2.5 Specific Speed and Synchronous Speed

The trial specific speed is selected on the basis of empirical formula involving design head.

Rotational speed of turbine is calculated from this specific speed.

The calculated rotational speed is rounded to the nearest synchronous speed and the specific speed is again calculated. Rated speed resulting in even number of pair of poles is normally preferred.

In case of high silt content, a lower step synchronous speed should be selected. However, the decision can only be taken after techno-economic analysis / studies.

4.2.6 Turbine Setting

Turbine setting depends on maximum net head, water vapour, pressure and barometric pressure corresponding to the site altitude. The centerline of the runner is kept above or below the min. TWL for reaction turbines as per the calculations carried out based on the basis of various design practices.

Deeper setting gives better performance of the machine at the expense of higher civil costs (in case of surface power station) as it reduces cavitation.

4.2.7 Runner Removal

Provision of runner removal for maintenance is made. There are two methods of removing the runner, one from the top and other from the bottom.

Removal of runner from bottom

Normally adopted for high speed turbines with due consideration for runner diameter.

Removal of runner from top

Normally adopted for low speed turbines. The generator rotor & shaft are removed first and then the runner is removed through the stator bore . This takes longer down time.

4.2.8 Main Inlet Valve

The inlet valve is placed (connecting penstock to the turbine) just before the scroll case in the water conductor system. MIV is used for normal operations & for isolating the unit in case of emergency/maintenance. These are of the following types: -

- Butterfly Valve (upto 200 m head)
- Spherical Valve (More than 200 m head)

Normally the opening of the valve takes place when the pressure on either side of the valve is the same or differ insignificantly. The equalization of water pressure is brought about by filling the spiral casing through solenoid operated bypass valve. Suitable air release valve should be provided at appropriate location on the downstream side to allow air trapped in the penstock to escape when it is filled with water through bypass valve and for supplying / admitting the air when the valve is suddenly closed.

4.2.9 Pressure Rise and Speed Rise

Pressure rise and speed rise are governed by the type of water conductor system, inertia of generating unit and the governor closing time.

The permitted speed rise for reaction turbines should not be more than 60% & for pelton turbine not more than 20%. However, a speed rise of about 50% is normally specified for reaction turbines to minimize vibrations.

Pressure rise shall not be more than 30 to 35% for Francis turbines 30 to 50 % for Kaplan turbines & for Pelton turbines not more than 15%.

In case the computed pressure rise exceeds the permissible limits for reaction turbines as indicated above, possibility of providing pressure relief valve should be examined and if required provided in consultation with the manufacturer of generating unit. The unit spacing considered in such a case should provide the space required for pressure relief valve.

Turbine shall be designed to withstand runaway speed (normally around 1.8 times the rated speed) for 30 minutes. However, it should be around 25 percent less than the critical speed.

A surge tank may be provided in a hydro project in consultation with the agency carrying out design & engineering of civil works & where the resulting reduction in water hammer pressure will provide a more economical turbine penstock installation and also in case where the computed percent of speed rise based on the rejection of the entire rated load for a unit operating independently cannot be reduced to about 45 percent by other practical methods.

For a unit which is one of the several units on a common penstock header system, the permissible percentage of speed rise will be computed on the basis of one unit operating alone.

4.2.10 Governing System

Application of microprocessor technology has enabled the use of digital systems for process control where high-speed control is required. These governors are mainly used for :

- Speed/frequency control
- Load control
- Speed/load control.

Performance requirements of the governor are given below:-

- Stability: Speed oscillation does not exceed $\pm$ 0.15% of rated speed.
- Dead time: 0.2 seconds
- Speed Dead Band : 0.02%
- Speed regulation : 0-10%

4.2.11 Pressure Oil System Equipments

Pressure oil system shall be provided for each turbine for operation of turbine wicket gates/Nozzle/deflector servomotors through governors and for control of MIV. For major H.E. projects, separate pressure oil system should be used for turbines & MIVs for reliability consideration.

The trend is towards using higher oil pressure. When the pressure of 60 Kg./cm^2 is specified it allows smaller valves, pressure tanks, pipings and servomotors.

For higher oil pressure, piston type accumulator with nitrogen bottles shall be used.

4.2.12 Materials

Special care should be taken to select the material of the under water parts. The material for runner and guide vane is 13:4 Cr-Ni stainless steel and for turbine shaft forged carbon steel. The material 16:5 Cr-Ni stainless steel is also used for manufacture of runner. The other parts like stay ring, spiral case, top cover, bottom ring, regulating ring, draft tube liner and pit liner are made of steel.

As most of the rivers in the northern belt of the country are heavily loaded with silt, it erodes the turbine under water parts. The efforts are being made by material technologists and the manufacturers all over the world over to develop various types of metallic and non-metallic coatings to check the problem of silt erosion in parts like Runner, Guide Vanes, MIV etc. The application of plasma nitriding, ceramics and polyurethane polymers coatings by Guns, High Velocity Oxy Fuel system (HVOF), etc. are being tried on parts like runner and guide vanes. Development of better material and alloys to withstand silt conditions in Himalayan region have also been identified for Research & Development.

4.3 GENERATOR/MOTOR – GENERATOR

The main important parameters to be specified/ finalized for the design of the hydro generator are:

i) Rated & maximum continuous MVA output, P.F., Voltage, Frequency.
ii) Synchronous speed
iii) Moment of Inertia required for generator rotor
iv) Bearing arrangement (Umbrella, semi umbrella or suspended Type)
v) Reactive power capability
vi) Rated voltage, reactances, efficiency, temperature-rise of stator, rotor with required voltage and frequency variation, bearings, damper windings etc.
vii) Insulation class

4.3.1 Generator Output Capacity

The rated capacity of a generator/motor-generator is defined in IEC-34-1 as the continuous output expressed in KVA available at the terminals at rated speed, frequency, voltage and power factor. In addition, motor-generators have a continuous output rating expressed in Kilowatts available at the shaft at a specified speed, frequency, voltage and power factor. Generator output/capacity is specified corresponding to the turbine rated output at rated net head, frequency, voltage and power factor. Motor – generators are specified with an additional motor shaft output corresponding to the pump input at minimum rated head and the pump overload capacity at minimum head shall be taken as 5%.

4.3.2 Rated Speed

The generator rated speed shall be matching the turbine or pump-turbine rated speed. Speed selection has an extremely significant impact on the generator/motor-generator design. Rated speed resulting in even number of pair of poles is normally preferred.

4.3.3 Rated Voltage

Generator Voltage is governed by the rated speed, number of parallel paths and the slot current. Higher Voltage means higher insulation cost but reduced current and copper cross-section/cost. To optimize the generator cost, the current flowing in stator slot should be limited to 3000-5000 Amperes with current through individual coil being limited to approximately 3000 Amperes.

4.3.4 Power Factor

The power factor is specified on the basis of the power system requirements. Most common value of power factor specified for hydro electric machines is 0.90.

4.3.5 Reactive Power Capability

Reactive power capability requirements dictated by power system and transmission line lengths should be appropriately specified.

The machine over and under excited reactive capacity along with the rated capacity and power factor, broadly define the machine characteristic.

The over excited rating of the machine is referred to as the " Synchronous condenser capability". It is the maximum amount of reactive KVA that the machine can generate when operating over excited, at rated frequency and voltage, without exceeding the rated temperature rise.

KVAr (over excited) = (1.40 – rated power factor) x maximum KVA output.

The under excited rating of the machine is also sometimes referred to as " line charging capability". It is the maximum amount of reactive KVA which the machine can absorb when operating under excited, at rated frequency and voltage, without exceeding the rated temperature rise and becoming completely self-excited or unstable.

KVAr (under excited) = 0.8 x (SCR) x (maximum KVA)/1.15

SCR : Short circuit ratio.

4.3.6 Machine Reactances

The convention has been to define two sets of reactances with the following designations:-

- Rated voltage reactance (Saturated value of reactance)
- Rated current reactance (unsaturated value of reactance)

Another value which is specified is the minimum **Short Circuit Ratio (SCR).** This value is used to give a measure of the relative strengths of the field and armature ampere turns. It is defined as the ratio of the field current required to produce rated armature voltage at no-load to the field current required to circulate rated armature current with the armature short circuited. Typical values of SCR for large hydro-generators are as follows:-

Power factor	SCR
1.00	1.250
0.95	1.175
0.90	1.100
0.85	1.050
0.80	1.000

4.3.7 Temperature Rise

The following temperature limits (above a 40 degree celcius ambient) are specified for class-F insulation system for both stator and rotor windings:-

- Stator winding (measured by embedded temperature detectors) – 80° C
- Field winding (measured by resistance method) – 90° C

The limit of temperature of the thrust bearing metal on large hydro-electric machines is generally 80° C. The guide bearing temperature limit is specified as 70° C.

4.3.8 Damper Windings

When generating machines run in parallel, particularly on fractional load, the generator may oscillate resulting in loss of synchronism. To prevent such oscillations in generators, damper winding and damper grids are provided in the laminated pole face of rotor. It is common practice to specify all hydro electric machines to have low-resistance damper windings. Two types of damper windings are typically specified-

- **Connected Dampers: -** These consist essentially of windings similar to squirrel-cage on an induction motor. They are continuous between poles and require additional bracing in the form of end ring. When connected damper windings are specified, the ratio Xq"/Xd"$\simeq$1.0.

- **Non-connected Dampers: -** The dampers in each pole face are independent from those in adjacent poles. This type of damper winding is less expensive than the connected damper winding and makes removal of poles easier. For non-connected damper windings, the ratio Xq"/Xd" is inherently greater than 1.0 and may be as high as 1.5.

4.3.9 Fly Wheel Effect

The fly wheel effect is defined by the equation

Fly wheel effect = GD^2 where

G = mass of the rotating parts (Kg)

D = 2x radius of gyration of the rotor (meters)

The fly wheel effect is expressed in terms of the machine H constant by the equation:

$H = 1.37 x GD^2 x n^2 x 10^{-6}$/rated KVA

n = rotational speed of generator

The inertia of the machine is an important factor in determining stability of the machine:

- It must be adequate to meet the transient stability requirements imposed by the interconnected electrical power system.

- It must be adequate to limit speed rise.
- It must have such a value which will not cause the machine natural frequency to be in resonance with the expected frequency of draft-tube hydraulic surges. Margin of approx. 25% should be maintained.

4.3.10 Generator Efficiency

Generally, only the value of efficiency at the rated machine conditions is specified. However, in those cases where the machine is expected to operate over a wide range of output, it is advisable to specify a weighted average efficiency based on the computed efficiencies at various outputs. The weighting factors should be selected to correspond to the average annual time (in percent) that the units are expected to be operated at a particular output. With the improved design of generator the weighted average efficiency obtainable is more than 98.65%.

4.3.11 Bearing Arrangements

There are three possible bearing arrangements for large vertical hydro electric machines, as follows:-

- Combined thrust and guide bearing mounted on a top bearing bracket above the rotor. This conventional bearing arrangement (suspended type with the thrust bearing located above the rotor is generally used for small diameter, long core, high speed machines),
- Combined thrust and guide bearing mounted on a separate bearing bracket located below the rotor (umbrella type arrangement).

The vast majority of large machines are constructed with the combined thrust and guide bearing installed on a lower bearing bracket below the rotor and called umbrella arrangement. An upper guide bearing is customarily installed above the rotor and installed on a separate, light-weight guide bearing bracket mounted on the top of the stator frame. This type of arrangement is termed as semi-umbrella arrangement.

- Combined thrust and guide bearing mounted on the turbine head cover. This design is often referred to as a “Close-coupled” machine.

4.3.12 Cooling System

Cooling of the machine should be as uniform as possible. The method commonly used for cooling the stator windings of high capacity hydro-electric machines is forced air cooling of the windings using either the natural fan action of the rotor or with supplementary motor-operated cooling fans.

4.3.13 Fire Protection System for Generator

Two types of fire suppression systems are generally specified: Water spray and CO_2. The water spray system has the advantage of being relatively inexpensive. The water acts both as a fire suppressant as well as an effective coolant. Its principal disadvantage is the danger of an accidental discharge inside the machine housing and the need to clean the windings afterwards. This system is normally put in manual mode. On the other hand, CO_2 is a clean suppression agent requiring no clean up after a discharge. However, it is more expensive and requires ducting to vent the CO_2 from the housing after a discharge. It is also more hazardous because it is an asphyxic gas which is both colorless and odorless and acts to displace oxygen in pits and low-lying galleries. Special precautions need to be taken for personnel safety in these areas.

As a rule, water spray system is adopted in underground power stations because release of CO_2 gas in underground installation will be more hazardous.

4.3.14 Generator Terminal Equipment

Isolated phase bus-ducts is the acceptable method of connecting generators to the step-up transformers for large sized units in modern power houses. The isolated phase bus duct is available in both continuous and non-continuous housing designs.

- The non-continuous design may be used for low-amperage circuit upto 6000 A.
- The continuous enclosure design is used for higher current ratings. The continuous housing design has higher losses than the non-continuous housing design because of the higher enclosure currents

circulated in the continuous housing design. However, the continuous housing design is always preferred.

- Self cooled bus ducts are preferable but forced cooling can be considered for bus ducts having current ratings above 15000 Amp.
- Segregated Phase bus ducts are not considered practicable beyond 5000 Amp rating due to excessive heating of the enclosure but can be used only in places where space limitations prevent the use of isolated phase ducts.
- Non-segregated Phase bus ducts are generally used where main lead currents are between 800 Amp and 3000 A.

- The starting bus for pumped storage plants shall be rated to carry the motor starting current during start up from VFC or back to back from another unit. For pumped-storage plants starting on back-to-back method the starting bus duct need be designed for currents as much as 3 times the starting current required for motor starting by VFC (Variable Frequency Convertor).

4.3.15 Neutral Grounding Terminal Equipment

All large hydro electric machines are having a wye-connected stator winding with the neutral brought out of the machine housing and grounded via a high-resistance circuit consisting of the following components:-

- A single-phase distribution type transformer connected between the generator neutral and ground. This transformer should preferably be either a dry-type or epoxy resin, cast coil type having a standard, high-voltage rating approximately equal to 1.5 times the maximum machine phase-to-ground terminal voltage rating. This higher voltage rating is recommended in order to avoid excessive magnetizing inrush current when a ground fault occurs. The secondary winding of this transformer is normally rated 240/120 V.
- A resistor is connected across the secondary terminals of the

distribution transformer. This arrangement makes the machine grounding effectively a high-resistance type.

4.3.16 Surge Protection

On large, unit connected machines, the windings are connected to the power system network via step-up power transformers. As voltage surges can only enter the machine winding via the power transformers, these are protected by surge arresters connected to the high-voltage side of the transformers. Surge protection comprising of surge arresters and surge capacitors shall be provided on the machine terminals.

4.3.17 Instrument Transformers

Current transformers should preferably be of single phase window type fitted around the bus conductors for meeting the protection & measuring / mounting requirements.

Voltage Transformers shall be located in separate cubicle for each of the three phases & mounted in withdrawable drawers.

Where surge protection is provided, it is customary to install the surge arrestors and/or the surge capacitors in the same cubicle as that of the Voltage Transformers with suitable barriers.

4.3.18 Continuous On-Line Machine Condition Monitoring Systems

With following Monitoring equipments/system, prediction of abnormality and preventive action in case of Rotating Electrical Machines can be possible.

4.3.18.1 Partial Discharge Monitoring (PDM)

A partial discharge analyzer (PDA) monitors the partial discharge activity (damage to insulation) of the machine winding. This indicates the condition of winding insulation systems. The system consists of permanently mounted partial discharge sensors (capacitive couplers) on the line & neutral windings and portable or permanently installed test equipment.

4.3.18.2 Air Gap Monitor

In the design of large machines, a high degree of dimensional stability is desired. The term "dimensional stability" essentially means the degree that the rotor and stator of the machine are capable of retaining their cylindrical configuration under all operating conditions. A uniform air gap under all conditions of operation below the ± 10% tolerance allowed by standards shall be maintained. The on line air gap monitoring system provides continuous monitoring of the air gap to detect any abnormal deformation of the magnetic core or the rotor before failure, thereby reducing the cost and length of failures. The air gap monitor uses stator mounted probes to monitor rotor and stator concentricity. The data provides an indication of structure weaknesses within the generator as well as the effects of centrifugal force, magnetic force and thermal expansion on the integrity of the machine.

4.3.18.3 Electromagnetic Core Imperfection Detection (ELCID)

The Electromagnetic Core Imperfection Detector is a new technique that can assess the condition of the stator core. This is an offline detection device.

4.3.18.4 Vibration Monitoring

The displacement of the bearings during the running of the units is monitored by using on-line vibration monitoring equipment for replicating the forces acting on the rotor. The armature must be designed in such a way that none of its own modes can be excited due to electromagnetic forces resulting from variations in induction on the air gap by any system.

4.3.18.5 Ultrasonic flow measurement device

An Ultrasonic Flow Measurement Device is installed for continuous monitoring of efficiency and discharge of the unit.

4.4. EXCITATION SYSTEM

4.4.1 Static Excitation System

Static, potential source rectifier exciters are generally used for medium to large generators. They are also used for smaller generating sets, partly owing to the free choice of location and the reduced length of the set and because of the fast-acting response to network transients. Static potential source rectifier exciters obtain the necessary electrical power directly from the terminals of the generator. They consist of a power transformer, the thyristor control element, the electronic regulator and the de-excitation unit.

4.4.2. Field Flashing and Initial Excitation Requirements

Starting is generally accomplished by flashing the field from the station battery. Another method commonly used is to rectify a reliable source of A.C. supply to initially excite the field. Typically, a 2-pole contactor is used to connect the D.C. field flashing supply to the field after the machine is brought upto approximately 90% speed. When the machine voltage rises to approximately 25% of rated, the rectifier starts to work. When the machine voltage reaches about 70% of rated, the contactor opens to disconnect the sources of D.C. supply voltage to the field.

4.4.3. Excitation System Rating

It is customary to specify the excitation system ratings for large hydroelectric machines to include the following features-

- Capacity to supply continuously 1.1 times the excitation current and voltage required by the generator at 100% rated kVA and 110% rated voltage. The overloading capability of 10% is added as a contingency in the event that the calculated field requirements are in error.

- Capacity to supply twice the excitation current required by the machine at 100% rated kVA and 110% rated voltage for a duration of one minute without damage.

A short time overload rating is specified to allow for both field forcing and the possibility that some malfunction in the protection circuits(e.g., faulty firing circuit or regulator) would cause the exciter to stay at ceiling voltage for some time. For certain special cases where system conditions demand, a negative ceiling voltage may be required to control machine over voltage conditions.

The equipment is also designed to supply negative excitation to meet line charging requirements or for out-of-step stability requirements.

4.4.4. Response time

The excitation system while operating at maximum KVA, terminal voltage, power factor & speed shall be capable of changing from rated field voltage to 90 percent of ceiling voltage within 25 ms for a sustained drop in generator terminal voltage of 5 percent.

The ceiling voltage shall be not less than 2.0 PU of rated exciter voltage.

The system shall meet all the requirements as specified under Generator Fault conditions.

Main & standby voltage Regulator with provision for Automatic Transfer is also recommended sometimes.

Power system stabilizer equipment/ adoptive control is provided for stability of the machine vis-à-vis the system to which it is connected.

Independent excitation system is also provided in case generator is provided with Dynamic Electrical braking.

4.5 GENERATOR STEP-UP TRANSFORMERS

4.5.1 Type and Ratings

- Water Cooled transformers, wherever feasible, are preferred for hydro power plants on account of their having lower weight and transport dimensions. As such, the type of cooling is generally OFWF/ ODWF.
- In case, provision of water cooling being not feasible, OFAF type generator transformers are provided.
- The transformer MVA rating, percentage impedence and secondary voltage are selected in such a way so as to optimise the use of the generator active (MW) and reactive (MVAR) capabilities in the system to which the transformer is to be connected. The primary voltage is selected based on the generation voltage and the secondary voltage based on transmission system considering the flow of power from the power stations to the grid. MVA rating is selected based upon:

- Generator maximum output
- Power factor
- Correction for altitude and ambient temperatures

Secondary voltage should be specified after duly taking into consideration the impedence voltage drop so that the voltage at the high voltage bushings matches the system voltage. Voltage variations specially for 400 KV system should be specified based on the power system studies.

4.5.2 Selection of Single Phase/Three Phase Transformers

Selection of single phase or three phase transformers for hydro power plants is governed by the transportation limitations and should be finalised considering the status of load carrying capabilities of bridges, etc.

4.5.3 Provision of TAP- Changer

- Provision of "Off-circuit" tap changer is made for generator-transformers of conventional generating units.
- Provision of "On-load" tap changer is required for pumped storage schemes having provision of reversible units.
- Range of operation for the tap changer is dictated by the system requirements.
- Normal range prescribed is $\pm$ 5%. However for 400 kV transformers, range prescribed is - 2½% to + 7½%.

4.5.4 Oil-Water Coolers

Transformers are provided with two complete independent sets of cooling equipment each with 100% capacity. The oil-water cooler shall be designed to facilitate easy cleaning. The cooler tube bundle shall be formed by double concentric tubes with an air space between oil and water path to prevent water mixing with oil. Water leakages shall be collected between the tubes.

4.5.5 Efficiency

With the improvement in designs, the efficiency obtainable at rated load for large power transformers is more than 99.7%.

4.5.6 Fire Protection System for Transformer

Mulsifyre fire protection system for generator-transformer is provided. This system is normally put in auto mode. If the space between the transformers is less than 15m, a fire wall is to be provided between them. The rating of the fire wall is to be for 3 hours and capable of withstanding exploding bushings and surge arrestors. The wall shall extend 0.31 m above top of tank/oil conservator and 0.61 m beyond cooling radiators.

4.5.7 Conservator

Diaphragm type oil sealing is provided in conservator to prevent oxidation and contamination of oil due to contact with moisture. Diaphragm of conservator shall be able to withstand the vaccum during installation/ maintenance periods. The connection of the air cell to the top reservoir is by an air-proof seal preventing entrance of air into the conservator.

BASPA HEP - Entrance to U.G. Machine Hall (H.P.)

4.5.8 On line Monitoring System

On line monitoring system predicts the condition of transformer which enables timely preventive action as required & helps in avoiding catastrophic failure and thus minimising maintenance costs. The following monitoring systems shall be provided.

i) On load tap changer monitor: - To monitor temperature/timing sequence/tap position, motor load and current.
ii) Dissolved/Evolved gas Analyser: - To monitor Hydrogen and Carbon monoxide.
iii) On line spectroscopy: - To monitor Methane/Ethylene/Ethane.
iv) Bushing Monitor: - To monitor bushing charging current.
v) Partial discharge Monitor: - To monitor partial discharge activity in the insulation.

4.6 ELECTRICAL AUXILIARIES

4.6.1 D.C. Supply System

The main objective of the DC supply system is to ensure uninterrupted DC power supply availability in a power station. This is achieved by proper selection of scheme & equipment. The various aspects to be considered are the type of cell, Amp- hour capacity, maintenance, life expectancy, market innovation etc.

D.C. Supply Systems for hydro power stations comprise of the following :-

- Batteries
- Battery Chargers
- Distribution Boards

4.6.1.1 D.C. Batteries

Batteries are required to cater for control, alarm annunciation, protection, communication, emergency lighting, solenoid operated valves and field flashing requirements of generating units. In general, lead acid batteries are widely used. The standard voltage rating for the batteries used are 110 V or 220 V depending on the DC load of the power station.

Batteries are generally designed with 10% design margin and 25% of ageing factor. For small and medium hydro plants, one battery set (110 V) with two battery chargers and for large hydro stations, two battery sets (220 V each) and one 48 V battery set with two (2) chargers for each battery are generally recommended. The sizing of the Battery is usually based on IEEE Std 485.

4.6.1.2 Battery Chargers

The battery charger having rectifiers with thyristors are usually used for charging the battery system. The charging is generally in float charging mode i.e. the batteries are kept in float charging condition in the normal operation and the load is met by the charger. The boost charger is used for quick charging the batteries during initial commissioning of the batteries.

4.6.1.3 D.C. Distribution Boards

D.C. Boards are designed to supply the following:-

- Normal continuous load
- Emergency lighting load
- Excitation current for field flashing of generators
- Indicating lamp loads.
- Bus bars are designed to supply short circuit power supply requirement from the battery.
- D.C. under voltage signal and alarm & D.C. fail buzzers are provided.
- D.C. Boards shall be self supporting with front and back hinged doors.
- The degree of protection provided by the enclosure shall be IP-44.

4.6.2 Grounding System

All electrical installations/ equipment have to be earthed / grounded to ensure :

- Dangerous potentials during normal as well as fault conditions are kept within the limits.

- Provide least resistance path for grounded neutral circuits.
- Facilitate relaying to clear ground faults.
- Provide a means of discharging current carrying parts which are to be handled by personnel.

The design of the system is usually based on National Electric Code, CBIP & IEEE-80 guidelines. MS Flats are used as ground conductors. Copper is also used in some countries.

For most of hydro-electric projects, separate, distinct grounding system should be provided for power house, switchyard & other civil/ hydraulic structures & inter-connected, if system design so dictates.

Criteria

Power house	-	To be designed to provide a max. resistance to ground as 1.0 ohm.
Switchyard	-	The resistance to ground not to be more than 1.0 ohm
Special attention	-	VFC drives, HV-GIS equipment Computer Networks, High frequency Cameras/ equipment.

- Separate ground mat, if feasible, be provided for power house, switchyard, remote structures such as control buildings, communication buildings, spillway gate structures, storage buildings, etc.
- If the control, computer and communication rooms are located in electrically noisy areas (e.g. VFC drives, high voltage GIS equipment etc), a "High-frequency signal reference ground grid beneath a false floor shall be considered, to provide a noise-free, low impedance ground to the equipment.
- The switchyard mat should extend 1.5 - 2.0 mts. outside the switchyard fencing. Grounding platforms should be installed at all switch operators inside the switchyard.
- Touch and Step potentials limit be maintained to an acceptable value.
- Normally IEEE 80 is followed for designing the grounding system

4.6.3 Illumination

Lighting for each area of the Project is required in order to have illumination needed to perform tasks normally associated with the area.

Illumination levels are based on BIS/ manufacturers catalogues. Type of luminaries are selected as per the requirement of the area plus asthetic factors. System is designed to ensure energy saving/ conservation by providing suitable sensors etc.

General indoor and outdoor lighting and receptacle are served by 3-Ø, 4 wire A.C. system. Transformers and panels are located so as to optimise wiring and to limit voltage drops to acceptable values. Fluorescent, incandescent and high intensity discharge lamps shall be used to obtain required intensities consistent with lamp life economy and functional appearance.

Nathpa Jhakra HEP Power House

- Fluorescent lamps are mostly used in interior spaces
- High-intensity Discharge (HD) Lamps:

Sodium vapour lighting fixtures are preferred for outdoor lighting such as switchyards, spillways and dams, parking areas etc. Automatic switching via photo electric cells can be adopted for outdoor lighting to optimise power consumption.

Metal-halide fixtures are used for certain indoor areas such as erection bay, generator hall, machine shop, turbine pit and other "high-bay" areas where proper colour rendition is needed and long-life is essential.

Incandescent lamps should be used only for battery powered emergency lights and for certain places where lights should not be turned on continuously or where fluorescent fixtures are impractical.

Emergency lighting is deployed in the event that normal A.C. power distribution system fails. The emergency requirements are at first met from the diesel generator sets and when all alternatives of A.C. supply fail, battery powered emergency fixtures provide the minimum requirement of lighting. The battery should have sufficient capacity to provide 4 hours uninterrupted illumination independently.

4.6.4 Power and Control Cables

Power cables for 11 kV systems are XLPE insulated with conductor and insulation screen. FRLS PVC outer sheathed cables are used for underground power stations. The 415 V system cables are of 1.1. KV grade, PVC insulated. The sizing of all power cables is being done on the basis of current rating taking into account proper derating factors for temperature, group deration, laying conditions, fault current and fault clearing time.

4.6.5 Cable Trench/ Rack System

For laying of cables in a power house, a broad based system involving cable gallery, trenches, cable racks, shafts etc. is provided.

In outdoor switchyards, a cable trench system is provided.

The main considerations/ practices are :

- High frequency cables/ control cables shall preferably be routed in separate fire resistant conduits.
- Segregation & proper spacing is maintained.
- Proper attention should be given to Ventilation/ heat dissipation aspects particularly in case of HV cables.

4.6.6 Unit auxiliary A.C. Supply System & Station Auxiliary A.C. Supply System

To feed the unit essential auxiliaries and the station auxiliaries, unit auxiliary/station auxiliary supply systems are provided.

4.6.6.1 Unit Auxiliary A.C. Supply System

As per the auxiliary supply scheme normally adopted each generating unit will be provided with unit auxiliary transformer to feed the essential loads of the unit. The unit auxiliary transformers, one for each unit, are fed from the unit's own generation. The essential load consists of mainly of the unit, cooling water pump motor load, excitation and AVR cooling fans, space heaters and OPU . The capacity of UATs is selected based on the consideration that it is able to continuously cater to the requirement of all auxiliary loads for their respective unit. During starting and stopping of units these loads are fed from SSB.

4.6.6.2 Station Auxiliary A.C. supply system

Basic Criteria	-	designed to provide a high degree of reliability & continuity of service
Primary function	-	to supply uninterrupted AC supply to Auxiliaries etc.

Various station supply loads such as fire-fighting equipment, illumination, drainage & dewatering pumps, oil purifier units, D.C. battery charger loads, ventilation & air conditioning loads, EOT crane loads, L.P. & H.P. air compressor loads, lift load etc. are determined and maximum demand is calculated at a diversity factor of 0.75. The availability of input supply is ensured from sources independent of station generation. In addition, adequate provision for meeting load of auxiliaries for one unit during starting/stopping of unit is also kept and for this purpose the UABs are connected to SSB through tie breakers.

- Besides it is customary to provide 2 Nos. SSTs of equal capacity; one SST being provided as a stand -by arrangement. In the event of A.C. supply failure, the station loads are supplied by a D.G. Set of suitable capacity.

4.6.7 Control and Protection

4.6.7.1 Unit and Station Control

- Control and data acquisition system is microprocessor/computer based distributed digital control system interconnected through fibre optic cables having hundred percent redundancy. Generally conventional control & metering devices are provided in Unit Control Board (UCB) and when computerized control system is envisaged, the unit control board shall have the control switches, micro-processor based equipment sequential controller / process control computer, status indicators (generator MW, Voltage, Ampere, PF & Frequency meters) and other devices such as alarm / annunciation facias, microprocessor based temperature monitor, vibration monitoring device, transducer and speed monitoring device units with the capability of communication with the process control computer shall be provided. An automatic synchronizer with double channel design having frequency and voltage matching including one set of synchronizing equipment for manual synchronizing shall be provided in each UCB. The electronic turbine governor provided by the turbine manufacture shall also be installed and fully integrated into the UCB. The turbine governor shall have communication with the process control computer.

Each generating unit has an independent programmable logic controller alongwith its peripheral input/output modules. The control system is divided in following groups with independent controls: -

i) Unit Control
ii) Common Control
iii) Station Control

iv) Switchyard Control
v) Dam Gate Control

The above groups are interconnected and also controlled from computerised control system (CCS).

Each of the above system may be provided with a separate process control computer. Normally, number of Operator Control / Work Stations (OWS) as part of the Computerised Control Equipment for control and monitoring of the plant from control room are provided. The plant can be operated from CCS in the following modes during starting, normal stopping and change over to another mode of operation (if applicable) :

- Automatic Mode either from OWS or from UCB
- Automatic Step by Step Mode either from UCB or from OWS
- Automatic Inactive Mode or local manual operation from UCB

In automatic mode, the operator gives one command pulse from OWS only once to start the program. No operator intervention is further needed for normal execution. This is the mode in which the plant normally operates. The automatic operation can also be initiated by one command pulse from UCB via Computerised Control System (CCS). Step by step mode is one which is usually used to execute the program in steps. Every time a step is ready to be executed, the operator has to initiate the step through a mouse command. This mode is normally utilized during commissioning and testing.

Normally, in automatic inactive mode the commands from CCS to functional group and drive control are blocked. All the indications including missing criteria display are active. However, if required, provisions to operate the drives from CCS in automatic inactive mode is also possible. But closing of generator circuit breaker for manual synchronizing is not normally permitted from CCS and in this case, synchronizing has to be done from UCB only.

The emergency shut down of the unit should take place in the following cases :

- From unit protective relaying systems and hydromechanical protections which operate relays of emergency shut down.

Emergency shut down does not normally take place through the CCS.

The pressing of the push buttons of emergency shut down at UCB at Mimic Board / Mimic Control Panel results in the operation of the relays of emergency shut down.

4.6.7.2 Protection

- Protective relays are used to detect electrical faults and to alarm, disconnect or shut down the faulted apparatus to provide for personal safety and equipment protection.
- All relays used are suitable for operation with CTs secondaries rated for 1 Amp or 5 Amps as per IEC/IEEE standards.
- Electrical faults are detected by protective relays arranged in overlapping zones of protection so that each fault condition is detected by at least two systems of protective relays. The relays are connected in two groups viz Group A & Group B. Group A & Group B protective relays should operate quickly to detect the fault and trip the appropriate circuit breakers to interrupt the flow of current to faulty apparatus. If one group of relays malfunction, the other group of relays will operate and clear the fault.
- Group A & Group B relaying systems should be completely separated by using separate set of instrument transformers, segregated wiring and dual/redundant C.B. trip coils.
- Basic Types Of Relays used In Protection Scheme are : -

a) Over current
b) Over current with voltage restraint
c) Directional over current
d) Directional power
e) Differential relays
f) Zero sequence, residually connected and Neutral connected ground fault relays
g) Synchronism check relay
h) Pilot wire
i) Over voltage, under voltage, voltage balance and reverse phase relays

j) Distance relays
k) Frequency relays
l) Temperature and pressure relays etc.

- IEEE C37, (102,101,97,91,96) standards are generally applied for protection of generators, busbars, transformers and motors.

- Generally, the protection system shall be designed by using of completely digital processing of the measured input currents, from the sampling and digitizing of the analogue input-values to the release of the trip signals for the circuit breaker.

- The digital techniques applied in the processing of the protection functions shall guarantee the suppressing of the influence of the switching currents, transients, and harmonic-current components and varying degree of CTs saturation.

- Three basic types of relays viz. Electro-mechanical, solid state & Digital have been in use. However, it is apparent that most future relaying schemes will be based on digital, microprocessor technology.

4.7 MECHANICAL AUXILIARIES

4.7.1 EOT Crane

EOT Cranes installed in the power station are not used so frequently after completion of construction work. Therefore, slow-speed cranes which are slow in hoist and travel are employed.

The span of the crane is determined by power house width in such a way that working range of the crane hooks is sufficient for the assembly and disassembly of the main equipment in the power house. This working range is expressed by the range of the travel and lift of the main and auxiliary crane hook. The top of the lift (upper limit) is decided so that it is possible to hoist and carry the rotor of the generator by maintaining sufficient clearance from the top of the other generators installed in the P.H. and to assemble the transformer in some cases, without any trouble. The bottom of the lift (lower limit) is decided to such a height as necessary for assembly and disassembly of the water turbine.

The capacity of the main hook is determined by the parts having the maximum hoisting weight in the power station. In many cases, it is the rotor of the generator. Generally, the capacity is chosen 10% more than the maximum weight to be lifted. If the maximum weight to be lifted is more than around 300 T, two cranes are deployed each of equal capacity to lift the heaviest package in tandem operation.

Remote Radio Control System comprising of a portable transmitter (carrying a harness, belt, shoulder strap etc.), an antenna & receiver on the bridge and a intermediate relay panel on the bridge to amplify the signals for the crane contactors is to be provided for carrying out remote operation of a EOT crane either individually or during tandem operation of two cranes for lifting heavier equipment weighing more than 200 tonnes. The maximum working range of radio control shall be limited to 40-50 m from the transmitter in order to reduce the likelihood of an accident caused by the crane operating beyond the operator's visibility. If the system of hardware error occurs the transmitter should switch off automatically after 15 seconds.

Each radio controlled, crane should be equipped with a 100 W amber indicator lamp located beneath the center of one of the bridge girders. This light should be energized whenever the crane is in the radio control mode and the crane's master contactor has been energized.

The radio control equipment shall be of the type accepted by and shall conform to all applicable Government rules and regulations. The frequency of operation shall be in the requisite frequency band. The typical frequencies used for radio controls are in between 450-170 MH as per relevant standard for which license is required.

In addition, Inverter Modules & Motor Control software for precision speed control are also provided.

4.7.2 Cooling Water System

Cooling water systems caters for the following cooling water requirement of the unit: -

- Generator Air Coolers
- Shaft Seal

- Turbine and Generator Bearings
- Generator transformer cooling

In addition to the above, very often cooling water requirement of the following system/equipment is also clubbed with the above: -

- Ventilation and Air-conditioning system
- Fire Protection System

The cooling water requirement is met through either of the following ways:-

- Penstock tapping
- Tail pool / draft tube water pumping

Penstock Tapping

Penstocks are tapped and a common header is formed to meet the above cooling water requirement.

- Penstock Tapping is suitable for pressure around 10 Kg/cm^2 in the penstock. As most of the requirement is in the range of net pressure of 3 to 5 $Kg./cm^2$, pressure of about 10 Kg/cm^2 can be reduced suitably by means of pressure reducer. Thus a higher pressure in the penstock beyond 10 $Kg./cm^2$ prevents the use of penstock tapping. For high head installation, penstock tapping is not recommended.

- Normally no pumping is required. However, sometimes booster pumps may be required/provided.

Tail Pool Water Pumping

Water is taken out from the tail pool / draft tube by means of pumps.

- Water can be directly fed into the cooling water header from which the tappings as required are taken out.

In silt laden projects, it is preferable to adopt closed circuit cooling water system.

4.7.3 Dewatering & Drainage System.

The unit is required to be dewatered during maintenance of the reaction turbines. Water trapped between penstock gate/main inlet valve and draft tube gate is drained out to the dewatering sump. The main aspects of the system are given as under :

- The water is drained out from the lowest part that is draft tube knee/ bend.
- The bottom level of the sump is the lowest elevation level in the power house defining the lowest excavation level.
- The water collected in the dewatering sump is pumped out to the tail race.
- The capacity of the pump is chosen in such a way that a single unit can be dewatered within a single shift operation without raising the level in the sump.

- All the drainage water within the power house is guided inside the drainage sump constructed near the dewatering sump.
- The drainage water is pumped out to the tail race.
- The drainage and dewatering sumps are inter connected by means of gate valve and non return valve which allows the flow of water from drainage sump to dewatering sump.
- At the top of the dewatering sump pressure hatch is provided to prevent any flow from the bottom. Drainage sump has no pressure hatch.

4.7.4 Fire Protection System

Provision of overhead/pressurised water tank of appropriate capacity to meet the following requirements is made: -

- Mulsifyre water requirement for one generator transformer for 40 minutes, plus
- Operation of one hydrant for 60 minutes

Provision of mulsifyre protection for oil filled transformers, water sprinkler system for oil plant rooms, specially in underground power house & fire hose cabinets/hydrants for power house indoor as well as transformer floor shall be made.

Provision of 2 No. of fire pumps each capable of pumping water to meet the water requirement of mulsifyre system of a generator transformer plus one hydrant operation shall be made.

The following fire protection measures shall also be provided:

- Portable Fire extinguishers
- Foam Type
- Carbon dioxide Type

To initiate alarm and give signal for operation for fire control in the affected area, the provision of latest / state of art Fire Protection System, Air Sampling Detection System, electrically actuated automatic Inert Gas Clean Agent Fire Extinguishing System particularly for underground H. E. Projects, Preaction Sprinkler System for Cable Spreader Room, Cable gallery / tunnel & Battery Room, addressable photoelectric Smoke Detectors & Heat Detectors, Deluge Water Spray Systems for oil sump tank, microprocessor based Main Fire Alarm & Control Panel etc. alongwith water based fire protection systems for transformers / oil supply tank etc. can be judiciously considered as per the requirements of project authorities. The use of the addressable photoelectric smoke detectors & heat detectors enables effective monitoring of their healthiness as their status can be continuously available on OWS of computerized control system as & when required.

4.7.5 Ventilation & Air-Conditioning System

To achieve proper working conditions inside the power house complex, ventilation and air-conditioning system is required to serve the following purposes:-

- To prevent temperature stratification.
- To remove contaminated air.
- To remove waste heat from equipment.
- To furnish outside air necessary for human comfort with regard to temperature, humidity & oxygen content.
- To extract/force out smoke and other toxic gases during fire.

4.7.5.1 Air-conditioning System

Normally, Control room, relay room, PLCC room, offices, reception, conference room etc. are recommended to be air-conditioned.

- The conditioned air should be between 22 to 25 degree C at around 50% relative humidity for comfort conditions.
- A choice of installation out of 3 different types of installations i.e. window type, package type or centralized air conditioning plants can be made on the basis of the required tonnage and suitability of the installation at that particular location.
- The fresh air requirement is calculated to provide for oxygen content as per the human occupancy and for diluting internal air contamination etc.
- The capacity (tonnage) of air conditioning required and the quantities of the air are evaluated on the basis of the sensible heat & latent heat from people, equipment and outside air.

4.7.5.2 Ventilation System

Clean, filtered, humidified, cool air is circulated in all other areas of power house where air conditioning is not provided. The main considerations for this system are given as under :

- Blowers are deployed with at least 50% additional capacity.
- Fresh air is inducted into the system from outside. In case of underground power stations, the air is brought in by means of closed ducts inside the tunnel or by tunnel itself.
- Exhaust fans to take out 90% of the inducted air are provided to keep the area under net positive pressure for proper circulation of the air.
- Exhausted air shall be collected from the upper zones in the power house.
- Standby provision for ventilation may be provided in the areas normally air-conditioned.
- Exhaust of the toilet, battery room etc. shall be isolated and shall be taken out in the closed ducts and be left at a safe height/distance.
- Exhaust and intake duct locations shall be such that no re-circulation of exhausted air takes place.
- The no. of air changes will depend on the amount of heat to be extracted from a particular area. Normally the numbers of air changes per hour are taken between 2 and 8 depending on the nature of the area as recommended in the relevant standards.

4.7.6 LP and HP Compressed Air System

Low-pressure compressed air system is rated at 7.0 Kg./cm^2 to meet the following requirements:

- Inflatable rubber seal of shaft glands.
- Operation of pneumatic tools.
- For cleaning.
- Generator braking and jacking.
- For boosting pressure in the fire protection hydro-pneumatic tank.
- For pneumatic detection line to operate deluge valve around transformer.

H.P. compressed air system caters to the requirement of turbine governing system and MIV. The governing oil pressure air compressor is of the order of 1.1 times of governor working pressure.

4.7.7 Power House Lift

Minimum one lift is provided in the power house alongwith two sets of staircase for the movement of passengers/goods. The lift can be designed as goods lift or passenger lift. Generally 10-16 passenger lift is provided in the power house. The factor of safety for any part of the lift should not be less than five

4.8 SWITCHYARD EQUIPMENT

4.8.1 High Voltage Switchgear / Switchyard

- Air insulated outdoor switchgear is generally preferred owing to its low cost compared to GIS. GIS is preferred at location having space constraints and underground switchgear rooms. A hybrid switchyard having GIS & conventional air-insulated switchgear is also a possibility in some cases. Advantages/merits of each type have to be considered before deciding upon the type of switchgear to be employed. However, cost, space & security aspects are the main factors to be evaluated.

- The following items needs to be evaluated to determine the site of a switchyard.

Control Room, Rengali HEP

a) General topographical features of the area

b) Accessibility to heavy equipment transportation (assembly as well as removal)

c) Public safety, audible noise, electric and magnetic fields effects on human health

d) Soil resistivity & switchyard grounding

e) Impact of weather and environmental pollution

f) Convenience of tower locations/ installations

4.8.1.1 Switching Schemes

Various switching schemes in vogue are Single Bus, Sectionalised Single Bus, Double Bus (Main & Transfer), Ring Bus, Double Bus plus Transfer Bus, 1 ½ Breaker Scheme, double bus and bypass isolator scheme, etc.

The Switching scheme selected must ensure : -

- Short circuit capacity
- Flexible operation
- High reliability
- Isolation of bus for maintenance
- Isolation of circuit breakers for maintenance
- Isolation of Bus-faults
- All switching should preferably be performed with circuit breakers
- Techno-economics of each alternative considered

4.8.1.2 Circuit Breakers

- Air blast circuit breaker or SF6 gas circuit breakers with standard voltage and current ratings are generally preferred.
- For voltages below 245 KV, breakers with a common 3 pole operating mechanism are adopted. System requirements may deem it necessary to use single pole tripping and at voltages higher than 245 V to improve system stability.
- Breakers with surge suppression resistors for limiting magnitude of surges generated during breaker closing are preferred for voltage rating of 400 kV and above, if system requirement so dictates.
- Factory and field testing should be according to IEC 56 / IEC 62271, ANSIC 3709.

4.8.1.3 Isolating Switches

Selection of a isolating switch (disconnector) is largely determined by the station layout and circuit breaker voltage & current ratings. The following type of the isolating switches are generally considered & preferred.

- Dual blade, horizontal center break
- Single blade, vertical break
- Double blade, vertical center break
- Single blade earthing switches (where these are not provided integrally with isolator).

4.8.1.4 Instrument Transformers

- Conventional current & voltage transformers for metering and relaying applications must conform to IEC 185 / IEC-600 44 –1 / 60044 – 2/ 60186

- For high voltages, above 400 kV it is economical to use CVT instead of voltage transformer
- High capacitance CVT can be equipped with broad based carrier coupling.
- Burden of CVTs/ VTs is selected based on application like revenue metering, suitability for SCADA system etc.

Non-conventional or intelligent instrument transformers in which electrical signal is converted into digital or analog optical signal are being developed.

4.8.1.5 Surge Arrestors

- Metal oxide/Zinc Oxide type arrestors are preferred owing to their:-

a) improved over voltage withstand capability
b) lower discharge voltage
c) higher reliability
d) lower height
e) improved protective margins

- Station class arrestors are used for heavy duty (10-20 KA) and for voltage ratings from 2.4 KV to 800 KV. They are typically used for protection of sub-station equipment, rotating machinery and other applications where premium protection is required.

- Surge arrestors are located near the equipment being protected, as per the requirement of insulation co-ordination studies.

4.8.1.6 Grounding

Switchyard grounding should be designed to conform to the requirements of IEEE-80 –'Guide for safety in substation grounding', CBIP & National Electric Code as already indicated in para 4.6.2.

4.8.2 Special Considerations for GIS Assemblies

- GIS should be sub divided in to separately monitored zones such as :-

a) Each power circuit breaker
b) Each termination
c) Each main bus or bus sections
d) Voltage transformers
e) Isolators associated with power circuit breakers
f) Surge Arresters

- Each zone should be furnished with continuous gas density monitoring device.
- All wirings to GIS be shielded and grounded at both ends
- Provide sub-assembly to sub-assembly ground conductors to assure safe voltage gradients
- The G I Bus duct enclosure wherever provided shall be of non magnetic material.
- Provide standard ground conductors for two paths to ground from "Main Ground Bus" or from each metallic enclosure and aux. piece of GIS equipment.
- GIS equipment shall be tested according to IEC 517, ANSIC 37, 122 & ANSI C37.09

4.8.3 Interconnection between generator transformer & switchyard / 400 kV equipment – Special consideration in case of underground power stations (HV cable or Bus-Duct): -

- Prudent studies to be made while making the choice
- Cost, maintenance, reliability, power carrying capacity, convenience in installation, fire hazards, heat loss are some of the important factors to be studied.

BENCHMARKING FOR DESIGN AND ENGINEERING OF HYDRO POWER PLANTS

	Description	International Practice	Indian Practice	Benchmarking for Indian Conditions
I	**TURBINE**			
1.	Hydro unit size	750 MW	250 MW	Technology for manufacturing unit size up to 500 MW to be developed.
2.	**Weighted Average Efficiency**			
	i) Reaction Turbine ii) Impulse Turbine	> 95% > 92%	>94% >92%	> 95% >92%
3.	Runner removal	Removal from bottom/top	Removal from bottom/top	Removal from bottom is preferred to reduce downtime.
4.	Pressure rise	Reaction turbine <35% Pelton turbine <15%	Reaction turbine < 35% Pelton turbine <15%	<35% <15%
5.	Speed rise	Reaction turbine <60% Pelton turbine <20%	Reaction turbine <60% Pelton turbine <20%	<60% <20%
6.	Governor response time	0.02 Hz	0.02 Hz	0.02 Hz
7.	Governor oil pressure system	More than 100 kg/cm^2 (piston type accumulator with nitrogen bottles)	60 kg/cm^2 (High pressure compressed air system)	More than 100 kg/cm^2 (piston type accumulator with nitrogen bottles). Technology updation required.
8.	Materials for Turbine under water parts viz runner, guide vanes etc.	13:4 Cr:Ni, 16:5 Cr:Ni Stainless Steel	13:4 Cr:Ni Stainless Steel	Better material and alloys to be developed to withstand silt abrasion.
II	**GENERATOR**			
1.	Short circuit ratio	More than 1.0	More than 1.0	More than 1.0
2.	Temperature rise	Stator winding 80^0 C Rotor winding 90^0 C	Stator winding 80^0 C Rotor winding 90^0 C	Stator winding 80^0 C Rotor winding 90^0 C
3.	Weighted Average Efficiency	More than 98.65%	More than 98.54%	More than 98.65%
4.	Fire protection	CO_2	Water Spray/CO_2	CO_2 or water spray depending on site conditions. Approval from TAC to be made mandatory.

5.	On line machine condition monitoring			
	Partial discharge analyser	Provided	Being introduced	Provision of online machine condition monitoring devices to be made mandatory. Technology upgradation in this field is required as presently these devices are being imported.
	Air gap monitor	Provided	Being introduced	
	Electromagnetic core imperfection detector (off line)	Provided	-	
	Vibration monitor	Provided	Being introduced	
	Ultrasonic flow measurement device	Provided	Being introduced	
III.	**EXCITATION SYSTEM**			
1. 2.	Type of automatic voltage regulator Ceiling voltage ratio	Digital AVR More than 2.0 PU of rated voltage	Digital AVR More than 2.0 PU of rated voltage	Digital AVR More than 2.0 PU of rated voltage as per system requirement.
IV.	**GENERATOR STEP-UP TRANSFORMER**			
1.	Type	OFWF/ODWF	OFWF/ODWF	OFWF/ODWF.
2.	Efficiency	More than 99.7%	More than 99.7%	More than 99.7%
3.	Tap changer	Off circuit-Conventional Plants. On load-Pumped storage plants.	Off circuit-Conventional Plants. On circuit - Pumped storage plants.	Off circuit -Conventional Plants. On circuit- Pumped storage plants.
4.	Single phase or 3 phase	Single phase or 3 phase as per transport limitation and site specific requirements.	Single phase or 3 phase as per transport limitation and site specific requirements.	Single phase or 3 phase as per transport limitations and site specific requirements.
5.	Oil-water cooler	Heat exchanger with double concentric tube	Heat exchanger with single tube	Heat exchanger with double concentric tube
6.	Oil Conservator	Air cell type	Conventional/Air cell	Air cell
7.	Fire protection	Mulsifyre/Nitrogen stiring	Mulsifyre/Nitrogen stirring	Mulsifyre/Nitrogen stirring.
8.	On line monitoring system			Provision of on line monitoring system to be made mandatory
	On load tap changer monitor	Provided	-	
	Dissolved gas analyser	Provided	Provided	
	Evolved gas analyser	-	Provided	
	On line spectroscopy	Provided	-	
	Bushing current monitor Partial discharge analyser	Provided Provided	Provided -	

V.	**GROUNDING SYSTEM**			
1.	Resistance to ground achieved.	<0.5 ohms	<1.0 ohms	Less than 0.5 ohms to be
VI.	**POWER AND CONTROL CABLES.**			
1.	Type	FRLS	FRLS	FRLS
VII.	**PROTECTION RELAYS**			
1.	Type	Numerical	Numerical/Static	Numerical
VIII.	**COOLING WATER SYSTEM**			
1.	Type	Closed circuit	Open circuit/Closed circuit	Closed circuit cooling water system to be made mandatory for silt laden projects
IX.	**FIRE PROTECTION SYSTEM**			
1	Fire detection and fighting system	Provided	Provided	Approval from TAC to be made mandatory
X.	**LIFT & STAIRCASE**			
1.	Lift	Minimum one lift	Minimum one lift with two staircases	Minimum one lift with two staircases
XI.	**HIGH VOLTAGE SWITCHGEAR**			
1.	Surge arrestor	Metal oxide/Zinc oxide	Metal Oxide/Zinc oxide	Metal oxide/Zinc oxide
2.	Enclosure material of GI Bus duct	Aluminum/Mild steel	Non magnetic	Non magnetic material