

## CHAPTER-7

### TURBINE AND GOVERNING SPECIFICATIONS

#### 7.1 Sample Technical Specifications of Large Hydraulic Turbines and Governing Equipment for Vertical Kaplan Turbines (suitable changes be made for other types)

##### Scope

Vertical shaft Kaplan type hydraulic turbines each with a capacity of ..... kW and each consisting of the following main assemblies:

- One set of embedded parts consisting of draft-tube cone complete with man-hole, knee-lining, pier-liner fabricated from structural steel in suitable number of parts keeping in view the transport limitations and necessary brackets, lugs, anchors supporting Jacks and bolts.
  - One set of Foundation parts consisting of spiral casing with stay-ring fabricated from steel plates with upper and lower rings, cast steel stay-vanes, complete flange bolts and jacks etc., Pit liner of fabricated steel and Runner Chamber of stainless steel.
  - Set of Guide Apparatus and Servomotors consisting of turbine top cover, lower ring, regulating ring, set of stainless steel guide vanes, bushes with housings, levers, links, connecting pins and two servomotors with mechanical/hydraulic lock on one of the servomotors.
  - Adjustable blade Kaplan Runner consisting of cast steel hub, set of stainless steel (13 Cr4Ni) blades, runner blade turning mechanism, runner cone, runner servomotor located within runner hub.
  - Forged carbon steel Turbine Shaft having integrally forged flanges at both ends and skirt for guide bearing with coupling bolts and guard.
  - Self-cooling turbine guide bearing of self oil-lubricated pad type, complete with necessary valves, sight level indicators-cum-relay, temperature measurement and signaling device.
  - Turbine Shaft Sealing of rubber lip type or any other design complete with connection for clean cooling water supply and inflatable type repair seal for maintenance of main seal without dewatering the turbine water path.
  - Oil distributing header for supply and distribution of oil to runner servomotor with required oil pipelines inside the turbine-generator shaft.
  - Set of limit switches for indicating shear pin failure along with connected cable up to terminal block in turbine pit and mounting arrangement.
  - Vacuum breaking valves on turbine top cover
  - Set of chequered plates for platform in turbine pit only
  - Set of mono-rail and chain –pulley block for assembly and dismantling guide vanes/guide bearing.
  - Set of chain pulley block and longitude mono-rails for handling drainage and dewatering pumps.
  - Pump motor set and one ejector with suitable water level sensors for drainage of leakage water from turbine top cover.
  - Necessary cable junction boxes and cables from electrical items for termination at convenient points.
  - Turbine Gauge Panel with necessary instruments and safety devices,
- b) Governing Equipment consisting of digital Electro-hydraulic governor, speed signal generator, over speed trip device, emergency shut down device, restoring mechanism, oil pressure unit oil leakage unit and oil pipe lines,
- c) Central Grease Lubrication System for Turbine if required,

- d) Governor oil, lubricating oil and grease for flushing and first filling of with 20% extra quantity, site consumables like welding electrodes, paints and cleaning agents etc. in sufficient quantity,
- e) Turbine Model Testing, if desired,
- f) All special tools, tackles and handling devices required for assembly/dismantling of turbine and inlet valve assemblies at site during erection and maintenance, templates for repair of turbine runner and pumps and test plugs for hydraulic testing,
- g) Set of Mandatory Spare Parts for five years trouble free operation as per schedule of spares,
- h) Insurance, transportation, receipt and storage of goods at site,
- i) Installation, testing, commissioning and acceptance testing of the turbines, inlet valves and associated equipment,
- j) Preparation and submission of Drawings of all equipment, Operation & Maintenance manual and Erection & Commissioning Manual including those for bought out items.

## 7.2 Standards

Turbines shall meet provision made in the following standards (latest edition) unless otherwise mentioned.

- (a) IEC 41: 1991, Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines.
- (b) IEC 193: 1965, International code for model acceptance tests of hydraulic turbines. Amendment No. 1 (1997).
- (c) IEC 193A: 1972, First supplement to IEC 193 (1965).
- (d) IEC 308: 1970, International code for commissioning, operation and maintenance of hydraulic turbines.
  - IEC 609: 1978, Cavitation pitting evaluation in hydraulic turbines, storage pumps and pump-turbines.
  - IEC 545: 1976, Guide for commissioning, operation and maintenance of hydraulic turbines.
- (e) IEC 60994: 1991, Guide for field measurement of vibrations and pulsations in hydraulic machines (turbines, storage pumps and pump turbines)
- (f) IEC 61362:- Guide to specification of hydro-turbine control systems.
- (g) ISO 3740: 1980, Acoustics- Determination of sound power levels of noise sources- Guidelines for the use of basic standards and for the preparation of noise test codes.
- (h) IEC 61366 Hydraulic turbine of giving outputs higher than rated outputs to match 10% overload capability of the generators.
- (i) VDI 2056 and VDI 2059; Vibration level in rotating machines

## 7.3 Turbine Basic Data & General Information on Water Conductor System

### Turbine Basic Data

- (a) Maximum water level (U/S) ..... m
- (b) Maximum tailrace level ..... m
- (c) Minimum tailrace level ..... m
- (d) Maximum gross head (static) ..... m
- (e) Maximum net head ..... m
- (f) Minimum net head ..... m
- (g) Rated Design head (net Head) ..... m

- |     |  |                       |
|-----|--|-----------------------|
| (h) | Rated Turbine Discharge                        | ..... cumecs          |
| (i) | Operating Head Range (115% to 67%)             | .....1 m              |
| (j) | Rated output at rated head and rated discharge | ..... kW              |
| (k) | Preferred rated speed                          | .....                 |
| (l) | Permissible Speed rise                         | ..... %               |
| (m) | Permissible Pressure rise                      | ..... % of rated head |
| (n) | Turbine Efficiency at rated head & discharge   | .....% ( Min.)        |
| (o) | Overload Capacity ( at max. head)              | 10 % continuous       |

**(Note:- Specify as per field data and performance requirement)**

#### **7.4 General Information**

The Vertical Shaft Kaplan turbine with adjustable blades and wicket gates shall be directly coupled to synchronous generator of ..... kW rating. The direction of rotation shall be clockwise when viewed from drive end.

General arrangements of the Power House and turbines have been tentatively outlined in contract drawings. There may be minor change in elevation of turbine Centre line based on the required minimum suction height recommended by the successful bidder, however no significant increase in suction height will be accepted.

Detailed information on water conductor system i.e. power channel, intake, penstocks, tail race structure and other details of site are given in Salient Features of Project.

##### **7.4.1 Basic Provisions**

Each turbine shall be designed to give a rated output of ..... kW (corresponding to ..... kW at generator terminals) at design head of ..... m with guide vane opening of not more than 95%. The turbine shall have adequate capacity commensurate with the 10% continuous overload capacity of the generators at maximum head.

The turbine should be capable of operating between 120% to 60% variation of rated head and 110% to 60% variation of rated discharge. The turbine shall comply in all respect of various standards with the requirement of the latest issue of Indian Standard and IEC – 41.

The specific speed of the turbine shall be selected as per the best modern practice and the turbine shall be of proven design. Similar machines designed on the basis of model offered against this tender should be under satisfactory operation at least on two different projects for at least last three years.

The turbine shall be so constructed as to allow all the removable parts to be dismantled conveniently. The design shall permit horizontal/vertical movement of runner shaft by an amount sufficient for adjustment of bearings and for cleaning the joint at the coupling between the turbine and generator.

Turbine main inlet valves of butterfly type for shutting-off pressure water supply from the penstock to the turbine distributor shall be provided, complete with necessary piping, control and gauge cabinet, up-stream connecting and down-stream connecting pipes with companion flanges, dismantling joint, bypass, drain and air bleeder valves, operating mechanism and necessary auxiliaries including gaskets, anchor bolts, sole plates, and other items necessary for a complete installation. Depending upon operating requirements, the valve shall be either fully open or fully closed and no partial opening of the valve is envisaged. In the closed position the valve shall be leak tight.

All the equipment shall be neatly arranged and shall be easily accessible for operation and maintenance. Necessary chequered plates for trenches and openings shall be supplied by the Contractor.

Contractor shall ensure the co-ordination between turbine & generator manufacturers (if both are separate) so that the generator to be coupled with the turbine is matched in respect of speed, runaway speed, moment of inertia, overload capacities, coupling other relevant requirements.

## **7.5 Performance Guarantees and Liquidated Damages**

### **7.5.1 Output and Efficiency Guarantees**

Maximum Output and efficiency of the turbine at design head shall be stated in Guaranteed Technical Particulars of Turbine and will be guaranteed by Contractor. The turbine shall also be suitable for safe and efficient performance at part loads lesser than 60 (sixty) percent of rated output with minimum head conditions.

Field test (as per IEC-41-1991) shall form the final basis to establish fulfillment of guarantees of the turbine and for purposes of liquidated damages and rejection of plant

### **7.5.2 Weighted Average Efficiency**

The Bidder shall guarantee the weighted average efficiency of the turbine at rated net head using the following formula for the purpose of bid evaluation, calculation of amount of penalty and rejection limits of the equipment:

$$\eta t (AV) = 0.40 \eta t_{(100)} + 0.40 \eta t_{(80)} + 0.20 \eta t_{(60)} \text{ (based on flow duration)}$$

where,

$$\eta t (AV) = \text{Weighted average efficiency}$$

$$\eta t_{(100)}, = \text{efficiency at 100\% of rated output at the design head of } \dots \text{ m.}$$

$$\eta t_{(80)}, = \text{efficiency at 80\% of rated output at the design head of } \dots \text{ m.}$$

$$\eta t_{(60)} = \text{efficiency at 60\% of rated output at the design head of } \dots \text{ m.}$$

**(Note:- Specify as per flow duration curve for annual energy)**

### **7.5.3 Bid Evaluation With Respect to Efficiency**

In the evaluation of bids, equalization on account of differences in efficiencies of turbines of the various Bids will be made at the rate of Rs. .... (Rs. ....) per turbine for each one tenth of one percent (0.1%) by which the rated average efficiency given in (or computed for) any offer is lower than the highest weighted average efficiency among the various offers. For differences lower or higher than one tenth of one percent (0.1%), the equalization will be computed on pro-rata basis.

**(Note:- This will depend upon energy costs)**

The basis for selection of the offers will be the overall economy to Owner considering power house civil works, values of efficiencies, prices of matching generators and power house auxiliaries etc. The speed and setting of the turbine and its design shall be such as to result in the most optimum generating unit at the least cost.

### **7.5.4 Output and Efficiency Tests**

Output and Efficiency test as per IEC-41 shall be conducted at different heads and guide vane openings to determine guaranteed efficiency parameters. Any deviation from IEC-41 shall be clearly stated in the offer. Bidder shall furnish details of test methods, agency which will conduct the test, provisions to be made for field testing, calibration of instruments for purposes of test and all other relevant details in the offer. Contractor shall be under obligation to accept these tests for purposes of liquidated damages. Purchaser reserves the right to appoint the contractor or any independent agency or agency recommended by contractor for conducting these tests.

### 7.5.5 Penalty for Shortfall In Weighted Average Efficiency and Output

For any shortfall in the tested values of rated output and weighted average efficiency (as determined on the basis described in clause 7.5.1 & 7.5.2 from the guaranteed values, penalty shall be applied at the rate of one half (1/2) percent of total unit price of turbine (including price of governing system) for each one tenth of one percent by which test figure is less than the corresponding guaranteed figure. The penalties on account of shortfall of output and efficiency shall be computed separately for each unit and the total amount of penalty shall be the sum of these two. No tolerance shall be permissible over the test figures of rated output. In case of efficiency, tolerance will be allowed as per appropriate IEC test code for model test and/or field acceptance tests for hydraulic turbines. The ceiling on the total amount of penalty on account of shortfall in the weighted average efficiency and the output will be 10% of total unit price of the turbine including price of governing equipment.

**(Note:- These figures of penalty depend upon purchasing authority)**

### 7.5.6 Rejection Limit

The Purchaser has the right to reject the equipment if the test value of either weighted average efficiency or the rated output is less than the corresponding guaranteed value by two (2) percent or more after allowing tolerance in computation of efficiency.

### 7.5.7 Cavitation Guarantees (For Reaction Turbine runners)

The Supplier shall guarantee the runner against excessive pitting caused by cavitation for 18 months from the date of commissioning or 8000 hours of operation, whichever is earlier as per clause 3.3.1 of IEC-60609-2.

Excessive pitting shall be defined as the metal removed from runner by a weight of  $W=0.15 D^2$  per 1000 hours of operation, where, D = Discharge diameter of the runner and W = weight in kg. If the 18 months of guarantee period expires before completion of 8000 hours of operation, the guarantee shall apply to the actual hours of operation proportionately.

In case of cavitation pitting exceeding the guarantee, the Contractor shall, at his cost, take corrective measures such as repair as per original design, repair as per modifications or replacement etc., and turbine after modification etc., shall be subject to fresh cavitation guarantee as for the original equipment. In determining whether or not excessive pitting has occurred, uniform metal removal by erosion, corrosion or by the presence of injurious elements in water, etc., shall be excluded.

**Setting of runner:** Setting of the runner below minimum tailrace water level shall be started in the bid and shall be taken into consideration for bid evaluation. All runners below minimum for tailrace water level will be loaded at the rate of . . . . per mm of purpose of evaluation.

**Critical and Plant Sigma:** Values of critical sigma as determined from cavitation model tests as per IEC 193 A shall be given in the form of curves for different heads of operation. Plant sigma curves as recommended by the manufacturer shall also be plotted on it clearly to show the safety margin available.

### 7.5.8 Vibrations and Noise Limit

Turbine design shall ensure smooth and quiet operation with low vibrations, pressure pulsation, power fluctuations and noise. The vibration amplitude at the shaft shall not exceed the values specified in ISO-7919 (part-1) and ISO-3945 or VDI 2056 and VDI 2059 when measured with instruments with 1 Hz cut-off frequency.

Maximum noise level resulting from any of the operating conditions shall not exceed 85 db (A) at any place 1.0 m away from any operating equipment in the machine hall.

### **7.5.9 Runaway Speed**

The maximum runaway speed shall be stated and guaranteed by the supplier. All rotating parts and bearings shall be capable of withstanding the forces and stresses occurring during runaway speed for at least 30 minutes without any damage to any part. The guide bearing and guide cum thrust bearing shall be capable to withstand runaway speed for 30 minutes without supply of cooling water and continuously with cooling water without abnormal increase of vibrations and temperature.

### **7.5.10 Speed Rise, Pressure Rise and Inertia**

The moment of inertia of the generating unit and closing time of wicket gate and runner blades shall be so selected that the maximum momentary speed rise of unit shall not exceed 35% of normal speed and pressure rise shall not exceed 20 % of maximum head. The turbine manufacturer shall coordinate with the generator manufacturer for achieving the required flywheel effect.

(Note: Specify speed rise as per Chapter 4).

### **7.6 Model Test**

The Bidders shall offer the turbine with already tested model and proven performance of prototype machines atleast at one project site for a period not less than two years. The Bidder shall enclose copy of the relevant model test report with operating points of the turbine offered marked on the hill chart of the model to substantiate the output, efficiency and plant sigma figures offered and guaranteed by the Bidder. Bidder shall arrange certificate of trouble free operation of the similar turbines from their owners and enclose the same in the technical Bid. If felt necessary by the Purchaser, the Bidder shall arrange physical inspection of the equipment at respective Power Houses before finalization of the order.

The Purchaser reserves the right to witness fresh model tests to ensure that the guaranteed parameters will be met by the prototype. For this purpose, the Bidder shall quote charges for conducting the model test in his laboratory and or in an independent approved laboratory in the presence of Purchaser's Engineers and their consultants.

- The tests shall be as per IEC test code publication No.193 and 193A. "International code for Model Acceptance Test of Hydraulic Turbines". Model test results shall be subject to the approval of the Purchaser. The contractor shall commence manufacture of the prototype after approval for the model test results. Prototype efficiencies shall be derived from model tests by the Moody's step-up formula as contained in IEC 193 for Francis turbines.

#### **Tests to be conducted on Model**

The final model test series shall include but not be limited to the following tests:

Performance (efficiency & output) test under various head conditions and corresponding to 100%, 80% and 60% rated output.

Determination of peak efficiency at rated design head at rated speed.

Measurement of hydraulic thrust and runaway speed test at full guide vane opening at maximum net head.

Complete Hill chart

Cavitation at maximum, rated and minimum head at openings corresponding to guaranteed output.

Checking of Model dimensions as per IEC.

### **7.7 Rectification to Meet Guarantees**

The Contractor shall be given three months or mutually agreed time to improve/modify the design of the turbine or to carry out rectification etc., as may be required so that the guarantees are met in case the model tests prove unsuccessful in meeting the guarantees. If the second attempt is also unsuccessful, penalty or rejection of the equipment, as the case may be, shall be applied. However, no delay in the original delivery schedule shall be allowed if the model test results do not meet the guarantees and rectifications are made by the Contractor there after within a period of three months or mutually agreed period as stated above.

## 7.8 Stresses and Factor of Safety

All parts of turbine shall be designed and constructed to safely withstand the maximum stresses during the normal running, runaway and short circuit conditions, out of phase synchronising and brake application. The maximum unit stresses of the rotating parts shall not exceed two thirds of the yield point of the material. For other parts, the factor of safety based on yield point shall not be less than three in normal conditions. For over-load and short circuit conditions, a factor of safety of 1.5 ( one and a half ) on yield point shall be permitted.

## 7.9 Deviations from Technical Specifications

All deviation from General Technical Specifications and Technical Specifications under this section should be clearly brought out at one place in the 'List of Deviations' from Technical Specifications. Any deviation not clearly mentioned in the List of Deviations, but described elsewhere in the equipment Description shall not be acceptable. After award of contract, the contractor has to fulfill all the requirements of technical specifications except the deviations clearly spelt out and accepted by Owner.

## 7.10 General Arrangement and Constructional Features of Turbine

General Arrangement and Constructional Features of the turbine and associated equipment shall meet the requirements described below:

**7.10.1 General:** All equipment shall be arranged so as to be easily accessible for inspection and maintenance without interfering the operation of other components.

### 7.10.2 Embedded Parts of Turbine

**Draft Tube Knee Lining:** Major portion of the draft tube knee, where velocity of water is comparatively high, shall be provided with steel lining. The liner will be fabricated from steel plates and heavily ribbed on its outer surface to give rigidity.

It shall be manufactured in number of parts to facilitate transportation and joined together by welding at site. The liner would be rigidly held in concrete with the help of anchors and jacks. Leveling bolts will be provided at the base of liner for leveling it during installation. Sufficient number of holes of suitable size will be provided at the base of liner for concreting and grouting. Plate plugs will be provided for plugging these holes after concreting.

#### **Draft Tube Cone**

The draft tube cone shall be fabricated from steel plates. Sufficient number of ribs will be provided on the outer surface of cone for rigidity. A hatch will be provided in the cone for access to the draft tube for inspection and minor repairs. The upper end of cone will be fixed to the runner chamber and the lower end to the draft tube knee liner.

#### **Pier Nose Liner**

For the concrete central pier for the draft tube, a pier nose liner shall be provided. The pier nose liner shall be fabricated from welded structural steel plates. The liner shall be adequately braced and provided with base pads and leveling screws for adjustment during installation.

#### **Foundations and Embedded Pipelines**

The details of foundations and embedded pipelines at various levels for turbine, inlet valve, governing and auxiliary equipment will be supplied as per the relevant drawings.

### **7.10.3 Foundation Parts of Turbine**

#### **Stayrings**

Stayring will be designed to withstand the hydraulic forces and part of the thrust bearing loads, generator stator and other dead loads above stayring, if required during design stage.

The stayring shall be a cast fabricated construction. It shall consist of upper and lower mild steel fabricated rims connected together by streamlined cast steel stay-vanes. The profile of stay-vanes will be designed to give the minimum hydraulic losses.

If required, stayring shall be manufactured in two parts and joined by bolts and nuts at site for the convenience of handling and transportation. Suitable foundation bolts and wedges will be provided for installation and fixing the stayring in position during erection.

Notes: Stayrings transmit hydraulic, equipment and concrete loads and supports most of the major turbine components through welded joints. It spans the water passages and transmits loads across the span to units foundation in Francis and vertical axial flow type turbine.

Generally number of stay vanes is the same as the number of wicket gates varying from 16 to 24. However under some conditions, such as low head units, only half as many stay/vanes as wicket gates may be used.

#### **Runner Chamber**

Runner chamber shall be fabricated from stainless steel plates with mild steel ribs. The chamber shall be made in two parts with flanged joints, if necessary, to facilitate handling and transportation. The portion above runner centerline shall be machined cylindrically to facilitate the lowering of the runner and that below the runner center line as spherical to ensure minimum clearance to reduce leakage at all runner blade openings.

The chamber shall be carefully shaped and heavily ribbed to maintain its circularity and to reduce vibrations. Necessary anchor bolts, turn buckles etc. shall be provided to support and facilitate erection. The chamber shall be machined at its upper end for bolted connections to stay ring/pivot ring and at its lower end for welding to draft tube cone liner.

#### **Turbine Pit Liner**

The turbine shall be provided with a steel lining from stayring to the chequered plate coverings. The liner will be provided with ribs on its outer surface and welded to the stayring at site. Turn-buckles and anchors will be provided for installation and securing the liner in position.

### **7.10.4 Working Mechanism**

#### **Guide Apparatus**

The guide apparatus regulates the flow of water through the turbine with the change in load and also serves as closing device. It shall consist of guide vanes, turning mechanism of guide vanes, guide vane bearing bodies containing the bearings for upper journals of guide vanes, turbine top cover, pivot ring with lower bushes of guide vanes, regulating ring and guide vane servomotors.

The guide vanes shall be cast from stainless steel. Each of the guide vanes shall have three supports - one for the lower journal and two for the upper journal.

The bushes for guide vanes support shall be made of bronze and grease lubricated. Feeding of grease to the upper bushes shall be done through a hole drilled in the flange of the guide vane bearing body. Grease to lower journal bearing shall be supplied by a separate pipe connected to the hole through the guide vane.



The bushes of the upper journal of the guide vanes shall be replaceable individually by removing the guide vane bearing body which is connected to the turbine cover with the help of studs. The lower and middle bushes shall be provided with rubber cup sealing to prevent the leakage of water.

The turning mechanism of guide vanes shall be designed to ensure the simultaneous equal turning of guide vanes during opening and closing of guide apparatus. It shall consist of regulating ring, link assemblies, straps, levers and shear pins.

The regulating ring shall be made of welded construction from mild steel plates. It will rest on a base rigidly fixed to the stayring. Self lubricated pads will be provided at the rubbing faces between regulating ring and its support to minimise friction. It shall be rotated with the help of two servomotors installed diametrically opposite in turbine pit.

The link assemblies shall be made in the form of turn-buckles which shall allow for adjustment in length during assembly. The bearing bushes for these pins shall be made of self lubricated synthetic material. The design of the wicket gates shall be such that, if any individual wicket gate becomes disconnected from the gate operating ring, no part of the gate can come in contact with the turbine runner and the failure of one shear pin shall not cause progressive wear of adjacent shear pins. The failure of shear pin / breaking link shall be indicated on annunciation panel through limit switch.

In the design of guide vanes, provision shall be kept for adjusting the face clearance between guide vanes and turbine top cover and between vanes and lower rings of guide apparatus. Also, guide vanes shall be prevented from lift under water pressure.

The turbine cover shall be fabricated from mild steel plates and shall be rigidly connected to the upper belt of stayring with the help of studs. One Pump Motor set and one ejector will be provided for the drainage of top cover leakages. Windows shall be provided in its internal vertical cylinder to have access to turbine sealing for repairs.

The lower ring of guide apparatus shall be fabricated from mild steel plates. The cups which house the bushes are made from forging. The lower ring shall be suitably fastened with the runner chamber with the help of bolts.

Suitable arrangement of breaking links or shear pins should be provided on all or alternate wicket gate to facilitate full closure of rest of the wicket gates if some foreign object is struck between two wicket gates. Electronic limit switches shall be provided to indicate the breaking/shearing of pin/link.

**Note:-** Some design incorporate individual servomotors for each wicket gate. However practice in India to have conventional arrangement using a gate operating ring and two gate servomotors. Small units use only one servomotor. In low specific speed machines, wicket gates are in close proximity to runner buckets or vane it is advisable to calculate the natural frequency of the gate to ensure that frequency is far removed to avoid resonance.

#### **7.10.5 Servomotors of Guide Apparatus:**

Two servomotors shall be provided for turning the regulating ring. One of the servomotors will be fitted with a manually operated stopper for retaining the turbine in closed position without oil pressure in it for long period. The stopper will be provided with contact switch to indicate its closed or open position on the control panel. The stopper shall be designed for hydraulic load on guide vanes in fully closed position. One scale shall be provided to indicate servomotor stroke.

The servomotor shall consist of a fabricated/cast cylinder, piston with cast iron rings, piston rod fastened with piston through pin, end covers and oil supply flange connections. Piston rod will be surrounded by a sleeve which will pass through one end cover. Stuffing box with gland sealing will be provided to arrest oil leakage through sleeve. Suitable sensors will be installed on one of the servomotor for transmitting servomotor position to governing system for regulation and indication.

### 7.10.6 Runner

Turbine runner shall be Kaplan type with adjustable blades and shall mainly consist of a hub, blades (preferably four no.), blades hubs, blade turning levers and cross head, servomotor, blade seals and end cone. Blades shall be operated automatically in conjunction with wicket gates by means of electro-hydraulic governor. The blade position Vs wicket gate position relationship at all operating heads shall be controlled electronically. Position feed back of runner blades shall be achieved through an electronic position sensor with 4 to 20 mA output analogue signal mounted on the oil distributing head. Pressure oil will be supplied to opening or closing side of runner blade servomotor through concentric pipes running through generator rotor and turbine shaft from distributing oil head located inside the bulb.

The control of runner blades shall be designed to give full opening command on loss of feedback signal or loss of control oil pressure.

#### **Blades**

Runner blades shall be cast or forged in 13%Cr 4% Ni stainless steel. The runner blades will be polished and ground smooth and will be free from roughness, blowholes, porosity, cracks and high spots etc. Blades shall be assembled on hubs/journals with pre-stressed coupling bolts. The holes of coupling bolts on blade stub shall be covered by welding stainless steel contoured cover plates. Clearance between blade inner edge profile and runner hub shall be kept minimum at all position of blades. Clearance between blade tips and runner chamber shall be minimum – not more than 3 mm and it shall be ensured that runner blades will not strike the chamber even at run-away speed.

#### **Runner Hub and Cone**

The runner hub shall be cast in 1.5% Mn. steel casting and shall be accurately machined spherically in the area of blade movement. It shall be free from any kind of casting defect like porosity, blow holes, hair line crack, surface crack etc. the blade windows shall be fitted with bronze bushes capable of taking outward thrust of blades. Runner cone of cast steel or fabricated from steel plates shall be coupled to downstream side of runner hub and its contour will provide smooth water flow.

The hub and cone shall be filled by lubricating oil (same oil as used in pressure oil system) for lubrication of all bearings/bushes and blade adjusting mechanism at a pressure of about 1.2 bar by means of an oil reservoir located at some height inside the machine hall.

#### **Blade Turning Mechanism**

The runner servomotor and blade turning mechanism will be accommodated inside the runner hub. The mechanism shall connect the blades with runner servomotor and shall ensure free movement and equal/identical position of all blades corresponding to any position of servomotor piston. All elements of the turning mechanism shall be designed to withstand maximum oil pressure in servomotor at all positions. The servomotor piston will be made in cast iron/steel with atleast two piston rings in nodal cast iron to prevent leakage of oil across the piston. The piston rod, levers and cross head/star shall be manufactured in forged steel the piston and the cross head will be securely fastened to servomotor rod by forcing and jack nuts. All the levers and axles will be securely fixed so that they are not loose over the years of operation. Bronze bushes shall be used in all moving joints and suitable nitrile rubber seals will be used to arrest leakage of oil/water. Suitable arrangement will be provided for limiting the blades movement. The centrifugal force acting on the blades and trunion will be transmitted to hub through thrust rings of bronze.

The blade turning angles will be engraved on all window covers and Z - axis/zero position mark on blade stubs.

Suitable number of nitrile reinforced rubber 'V' shape or any other suitable shape seals shall be provided around journals of all blades to prevent leakage of oil outside the system or entry of water into the hydraulic system.

One drain plug will be provided in the bottom of cone to drain oil. Air bleeding plugs will be provided at suitable places in hub and cone to release air while filling the oil in runner.

The final assembled runner shall be statically balanced in the works before dispatch. The balancing weights will be fixed by welding and covered by cover plates to avoid their rotation directly in water.

The runner arrangement shall be designed to permit vertical movement of the shaft to facilitate and dismantling of the generator thrust bearings, jacking of the unit and clearing male and female portion of the shaft coupling.

**Note:** Francis turbine runners for Bhakra Left Bank were cast steel with stainless steel overlay on water passages. Stainless coating was specified to be not less than (3/16”).

**Material:** The material selected for new project, or upgrade constructions of hydraulic turbine runners has, over the years, become, almost exclusively, stainless steel. Martensitic grades of stainless steel (13 to 16% Chrome, 3 to 5 % Nickle) have been used to a large degree because these materials offer a combination of good weldability, high strength, and cavitation resistance. Austenitic stainless steel offer excellent cavitation resistance and weldability, but tend to have lower strength characteristics. Austenitics (18 to 20% chrome, 3 to 12% nickel) inherently have better corrosion characteristics than martensitics due to the higher chrome content. With any stainless, steps should be taken to avoid contamination during manufacturing and handling.

**Deflection:** The expansion of the runner crown and band (primarily, the band) for all normal operating conditions must be checked to ensure that the tight running – seal clearances at the wearing rings will not contact. This must be checked in combination with the shafting system deflections.

**Stress:** The crown, band, and blade, or vane, thicknesses should be compatible, particularly at the discharge edge junction of the blades, or vanes with the crown and band. This allows each component to carry its share of loads and moments without unnecessary constraint.

Adequate stress transition must be provided between blade, or vane, discharge edges and crown and, to a lesser extent, the band.

**Natural frequency:** The runner’s natural frequency should be calculated to ensure that it is sufficiently separated from the normal operating frequencies of the unit to avoid resonance.

#### 7.10.7 Oil Header

Oil header shall be mounted on the top of the generator and shall incorporate parts for supplying oil to the runner blade servomotor cavities. It shall be complete with special piping passing down the bore of the main shaft to the runner, return motion lever and gear.

The blade control apparatus shall be designed to adjust automatically and also manually, the angle of the runner blades as and when required corresponding to the guide vane opening such that the optimum efficiency of the turbine is obtained under all conditions of heads and discharges. A device shall be provided to ensure optimum relation between gate opening and blade angle over the entire range of heads.

#### 7.10.8 Turbine Shaft & Coupling

The turbine shaft shall be designed to operate safely in combination with the generator rotor at any speed up to the maximum runaway speed without detrimental vibration or objectionable distortion. It shall operate at the rated speed and maximum specified output without exceeding the maximum allowable stresses. The couplings for connecting to turbine runner and generator rotor shall be friction type with pre-stressed coupling bolts. The tightening torque for coupling bolts will clearly be mentioned on drawing. If necessary, torque transmitting pins will be provided on coupling flanges. Proper size rubber cords shall be used between coupling joints to avoid leakage of oil/water. Torque tightening wrench will be included in scope of supply under special tools.

The shafts and coupling bolts of all the units shall be made interchangeable.

The turbine shaft will be 1.5% Mn. steel forging conforming to Indian standard or equivalent International Standard. It will have integrally forged coupling flanges for coupling to generator shaft at upper end and turbine runner at lower flange. A central hole will be provided to allow internal non-destructive inspection and for carrying two concentric pipelines for supplying oil to runner blade servomotor. The shaft is provided with a bearing belt.

Necessary tackles and devices shall be included and supplied for lowering the shaft with runner in turbine pit and coupling the same with generator shaft.

#### 7.10.9 Guide Bearing

Self lubricating turbine guide bearing shall preferably be segment type and adequate number of babbit lined segments shall be used along the outer circumference of the bearing belt of the shaft. Arrangement shall be provided to adjust the bearing gaps and lock the pads in position. Alternatively, shell type bearing can also be offered.

The babbit material of the bearing shell lining will have following composition:

Sn – 90%, Sb – 6.5%, Cu – 3.5%, Pb <0.2%

The bearing body shall be made of mild steel plates and shall be fixed to the cover of turbine with the help of studs. The guide bearing cooler shall be located on turbine top cover and will cool the guide bearing oil by water passing through turbine babbit lined segments.

Level relay with alarm shall be provided for indicating low oil level in the bearing body. For thermal control the sensing heads, of two thermo-signalisers and two resistance thermometers shall be provided in the bearing segments/shell. An Electro-contact flow relay shall be provided for signaling the stoppage of flow of cooling water supply. .

**Note:** The adjustable shoe or segment type bearing is self lubricating since it uses a self generated hydrodynamic fluid pressure distribution enhanced by the pivoting capability of the shoe or segment.

The type of guide bearing that offers adjustability, good combined (oil and structural) stiffness, and the closest load support to the runner is the adjustable shoe or segment bearing. The resulting close proximity of the guide bearing to the runner, and, therefore, the shaft seal, limits space and precludes the use of a large oil basin necessary for a self pumping bearing. Therefore, the benefits of this bearing arrangement are fully realized when the lubricating oil is pumped from an external sump that includes cooling coils (or heat exchangers). Controls, redundant pumps and motors.

#### 7.10.10 Turbine Shaft Gland

The turbine shaft gland shall effectively prevent leakage of water along the shaft under all operating and standstill condition and prevent entry of air. Shaft gland shall be of stuffing box (carbon ring) type with self-lubricated packing and lantern ring. Any other suitable type of shaft gland will also be considered. Arrangement of providing clean cooling water supply to the gland at pressure sufficient to stop dirty water coming up shall be made by the Contractor.

An air inflatable type service seal shall be provided so that sealing rings can be replaced through turbine top cover without dismantling the guide bearing. A pressure gauge and an Electro-contact flow relay shall be provided for measuring the pressure in the turbine seal and signaling the stoppage of flow of cooling water supply. .

**Note:** - Two versions of the basic “axial” face seal concept have been used: hydrostatic, which requires clean water injection into the sealing interface, and hydrodynamic, which generators its own interface liquid film by using the fluid being sealed.

The use of hydrostatic seals is especially advantageous when the following special operation requirements exist:

- Lowest possible face wear rate;
- Contaminated operating water, particularly when the contaminants are abrasive solids;
- Synchronous condenser operation (with runner operating in air)

The packing-box type of main shaft-seal is the simplest configuration of the mentioned shaft seals. The sealing element is generally a series of square woven packing compressed by a packing gland to provide sufficient packing pressure on the main shaft to provide controlled leakage through the packing box. It should be pointed out that packing box seals require a small amount of leakage to cool the seal properly.

For shaft seals where the seal remains submerged even at minimum tailrace water elevation, a separate maintenance seal is normally specified. This maintenance seal, when actuated, will allow exchanging the main sealing elements of the shaft seal without dewatering the draft tube.

#### **7.10.11 Mounting Of Shear Pin Contact**

The limit switches shall be provided for the shear pins/breaking links to give the alarm signal when any of the shear pins / breaking links gets broken due to jamming of guide vanes. The cables used for inter-connecting the limit switches shall be weather proof type and withstand the surrounding moist atmosphere. The limit switches shall be oil/water tight and special glands be used to prevent entry of water in the limit switches through the cables.

#### **7.10.12 Plate Form In Turbine Pit & Hatch Covers**

Suitable removable type platforms/supports shall be provided on turbine cover for inspection and maintenance of the equipment.

Suitable hatch covers, ladders and railings shall be provided wherever necessary for easy approach and safety.

#### **7.10.13 Centralised Grease Lubrication System**

The centralised grease lubrication system shall be of adequate capacity to pressurise the turbine and inlet valve grease lubrication points periodically by timer as per requirements. The equipment comprises of an electric motor driven grease pump, starter, grease reservoir, pressure regulator, solenoid valve, set of grease dosers and pipes etc.

The control panel with control indicators, manually starting push buttons, fault indicators etc. shall be supplied. The control panel shall be of wall mounted type. One hand operated transfer pump shall be supplied for transferring grease from commercial standard grease drums to reservoir of automatic grease lubrication system.

One number manually operated pump for greasing the points when the automatic system is not in operation shall be supplied.

#### **7.11 Inlet and Pressure Relief Valves**

Inlet valves for closure on shut off are provided on long penstock and where single penstock headers are branched near powerhouse for individual units. Pipes for underground pumped storage projects have valves on the upstream and downstream side to the pump turbine.

Turbine inlet valves normally operate under zero flow condition and have by pass piping for equalizing pressure before opening and during closing. These are generally operated fully open and fully closed position. Throttling of these valves for flow control should not be allowed. Design pressure rating should include the effects of water hammer for capability for emergency closing on full load rejection.

Hydraulic servomotor usually operates inlet valves. In small hydro the practice is to have a common pressure oil system for closure of turbine wicket gate and inlet valve. These valves especially in SHP are held in open position by oil pressure and closed by weight on release of oil pressure.

### 7.11.1 Butterfly Valves

Butterfly valve are commonly used inlet valves being rugged; compact, simple design and low cost. Large butterfly valves have been used involving heads up to about 100 meter and diameters up to 9 meters. Small butterfly valves have been used up to 300 meters head.

Pong power plant (60 MW unit size) inlet butterfly valves are of Lattice construction; rated head is 65.5 meter and maximum head including water hammer head is 123.8 m. it is the heaviest assembly to be lifted by powerhouse crane.

Sobla small hydro power plant inlet valves are for 185 m head. Normally butterfly valves should be larger than turbine inlet diameter.

### 7.11.2 Spherical valves

These valves are used up to 1200 meters and diameter up to 4.5 meter.

Dehar power plants are provided with spherical valves. Design Head is 380 m and unit size 165 MW.

### 7.11.3 Pressure relief valves

These valves of water saving type have been used in Pong power Plant on River Beas Dam. These are cylindrically balanced type and controlled by the governor and operated by the combined guide vane and relief valve servomotor.

## 7.12 Turbine Instrumentation, Control, Safety Devices and Unit Control Board

Each turbine shall be provided with a complete set of instruments, gauges, controls and safety devices on unit control board provided for monitoring the condition of the unit during normal running and emergencies. These shall permit the unit to be started and brought up to speed no load position at the governor location and control during normal running. The instruments and gauges for the turbine include, inter alia, pressure gauges, level indicator, indicating lamps for status indication etc. These shall be placed near the locations of apparatus or in the Unit Control Board (UCB) or both. The safety devices shall comprise equipment and devices for sensing abnormal operating conditions, for giving visual and audible annunciation and shut down the unit, if required. A list of these instruments, controls and safety devices is given in tables A and B. The items, quantities and location are to suit the requirements for safe and satisfactory operation of the generating units and the auxiliary systems.

**TABLE 'A'**

Schedule of Indicating / Recording instruments for Turbine, Governing and Auxiliaries Equipment

SL No.	Parameter indicated / recorded	Type of Instrument	Location	Qty.	Remarks
<b>A</b>	<b>Temperature of :</b>				
01	Turbine guide bearing pads	RTD	Turbine Guide Bearing	2	Indication /Alarm at UCB & SCADA
02	Turbine guide bearing pads	TSD	- do -	1	Alarm/ Shutdown
03	Turbine guide bearing oil	RTD	- do -	1	Indication /Alarm at UCB & SCADA
04	Oil in OPU sump	RTD	Local	1	Indication/Alarm at UCB

<b>B</b>	<b>Pressure of :</b>				
05	Oil in Pressure Accumulator	PG	Local	1	Local Indication
06	Oil in Governor Actuator	PG	Local	1	
07	Oil in Servomotor	PG	TG Panel	2	
08	Before guide vanes	PG	TG Panel	1	
09	Draft Tube	PVG	TG Panel	1	
10	Water in Shaft Seal	PG	TG Panel	1	
11	Air in Shaft Seal	PS	Local	1	
12	Water before inlet valve	PG	local	1	
13	Water after inlet valve	PG	local	1	
14	Water after inlet valve	PS	local	1	
15	Air in HP air receiver	PG	Local	1	
16	Air in LP air receiver	PG	Local	1	
17	Cooling Water	PG	Local	1	
18	Low/Very Low/ Emergency Low Pressure in OPU	DPS	Local	3	For control of OPU pumps /emergency shut down
19	Low/Very Low air pressure in HP air receiver	DPS	Local	2	For control of compressors
<b>C</b>	<b>Levels of :</b>				
20	Oil in Turbine Guide Bearing	SG	Local	1	
21	Oil in Turbine Guide Bearing – Low/High	ELC	Local	2	Alarm in UCB
22	Oil in OPU sump -High/Low	FSW	Local	1	Alarm in UCB
23	Oil in Pressure Accumulator – low/very low/high	FSW	Local	3	Alarm/shut down/ control of air qty.
24	Oil in oil leakage unit	FSW	Local	2	Control of pump / alarm
25	Oil in oil leakage unit	SG	Local	1	
26	Leakage water in turbine cover	FSW	Local	2	Alarm in UCB
27	Water in dewatering sump	ELC	Local	3	Control of dewatering pumps / alarm
28	Water in drainage sump	ELC	Local	3	Control of drainage pumps / alarm
<b>D</b>	<b>Flow of :</b>				
29	Cooling water in main line	MFR	Local	2	Control of Pumps / alarm
30	Cooling water at TGB outlet	FR	Local	1	Alarm / starting interlock
31	Cooling Water in shaft seal	FR	Local	1	alarm

<b>E</b>	<b>Other Instruments / Indicators</b>				
32	Guide Vane Position ( % )	Mech. Indicator	Governor Actuator	1	Duplication at UCB
33	Guide Vane Limiter Position (%)	Elec./Mech. Indicator	- do -	1	Duplication at UCB
34	Runner Blade Position ( Degrees)	Mech. Indicator	- do -	1	Duplication at UCB
35	Speed of Generating set ( 0-200 % )	Elec. Indicator	- do -	1	Duplication at UCB
36	Control Current in Actuator Solenoid	Elec. Indicator	- do -	1	Duplication at UCB
37	Speed Setting Indicator	Elec. Indicator	- do -	1	Duplication at UCB
38	Gate setting Indicator	Elec. Indicator	- do -	1	Duplication at UCB
39	Servomotor locked / unlocked	LS	Local	2	Starting Interlock
40	Guide Vanes sear Pins fail	LS	Local	24	Alarm

RTD - Resistance Thermometer (these will be wired up to Temperature Indicator & Recorder Instrument mounted on control & Metering Panel)

TSD - Thermo Signaling Device (With two set points for Alarm and Trip commands)

PG - Pressure Gauge

FSW - Float Switch

FR - Flow Relay

MFR - Magnetic Flow Relay

ELC - Electronic Level Controller

**TABLE 'B'**

**SAFETY DEVICES (FOR ALARM/ SHUT DOWN )**

<b>SL No.</b>	<b>Parameter</b>	<b>Type of Instrument</b>	<b>Location</b>	<b>Qty.</b>	<b>Remarks</b>
01	Turbine guide bearing pads	RTD	Turbine Guide Bearing	2	Alarm
02	Turbine guide bearing pads	TSD	- do -	1	Alarm/ Shutdown
03	Turbine guide bearing oil	RTD	- do -	1	Alarm
04	Oil in OPU sump	RTD	Local	1	Alarm
05	Very Low/ Emergency Low Pressure in OPU	DPS	Local	2	Alarm/ Shut down
06	Very Low air pressure in HP air receiver	DPS	Local	2	Alarm
18	Oil in Turbine Guide Bearing – Low/High	ELC	Local	2	Alarm
19	Oil in OPU sump -High/Low	FSW	Local	1	Alarm



20	Oil in Pressure Accumulator – Low/ Very Low	FSW	Local	2	Alarm/Shut down.
21	Oil Level in oil leakage unit - High	FSW	Local	1	Alarm
23	Level of Leakage water in turbine pit - High	FSW	Local	1	Alarm
24	Water Level in dewatering sump-High	ELC	Local	1	Alarm
25	Water Level in drainage sump-High	ELC	Local	1	Alarm
26	Flow of Cooling water in main line -Low	MFR	Local	2	Alarm
27	Flow of Cooling water at TGB outlet- Low	FR	Local	1	Alarm / starting interlock
28	Flow of Cooling Water in shaft seal - Low	FR	Local	1	Alarm
37	Guide Vanes sear Pins fail	LS	Local	24	Alarm

RTD - Resistance Thermometer ( these will be wired up to Temperature Indicator & Recorder Instrument mounted on control & Metering Panel )

TSD - Thermo Signaling Device ( With two set points for Alarm and Trip commands )

DPS - Differential Pressure Switch

FSW - Float Switch

FR - Flow Relay

MFR - Magnetic Flow Relay

ELC - Electronic Level Controller

### 7.13 Governing System and Accessories

#### Governing System And Accessories

**Scope of Supply :** Each governing system shall comprise of :

- Electro-hydraulic Governor consisting of Electronic cubicle and E-H Actuator
- Speed signal generator (SSG)
- Centrifugal type over speed switch
- Restoring mechanism
- Oil Pressure Unit
- Leakage oil unit
- Oil piping

#### 7.13.1 Electro Hydraulic Governor

##### 7.13.1.1 Rating, Performance And Basic Provisions Of Governor

The governor shall be Digital electronic type with electronic speed sensing, electronic hydraulic transducer, and oil-pressure actuator. It shall have adequate capacity to operate the wicket gate servomotor through a complete opening or closing stroke in desired time under maximum operating head and with minimum permissible oil pressure in oil pressure accumulator.

The governor shall meet the requirements of IEEE –125 “Recommended Specification for Speed Governors of Hydraulic Turbines”.

### **Stability (Current Practice)**

The governor operation shall be deemed stable:

If peak to peak magnitude of the sustained load oscillation caused by the governor, with 4% or more speed droop setting, does not exceed  $\pm 0.15\%$  of the rated capacity - the generator being connected to the grid with sustained load demand.

The governor shall control, with stability, the turbine at any speed between 85 and 105% of rated speed when operating isolated from the system and while connected to the system at any load between zero and the load corresponding to maximum opening of the guide vanes.

With the turbine running at its rated speed, the total amplitude of speed variations not resulting in any measurable difference in the guide apparatus servomotor position shall not exceed 0.02% of the rated speed at any gate opening.

**Dead Band** - The dead band adjustment range shall be 0 to  $\pm 3\text{Hz}$ . The governor dead time shall not exceed 0.2 seconds with a sudden load change of 10% or more of the capacity of the turbine.

**The adjustment of permanent speed droop shall have a range from 0 to 10%.**

The governor adjustments shall enable synchronizing over the range of 85 to 105% of rated speed and shall be adaptable for automatic synchronizing and automatic load or frequency control.

Governor shall have provision for local-manual, local-fully automatic and remote fully automatic control of the turbine. These auxiliary devices shall permit transfer from one method of control to the other, without disturbing the operation of the turbine. Transfer from local to remote control will be initiated by a two-way position selector switch located in UCB (Unit Control Board).

The electronic regulation panel shall be micro-processor based digital system of proven design. Governor shall use PID (Proportional Integral Derivative) loop control in which three derivatives of speed are used for speed stabilization.

Control modules of governor regulator shall be suitable for following auxiliary supply voltages:

AC	:	415 Volts AC + 10%
DC	:	110 Volts DC -20% to +20%

Starting and stopping of the generating unit shall be possible locally from the governor panel and also remotely from Microprocessor based DACS and auto start/stop control system (Unit control boards).

Governing shall be fail-safe on the failure of the speed sensing element, loss of oil pressure or defect in the actuating system so that under any of these conditions, the machine shall be automatically shutdown, with alarm and indication.

Relationship between runner blade angle and wicket gate opening at all working heads shall be achieved digitally in micro-processor. The governor regulator cubicle shall be capable of accepting independent analogue signal (4 to 20 mA) from head race and tail race water level sensors and signal for gross head. The combinatory relationship i.e. runner blade angle Vs Wicket gate opening will be adjusted as per gross head signal. The electronic gate limit shall also be applied as per head signal.

Provision for level controlled units e.g. canal etc.

Provision shall be made in each governor regulator to control wicket gate opening based on water level in power channel so as to utilize available water for power generation and avoid flowing through bypass gates. Sufficient flexibility will be provided in control philosophy to choose control of any of the unit using

load-frequency control, gate limit control, manual control and control as per water level in power channel. *This point has to be clarified specifically in the Bid.*

Hand control device for stroking of governor shall be provided.

Partial Shutdown / Controlled Action Shutdown device shall be used for automatically shutting down the turbine to the speed-no-load position by the operation of certain protective devices.

#### **7.13.1.2 Performance Requirements as follows were generally specified earlier.**

**Stability:** The governor system shall be capable of controlling with stability the speed of the turbine when operated at rated speed and no load or when operated at rated speed with isolated load at all power outputs to and including maximum output of the turbine. The governor system shall also be capable of controlling with stability the power output of the turbine at all power outputs between zero and maximum power output of the turbine at all power outputs between zero and maximum power output inclusive when the generator is operating in parallel with other generators in a plant or in a transmission system. The governor system should be deemed stable, if the hydraulic system of turbine and water conduit is inherently stable, when:

- a) The magnitude of the sustained speed oscillation caused by the governor does not exceed 0.3% of rated speed with the generator operating at rated speed and no load or operating at rated speed and isolated sustained load and with the governor speed droop set at from two to five percent inclusive.
- b) the magnitude of the sustained power output oscillation caused by the governor does not exceed three percent of the rated capacity of the turbine with the generator operating under sustained load demand in parallel with other generators which are themselves capable of operating in parallel with other generators and with the governor speed droop set at from two to 5% inclusive.

**Dead Time:** The elapsed time from the initial speed change the turbine servomotor for a sudden load change of more than 10% of the full load rating of the turbine shall be not more than 0.25 second as demonstrated during field tests.

**Dead Band:** The total magnitude of the sustained speed change within which there is no resulting measurable change in the position of the turbine gate servomotors at rated speed of the turbine shall not exceed 0.02% of the rated speed of the turbine at any gate opening as demonstrated by shop tests. For purpose of determining compliance with guaranteed characteristics, the minimum speed change in % of turbine speed to which the governor will respond is defined as one-half the measured dead band.

**Runner Blade Lost Motion:** The runner blade position shall be maintained in the proper relation to the gate position with a minimum of lost motion. The steady state position of the runner blades as measured by the position of the top of the inner oil pipe at the oil head for any given cam position following a movement in the opening direction shall not vary more than one-eighth of an inch from the steady state position of the runner blades following a movement in the closing direction to the same cam position.

**Speed response Elements:** The speed of the speed responsive element shall vary directly with the speed of the main shaft of the turbine for all rates of acceleration and deceleration. The governor drive shall not be affected by variations in the voltage or current of the main generator or exciter or of the power system to which the main generator is connected.

#### **7.13.1.3 Working Principle**

Working principle of Governor Controller will be as follows:

The speed signal will be derived from Speed Signal Generator (SSG). This signal will be converted to a DC signal by a pulse converter and a frequency to voltage converter. Feedback signal corresponding to gate position will be obtained from a variable resistor or a LVDT. The subsequent stages of control and regulation will be carried out in the micro-processor hardware. The required transfer function for the controller will be realized in software by using suitable function block language. The reference values

(Speed setting, Gate setting, Gate limiter position etc.) and parameter values of PID controller, temporary and permanent droop functions will be set in the processor.

The reference values to be varied using raise/lower switches in the panel and parameters to be set during commissioning using programming tool. The output of the regulation function block will be fed to an analog output module. This signal will be further amplified by a booster amplifier and fed to electro-hydraulic transducer in actuator cubicle.

#### 7.13.1.4 Constructional Features

The governor electronic cubicle should have the following features:

- Modular, bus based architecture which will allow flexibility in hardware configuration.
- Inter module communication through serial bus .
- Module level self diagnostics to be ensured. Each module shall contain circuits for monitoring its most important functions. If a fault occurs, the type and possible location to be indicated by light emitting diodes and output signals
- Non-volatile RAM (read only memory) to be made available on the processor module for retaining important parameter values even when power failure occur.
- Power supply requirement: Station battery 110 /24 V DC.

#### Software:

A complete set of programme and data base files and software configuration and programming tools shall be provided for all digital devices installed in the system as per IEEE 125.

Interface to other plant systems shall be provided as follows:

Interface to unit controllers, plant controller central control room, plant monitoring system and remote terminal unit for offsite control as required.

- PID/temporary droop control scheme for regulation.
- Start up and Shutdown logic.
- Speed relays.
- Electronic limit.
- Function block programming language to be used same as in Unit Control panels
- The digital modules used in the controller belong to the same family hardware which are also being used in unit Control Panels.

The cubicle shall be a steel cabinet with doors for convenient adjustment, test and maintenance. Micro terminal for indications and control shall be mounted on the front rack with transparent cover. The cubicle shall be mounted at a suitable location along with unit control board panels.

All electrical wiring shall be neatly concealed inside the cubicle and terminated in readily accessible terminals. Cable entry shall be from below the cubicle.

All settings like speed droop, temporary droop on line/ off line, temporary droop time constant on line/ off line, dead band, permanent speed droop and sensitivity etc shall be achieved through digital type micro terminal. It should be possible to change the once adjusted values through password only.

Governor shall accept digital set commands from unit control panels for various controls i.e. speed / gate setting, limit setting, start, stop, main circuit breaker position, shutdown, and other signals necessary for proper operation and as per logic control scheme approved by purchaser.

Following analogue/digital output signals shall be provided as input for unit control panels:

- Speed , Wicket gate position and gate mechanical limit position, Wicket gate electrical limit,
- Actuator balance current, Speed setting, Gate setting, Speed relay signals,
- Position of various limit switches, position of various solenoids and any other signal considered necessary for ensuring proper control

Command signals at the following speeds shall be available at regulator output terminals:

- At speeds above 120 % of rated speed to cause unit shut down through the shutdown solenoid via protection circuits
- At 90 % of the rated speed for initiating excitation and synchronising functions.
- At 80 % of the rated speed for changing over the governor to auto speed regulation.
- At 25 % of the rated speed activate the generator brake application.
- At zero speed to indicating unit standstill.
- At 150 % speed to announce emergency condition and drop intake gates.

#### **7.13.1.5 Electro-Hydraulic Actuator**

The electro-mechanical transducers, pilot valves, main distributing valve for wicket gates and runner blades control, auto clean strainers for transducers / pilot valves, shut-down solenoid, terminal blocks and other accessories necessary for the hydraulic actuator shall be housed in a suitable cabinet. Following indicators shall be mounted on the front panel of the actuator:

- Wicket gate position and gate mechanical limit position indicator
- Speed Indicator (with marking as 0 to 200 %)
- Actuator balance current indication
- Speed setting indicator ( with marking as 45 Hz to 55 Hz )
- Gate setting indicator ( with marking 0 to 100 % )
- Runner Blade angle indicator (with marking – min. to max blade angle)
- Pressure gauge for oil pressure in transducer

Following controls shall be provided on the actuator cubicle:

Gate limit control device which can be operated manually at the actuator and electrically from the unit control board (suiting to 110 volts DC). Manual gate control should be possible by this device when control changed over to 'Manual'. Push button for Auto/Manual Changeover for Gate Control. Device for Manual Control of Runner Blades during maintenance Emergency shut down device which can be operated manually at the actuator, electrically by remote control or by emergency shut down signal from Unit Control Panels.

Auto clean double element filter set shall be provided in governor actuator to ensure that impurities of 10 microns or above are avoided. The change over to standby filter and cleaning of clogged filter must be possible while unit is under operation.

The control mechanism shall be equipped with means of independent adjustment of the opening and closing times of the guide vanes and runner. The adjustments shall be secured and will not be liable to change at its own under any circumstance. The time for the gate closure under full load throw off shall be adjustable to limit the speed rise and pressure rise within guaranteed values.

All bearings in the governor actuator cubicle shall be grease packed or self-lubricated.

#### **Gate Position Switches**

A bank of switches / master switch assembly will be provided in actuator cubicle or on the restoring system. Its switches shall be adjustable independently corresponding to different positions of wicket gates as desired for fulfilling the requirement of control sequence. At least two switches will be provided for gate full closed position and two switches for slightly higher position than no load gate position.

#### **7.13.1.6 Speed Signal Generator (SSG)**

A toothed wheel type speed signal generator shall feed speed signal to the governor electronic cubicle for regulation and speed relays. The toothed wheel shall be mounted on the turbine shaft and two magnetic pick-ups shall be mounted near the toothed wheel. One of the two pickups will work as redundant. The square wave output of the magnetic pick-up shall be fed to the frequency-to voltage converter module in the governor electronic cubicle. The output of this converter shall be fed to the governor analogue input signal module.

The capacity and characteristics of the SSG shall fully match with the requirement of speed responsive elements and governor regulation and control system. It shall be designed to withstand satisfactorily the maximum runaway speed of the turbine.

The digital governor shall have the provision of speed sensing through a potential transformer. The PT shall be included in the scope and provision of its mounting in the LAVT cubicle. The VA burden and classification of PT shall be as per IEEE.125.

#### **7.13.1.7 Over Speed Device**

A centrifugal type over speed protection device with provisions for electrical and mechanical tripping, shall be mounted on the turbine shaft above the guide bearing. The tripping points shall be adjustable independently for speed higher than the maximum speed the turbine can develop with loss of full load. The mechanical tripping device shall directly actuate the governor actuator shut-down valve through a hydraulic connection. The electrical tripping contact shall be wired to the turbine terminal cubicle. The rotating parts of the over speed protection shall be protected by a guard.

#### **7.13.1.8 Restoring Mechanism**

Restoring mechanism – solid rod & levers, wire rope with pulleys or fully electronic, will be provided to feed position of wicket gate and runner servomotors to governor for stabilizing and indication. Design of restoring mechanism should ensure minimum backlash to achieve overall sensitivity of the governor. Mechanism shall be provided to monitor the health of restoring mechanism so as to give emergency shut down signal in case of its failure.

#### **7.13.1.9 Oil Pressure System**

Each turbine will be provided one independent oil pressure unit to supply oil under desired pressure to guide apparatus servomotor through governor hydraulic actuator. Oil pressure system shall consist of oil pumping unit and an air-oil pressure accumulator. The operating oil pressure shall be not less than 40 kg/cm<sup>2</sup>. The bidder may offer higher operating pressure if the runner operating mechanism permits so. While selecting the operating oil pressure, care should be taken that servomotor should be capable of closing the wicket gates under all operating conditions at the emergency low pressure.

*In SHP Oil Pressure system of higher rated pressure with Nitrogen Cylinders can be offered as ALTERNATIVE offer with explanation of advantage and cost benefits.*

##### **Oil Pumping Unit**

Oil pumping unit shall consist of one sump tank with two numbers oil screw pumps driven by a 3 phase 415 VAC electric motors, check valves, idler and relief valves, oil level indicator and transmitter, oil filters at the suction of pumps and oil temperature detector. The sump tank shall have adequate capacity to drain the entire governor oil system including servomotors. It shall be provided with a manhole and oil centrifuging and drain connections.

The oil pump shall be screw type and have a capacity sufficient to operate the complete governor hydraulic system but not less than 200 l/m when operating under the recommended pressure. The main duty pumps shall be operating continuously even when the required pressure in oil pressure accumulator has been built up.

The electric motors shall be direct connected 3 phase AC motor, 415 volts + 10%, 50 Hz completely enclosed frame, squirrel cage rotor type with class F insulation.

The motor starter panel housing contactors, switch fuse units and meters etc. shall be mounted on the wall near the sump and wired complete with leads labeled. The connections to each motor shall be arranged so that either pump may be removed for repair or replacement without interfering with the continuous operation of the other.

A complete pump logic control system shall be provided in the main PLC system of turbine control. It will permit the selection of either pump, as the main unit with the other pump acting as a standby, which will cut in automatically to supply the oil and close a set of alarm contacts. Suitable number of adjustable differential pressure switches will be used to obtain the desired logic.

### **Oil Pressure Accumulator**

The capacity of the pressure accumulator shall be sufficient to operate the servomotors of the turbine, with minimum pressure of normal operating range and under other normal operating conditions, through three complete servomotor strokes (3 x sum of guide apparatus and runner servomotor volumes) with the oil pumps **not operating**. Design calculation of capacity of oil pressure system shall be furnished. .

The pressure tank shall be constructed in accordance with part UW of the ASME Code for Unfired Pressure Vessels, Section VIII, for the maximum working pressure of the governing system.

Following safety / control features shall be provided on the accumulator:

- Air pressure relief device, mounted on or near the top of the tank.
- Two low oil level devices with independently adjustable closing contacts
  - One low oil level device shall be set to operate an alarm when there is sufficient oil under pressure to provide only two full strokes of all servomotors.
  - The other low level device shall be set to shutdown the unit when there is sufficient oil under pressure for approximately 1-½ strokes.
- Two oil level devices with independent adjustable contacts for control of high pressure air replenishment.
- Sight oil level gauge with guard, shut off valves and automatic shutoff device.
- Connection for compressed air line with shutoff valve and check valve.
- Air blow off valve, pressure gauge, manhole, drain connection, lifting lugs, anchor bolts, and all necessary equipment for a complete assembly.

#### **i) Oil Leakage Unit**

One oil leakage unit will be provided to collect leakage oil from servomotor, oil distributing head and other governing elements. Provision shall be made to drain oil pipelines and servomotor through oil leakage unit and pump it to oil handling system or OPU sump.

Oil leakage unit should consist of one oil tank of at least 100 liters, one pump motor set with set of valves, oil level relay and sight gage glass.

#### **ii) Oil Pipe Lines**

Oil pipe lines of adequate size along with necessary valves, connecting flanges, fittings and fasteners shall be supplied for interconnection between different hydraulic elements. Sufficient joints will be foreseen in pipelines for their easy dismantling and cleaning. Pipelines shall be fabricated at site to suit the civil structure of the power house and provide neat layout. All weld joints in pipelines shall be done by Tag welding and inside surfaces of pipes will be cleaned by metal wire brush and acid pickling and flushed to metallic shine. All pipes above 15 mm internal diameter shall be carbon steel seamless pipes and up to 15mm size, these will be stainless steel pipes. Pipes shall be rigidly clamped on walls, floors or trenches with suitable clamps to avoid their vibrations. Covers for trenches shall be included in the pipeline scope of work.

Isolating valve in pressure oil pipeline between pressure accumulator and governor actuator cubicle shall be hydraulically operated through a solenoid valve.

## References

- IEC: 61362 (1998) - Guide to specification of hydraulic turbine control systems
- IEC: 61366 - Hydraulic turbine
- IEC: 61366-1 (1998) - Part 1: General and Annexes
- IEC: 61366-2 (1998) - Part 2: Guidelines for technical specifications for Francis turbines
- IEC: 61366-2 (1998) - Part 3: Guidelines for technical specifications for Pelton turbine
- IEC: 61366-2 (1998) - Part 4: Guidelines for technical specifications for Kaplan and Propeller turbines
- IEC: 61366-2 (1998) - Part 5: Guidelines for technical specifications for Tubular turbines
- IEC: 61366-2 (1998) - Part 5: Guidelines for technical specifications for pump turbines
- IEC: 61116 (1992) - Electro- mechanical equipment guide for small hydro electric Installations
- IEEE: 125-2007 - IEEE recommended practice for preparation of equipment specifications for speed governing of hydraulic turbines intended to drive electric generators