STANDARDS / MANUALS / GUIDELINES FOR SMALL HYDRO DEVELOPMENT

SPONSOR:
MINISTRY OF NEW AND RENEWABLE ENERGY
GOVERNMENT OF INDIA

GUIDELINES FOR MODERNISATION, RENOVATION AND UPRATING OF SMALL HYDRO PLANTS

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ALTERNATE HYDRO ENERGY CENTRE
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GUIDE FOR RENOVATION, MODERNISATION AND UPRATING OF SMALL HYDRO POWER PLANTS

1.0 GENERAL

1.1 OBJECTIVE

The purpose of this guide is to provide guidance for identifying the old power plants needing renovation, modernization and uprating (if possible) and increasing their service life. For this condition assessment, residual life assessment, diagnostic tests of main generating units, associated electrical, mechanical, hydro mechanical and hydraulic components of the plant are necessary which have been covered in this guide. A section “Guide lines for preparation of RM&U proposal for hydropower plants” has also been included in this guide for reference and guidance.

1.2 REFERENCES

This guide shall be used in conjunction with the following specification, codes, conference papers, and manuals.

References:

A. Books; Manuals, Conference proceedings:
   (i) Civil works for Hydroelectric Facility – Guidelines for life extension and upgrade – ASCE
   (ii) Guidelines for evaluating ageing penstocks – ASCE.
   (iii) Up rating and refurbishment of Hydropower Plant – Dr. B.S.K. Naidu
   (iv) Manual on Renovation, Modernization, uprating and life extension of Hydropower plants – CBI&P

B. Conference Papers
   (v) Conference papers, National conference on RM & U of Hydro Electric Projects – A trend in accelerating power development in India held – May 08, 2000 Nangal township. Organised by BBMB & BHEL – BBMB & BHEL
   (vi) Seminar on uprating and refurbishing of Hydro Plants held on 17-19, Nov. 1994 at Chandigarh – CBI & P and S.P.E. (I)

C. Technical Paper

| (i) | Up rating and renovation of Hydro generator | Sri Rajendra Singh, BHEL Haridwar |
| (ii) | Renovation, Modernisation & uprating of Hydro Power Plants – Guidelines for Residual life Assessment & Life Extension | Er. Amrik Singh & Er. Ashok Thaper, BBMB, Chandigarh |
| (iii) | Renovation Modernisation and up gradation of Hydro Plants in Bhakra Beas River Valley Development | Er. Rakesh Nath, Chairman BBMB, Chandigarh |
1.3 INTRODUCTION

Hydroelectric generation is generally considered environment friendly, non polluting, renewable and highly reliable source of energy but because of long gestation period and large capital investment required for construction of new project, possibility of upgradation of old hydro units by renovation, modernization and uprating is considered to be most cost effective means of capacity addition in short span of time. RM&U & LE on one hand improves reliability, availability of the plant, better efficiency on the other hand enhances life of the plant by several years.

(i) Renovation

The economy in cost and time essentially results from the fact that apart from availability of existing infrastructure, only selective replacement of critical components such as turbine runner, generator winding with class ‘F’ insulation, excitation system, governor etc. and refurbishment of all other worn out parts can lead to increase efficiency, peak power and energy availability apart from giving new lease of life to the power plant/equipment.

(ii) Modernization

Modernization is a continuous process and can be part of renovation programme. The reliability of plant can be further improved by using modern equipment like static excitation system, microprocessor based control, electronic governor, high speed static relays, data logger, vibration monitoring and silt content analysis etc.

(iii) Uprating

Besides modernization and renovation possibility of uprating of hydro plant is also explored which calls for systematic approach as there are number of factors such as hydraulic, mechanical, electrical and economics, which play vital role in deciding course of action. For techno economic considerations it is desirable to consider uprating with renovation and modernization of hydro plant. Uprating is possible by changing partly or wholly the electro-mechanical equipment within the existing civil works as keeping liberal safety margins was in practice for designing and manufacturing of hydro units to meet the guaranteed parameters and specifications. Further technological advancement, computer aided precise design techniques and advancement in material science have made it possible to design new equipment with uprated capacity without changing the existing civil structures.

(iv) Silt Affected Power Plants

Normally life of hydro power station is 30-35 years after which renovation becomes necessary. But power station located in Himalayan region face typical problem of heavy silt erosion, especially during monsoon season. Highly abrasive silt laden water containing high percentage of quartz passes through machines and damage underwater parts extensively causing frequent forced outages of the plant.

Besides this silt prone power stations face a variety of operation and maintenance problems viz. frequent choking of strainers, requiring frequent cleaning, choking and puncturing of cooler tubes, damage to cooling water pumps, frequent failure of shaft seal, damage to drainage/dewatering pumps, valves, piping, damage to intake seals, inlet valve seals, damage to intake gates, D.T. gates etc.
Renovation of such power station is required to be taken up much earlier than the operating life of 35 years and the works to be taken up as per condition assessment of eroded under water parts and other silt affected components.

(v) Cost Benefit

The cost benefit analysis of RM & U for improvement in reliability/availability, reduction in generation loss and operation of plant at higher rating, supplying additional peak power, is often found a very rewarding proposition.

1.4 OPTIONS AVAILABLE FOR OLD SHP

(i) Continued Upkeep

The strategy consists of maintaining the plant in an operating condition by timely repairs and/or installing spares before failure occurs in such a way that capacity of plant is not derated.

(ii) Refurbishing & Modernization

Older plants can be made productive and cost effective by using suitable retrofit and replacement of obsolete system and wherever possible uprating their capacity utilizing existing civil works.

(iii) Redevelopment

The strategy involves installing a new plant and facility to augment or replace the existing plant in view of change of hydrology over years of its operation.

(iv) Retirement

This involves removing the facility from service to avoid future operation and maintenance costs. Replacing the complete set with modern designed sets can prove feasible in this type of situation if civil structures are found healthy during RLA studies.

(v) The decision on the above four options is usually based on the analysis of present performance, remnant/safe life and also the scope of redevelopment and modernization. In all the options cited above one of the most important activity that is needed to be carried out is the evaluation of present performance, remnant life and also various risk factors for each components of the hydro sets.

1.5 CATEGORIZATION OF POWER STATIONS FOR R.M. & U

For these guidelines old power stations have been categorized as under:

(i) Old power stations which have outlived their normative life of 30 to 35 years and are neither silt affected nor there is any possibility of uprating – need only renovation & modernization for performance improvement and life extension. This will restore their derated capacity, improve generation by way of availability, reliability and better efficiency of plant. This opportunity is availed for modernization of certain obsolete equipment and system.

(ii) Old power stations where there is possibility of uprating due to increased head or discharge – need renovation, modernization and uprating of plant by suitable
retrofits in the existing civil structure and modernization of obsolete equipment and system.

(iii) Power stations which are silt affected – need special study covering precision design of runner, use of silt resistant material etc. and accordingly refurbishment or replacement of under water parts, cooling system, shaft seals, turbine guide, bearings etc. will be decided for extension of life of plant. There may be some power stations where possibility of uprating also exists, due care should be taken for this aspect also while considering RM & LE of such plant.
2.0 STUDIES AND TESTS FOR RENOVATION & MODERNIZATION

Following steps are required to be taken up before taking up renovation and modernization of any old SHP which has outlived its normative life:

2.1 CONDITION MONITORING

2.1.1 Collection of Data & Operating Parameters

This is very important as at most of the power stations record keeping is not proper and one will have to try hard for collection of past records.

- **General Information**
  - Name of Power House.
  - Name plate rating such as MW, MVAR, kV, PF, Hz etc.
  - Overload rating, if any.
  - Date of commissioning.
  - History of major outages and remedial measures since commissioning.
  - History of modifications of various components or systems made since commissioning.
  - Details of faults repeated frequently.
  - Unit wise annual running hours since commission.
  - Unit wise annual generation since commissioning.
  - No. of start/stop operation – unit wise since commissioning.
  - Availability of discharge month wise for every year since commissioning.
  - Year wise datas of silt (PPM) especially during months of Monsoon and details of petrographic analysis, if any.

- **Operational Data:**

  (i) **Generator:**
  - Output at rated head & discharge.
  - Stator winding temperature at rated load.
  - Field winding temperature at rated load.
  - Hot and cold air temperature.
  - Excitation current at rated load.
  - Excitation voltage at rated load.
  - Vibration and noise level.
  - Wobbling at coupling, LGB & UGB.

  (ii) **Turbine:**
  - Pressure pulsation in water path.
  - Vibration level of shaft and bearing.
  - Guide vane opening/runner blade opening at full load.
  - Servomotor stroke/Guide vane opening.
  - Noise level in draft tube
  - Runner – natural frequency.
  - Load throw off test at various loads.
• Wobbling at TGB & Coupling.

- **Original Manufacturers Drawings**

  (i) **Generator**
  
  - Cross sectional arrangement.
  - Foundation drawing, giving existing load on the foundation.
  - Winding connection diagram.
  - Stator coil drawing.
  - Stator punching drawing.
  - Pole coil drawing.
  - Stator core assembly.
  - Wound stator assembly.
  - Pole assembly.
  - Rotor assembly.
  - Thrust bearing arrangement.
  - Lifting arrangement, drawings for major components.

  (ii) **Turbine**
  
  - Cross sectional arrangement.
  - Shaft seal arrangement.
  - Turbine guide bearing details.
  - Guide apparatus and servomotors.
  - Oil leakage unit.
  - Grease lubrication system for guide vane.
  - Guide vane.
  - Stay ring.
  - Runner chamber (Kaplan only)
  - Top cover drain arrangement.
  - Other relevant drawings.

  (iii) **Hydraulic system – All civil structure & layout drawings.**

  (iv) **Hydro mechanical equipment – Manufactures drawing.**

  (v) **Power House building & Tail race – All layout and civil structure drawings.**

- **Documents**
  
  - Operation & maintenance manuals.
  - Commissioning Reports of each unit.
  - Technical data and description of main unit & various other equipment installed in P.S.
  - Any other information or data relevant to these studies.
2.1.2 Studies for Assessing Condition

For assessing existing condition of the plant detailed inspection of all components of hydraulic system, civil structure, hydro-mechanical equipments, penstocks, MIV, spiral casing, draft tube, stay ring, guide vanes, runner, top cover, TGB, shaft, guide apparatus, governor, OPU system, GGBs, thrust bearing, rotor shaft, bottom bracket, top bracket, rotor spider, rotor rim, rotor poles, pole to pole connection, stator frame, stator core, stator winding, stator air cooler, rotor fans, ventilation ducts, baffle plates, braking & jacking system. Besides this all unit and station auxiliaries are to be inspected and checked for existing conditions. Obsolete and sluggish items to be identified for replacement latest versions.

Detailed study of design parameters, operating parameters, history of machines over years of running, major events, repair works done in past, repeated problems it faced during operation. Comparison of operating parameters and designed/original parameters will also go in a long way in decision making. Most of the old units get derated due to ageing (fatigue, stress, corrosion, biofouling etc.) of various components and systems resulting in reduced availability of machine and energy generation. Such units are selected for RM&U straightway. However, detailed electrical tests and mechanical tests are required to be carried out and before taking up RM&U.

Some pre shutdown and post shutdown observations indicating existing condition are required to be conducted:

Post Shut down for Pre-RLA

- Dimensional checks of under water parts.
- Measurement of bearing clearances.
- Centering of shaft, verticality of shaft, rotor level are to be checked & recorded.
- Inspection of all underwater parts after dewatering.
- Inspection of shaft seals, slieve, TGB housing, pads, shaft guard, coupling, head cover.
- Inspection of all generator bearings (housing, pads), thrust bearing, rotor, stator, ventilation system, stator air coolers etc and excitation system.
- Inspection of OPU system, running of OPU pumps.
- Inspection of control, protection & metering system.
- Inspection of power & control cables.
- Inspection of D.C. System.
- Inspection of fire fighting system.
- Inspection of power transformers & switchyard equipment.
- Inspection of all station auxiliaries.
- Inspection of hydro mechanical equipment.
- Chemical analysis of water.
Pre Shutdown Checks for Pre RLA Studies

- Maximum output of each unit at rated head and discharge. In case less output than reasons are to be found out.
- Guide vane opening, servomotor stroke at rated head & rated discharge & available output.
- Wobbling of TGB, coupling & generator guide bearings.
- Measurement of vibration and noise at various accessible points of machine.
- Leakages through accessible points of water conductor & cooling water system inside power house.
- Leakage through pressure oil pipe and valves of OPU system.
- Excitation current and voltage.
- Stator current, system voltage, MVAR output and p.f. etc.
- Condition of power transformer, its cooling water system, mulsifyre system (if installed) in running condition.
- Inspection of switchyard equipment and bus bars in charged condition.
- Inspection of all, main & unit control boards, LT boards while power station is generating electricity.
- Condition of all station and unit auxiliaries in running condition.
- Inspection of complete water conductor system and hydro mechanical equipment while the plant is generating.

The study of records and observation collected during pre RLA studies:

These studies would reveal the following facts:

- Components to be replaced due to their being irreparable or obsolete & sluggishness.
- Components which needs to be refurbished after establishing their ramanant life through RLA studies.
- Margins for uprating of units.
- Components to be got redesigned with latest techniques of precise design and advancement in material science.

2.2 RESIDUAL LIFE ASSESSMENT STUDIES

Hydro Turbine

As the old turbines remained under continuous operation since their commissioning, it is considered necessary to assess the ageing effect on materials of components proposed to be retained and determine their life expectancy. Material investigation test are done in the following phases:

(i) Non Destructive Tests

- Visual inspection & critical examination
- Mechanical
- Metallurgical
- Chemical

(ii) Dynamic Behavior Tests
− Pressure Pulsation
− Vibration
− Noise
− Load throw off
− Ventilation and air flow analysis

(iii) Hydraulic Studies

Non Destructive Tests

(i) Visual Inspection:

- Accessible areas of tubes, surfaces are examined for swelling, blistering, wrapping. Amount of swelling, wall thinning is determined by mechanical or ultrasonic methods.
- Thorough examination of possible signs of corrosion or erosion.
- Examination of surfaces to detect misalignment due to wrapping and disengagement.
- Identification of signs of distress.
- The components liable to deformation/distortion/bulging due to wear/creep, like bolts, valve stems, bushings etc. are thoroughly cleaned and dimensions measured to compare with the original for any change.

(ii) Mechanical Tests:

- The components subjected to high tensile stress viz. turbine runner, generator rotor, shafts, weld joints are examined by Magnetic Particle Test to check for any surface and subsurface defects.
- Dye penetration test using coloured or fluorescent dye are used to detect surface crack/porosity/discontinuity. The components subjected to tensile stress are examined by DPT.
- Ultrasonic test is used to determine:-
  - Wall thickness of tubes/surfaces due to pitting and corrosion.
  - Cracking due to corrosion fatigue.
  - Thickness of oxide layer of the inner wall of tubes/surface due to deposition of corrosion product.
  - Subsurface material defects.
- Radiography will supplement ultrasonic test for detection of the following:-
  - Surface & subsurface discontinuities
  - Dissimilar metal weld cracks
  - Caustic gauging/corrosion
  - Hydrogen damage
  - Corrosion fatigue
  - Welding defects
- When diameter of targets is low and do not permit direct examination (such as headers, piping tubes) examination is performed by remotely operated miniature video camera (video probe). It has its own light source and is capable of being manipulated adequately for 100% of inside surface inspection.
• Natural frequency test – turbine blades are examined to measure natural frequency of blades to ascertain healthiness/rigidity. FFT analysis is used for the purpose.

(iii) Metallurgical Tests:

• To assess present micro structure condition of components subject to damage due to embrittlement, stress corrosion cracking etc., examination by portable optical microscope and surface replication techniques are carried out.
• The locations selected are properly polished with portable grinder, sprayed with suitable chemical for examination under portable microscope.
• The reverse image replica of metal surface is taken on a plastic replicating film for detailed laboratory examination under optical microscope.
• In situ hardness test is carried out on components operating at high stress to examine the extent of micro structural degradation. The location of hardness measurement is selected based on tests and visual inspection.

(iv) Chemical Tests:

1. Chemical examination of small samples taken from components operating at high stress to ascertain their chemical composition and compare the results with the designed figures.
2. Chemical analysis of water.

Dynamic Behavior Tests

• Measurement and spectrum analysis of bearing vibrations (Turbine/Generator).
• Measurement and spectrum analysis of shaft vibrations alongwith orbit analysis (Turbine/Generator).
• Measurement and spectrum analysis of draft tube man holes and in turbine pit.
• Pressure pulsation measurement and spectrum analysis in the water path at following points:-
  – Before inlet valve
  – After inlet valve
  – In the annular space between guide vanes and runner.
  – In the turbine top cover before and after labyrinths.
  – In the draft tube cone.
• Vibration measurement in penstocks.
• Speed rise and pressure rise at load throw off.
• Noise signal analysis at turbine pit, draft tube area or any other affected area of unit.
• Pressure test – affected areas are tested, recorded and analyzed.
Hydro Generators

Visual Inspection and diagnostic testing

Before arriving at a final decision for renovation and up rating of the old hydro generators, it is necessary to go into detailed history of the operation of machines including their performance, abnormal behavior and failure data and inspect them thoroughly as detailed below:

● **Stator**

  Stator winding should be inspected for detection of major external changes such as:

  – Signs of overheating.
  – Change in color and texture of coil surfaces.
  – Contamination due to grease, oil, brakes dust etc.
  – Presence of white powder or any other powders.
  – Looseness of wedges, spacers and bindings.

  In addition to above diagnostic testings like polarization index, Tan delta and tip up tests, Dielectric loss measurement, Partial discharge measurement and winding resistance measurement and AC/DC H.V. test can be carried out on the stator winding.

● **Stator Core**

  Stator core is inspected for major external changes such as:

  – Looseness of core laminations.
  – Mechanical damages.
  – Locally overheated spots and core burning.
  – Deposits in cooling/ventilating ducts.

  ELCID/CORE FLUX test should be carried out to check the shorts in the core and its laminar resistance.

● **Rotor**

  The rotor is inspected thoroughly for:

  – Signs of overheating.
  – Cracks in shaft end or in body.
  – Damages/cracks in coupling system.
  – Presence of powdered insulation.
  – Condition of cooling ducts.
  – Condition of fan blades.
  – IR values and field winding impedance measurement.
  – Condition of various weld joints.
  – O.C.C. and S.C.C. tests.

● **Other components**

  Other components should also be inspected such as:
– Stator casing, brackets etc. for cracks and tightness.
– Bearings for wear and tear.
– Commutators, brushes, brush holders and slip rings for wear and tear and other damages.
– Coolers for deposits, corrosion of tubes and water chambers.
– Fan blade surfaces, bearing and contact area.

**Electrical Tests:**

(i). IR – It indicates status of insulation, however it fails to detect cracks and voids. Its absolute value is less important than continuous steep fall. Minimum IR value should be 2 Ft (2 kV + 1) at 40°C where Ft depends upon life of machine.

(ii). PI – It indicates dryness of insulation. Minimum value of class ‘F’ insulation should be 2.

(iii). Over voltage power frequency test – It is a destructive test which either passes the insulation or fails it. However, this test is unable to detect overall deterioration of winding. It is universally recognized acceptance test. The winding of in service machine should withstand 1.5 Un for 1 min.

(iv). Over voltage DC and 0.1 Hz test – As above except that these test are not universally recognized acceptance test and stresses produced during test are less than produced during power frequency withstand test. However, due to small size of test equipment, these are quite popular and have been recognized by some standards as acceptance test.

(v). Tan Delta and Tip Up tests – It detects loss component of current in dielectric as a factor of capacitance current. It indicates losses in solids and voids of insulation and indicates general health and deterioration of winding with age. High Tan-Delta indicates poor insulation. Maximum tip up for class ‘B’ insulation should be 0.1 and for class ‘F’ 0.006 for 11 kV machine.

(vi). Capacitance Test – Increase in capacitance with time, temperature or voltage indicates voids, moisture & contamination in the insulation. The maximum value of capacitance tip up should be less than 0.02 for class ‘F’ and 0.005 for class ‘B’ insulation in 11 kV machines.

(vii). Partial discharge test – It measures inception and extinction voltage i.e. the voltage at which partial discharges commences and extinguishes. It also measures quantity of discharge in pica columns. The minimum inception voltage for an old in service 11 kV machine should be more than 3.5 kV.

(viii). Dielectric loss analyzer – It measures total loss due to partial discharges in the insulation. The maximum loss for in-service machine should be less than 500 P.C. at 0.2 Un and less than 7500 P.C. at 1 Un.

(ix). Inter laminar insulation test – It indicates the condition of stator core. Maximum core loss during test should be with in 103% of design/commissioning losses. Hot spots, if any should disappear after taking remedial measures.

(x). Impedance test on Rotor Field Coils. It indicates poor insulation & short circuit in rotor field winding. Impedance of field coil should be within ± 5% of average impedance of each coil.

(xi). ELCID Test: It is a stator core imperfection detection test and establishes healthiness of the core.

**Mechanical and metallurgical tests on Generator stator frames, rotor spiders, thrust collars, thrust bearing housing etc.**
Metallurgical test (like electrical tests for insulation) reveal existing condition and the rate of deterioration of mechanical parts. Following mechanical and metallurgical tests are carried out:

(i) Visual Inspection:
   This will indicate apparent general condition.

(ii) Dye Penetration Test:
   It detects surface cracks & pitting.

(iii) Magnetic Particle Test:
   It detects subsurface cracks and blow holes.

(iv) Ultrasonic Test:
   It detects deep cracks, blow holes and flaws in the welding.

(v) Hardness Test:
   It detects hardness.

(vi) Tensile Strength:
   Test on a piece taken from the part, fairly indicates tensile strength of that part.

(vii) Metallographic Examination:
   It will indicate change in micro structure of the part under examination, which in turn indicates deterioration.

(viii) Structural Studies:
   These studies indicate matching of resonant frequency of a part of equipment with hydraulic excitation frequency. Comparison of these values with original/old record will reveal effect of ageing on metal parts.

(ix) Ventilation and Air Flow Studies:
   Ventilation and air flow analysis is carried out for generator air path, ventilation ducts, fans, air baffles etc. to establish the reliability of system.

All the above studies carried out on generator and turbine indicate the health and residual life of machine and are main deciding factors for replacement or repair of different components of machine.
3.0 STUDIES FOR UPRATING OF HYDROGENERATOR UNIT
3.1 HYDRO TURBINE

3.1.1 General
Hydro turbines hold substantial potential for uprating at the time of renovation. Hydro turbines installed 15 to 20 years back can now be uprated by at least 15% through minor changes and by 30% through major modification. Development in the following areas has made it possible to upgrade the existing old power plants due for renovation:
- Development of higher specific speed runner.
- Improved material capable of withstanding higher velocity and cavitation.
- Computer aid precision design techniques in the field of hydro-dynamic design and stress analysis.
- Higher speed rise becoming acceptable to the expanding power grid.
However, for uprating all the components of plants require rechecking for their suitability under new operating condition and assessment of their residual life expectancy should be made.

3.1.2 ASSESSMENT OF UPRATING POTENTIAL
Following points make it essential to assess possibility of uprating of old units:
- Hydraulic conditions at a particular site may change over years due to additional tapping of basin upstream, higher head loss in the water conductor system etc. Change in head-discharge combination influences the uprating potential.
- Ever expanding power systems demand higher peaking support during limited period of the day.
- Availability of better cavitation resistant material capable of withstanding stringent hydraulic conditions under the uprated capacity decides the upper limit of rerating.
- Computer based precision design techniques of course augment the uprating possibilities.
- With ageing of machine, higher plant outages are required for preventive maintenance. Increase in the capacity by uprating may enable one of the units to be treated as stand by.

3.1.3 OPTIONS FOR UPRATING
- It is an universally adopted engineering practice to design a hydro turbine for its rated output at rated head at partial opening of guide vanes (70% to 80% of full G.V. opening). Such an arrangement provides an opportunity to up rate machine further at later date by opening the reserved portion of guide apparatus, thereby permitting higher discharges.
- Hydro turbines are capable of producing higher outputs than their rated capacity at heads higher than the designed head. Thus higher out puts are possible in the vicinity of maximum head provided other hydraulic factors such as cavitation, hydraulic torque, speed rise, pressure rise, axial thrust do not restrict this.
- The discharge capacity of existing runner can be increased by making some modifications without interfering with its basic design. Inlet and exit edge of all the runner blades can be cut uniformly along the radial lines. By doing so it is possible to achieve higher specific speed and higher output with in the existing constraints on physical boundaries. Though such modification may result in higher value of critical sigma which has to be ascertained through model testing.
- As much as 30% uprating is possible by replacement of runner with a higher specific speed profile, designed through modern computerized techniques a different combination of number of runner blades and blade length can be adopted for designing
new runner. Runner replacement on one hand improves efficiency which dropped due to ageing and on the other hand step up efficiency of hydraulic energy conversion in the existing turbine space through improved design. This improves efficiency by 4 to 6%. Further, a higher discharging capacity of new runner further enhances the output substantially for peaking purposes. A change of runner may be accompanied by a change of guide vanes also for compatibility of flow characteristics.

3.1.4 HYDRAULIC PARAMETERS TO BE CONSIDERED WITH UPRATING

- Axial hydraulic thrust
- Runner speed:
  - Normal
  - Runaway
- Velocity at:
  - Spiral inlet
  - Runner exit
  - Draft tube exit
- Governing parameters:
  - Maximum speed rise
  - Maximum pressure rise
  - Guide vane closing time
  - Inertia of rotating mass

The hydraulic thrust is affected by quantity of water flowing through the runner and leaking through the clearances. The magnitude is therefore, decided by discharging characteristics of runner and its labyrinth design.

In case existing runner is retained runaway speed may marginally increase by 10 to 15%. But with new high speed runner it may increase by 30 to 50%.

The velocity will increase with the increase in quantity of water passing through turbine as a result of uprating. Higher runner exit velocity will increase erosion in draft tube throat. A good quality concrete draft tube can with stand water velocity upto 7 m/s.

It is preferred to retain guaranteed maximum pressure rise so that the old repaired spiral casing and penstocks may with stand the same. However, higher speed rise is acceptable in the large modern power grid, frequency of which is hardly influenced by an individual unit rejecting load.

The rotational inertia is maintained with marginal limits, the guide vane closing time has to be progressively increased for higher output variations to contain pressure rise even at the cost of slight speed rise.

3.1.5 MECHANICAL CONSIDERATIONS FOR UPRATING

- Mechanical strength and material composition of machine components is important as further loading under higher rating can not be ruled out.
- Design review of such components, using latest computerized techniques will reveal stress level and also indicate excessive safety margin of original design.
- During uprating programme following parameters may vary, which have direct bearing on mechanical integrity of various turbine components as mentioned below:
- Net head – Runner, guide bearing, spiral casing, speed ring, top cover, pivot ring and guide apparatus (comprising of guide vanes, servomotors, regulating ring, turning mechanism).
- Turbine Discharge – Spiral case, speed ring and guide apparatus.
- Velocity of Water – Spiral casing, draft tube.
- Torque on Turbine Shaft – Shaft & guide bearing.
- Normal Speed – Shaft, guide bearing, shaft gland.
- Runaway Speed – Runner, shaft, guide bearing.
- Pressure Rise – Runner, spiral casing, speed ring, top cover, pivot ring and guide apparatus.

### 3.1.6 USE OF BETTER MATERIAL FOR TURBINE COMPONENTS

As a result of uprating the turbine will experience higher velocity, higher pressure pulsation and increased cavitation and erosion and as such better material especially for runner, guide vane, runner chambers (Kaplan) are used so that these may withstand changed/increased parameters for longer time.

Previously mild steel, 13:1/Cr Ni steel were used for hydro turbine runner and guide vanes. Recently 13:4/CrNi steel has been developed which have following advantage over other steels:

- Improved mechanical properties, especially good impact value, even at low temperature.
- Good weldability.
- Improved cavitation erosion resistant.

The opportunity of manufacturing of the runners and guide vanes for uprating purposes with 13:4/CrNi steel can be utilized to provide additional protective overlays such as plasma coating in the hydraulically critical zones viz. trailing edges of the blades, outlet edge of guide vanes etc.

### 3.1.7 DESIGN REVIEW

Thorough design review is essential to check all the components for their suitability under uprated conditions, particularly those giving rise to instability. Range of transient parameters in case of reaction turbine is as follows:

- Vibration 0 – 100 microns
- Noise level 0 – 100 db
- Shaft run out 0 – Bearing clearance
- Pressure fluctuations 3 to 5% of net head
- Power swing 2 to 3% of rated output

Design review makes it possible to anticipate the quantum of change in the transient behavior of the machine and also reveal the design margins which can be made use of retaining the machine in the acceptable operational mode even after uprating. Design studies also make it possible to identify the machine components to be replaced by modern and latest versions to match with the uprated conditions.
3.1.8 FIELD INVESTIGATIONS

Design studies should be backed by certain appropriate field investigations such as assessment of ageing effect on the materials of turbine components and prediction of their life expectancy under the changed operating conditions.

‘Signature analysis’ is necessary to feel the ‘pulse’ of existing machine, during normal operation & transient conditions. It is done by obtaining a record of time dependant variables such as pressure, pulsation, vibrations noise etc. called ‘signature’, or ‘finger print’ of machine on UV recorder.

The recording reveals the margins available in finger print parameters.

Uprating is nothing but continuous over-loading of machine involving higher stress components higher velocity levels, changed pressure pulsations, imbalance of higher order during load throw off i.e. voltage, pressure, speed rise etc. Site investigations should go hand in hand with design review for optimum results.

3.2 HYDRO GENERATOR

Generally rating of machine is assigned by the manufacturer to meet specific performance parameters. In actual operation, the machine may be able to deliver higher output without effecting operating parameters. Therefore, it is possible to up rate the capacity of existing unit by utilizing existing margins between the design and actual operating parameters and also taking advantage of development in this field.

- Technical advancement in following areas of design and construction of hydro generators in the recent years have made uprating of old hydro sets possible:
  - Stator & rotor winding insulation system.
  - Improvement in ventilation and cooling system.
  - Application of computers for optimum design and accurate prediction of performance parameters for maximum utilization of material.

- Various possibilities of uprating of generators are as follows:
  - Overloading of machine by utilizing built in designs/specification margins, if available. This can be established by performance evaluation at site and analysis of data.
  - Replacement of some systems/components by modern system to remove restrictions in over loading of machine viz. AVR & Excitation system, control and protection system.
  - Replacement of complete unit by new unit of higher rating which can be accommodated in the same pit and utilizing the same embedded parts.

- Temperature rise of active materials, exciter capacity, thermal system etc. are the main load limiting factors besides turbine capacity which decide the extent of uprating. Various components and system which require detailed considerations are as under:
3.2.1 Stator Winding

Most of the old machines have class ‘B’ insulation system for stator winding. The present day insulation system class ‘F’ provides higher allowable working temperature, better thermal conductivity & dielectric properties compared to class ‘B’ insulation system. Moreover it has following additional advantage:

- The total volume of copper per turn can be increased within the existing slot.
- Current density of copper can be increased because of higher temperature rise of this class of insulation.
- The winding arrangement can be simplified wherever possible.
- The windings have better resistance to moisture and better fire resistance property.
- Roebel or Semi Roebel transposition of elementary conductors can be adopted to reduce eddy current losses, if not existing earlier.

The overall effect of all above factors will be 15% over loading of new winding with temperature rise still limited to class ‘B’ limits.

3.2.2 Field Windings

The original winding can usually carry the increased current associated with uprating as these are liberally designed. But to withstand higher temperature rise due to uprating the insulation system of field winding should be replaced from class ‘B’ to class ‘F’ epoxy insulation system.

3.2.3 Excitation System

Exciters are normally designed with liberal margins varying from 20 to 30% to account for uncertainty in excitation current requirements due to unavoidable variations in design and actual value of air gap. Mostly existing excitation systems are outdated and need be replaced preferably with new static excitation system.

3.2.4 Thermal System

Use of computers to accurately predetermine the temperature of stator coil, core, tooth, field winding etc. by solution of heat transfer equations formulated by thermal networks minimize the built-in margins & the possibility of exceeding the guaranteed temperature rise.

3.2.5 Ventilation and Cooling

Generally, it is possible to improve effectiveness of the ventilation system by providing new air guides, use of air baffles to direct the air flow & replacing fan blades with improved design. Coolers usually have liberal margins & by increasing the water flow these can be made to absorb additional losses.

3.2.6 Mechanical Aspects

Proper consideration should also be given to the design of mechanical components during uprating while stator and/or rotor windings may be considered for replacement with better designs & materials, the mechanical components like shaft, spider, rim, bearings etc. may remain
unaltered even with higher rating. Some of the important components which are of concern for uprating are discussed below.

3.2.7 Shaft

The shaft has to be checked for stresses corresponding to higher torque at increased rating. In addition to stresses in the shaft, coupling flange & the fitted bolts are also to be checked for their integrity.

3.2.8 Spider and Rim

Spider carries the full torque, therefore the stresses in the critical areas must be checked. If runaway speed also changes, then spider & rim are required to be checked for mechanical strength due to additional centrifugal forces.

3.2.9 Bearings

Up rating may involve due to change in axial hydraulic thrust. Thrust bearing has to be checked for increased loading.

Load on guide bearings is affected by unbalanced magnetic pull which is governed by air gap magnetic loading. The change in the load may be negligible, if the stator design is not modified.

3.2.10 Foundations

Modifications in design resulting in changes in electromagnetic loadings may also increase loading of generator foundations. Therefore, the margin available on the existing foundations will have to be checked by the civil designers.

3.2.11 Other Equipment

Other equipment which needs attention of the utilities while considering limits of uprating are the unit transformer, bus duct, CTs, switchgear etc.

3.2.12 Instrumentation

Hydro generators are provided with instruments for safe and reliable operation. Instrumentation and thermal control system for most of the old hydro sets are inadequate & have become obsolete. To ensure trouble free operation of old hydro sets, adequate modern instrumentation with safety devices for thermal, lubrication, cooling water circuit and other systems are necessary as a part of renovation & modernization programme.

3.3 ADDITIONAL FEATURES

In the process of uprating and renovation of the existing machines, possibility of adding additional features should be looked into for incorporation which can improve the performance of the machine and add to the reliability and give better control of the system.

a) Modernization of brake/jack system for automatic operation.

b) Provision of brake dust extraction equipment.

c) Provision of modern instrumentation and thermal control system.
d) Modernization of excitation system, voltage regulation, neutral grounding, surge protection system etc.

   e) Provision of automatic fire protection system for generator, if not provided

   f) Provision of online monitoring system for vibrations at vital points.

   g) Provision of multisensory protection system for fire protection of power transformers.

   h) Provision of SF6 circuit breakers in switchyard.
4.0 RENOVATION MODERNISATION OF OTHER EQUIPMENTS

So for renovation modernization and up rating of Hydro turbine and Hydro generator was being discussed. But there are other electrical systems & Hydro mechanical equipments installed in the power station. The studies pertain to the following equipment and area relating to station auxiliary/unit auxiliary transformers and other electrical and hydro-mechanical equipments as below:

4.1 Electrical Systems
(i) Unit auxiliary / station auxiliary Transformers.
(ii) Generation bus ducts/Main power cables.
(iii) Power and control cables.
(iv) LT AC/DC Systems
(v) Switchyard equipment viz. circuit breaker, isolators, CT, PTs, CAs etc.
(vi) Black start arrangement viz D.G. set etc.
(vii) Ground resistance.

Condition assessment and electrical tests as per relevant ISS or IEC code to be carried out for assessing repair or replacement. Tests required for circuit breakers, power cables, surge arrestors are given in Annex-IV and transformers in Annex.-III.

4.2 Hydro-mechanical Equipment
(i) All gates, stop log gates, their embedded parts, their operating mechanism in water conductor system from intake to exit.
(ii) Spillway gates, their operating mechanism
(iii) Trash racks their cleaning and operating mechanism at the intake, stop log gate.
(iv) Silt extruder gates their operating mechanism
(v) Under sluice gate and their operating mechanism
(vi) Any other gates and valves in the system.

The study will involve condition assessment of hydro-mechanical equipment, by reviewing available data, conducting inspection and necessary / relevant tests etc. the following checks need to be done.
- Accessible components of gates for pitting, any crack of welded joint, paint condition, any other deterioration and damage of components.
- Checking surfaces and components of gates (normally not accessible being under water) by exposing them either by dewatering or removal from the water as the case may be and as necessary such gates, guides, tracks, seals, seal seats, condition of concrete surrounding the embedded parts of gate system, gate frames gate bonnet, gate leaf, skin plates and other structural members, effectiveness of seals.
- Check components and operation of various type of hoists – threaded stem (screw) type, hydraulic type, chain type, wire rope type check wire ropes, brakes, hydraulic fluid (oils), taking visual / photograph images of condition of the components as necessary for illustration and record.
5.0 RENOVATION MODERNIZATION, I.E. OF POWER TRANSFORMERS

5.1 INTRODUCTION

Power transformers are one of the most important components of power plant, with careful monitoring and regular maintenance life of transformers can be extended to about 30 to 35 years. With the advent of new and improved quality of material, fittings and accessories, improved design, technologies manufacturing and process technology it is possible to up rate transformer.

5.2 CONDITION ASSESSMENT

While considering modernization and renovation of the power plant the power transformer must also be checked for following points:

- Check condition of transformer, assess possibility of life extension by refurbishment/repair
- Possibility of up rating along with life extension
- Necessity of replacement by the new one with modern specifications
- Necessarily of replacement by new transformer of up rated capacity.

On line condition base monitoring (CBM) involves measurement and checking of all vital primary and secondary parameters or signals given out of the transformer during its operation. The primary parameters are current, voltage, winding temperature, oil temperature. The secondary parameters are noise, deterioration of insulation etc. The basic purpose of condition monitoring is:

- Minimise / avoid forced outage.
- Improve safety to personnel and the environment
- Improve equipment or power system availability and reliability
- Optimize maintenance cost

About 80% of transformer failure in transformer can be predicted and prevented if an effective diagnostic system is used.

The major transformer components that can be monitored on line are:

- Main winding
- Magnetic circuit
- Insulation system
- Auxiliary systems such as bushings, transformer cooling system, tap changer etc.

For condition assessment following tests is carried out:

(i) Routine Tests
(ii) Special Tests
Routine Tests:
- Visual inspection of transformer and its associated accessories
- Dissolved gas analysis (DGA) along with formaldehyde concentration, moisture and acidity measurement is done once a year.
- Loss tangent tests on bushings
- Insulation resistance to check care & frame earthing is intact
- Inspection of tap selector and diverter switch
- Functional checking of coolers
- Winding resistance to check broken sub conductor and tap changer contact problem.
- Frequency response test to detect mechanical distortion of winding, which occurs only after a specific event.
- Out sample testing for BDV value
- Working winding temperature and oil temperature indicators
- Working of air vent breather
- Working of buchholz Relay protection

Special Tests:

Special tests are the subject of continuous research and development both in techniques employed and interpretation of results. Currently applied techniques are:
- Frequency response analysis to detect winding mechanical distortion
- Loss tangent or power factor tests, as a general indication of insulation quality with some indication of location
- Polarization spectrum or recovery voltage measurement giving a general indication or moisture in insulation and possibly paper ageing and oil condition. D.P. test (degree of polymerization) must also be carried out on sample of paper insulation.
- Winding resistance, indicates broken sub conductor and tap changer contact problems
- Acoustic Discharge location provides valuable diagnostic information following discharge detected by DGA to determine if the problem can be fixed or if the discharge is likely to be damaging.
- Radio interference measurements, using a high frequency current transformer.
- Magnetizing current and turns ratio, detects electrical problems, useful for confirming that transformer requires repair or replacement but not as sensitive as FRA.
- Insulation resistance mainly used to check core and frame earthing is intact.
- Visual inspection, directly or by means of CCTV or endoscope
- Infra red thermal survey

5.3 RESIDUAL LIFE ASSESSMENT

5.3.1 The factor which determines residual life of a transformer can be categorized as under:

(i) Strategic:
It relates to the ability of transformer to carry the loads, short circuit currents, network service voltage, over voltages and normal stress applied to it during service. It is also known as ‘load ability’ or ‘rating’ factor. When the load is increased beyond the rating of transformer, there may be two options, either to move it to other location or take it out of the service. Moving transformer to other site is generally quite risky especially in case of old units. Transformers can continue working satisfactorily despite their age, provided they are not disturbed mechanically.
(ii) **Economic:**
This factor includes cost of losses and maintenance cost, losses on account of undelivered energy and more expensive alternate supply arrangement are considered for this purpose. Frequency of outage of unit is the main consideration for decision making.

(iii) **Technical:**
Mainly ageing mechanical & electrical over stressing and contamination are the main technical factors.

- **Mechanical overstress:**
Mechanical overstressing may be caused due to current stress e.g. overloads, short circuit or in rush currents which, imposes electromagnetic forces on the winding structure leading to displacement and possible dielectric breakdown, Mechanical overstressing may also arise due to vibrations caused transport shocks or resonance phenomena.

- **Electrical overstress:**
Causes of electrical overstress resulting in dielectric break down are as under:
  - lightening
  - switching over voltages
  - internal influences such as winding resonance
  - secondary effect of range of primary / cause over fluxing caused by high service voltage or low frequency cause over heating resulting in failure of insulation.

- **Contamination:**
Contamination of oil can cause dielectric failure. Gas bubble evolution as a result of high moisture content may also cause failure. DGA test and oil testing will identify many contaminates. Reprocessing of oil is required in such situation.

### 5.3.2 Ageing Factor

Life assessment of transformer is not simple due to complex behavior of insulation. The ageing of insulation in transformer depends on
- Long term and short term overloads
- Number and intensity of short circuits
- Internal faults

Life span depends on
- Design
- Quality of manufacture
- Service conditions
- Maintenance standards

The best way to check the condition of insulation is to take sample of paper and measure degree of polymerization (DP). However as it is not possible to take sample from in service transformer indirect methods targeting the by products of paper degradation such CO₂, CO, furan, sugar and water are adopted.

### 5.3.3 RLA Studies
RLA studies comprises following tests on transformers:
- Physical properties
- Chemical properties
- Electrical properties
- Special property like DGA
- DP of insulating paper

For conducting test on transformer normally three oil samples are collected from the transformer.
- First oil sample from running transformer
- Second oil sample from running transformer after one month from first sample.
- Third sample from running transformer after about one month from the second sample.
- After taking third oil sample paper sample is also to be collected from the transformer coil / lead.

Normally collection of paper sample is done during planned maintenance shut down.

If RLA study reveals that life of winding insulation is very less and needs replacement, action to replace winding can be taken up.

5.4 LIFE EXTENTION

Following information / data are collected and analysed for assessment of LE:
- Design specification and details
- Service history
- Operational problems
- Result of present condition assessment diagnostic tests (visual, chemical, electrical) as well tests done earlier during the life of transformers.

Considering the complexity of the sub-system of transformers it is not possible to quantitatively assess the residual life of transformer.

Any decision on refurbishment, repair or replacement must be made with reference to age of the transformer and the complete service record.

Economic, technical as well as strategic factors determine the effective and life of the transformer. Based on the condition monitoring, test results decision can be made for the extent of renovation / reclamation / part replacement required.

5.5 UPRATING

Following factors should be studied for uprating of old transformer.
- Original electrical design calculation available with the manufactures
- Thermal design calculations and test records available with the manufactures
- All manufacturing drawings
- Computer calculations available with manufactures
Following aspects should be analysed carefully by the designer:

- Current load to be allowed with out overheating with existing conductor
- Check the insulation paper over conductor is overheating
- Check cooling ducts are sufficient for higher load and check whether these are over heating in the end frame, tank cover, core or in bus base beyond permissible limits
- Check suitability of accessories like bushings, on/off load tap changer for higher load
- Margin in the temperature rise limit
- Availability of space for additional cooling fans / pumps, if required.
- For additional cooling, explore possibility of modification of cooling system.

With the consideration of above factors power transformers can be uprated by 10% to 15% at site.

5.6 REFURBISHMENT

5.6.1 Previously only preventive maintenance was done to minimize service interruption and save expensive repairs. During last 10 to 15 years the refurbishment of old power transformer was felt necessary in view of the following points:

- This slows up the ageing of paper insulation, and of the oil as well as improves the electrical and insulating properties of oil.
- Keeps humidity of paper insulation at the level of less than 3%.
- Improves the short circuit strength (the axial forces pressing the windings are reduced due to ageing process in the solid cellulose parts)
- Other general reasons like changing of gaskets, repairing or replacing bushings protective devices, indicators fitted on the transformer.
- Inspection testing and repair of on load or off load tap changer, Bucholz relays, air vent breathers etc.
- Fitting of new / latest condition monitoring system
- Desludging and tightening of various joints.
- D.P. test of paper insulation and inspection and cleaning of HV, LV windings of possible.
- If oil parameters are with in limits vacuum reconditioning of same is done.
- In case oil is found deteriorated beyond possibility of recondition, the same should be changed. This will improve over all insulation characteristic.
- Reconditioning or modification of conservator sealing system.
- Improve life expectancy and reliability is restored.

5.6.2 REFURBISHMENT ACTIVITIES

- Lifting of active part from the tank and thorough inspection of core, clamping arrangement, insulation of winding, earthing and internal joints.
- Chemical and electrical measurements to determine condition of monitoring.
- Inspection and cleaning on & off load tap changers selector switch
- Inspection and cleaning of diverter switch and motor drive unit.
- Cleaning of active parts by flushing with oil or in a vapor phase oven.
- Oil treatment (filtering and drying)
- Drying of transformer with heat and vacuum or vapor phase process (the active parts are dried in its own tank with vacuum less 0.5 m bar)
- Tightening of windings
• Checking repairing or replacement of protective devices (gas relays, oil thermometers etc.)
• Check and inspection of bushings
• Replacement of all gaskets.
6.0 RENOVATION, MODERNISATION, UPRATING & L.E. OF CIVIL WORKS

6.1 INTRODUCTION

The intent of RMU&LE study of the civil engineering elements/components of the hydro plants is to determine optimum works of renovation and modernization to restore/enhance safety, reliability of operation of the elements/components and also to meet any additional performance/requirement, and to extend life by another block of years matching with the life extension of main generation equipment.

Terminal points of studies pertain to the following type of civil engineering elements / components of the hydro plant system:

- Dam (Storage, Diurnal, Diversion), Barrages, weirs, Fore Bays, Balancing Reservoirs, De-silting Ponds.
- Water Intake and Water Conductor System for the turbines comprising tunnels, desilting chambers, surface channels, canals, penstocks.
- Power house and other buildings and yards including equipment foundation etc.
- Any other civil engineering elements and appurtenants forming part of the hydro plant but not specially mentioned above.

6.2 INSPECTION, NON-DESTRUCTIVE TESTS (NDTS) AND DESTRUCTIVE TESTS (DTS)

6.2.1 Dam, weir, barrage

Visual inspection of dam/barrage/diversion dam/weir/spillway including upstream water affected faces covering full maximum face(in draw down conditions, if possible) for detecting any signs of physical defects, ageing factors, cracks, excessive seepage/leakage under worst conditions of upstream, presence of erosion of parts, examination of records of any physical surveys.

The condition and behavior of the critical civil engineering elements such as dams etc. shall be inspected with the help of any existing condition / behavior monitoring and recording instruments (strain gauges, stress gauges, piezometers, seepage / leakage flow meters etc.)

Checking of stability of dam/weir structure taking all relevant factors conditions, forces, erosions, changes in surroundings etc. into account.

6.2.2 Spillway

Checking adequacy of spillway design and possibility of enhancement of capacity if needed, taking all factors, post project developments in the vicinity, downstream etc. such as habitation, etc., checking / studying sedimentation problem in its various aspects based on fresh surveys of reservoir or past surveys / records.

6.2.3 Power house and other structures

Inspection of power house structure, principal foundations, for any sign of physical distress damage/defect, NDT and DT where required, any(excessive)ingress of external water, excessive humidity.
6.2.4 Water conductor system

Visual inspection of civil and structural conditions of intakes, water conductor system, expansion joints, water ways both internally and externally, for detecting any apparent and incipient defects / damages, conducting any essential NDTs and/or DTs on the water conductor system elements for in depth study of defects for studying remedial measures, inspection of conditions and stability supports structures, analysis of flow capacity of existing water conductor system using latest techniques/tools taking existing physical conditions into account and possible means for restoration, enhancement of capacity for rated power generation and any uprated power generation compatible with the integrated power system operation of the plant at appropriate/reasonable load factor, uprating culminating in too low a load factor for the plant shall not be economical appropriate. Study of ways and means of combating pitting and corrosion damage internal as well as external if any, wall thickness of steel lined penstocks / passages(such as steel lined pressure shafts) shall be checked suitably where essential.

Possibility of only long-term durable painting system for internal surfaces of penstocks / steel lines, if any, shall be studied where considered beneficial (short term durable painting system shall not be proposed) with overall economics of adopting the same.

6.3 TESTS

There may be a need for conducting ND type tests on some parts of critical concrete structures on the basis of symptoms / visual inspection etc. In such a case, tests such as ultrasonic test etc. may need to be performed on affected concrete structure to ascertain its condition. DT tests, (such as by core samples taken from affected component by core drilling and testing in a lab) may be allowed, if essential.
7.0 GUIDE LINES FOR PREPARATION OF RM&U PROPOSAL FOR SHP

7.1 SCOPE OF WORK

The complete scope of works needs to be identified and all relevant sketches and layout/schematic drawings may be included in the proposal wherever required. The proposal should cover unit wise R&M / Restoration / Up rating / Life Extension works under the following broad heads:

(i) Turbine and auxiliaries.
(ii) Generator and auxiliaries
(iii) Transformer (Main/Stn./Unit Auxiliaires)
(iv) Station auxiliaries
(v) Control and instrumentations/ automation, etc.
(vi) On-line monitoring system
(vii) Civil works, Hydro mechanical components
(viii) Misc. works

7.2 PRIORITIZING OF ACTIVITIES

The works, which have a short gestation period but having immediate beneficial impact on improvement of availability, generation etc, will be assigned higher priority.

7.3 FORMAT FOR PREPARATION OF R&M PROPOSAL

The proposal may be formulated as per following format:

(a) Section – I

This will broadly include:

(i) Name of the power station, original installed capacity(No.×MW), brief history of the power station, approach to power station from main nearby cities.
(ii) Unit –wise rated/derated/uprated capacity, unit –wise commissioning dates and make of main equipments.
(iii) Particulars of generating units/transformers/switchgears mentioning their type, capacity, supplier, spare available, problems with the operation of the equipments, if any
(iv) Unit –wise and station wise performance data for the last 5 years as per Annexure V & VI.
(v) Major failure/accidents occurred, major components replaced, generation problems/design deficiencies and possible solutions.
(vi) Details of major R&M works carried out earlier and benefits/improvement achieved.
(vii) Major forced and planned outages during last 5 years (No., duration, reasons, remedial measures taken etc.)
(viii) Machine availability/planned outages/forced outages (% wise for last 5 years).

(b) Section – II

This shall include:

(i) General write-up on the proposal highlighting the benefits to be achieved after R&M works.
(ii) The list of R&M works along with estimated cost identified under R&M programme and covered in the proposal.
(iii) List of line monitoring system.
(iv) Results of RLA studies carried out, if any
(v) Abstract of cost estimate of the R&M programme.
(vi) Phasing of expenditure.
(vii) Bar-chart showing all the main components under R&M.
(viii) Implementation schedule.
(ix) Benefits anticipated in terms of MW/MU after carrying out the R&M uprating /Restoration/Life extension of the generating units.
(x) Expected increase in life of generating units/transformers /switchgears after LE.
(xi) Techno-economic evaluation and justification considering various methods like payback period, comparison with the cost of new capacity installation, discounted cash flow etc.
(xii) Addition in the estimated cost based upon RLA may be considered in the cost.

e) Section-III

Broadly conclude the following: Title of the R&M/ Restoration /Up rating /LE activities
(i) Need for Renovation-Details of problems experienced, frequency and duration of outages, loss in generation, etc., for the last five years
(ii) Feasible engineering solutions (The feasible technical solutions to overcome the problems).
(iii) Benefits expected after R&M (Improvement in performance, extra generation, peaking power etc. as applicable).
(iv) Details of RLA studies to extend the plant life.
(v) Implementation schedule (Approximate time required for placement of orders, delivery schedule of equipment/materials and execution)
(vi) Estimated cost of the activities and its basis.

7.4 METHODOLOGY OF IMPLEMENTATION OF R&M PROGRAMME

• Generation Company to identify the R&M works required to be carried out and prepare detailed project report (DPR) for implementation of R&M scheme.

• RLA studies to be conducted on the main equipments/plants, which have completed their normative life of 30 -35 years of operation.

• RLA studies should be conducted from an independent source, other than the manufacturer for an unbiased decision. RLA studies may not be required for the parts needing uprating as these parts are required to be changed.

• The performance test to be conducted before taking up the uprating / life extension works to know the operating parameters of the units.

• Provision of model testing of turbines should be included in the tender documents in case the existing runners are changed with uprated runners.

• Preparation of detailed project report (DPR) for life extension works based on RLA report. The company will tie up for the necessary finances.
• Preparation of technical specifications and bid documents incorporating performance guarantees and penalties for deviations from the guaranteed performance, etc.

• Stringent provisions need to be made in the contract regarding the terms of payment and liquidated damages, so that the contractor does not abandon the contract in between and also completes the contract as per the agreed schedules.
## TEST RELATING TO TURBINE, GENERATOR, STATOR AND ROTOR

<table>
<thead>
<tr>
<th>Components/Location</th>
<th>VI</th>
<th>DIM</th>
<th>DPT</th>
<th>MPI</th>
<th>UT</th>
<th>WTT</th>
<th>NFT</th>
<th>HM</th>
<th>RPL</th>
<th>TELCID</th>
<th>DCR</th>
<th>SWT</th>
<th>IR/PI</th>
<th>CT</th>
<th>VT</th>
<th>VAA</th>
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</table>
**ABBREVIATIONS:**

<table>
<thead>
<tr>
<th>VI</th>
<th>Visual inspection</th>
<th>DCR</th>
<th>DC resistance</th>
<th>FFT</th>
<th>Furfural test</th>
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<tr>
<td>DPT</td>
<td>Die Penetrant test</td>
<td>SVT</td>
<td>HIPOT step voltage test</td>
<td>MCR</td>
<td>Measurement of contact resistance</td>
</tr>
<tr>
<td>MPI</td>
<td>Magnetic particle inspection</td>
<td>IR/PI</td>
<td>Insulation resistance/polarization index</td>
<td>MSR</td>
<td>Measurement of specific gravity</td>
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<tr>
<td>UT</td>
<td>Ultrasonic test</td>
<td>CT</td>
<td>Capacitance test</td>
<td>MV</td>
<td>Measurement of voltage</td>
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<tr>
<td>WTT</td>
<td>Wedge tightness test</td>
<td>RVM</td>
<td>Recovery voltage measurement</td>
<td>MAH</td>
<td>Measurement of ampere hour</td>
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<td>NFT</td>
<td>Natural frequency test</td>
<td>SCT</td>
<td>Surge comparison test</td>
<td>MC</td>
<td>Measurement of capacity</td>
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<td>HM</td>
<td>Hardness measurement</td>
<td>CL</td>
<td>Core loss</td>
<td>TVS</td>
<td>Thermo vision scanning</td>
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<td>RPL</td>
<td>Replication</td>
<td>BDV</td>
<td>Breakdown voltage</td>
<td>GCA</td>
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<td>ELCID</td>
<td>Electromagnetic core imperfection detection</td>
<td>DGA</td>
<td>Dissolved gas analysis</td>
<td>VAA</td>
<td>Ventilation and air flow analysis</td>
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## TEST OF GENERATOR

<table>
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<tr>
<th>Test</th>
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<th>Item</th>
<th>Required Condition of Machine</th>
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<tbody>
<tr>
<td>IR and PI</td>
<td>Detects serious flaws, moisture absorption and cleanliness of winding</td>
<td>Stator and field winding</td>
<td>Bus bars and neutral connection has to be isolated</td>
</tr>
<tr>
<td>Tan Delta / Power factor</td>
<td>Evaluation of stress grading, dielectric losses and homogeneity of the winding insulation</td>
<td>Stator winding</td>
<td>-do-</td>
</tr>
<tr>
<td>DC Winding Resistance</td>
<td>Detects poor connections and conductor shorts</td>
<td>Stator &amp; field winding</td>
<td>-do-</td>
</tr>
<tr>
<td>DC HV step voltage / Leakage Current</td>
<td>Detects Ins. Weakness and possibility of warning of breakdown of incipient fault</td>
<td>Stator Winding</td>
<td>-do-</td>
</tr>
<tr>
<td>Partial Discharge/Corona / TVA Probe</td>
<td>Evaluation of stress grading system and location of PD sites</td>
<td>Stator Winding</td>
<td>Bus bars and neutral connection has to be isolated. Stator slot exits are be accessible and if necessary rotor has to be threaded out. PDA coupling coils may have to be fixed to the machine.</td>
</tr>
<tr>
<td>Computerised Digital ELCID Wedge Tightness Check</td>
<td>Determines healthiness of stator core inter laminar insulation</td>
<td>Stator core insulation</td>
<td>Rotor has to be treaded out in TGs, whereas rotor poles has to be removed minimum in case of HGs.</td>
</tr>
<tr>
<td>Wedge Tightness Check</td>
<td>Determines wedge tightness</td>
<td>Stator wedges</td>
<td>Rotor has to be threaded out</td>
</tr>
<tr>
<td>AC Impedance</td>
<td>Detects of presence of short circuit turns</td>
<td>Field Winding</td>
<td>Rotor winding should be isolated from excitation system</td>
</tr>
<tr>
<td>Recruitment Surge Oscillograph (RSO)</td>
<td>Detects Interturn and Earth faults in winding</td>
<td>Field Winding</td>
<td>Rotor winding should be isolated from excitation system</td>
</tr>
<tr>
<td>O.C.C.</td>
<td>Detects shorted turns</td>
<td>Field Winding</td>
<td>On-line test</td>
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<tr>
<td>Thermal Sensitivity Test</td>
<td>Detects Vibration cause</td>
<td>Rotor</td>
<td>On-line test</td>
</tr>
<tr>
<td>Partial Discharge Analysis</td>
<td>To assess delamination, stress control, slot support tightness</td>
<td>Stator Winding</td>
<td>PDA Coupling coils has to be fixed to the machine</td>
</tr>
<tr>
<td>Metallurgical Tests on rotor retaining rings i) DP and ii) UT</td>
<td>Detects surface and sub surface cracks</td>
<td>Rotor retaining rings</td>
<td>Rotor has to be threaded out</td>
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### TEST OF TRANSFORMER

<table>
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<th>Test</th>
<th>Purpose</th>
<th>Item</th>
<th>Required Condition of Machine</th>
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</thead>
<tbody>
<tr>
<td>Insulation Resistance and Polarisation Index</td>
<td>Detects serious flaws, moisture absorption and cleanliness</td>
<td>Winding</td>
<td>Winding has to be isolated</td>
</tr>
<tr>
<td>Dielectric Loss/ Tan Power factor / Cap. At HV</td>
<td>Indicates Insulation deterioration, contamination and physical damage</td>
<td>Winding, Oil and Bushing</td>
<td>Winding has to be isolated, Oil sample should be collected</td>
</tr>
<tr>
<td>Excitation Current at high voltage</td>
<td>Indicates defects in the magnetic core structure, shifting, failure in run-of-turn insulation</td>
<td>Winding</td>
<td>Winding has to be isolated</td>
</tr>
<tr>
<td>Turn Ratio</td>
<td>Indicates short circuited turns and internal connections</td>
<td>Winding</td>
<td>-do-</td>
</tr>
<tr>
<td>Winding Resistance</td>
<td>Detects poor connections and conductor shorts</td>
<td>Winding</td>
<td>-do-</td>
</tr>
<tr>
<td>Core Insulation resistance and inadvertent Grounds</td>
<td>Indicates deterioration of core insulation system</td>
<td>Core</td>
<td>-do-</td>
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<tr>
<td>Water Content</td>
<td>Indicates moisture level in oil</td>
<td>Oil</td>
<td>Oil sample has to be collected</td>
</tr>
<tr>
<td>Total Acidity, Neutralization Number (NN)</td>
<td>Measures organic/ inorganic acids</td>
<td>Oil</td>
<td>Oil sample has to be collected</td>
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<tr>
<td>Dissolved Gas Analysis</td>
<td>Indicates specific gases generated</td>
<td>Oil and Winding</td>
<td>Oil sample has to be collected</td>
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<tr>
<td>Furanic Compounds</td>
<td>Indicates cellulose degradation</td>
<td>Winding</td>
<td>Oil sample has to be collected</td>
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### TEST ON CIRCUIT BREAKER

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<th>Item</th>
<th>Required Condition of Machine</th>
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</thead>
<tbody>
<tr>
<td>Insulation Resistance</td>
<td>Detects serious flaws, moisture absorption and cleanliness</td>
<td>Overall Insulation System</td>
<td>CB has to be isolated</td>
</tr>
<tr>
<td>Dielectric Loss / Tank Los Index</td>
<td>Indicates insulation deterioration, contamination and physical damage</td>
<td>-do-</td>
<td>CB has to be isolated</td>
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<tr>
<td>DC High potential test (Optional)</td>
<td>Determines condition of insulation</td>
<td>-do-</td>
<td>CB has to be isolated</td>
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<tr>
<td>Contact Resistance Measurement</td>
<td>Detects poor contacts</td>
<td>Contacts</td>
<td>CB has to be isolated</td>
</tr>
<tr>
<td>Timings</td>
<td>Detects faulty dashpots, weak accelerating springs, defective shock absorbers, buffers and closing mechanisms, or broken parts.</td>
<td>Overall Breaker</td>
<td>CB has to be isolated</td>
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### TEST ON POWER CABLES

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<tr>
<td>Insulation Resistance</td>
<td>Detects serious flaws, moisture absorption and cleanliness</td>
<td>Overall System Insulation</td>
<td>CB has to be isolated</td>
</tr>
<tr>
<td>Dielectric Loss / Tan/Power factor/ Cap. at HV</td>
<td>Shows Ins. Deterioration contamination and phys. Damage</td>
<td>Overall System Insulation</td>
<td>CB has to be isolated</td>
</tr>
<tr>
<td>DC Step Voltage test</td>
<td>Determines condition of insulation</td>
<td>Overall System Insulation</td>
<td>CB has to be isolated</td>
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<tr>
<td>Resistance of bolted connections</td>
<td>Determines condition of insulation</td>
<td>Bolted Connections</td>
<td>CB has to be isolated</td>
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### TEST ON SURGE ARRESTORS

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<th>Required Condition of Machine</th>
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</thead>
<tbody>
<tr>
<td>Insulation Resistance</td>
<td>Detects serious flaws, moisture absorption and cleanliness</td>
<td>Overall Insulation System</td>
<td>Arrested has to be isolated</td>
</tr>
<tr>
<td>Watts loss test</td>
<td>Shows Insu. Deterioration contamination and phys. Damage</td>
<td>Overall Condition</td>
<td>Arrested has to be isolated</td>
</tr>
<tr>
<td>Resistance of bolted connections</td>
<td>Detects poor contacts</td>
<td>Bolted Connections</td>
<td>Arrested has to be isolated</td>
</tr>
</tbody>
</table>
## UNIT WISE PAST PERFORMANCE DATA
(For five years)

Name of the Powerhouse : 

Unit No. : 
Rated Capacity (MW) : 
Make of Generating units
  - Turbine : 
  - Generator : 
De-rated Capacity (MW) : 
(As approved by CEA)
Uprated Capacity (MW) : 
(As approved by CEA)
Data of Commissioning : 
Total operating hours by (date) : 

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Particulars</th>
<th>Past performance Data</th>
<th>Expected performance data after R&amp;M</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Actual maximum output (MW)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Energy Generation (MU)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Availability (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Forced outage (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Planned outage (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:  
1. Major constraints for operating the units at their rated capacity may be given  
2. Major reasons for low generation during a year may be given
## STATION WISE PAST PERFORMANCE DATA  
(For five years)

Name of the Power Station : 

<table>
<thead>
<tr>
<th>No of Units</th>
<th>Total Installed Capacity (MW)</th>
<th>Total De-rated Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(As approved by CEA)</td>
<td>(As approved by CEA)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Particulars</th>
<th>Past performance Data</th>
<th>Expected performance data after R&amp;M</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Energy Generation (MU)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Availability consumption (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Cost of generation (Rs./kWh)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: 1. Major constraints which limit load on units may be given.