भारत सरकार
**Government of India**
विद्युत मंत्रालय
**Ministry of Power**
केन्द्रीय विद्युत प्राधिकरण
**Central Electricity Authority**

जल विद्युत अभियांत्रिकी और नवीनीकरण एवं आधुनिकीकरण प्रभाग
**Hydro Engineering and R&M Division**

नई दिल्ली
**New Delhi**

# जल विद्‌युत गृहों के नवीनीकरण और आधुनिकीकरण के लिए दिशानिर्देश

# Guidelines for Renovation & Modernisation of Hydro Power Stations

**July, 2020**
**जुलाई, 2020**

# INDEX

# GUIDELINES FOR RENOVATION & MODERNISATION (R&M) OF HYDRO POWER STATIONS

## 1.0 INTRODUCTION

Renovation & Modernisation, Uprating and Life Extension (RMU&LE) of the existing old hydro electric power projects is considered a cost effective option to ensure optimization of resources, efficient operations, better availability and also to augment (uprating) capacity addition in the country.

The R&M works at 104 (21 in Central and 83 in State Sector) hydro power plants with an aggregate installed capacity of 20611 MW have been completed by the end of the XII Plan, accruing total benefit of 3636 MW through Life Extension, Uprating and Restoration.

During 2017-22, an aggregate capacity of 9197.45 MW at 46 Hydro Electric Power Station is programmed for R&M which will accrue benefit of about 4527.35 MW through Life Extension and Uprating.

For timely implementation of R&M Works without cost over-run and without losing the plant generation, Central Electricity Authority has prepared guidelines on Renovation & Modernisation (R&M) of Hydro Power Station. These guidelines would be beneficial to power utilities for all Renovation and Modernisation works which help in restoration of lost capacity, uprating of original capacity, extension of life of plant and improvement in efficiency & reliability of plant.

**Need for R&M Guidelines**

Currently utilities adopt different methods for defining scope of work, preparation of contract document and implementation of R&M projects. Moreover, the utilities come across various unforeseen technical/equipment failure problems after starting the R&M works, which leads to taking up of replacement of parts and other works beyond the scope of works considered in the contract document. This results in delay of work and start of new administrative process leading to time & cost overrun. Therefore, various utilities have requested CEA from time to time to publish standard norms and procedures/ Guidelines to be followed during implementation of R&M

works.

These guidelines will provide basis for decision making to utilities whether they should go for R&M of plant or uprating of plant with Residual Life Assessment (RLA) study. The guidelines will address the challenges faced by utilities in the country in deciding whether they should go for refurbishment or part/ complete replacement of equipment under R&M programme. This will also help in presenting crystal clear distinction between carrying out R&M, Life Extension and Uprating of hydro power plants. Many technological development and new technologies based on problems faced in various projects have been suggested in the guidelines which will be helpful for other utilities in carrying out RMU& LE work in time without cost over-run.

## 1.1 Approaches to Renovation & Modernization

1.1.1 Hydro-Electric Power generation has many well recognized advantages. It is environmentally clean and uses renewable energy source with a high degree of flexibility and reliability.

1.1.2 In the overall economic interests of the country, Hydro generation has to be efficiently operated by constant maintenance, renovation and modernization of hydro plants. While undertaking R&M works for life extension, possibility of uprating should be explored. The existing hydro generating capacity can be enhanced by any of the following measures:

a) Installation of New Power Plants
b) Rehabilitating/ renovating old Power Stations
c) Uprating of running power plants

1.1.3 From the view point of optimal economy, achieving higher energy yield by renovating and uprating the existing operating power plants is substantially superior in comparison to building new power plants.

1.1.4 Normal life expectancy of a hydroelectric power plant is 35 years after which it needs renovation. In a fast changing technological environment, Control system, software etc. becomes outdated in a period of about 10 to 15 years itself and spares also becomes unavailable. These equipments can be modernized for reliability and higher yield by minor modifications.

1.1.5 In peculiar situations like run of the river schemes in Himalayan and Sub- Himalayan range where excessive silt contained in the inflows causes enormous damage to the hydraulic structures and turbines, periodic repair &

maintenance is required to be carried out almost every year. Such situations call for technological innovations and modernization of repair & maintenance techniques for optimizing the renovative down time.

1.1.6 While renovating the machine, opportunity should be utilized to replace the old items by the new technological alternatives such as epoxy insulation against bitumen in the generator, $SF_6$ switchgear against conventional switchgear etc. Even the turbines can be renovated to produce higher outputs by modifying their flow passages and by replacing with a modified runner profile design.

1.1.7 Modernisation is a continuous process. It can as well be a part of the renovation programme. By adopting modern equipment like Static Excitation system, Micro-processor based governors, numerical relays, Data Recorder/ Event logger, optical instruments for monitoring vibration, silt content in water etc. the power plant performance can be improved in respect of its reliability.

1.1.8 Uprating of hydro plants call for a systems approach in view of a number of influencing parameters pertaining to the prime mover besides its repercussions on the total hydroelectric development which itself may be a sub system of an integrated power development programme. A number of factors like hydraulic data, electrical and above all economics play a vital role in deciding the course of action and the modalities of an upgrading/ uprating programme. For correct assessment of uprating It is also necessary to provide all technical hydraulic data, all relevant drawings of civil structures, water conductor system, major breakdown data etc. and retained/old equipment to the agencies/contractor/bidders.

1.1.9 Uprating of hydro power plant cannot thus be considered in isolation. It has to be strategically planned, keeping in view all the techno-economic considerations.

1.1.10 A conceptual systematic approach would help in evolving a concrete strategy for renovation and modernization of Hydro Power Plants aiming toward not only the upkeep but also upgrading on a continual basis.

## 1.2 R&M of Silt affected and acidic water affected Hydro Power Stations

1.2.1 Most of the reservoir based hydro schemes do not require much maintenance during their effective life span. The situation is entirely different in case of run-of-river plants, which are located on silt-laden rivers especially in Himalayan foothills. The silt originating from soil erosion clubbed with glacial silt in case of snow fed rivers enters the water conductor system and causes enormous damage to the hydro-mechanical structures and power equipment calling for repair & maintenance almost every year in the form of a hectic repair & maintenance programme.

1.2.2 Renovative maintenance calls for technological innovations and modernization of rehabiliting techniques for optimizing the down time. By adopting modern equipment, power plant can be improved in respect of its reliability and operational efficiency. While modernizing a silt prone power station, special attention is required to be paid to the use of new materials and protective coatings to withstand the silt erosion. Silt measuring instruments with online monitoring/telemetering systems, radiographic equipment for video display of damage inside the machine etc., could be considered for modernizing a silt affected power station.

1.2.3 Damages and Nature of problems faced by silt prone power stations:

Extensive damage is faced in the power stations where silt load passes in several thousands of ppm containing hard quartz in large proportions (85 to 99%). The particle size of silt also matters. Generally, particles of size 150 microns and below are difficult to arrest by normal de-silting chambers. Due to recent developments in desilting chambers particle upto 20 microns size can be arrested which extends life of underwater parts. However, the loss of material from the underwater parts in such cases can be a couple of tonnes every monsoon, when silt load is maximum.

1.2.4 Besides facing regular carnage to underwater components, silt prone power stations face a variety of operation and maintenance problems listed below: -

a) Frequent choking of strainers requiring their cleaning every week and in some situations even every day.
b) Choking and puncturing of cooler tubes resulting in pollution of bearing oil.
c) Damage to cooling water pumps
d) Frequent damage of shaft seal.
e) Damage to drainage and dewatering pumps, valves, piping etc. in addition to siltation of sumps.
f) Higher leakage through runner labyrinths seal to their damage resulting in high pressure inside the top cover.

g) Damage to guide vane bushes and seals

h) Damage to intake valve seals and main inlet valve seals.

i) Damage to hydro mechanical intake gates and draft tube gates causing maintenance problems.

j) Damage to Trash Rack Cleaning System.

1.2.5 The power stations facing extensive damage in Himalayan belt area due to high silt content require (renovative) maintenance in under water parts every year. Latest technology techniques may be adopted for under water parts like runner, which facing substantially high damage require renovative efforts after every 3 years or so. Such cases may be taken up by projects under partial renovation with technological upgradation.

Power stations facing considerably less damage generally do not require periodic renovation but may need considerable effort and resources during major renovation programme undertaken after 10-20 years or more of running when the critical items like turbine runner, guide vanes etc damaged substantially and require replacement as repair of these parts may be uneconomical as compare to replacement.

1.2.6 Power Stations subjected to acidic water/ environment may be taken separately by changing under water parts, cooling water system, drainage and dewatering system etc. to stainless steel pipes valves/impellers etc.

## 1.3 Strategy for Renovation and Modernization

1.3.1 The repair & maintenance efforts in some cases illustrated in above 1.2.5 have been reported to be so massive that they cannot be classified under normal O&M activity. The concerned power stations need resource support to implement the challenging renovative measures. The imbalance between the requirements of such power stations and normal power stations has been taken care of by suggesting the R&D based measures. These are listed below: -

a) Application of advanced techniques like plasma/ High Velocity Oxy Fuels (HVOF)/ High Velocity Air Fuel (HVAF) based thermal spray coating (if suitable) on under water parts of turbines.
b) Cupro Nickel tubes to replace the conventional admiralty brass tubes of coolers.
c) Cyclone separators to be incorporated in the cooling water system.
d) Adoption of modified runner profile designs suitable for silt laden flows.

e) Any other technological development.

1.3.2 A recent technological break-through in the form of plasma and HVOF/HVAF coatings can protect the underwater parts from onslaught of silt. However, the type of coating to be used may be decided depending on cost benefit analysis considering the silt load at power stations.

1.3.3 Conventionally used admiralty brass tubes for the coolers have proved in- effective against silt damage. The gradual puncturing and remedial plugging of respective tube makes the whole set in-effective in a few years time. The solution has been found in employing cupronickel tubes, which have proved effective.

1.3.4 The strainers incorporated in the cooling water circuit have their own limitations in arresting small size particles of silt resulting in choking and puncturing of cooler tubes. The solution lies in deploying additional cyclone separators on the discharge side of the cooling water pumps. The cyclone separators draw water through tangential slots and accelerate the filtration process taking advantage of the centrifugal force. It is claimed that they can arrest 90% of silt particles of size as small as 20 microns.

Existing cooling water system (like open loop) may be explored to replace with closed loop cooling water system in high silt prone power stations or where heat exchanger is to be kept under tailrace.

1.3.5 While replacing the runner, attempts should be made to acquire runner of modified profile design suitable for silt laden flows. The hydraulic design modification can be in terms of decreasing the curvature of runner blades, relocating the point of maximum curvature nearer to the inlet edge, reducing the angle of incidence to a minimum, increasing the length of runner blades and reducing their number etc.

1.3.6 Modular approach to repair & maintenance can be very helpful in optimizing the down time. Certain modules i.e. independent components or sub-assemblies of generating units such as runner, guide vanes, liners, seals etc. which are most critical can be stocked for ready replacement. Modular construction of machine parts wherever not existing should also be innovated to speed up the repair process. For example, the top cover and bottom ring liners in some cases are integral parts and consume a lot of time during weld repairs. Their designs should be changed to segmental type replaceable plates.

1.3.7 Up-rating of plant is possible incidental to major renovation mainly through following changes in the main equipment :-

a) Replacement of runner with modified runner profile design and a higher specific speed version would also require new Guide vanes.
b) Replacement of stator winding from Class-B to Class-F insulation.

1.3.8 There is likely to be a marginal increase in the velocity levels with uprating of units, which may slightly aggravate the silt erosion. But considering the recent advancement in material technology and profile design techniques for silt laden flows besides remunerative gains of uprating, it is worthwhile going for a conscious step by step upgrading of the plant.

1.3.9 The uprating of silt prone power stations should be accompanied by conscious condition monitoring through modern instruments like Laser silt meter, photo-electric silt meter for silt measurement and video probes to inspect the extent of damage inside the generating unit without dismantling it.

1.3.10 All components of the plant may be selected in such a way that they meet the main objective or Renovation and Modernization. Following measures may be introduced during Renovation & Modernization of Power plant:

a) Introduction of Numerical Relays, SCADA, Digital Voltage Regulator, Digital Governor, etc. has changed the environment of operation and maintenance.
b) Digitalization of the signals using optical fibre and RTUs in place of hard wiring.
c) Change of servo valve based Governing System in Place of conventional one.
d) Introduction of self-lubricating nonmetallic bearings.

1.3.11 Provisions shall be made for the protection of power House against flooding as per CEA regulation.

1.3.12 Besides all corrective measures as stated above, some long term measures like afforestation, stabilization of hill slopes and soil conservation around the catchment would go a long way in protecting the hydro power stations from the unwanted silt.

## 2.0 STEPS TAKEN UP BY GOVT. OF INDIA FOR IMPLEMENTATION OF RENOVATION, MODERNISATION, LIFE EXTENSION AND UPRATING OF EXISTING HYDRO GENERATING STATIONS

2.1 Government of India set up a National Committee in 1987 to formulate strategy on renovation & modernization of hydro power plants. Based on the recommendations of National Committee & subsequent reviews, 55 hydro schemes with an aggregate capacity of 9653 MW were identified under Phase I for implementation of renovation, modernization and uprating work.

2.2 Government of India in its policy on hydro power development declared in 1998 have laid stress on the need for R&M of hydro power plants according priority to R&M programme. Accordingly Ministry of Power set up a Standing Committee comprising members from CEA, PFC, PSUs to identify new hydro R&M schemes to be taken up for execution under Phase II. The Standing Committee recommended 67 hydro schemes with an aggregate capacity of 10318 MW and implementation of RM&U work under Phase II.

2.3 The Parliamentary Standing Committee on Energy in their 11th report (1998-99) submitted to Parliament in March, 1999 had emphasized the need for well defined National Perspective Plan for 10 to 15 years for R&M and life extension of power plants. Accordingly, Perspective Plan for Hydro R&M schemes has been formulated by CEA in June, 2000 for implementation of the proposals under Phase II along with the left out schemes of National Committee (Phase I) under implementation/yet to be implemented.

2.4 The schemes identified by CEA under the National Perspective Plan (Phase I & Phase II) and not yet completed were further reviewed by CEA in consultation with the SEBs, PFC, PSUs during April, 2002 & again in May, 2003.

2.5 The R&M works at 104 (21 in Central and 83 in State Sector) hydro power plants (13 up to the VIII Plan, 20 in the IX Plan, 32 in the X Plan, 18 in the XI Plan & 21 in the XII Plan) with an aggregate installed capacity of 20611 MW have been completed by the end of the XII Plan, total benefit of 3636 MW through Life Extension, Uprating and Restoration has been accrued.

## 3.0 BENEFITS OF RENOVATION, MODERNISATION, LIFE EXTENSION AND UPRATING

3.1 In a hydro power plant if machines are properly designed, manufactured, assembled, maintained during service, they can give trouble free service of 30 to 35 years or even more except under water parts of silt affected power plants which may require more extensive repair/early replacement. By refurbishment and modernization i.e. redesigning & retrofitting some of components of the machines, enhanced power plant life by 20 to 25 years and higher capacity with better efficiency can be achieved with technological developments by taking following measures and steps:

a) In earlier designs, higher safety margins can be usefully exploited to get 10 to 15% enhanced capacity.

b) Machines designed in early eighties and before were provided with Class 'B' insulation for stator & rotor winding. With the development of Class F insulation, the copper area of conductor in the existing slots can be increased by about 30%. This increases the capacity of stator & rotor. With the existing margins in turbine & shaft and water conductor system the units can be uprated by 1 0 to 25% besides giving new lease of life to machine.

c) By replacement of runner with latest design having 3-4% higher efficiency and improved profile retaining same under water embedded parts, machines can be uprated to give higher output.

## 4.0 CATEGORISATION OF RENOVATION WORKS

4.1 Renovation works to be carried out at Hydro Power Stations falls under the following three categories:-

a) Short Term Renovation Works
b) Medium Term Renovation Works
c) Long Term Renovation Works

### a) Short Term Renovation Works

The renovation works falling under this category involve replacement of equipment/components worn out over the period, which is affecting the station generation. Such works/activities normally falling under O&M get accumulated over the period because of neglect of maintenance under O&M. This is a short time activity and is essential for improving the plant availability and consequentially the station generation. Replacement of various pumping sets, compressors, seals, valves, repair of under-water part , overhauling, etc. fall under this category. Such renovation works are required to be carried out in the shortest possible period for improving the station generation.

**b) Medium Term Renovation Works**

Renovation and modernization works required to be carried out at hydro power stations in the middle of their normative operating life falls under this category. The works/activities under this category involve replacement of troubling equipments/components by equipments/components of improved quality/design. These works may be necessitated because of enormous damages caused to the hydraulic structure and turbines due to excessive silt contained in the water flows or on account of replacement of equipment needed to meet the system requirements for operating hydro generating unit in Grid/System.

**c) Long Term Renovation Activities/ Life Extension**

Life Extension of hydro generating units in operation over 30 to 35 years who have outlived their operating life and uprating of hydro generating unit through replacement of generator winding and/or turbine or complete replacement of generating unit falls under this category. Residual life assessment (RLA) studies and life extension programmed for these generating units would have to be taken up on priority for finalizing the life extension programme for above hydro generating units/stations.

4.2 Hydro R&M schemes are generally classified based on the scope of works. The following classifications are followed while identifying the R&M schemes: -

a) Renovation & Modernisation
b) Restoration
c) Life Extension and Uprating

**a) Renovation & Modernisation (R&M)**

The main objective of Renovation and Modernisation (R&M) of hydro generating units is to make the operating units well equipped/modified/augmented with latest technology equipments/ components/systems with a view to improving their performance in- terms of efficiency, output, reliability and availability to the original values, reduction in maintenance requirements and ease of maintenance. R&M is not a substitute for regular annual or capital maintenance, which forms a part of operation and maintenance (O&M) activity. The R&M programme is aimed at overcoming problems due to generic defects, design deficiency, ageing, obsolescence of equipment/components and non-availability of spares, low efficiency of generating units and safety requirements etc.

Hydro power plant equipment requiring modernization are indicated below:-

a) Governing System
b) Excitation System
c) Controls & Protection equipment
d) Runners (material having better metallurgy & modified profile)
e) Generator laminations and winding insulation
f) Switchgears & EHS Switchyard Equipment's
g) Modern On-line vibration monitoring system for generator and turbine shafts and bearings
h) Air gap monitoring systems for Generators

The Indian manufacturers have the requisite infrastructure and manufacturing facilities for supplying state of the art equipment for the power plant equipment/components. There is no technological gap on this account.

**b) Restoration (Res)**

There may be some hydro power stations where the generating units are not operating at their rated capacities due to the reasons as described under R&M above. After R&M activities, it may be possible to restore the generating units to their rated capacities and hence there may be benefit in terms of MW and MU. The hydro R&M schemes which were not giving output at their rated capacity but after carrying out R&M activities, are able to generate to their rated capacity or nearer to their rated capacity is classified as

Restoration (Res) Scheme.

**c) Life Extension (LE) and Uprating (U)**

The Life Extension programme is a major event in the hydro power station, as it envisages extension of life over a considerable period of time. At this time it is a good practice to examine whether a power station/generating unit requires a viable modernization which has not been carried out earlier so that during the extended life the power station operates efficiently and delivers the rated capacity. More emphasis has to be laid on LE of generating units having completed or completing in the near future normative operating life of 30-35 years. Scope of works for LE schemes has to be firmed up based on RLA studies.

Unlike thermal power plants, hydro prime movers hold substantial potential of uprating at the time of Renovation & Modernisation, thereby making uprating proposals cost effective. In view of the fact that hydro electric plants are used mostly for peaking purposes, the enhancement of peaking capacity has to get due cognizance. Extra benefit in case of run-of-river schemes is of course an added incentive. Uprating, if feasible, shall also be taken up along with LE programme.

R&D innovations in the field of hydro dynamics make it possible to derive higher outputs from the existing hydraulic space in turbines by employing higher specific speed profiles. Also, development of Class F epoxy insulation makes it possible to use larger conductor size in the existing stator slots/ Rotor for obtaining higher outputs.

While finalizing the R&M programme of a hydro power station, emphasis has to be given for achieving higher output by virtue of rewinding of stator/rotor of generator with class F insulation, better ventilation design runner with modified/improved profile, replacement of existing governor and excitation system with latest micro processor based governor and excitation system, augmentation of water conductor system (which may increase the discharge and hence the peaking capacity and additional generation), utilizing spilled water from the reservoir etc.

For units under operation for more than 50 years, project authorities may decide whether to take RLA studies or not based on the historical O&M data, generation loss and condition of machines. In such cases project authorities may not conduct RLA study if it goes for complete replacement with a new generating unit.

## 5.0 CRITERIA FOR RLA STUDIES

5.1 Conducting RLA Studies in respect of ageing hydro power plants having operated for more than 30 to 35 years is essential for firming up scope of R&M works and to carry out renovation of power plants in a scientific manner.

If capital overhauling of plant coincides with the plant completing about 30 years, the RLA studies may be planned at that point of time itself to avoid loss of generation/ shutdown period during RLA studies.

For RLA studies, the Civil, Hydro mechanical and Electro mechnical aspects of plant (embedded and existing equipment which are retained and cannot be replaced) shall be given due consideration while preparing the report. Any uprating requirement shall change the hydraulic parameters and will influence the existing civil foundations.

5.2 RLA, studies should be conducted through competent vendors and the Detailed Project Report (DPR) for the scheme be prepared based on the findings of RLA studies. Job of RLA studies including preparation of DPR and execution of R&M works should be tendered out separately with the later being based on the findings of the first one.

5.3 At present in India, many agencies claims to have the requisite equipment and expertise for carrying out such studies. However, manufacturers can also carry out such studies if they have expertise (or) collaboration with relevant other agencies to conduct all RLA studies including civil works etc to prepare DPR/report etc.

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

5.5 After conducting RLA study if it is found that replacement/refurbishment of major items are to be carried out then the same should be carried out within 5 years (depending upon finances and time schedules of plant shutdown etc.). For any reason/case the above works are not carried out within 5 years, the RLA studies are not required to be carried out again in case previous RLA study report suggested for total replacement of major equipments/ itmes. In other cases, beyond five years it needs to be updated for any additional item to be included.

5.6 RLA studies should be conducted preferably from an independent source, or reputed manufacturer. RLA studies may not be required for the parts needing uprating as these parts are required to be changed. Further, the agency/ manufacturer which has done RLA studies/ DPR preparation work could be entrusted with R&M work execution provided it is on open tender basis.

5.7 Performance analysis based on historical operating parameters to be done before taking up the uprating/ RLA study.

5.8 Provision of model testing of turbines should be included in the tender documents in case the existing runners are changed with uprated runners for large sizes/more then one number of replacements. Whereas for small size/number of replacement is less, only simulation (numerical modeling/CFD) is a cost effective option.

5.9 For life extension and uprating works, RLA studies should be conducted.

5.10 Technical specifications and bid documents should incorporate performance guarantees and penalties for deviations from the guaranteed performance etc.

5.11 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. It is also necessary to safeguard the contractor for timely release of payment and smooth cash flow for the works.

## 6.0 RESIDUAL LIFE ASSESMENT(RLA) and UPRATING

A systemic Study called the Residual Life Assessment (RLA) study involving non-destructive and destructive tests would reveal the remaining life of various critical component of plants and equipment so as to take steps to extend the life of plant by a further period of about 15-20 years by appropriate repair/replacement.

### 6.1 RLA & Uprating of Generating units

6.1.1 The existing condition of machine & its various components is to be established for taking up renovation works. The important parameters such as temperature rise, insulation condition, vibration, and metallurgical condition need to be thoroughly analyzed for this purpose. History of operation of the machines such as period of operation, reasons leading to outages of the machines, etc. need to be carefully examined and analyzed.

6.1.2 Before taking up the R&M works, it is also essential to study the guide vane openings in case of pelton turbine nozzle openings/ stroke with respect to load, servomotor stroke and pressure pulsation, if any, with respect to original data/ design data of the machines.

## 6.2 Diagnostic tests on Generating Units

6.2.1 Diagnostic tests on main components of machine viz. stator, rotor, shaft, runner, head cover, bearings, coolers etc. need to be carried out.

**A. Electrical Tests**

**1. <u>Tests on Stator</u>**

a) **Insulation Resistance and Polarisation Index tests** are conducted to ascertain the soundness of the stator insulation against dirt, moisture, oil etc. If the test results are not found satisfactory, the windings are dried up and the tests repeated till the test results are found satisfactory.

b) **Wedge Tightness Test** Stator wedges are checked for tightness and a record of all loose wedges are maintained for further references.

c) **Tan-delta test** indicates losses in solids & voids of insulation and indicates general health and deterioration of winding insulation with age. High tan deIta indicates poor insulation. Records of Tan Delta Test need to be maintained and compared with original value of Tan Delta for assessment deterioration in the winding insulation.

d) **Capacitance test** The capacitance increase with time, temperature & voltage and indicates voids, moisture & contamination in the insulation. The capacitance test therefore gives the status of health of the stator winding insulation.

e) **The partial discharge test** measures partial discharge taking places in the winding, which suggest the corrective action needs to be taken to avoid development of major fault.

f) **Inter laminar Insulation (**Electromagnetic Core Imperfection Detection (ELCID)) is conducted to indicate the condition of stator core. If any hot spots are noticed, suitable remedial measures should be taken.

2. **Tests on Rotor**

a) Winding Resistance
b) Insulation Resistance ("Megger")
c) Polarization Index (PI)
d) High Potential Test ("HIPOT")
e) Controlled DC Over-Voltage
f) Repetitive Surge Oscillograph (RSO) (shorted-turns)
g) Open Circuit Characteristics (shorted-turns)
h) Impedance vs. Speed (shorted-turns)
i) Pole drop (shorted turns)
j) C-core (shorted-turns) (requires rotor outside bore)
k) Shorted-turn location (requires removing retaining-rings)
l) Eddy Current (ECT)
m) Locating winding grounds, if required

**B. Diagnostic Studies on Mechanical Equipment viz. runner, guide vanes shaft etc.**

These studies should be conducted in areas of distress which are apparently affected by service condition like corrosion, distortion, erosion, cracking in area of high stress and sections involving change of cross section, weld joints, other geometrical stress raisers. Randomly four to ten locations (as per size and conditions of the plant/component) may be scanned using suggested tests for each component in such a way that representative health (soundness) status of component in consideration is established. The observations should be documented with supporting relevant evidences. In case macroscale discontinuities are observed during tests, fracture mechanics principles may be applied to evaluate the severity of such defects/discontinuities for static/dynamic loading for arriving at conclusion.

Diagnostic **test** which generally include the following, reveal existing condition and the rate of deterioration of mechanical parts.

a) **Visual Inspection** All components shall be visually examined for abnormalities namely dimensional change, breakage, crack, abrasion, porosity, erosion, corrosion and pitting.

b) **Dye Penetration (DP) Examination** is carried out for detection of surface crack/ porosity/ discontinuity for the components subjected to tensile stress namely weld joints, bearing pads, generator rotor fan blades, coupling bolts, shaft flanges etc. All relevant indications are recorded by identifying their location, nature and size etc.

c) **Magnetic Particle Inspection (MPI)** is done for detection of surface and sub-surface defects. The examination is conducted using continuous method i.e. the magnetizing field remains ON while fluorescent particles are sprayed. These areas are examined under ultra violet light of adequate intensity. Magnetization is done at least in perpendicular directions to ensure detection of discontinuities in all possible orientations. In case of detection of any crack, the depth is measured with the help of ultrasonic crack depth meter. All relevant indications are recorded by identifying their location, nature and size etc. along with a photograph.

d) The components subjected to high tensile stress namely turbine runner and generator stator, rotor, shafts weld joints etc. are examined by MPI to check for any surface and sub-surface defects.

e) **Ultrasonic Examination** method is employed for detection of surface & sub-surface crack, internal metallic interfaces due to poor bonding, material defect or any kind of discontinuity to ensure internal soundness of the components for further use. The examination is carried out on the components namely turbine runner, generator and turbine shafts, welded joints, bearing pads, upper and lower brackets etc

f) **Metallographic Replication test** is carried out to assess the present micro- structural condition of the components namely turbine & generator shafts, coupling flange, butterfly valve, spherical valve, generator rotor rim, generator upper and lower bracket etc. subjected to damages due to embrittlement, stress, corrosion, cracking, change in grain and phases structures suggesting material degradation due to long exposure during service under unfavourable conditions etc.

g) **Hardness Measurement** In-situ hardness testing is carried out on components operating at high stress to examine extent of micro structural degradation.

h) **Natural Frequency Test**. The turbine blades are examined to measure natural frequency of blades to ascertain its healthiness/rigidity.

i) Ultrasonic test and strain Measurement of penstock is to be carried out to check the condition of Penstock.

j) **Hydrostatic test of Oil and water coolers** Hydrostatic test to be conducted for healthiness assessment of coolers.

**C. Dynamic Behavior Tests**

a) **Vibration Test:** Turbine shaft, generator shaft, upper bracket, lower bracket and thrust bearing support vibration at various points are measured and analyzed.

b) **Noise Signal Analysis:** Noise signal analysis is generally carried out at turbine pit and draft tube area and on any other affected area of the generating unit.

c) **Pressure Pulsation Test:** Pressure pulsation tests in the draft tube, at penstock and/or any other affected locations are carried out, recorded and analyzed for remedial measures.

d) **Ventilation and air flow analysis:** Ventilation and air flow analysis is carryout for generator air path, ventilation ducts, fans, air baffles etc. to establish the reliability of the system.

**D. Structural Studies**

a) These studies are required to indicate the health and residual life of generating unit and to decide the replacement/ refurbishment of different components.

b) The residual life evaluation of critical Turbine and Generator shafts with identified cracks, if any, shall be carried out based on the Fatigue Crack growth rate studies considering the increased stress intensities arising out of uprating conditions.

c) Healthiness of generator foundation (Stator sole plates, bottom bracket sole plates and radial jack, as applicable to be checked.

**E. Non-Destructive and Destructive type tests**

**i) Electrical System**

The tests to be conducted at site shall only be of non-destructive type using standardized testing equipment.

| **Equipment** | | **Tests to be conducted** |
|---|---|---|
| Station/ Unit aux. transformers | - | Similar to Main transformers |
| Generator Bus duct | - | Visual, thermo-vision scanning, general check up for adequacy & improvement |
| Circuit Breakers | - | Visual inspection, tan delta test, capacitance test, insulation resistance, static Contact Resistance Measurement (CRM) & Dynamic Contact Resistance Measurement (DCRM) and thermo-vision scanning, Dew point of SF6 gas, Dew point of Operating air, Breakdown voltage of oil |
| CTs, PTs, CVTs, | - | Visual inspection, Tan delta test, capacitance test, insulation resistance |
| LAs/ Insulators | - | Visual inspection, general check up for adequacy & improvement, Online Third Harmonic Resistive Leakage Current (THRC) Measurement, DC Resistive Leakage current Measurement |
| Line Isolators and Earth Switches | | Visual Inspection, Insulation resistance and Static Contact Resistance (CRM) at feasible locations. |
| Switchyard hardware's including bus, conductors, PG clamps, structure, etc | - | Visual Inspection and thermos – vision scanning |
| Battery | - | Visual inspection, DC resistance, measurement of specific gravity, measurement of voltage, and |

| | | |
|---|---|---|
| | | measurement of ampere hour |
| Battery charger & DC board | - | Visual inspection, general check up for adequacy and improvement |
| Power & Control Cables | - | Visual inspection, Tan delta test, capacitance test, insulation resistance |

**ii) Hydro Mechanical equipments**

The study will inter-alia involve condition assessment of hydro mechanical equipment, by reviewing the available data, conducting inspection and necessary/relevant tests etc.

- Accessible components of gates for pitting, any cracks in welded joints, 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 by removal from water as the case may be and as necessary such as gates, gate guides and tracks, seals and 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.
- Checks of components and operations of various type of hoists - threaded stem (screw) type, hydraulic types, chain type, wire rope type, check wire ropes, brakes, hydraulic fluid (oil), taking visual/photo graphs/images of condition of the components as necessary for il1ustration and record.

## 6.3 Uprating and Refurbishment of Generator

6.3.1 Before taking up the work of uprating and refurbishment of hydro generator, the following data are compared with existing parameters to find out available margin-

a) Any workload capacity of short/ long duration
b) Ambient temperature
c) Cooling water temperature
d) Stator winding, stator core and Rotor (field winding) temperatures

e) Hot air temperature
f) Cold air temperature
g) Excitation current & capacity

6.3.2 From the above details, available margin in capacity of generator can be decided. A margin of about 10% is generally available in old generators.

6.3.3 Generally stator core is not changed as these are non-ageing. But sometimes, incidents of repeated faults may require partial or complete replacement of stator core.

6.3.4 Higher capacity of generator due to up-rating would result in higher losses requiring more heat dissipation arrangement and hence better ventilation/cooling. This would require modification/redesigning of fan blades, air passages baffles and change of generator air coolers etc.

6.3.5 Increased output from stator winding due to up-rating need detailed study of field coils. After detailed study, if it is found that the field coils do not have sufficient margins, then remedial measures such as increase in conductor size and/or no. of turns and conversion of class of insulation from B to F by replacement of rotor coils may be considered. It is observed that for uprating upto 20%, generally poles may not require replacement. However, when pole coils are changed with higher weight coils, then for extra centrifugal forces acting on pole, the adequacy of end plate and keys need to be examined. The load on thrust bearing directly increases with weight of rotor poles and axial thrust. Load on guide bearings also increases due to greater hydraulic unbalanced forces. These details need to be checked while changing the rotor poles.

6.3.6 Suitability of brackets through which loads pass to the foundations need to be analyzed for enhanced load due to uprating.

6.3.7 The designing of shaft & coupling bolts need to be analyzed for axial hydraulic thrust, natural speed, run away speed & critical speed.

## 6.4 Up-rating and Refurbishment studies of Turbine

6.4.1 The decision on replacement/refurbishment of different parts of turbine is taken after conducting necessary tests. Manufacturers' recommendations for possible higher output by utilizing available margins either by passing more water or utilizing higher available head also be considered.

6.4.2 When more output is obtained from the turbine by either utilizing water or head, turbine's critical coefficient increases. It is therefore necessary to check that sufficient margins are available from cavitations point of view at higher output. For this fresh model/ Computational Fluid Dynamic analysis for evaluation of flow instabilities/ changes in cavitation intensities upon uprating shall be carried out from navigational as well as output point of view .

6.4.3 All rotating parts are designed for centrifugal forces at run away speed, which increases on up rating and hence such parts need to be checked for it.

6.4.4 The speed & pressure rise at different load throw off conditions need to be carried out and analyzed. The behavior of governor oil pumps, servomotor & pressure variation in draft tube are checked during this test with the same rotor at higher output.

6.4.5 Adequacy of penstock, scroll case and surge tank etc. for extra pressure rise and mechanical strength of all under water parts due to uprating need to be checked and analyzed.

6.4.6 Due to increase of velocity during refurbishment/ uprating, affect of extra loss of head in water conductor system and increased erosion in silt affected Power Plant needs examination.

6.4.7 During R&M, new digital governor of latest design to replace obsolete sluggish governor is recommended and adequacy of existing servomotors to meet uprated requirements need careful examination and analysis. During R&M and uprating all bushes may be made of self-lubricating type.

## 6.5 RLA & Up-rating of Transformers

6.5.1 When considering the modernization and renovation of the power plant, the condition of Generator Transformers are also examined in view of enhanced MVA capacity of the generating units due to uprating and life extension program.

6.5.2 'CIGRE Transformer Study Committee A2' studied the issues of uprating and LE in general for Power Transformers and came out with two guides "Guide for Life Management Techniques" (Brochure No.227 by WG A2.18) and "Guide on Economics of Transformer

Management" (By WG A2.20). The Life Management guide, in addition to the general knowledge and theoretical issues on the subject, covers the diagnostic and Monitoring methods available for assessing the transformer condition, viz. probable residual life and areas requiring refurbishment/repair.

### 6.5.3 Residual Life Assessment

1. RLA study comprises of following tests:

**a) On Transformer Oil/ Paper**

i) Physical property
ii) Chemical property
iii) Electrical property
iv) Special property like DGA, furfural content & Degree of Polymerization (DP) of insulating paper

For conducting test on transformer, generally three oil samples are collected from the transformer.

i) First oil sample from running transformer.
ii) Second oil sample from running transformer after about one month from the first sample
iii) Third sample from running transformer after about one month from second sample

After taking third oil sample, paper sample is also to be collected from transformer coil/lead. Normally the collection of paper sample is synchronized with planned maintenance shut down for overhauling/refurbishment.

2. **Electrical Tests**

i) Insulation Resistance & Polarization Index Test
ii) Tan delta and Capacitance Test on Transformer windings
iii) Tan delta and Capacitance Test on HV Bushings
iv) Sweep Frequency Response Analysis (SFRA) Test
v) Moisture Estimation by Frequency Domain Spectroscopy or Time Domain Method like Recovery Voltage Measurement (RVM) or

Polarisation Depolarisation Current (PDC) Method.

vi) Winding Resistance Measurement

vii) Transformer Turns Ratio (TTR) Measurement.

viii) Short Circuit Impedance Measurement

ix) Magnetizing / Excitation Current Measurement

3. If RLA study indicate that the life of transformer winding insulation is very less & it needs replacement, action to replace winding can be planned.

### 6.5.4 Life Extension

1. Transformer condition can be assessed by taking into account all relevant information viz. design information, service history, operational problems and results of current condition monitoring/diagnostic tests (visual, chemical and electrical tests) as well as tests done earlier in the life of the transformer. Considering the complexity of the sub systems involved in the transformer, it is not possible to quantitatively assess the residual life of a transformer. This also makes the transformer replacement decision a difficult one. Any decision on rehabilitation, repair or replacement must be made with reference to the age of the transformer and the complete service records. Economic as well as technical and strategic factors determine the effective end of life of the equipment. Based on the condition monitoring test results, decision can be made for the extent of renovation/reclamation/parts replacement required.

2. Some key issues concerning the condition monitoring/life extension of generator transformers are given below: -

   i) A general issue with regard to generator transformers in hydro electric power plants is the cooling especially condition of the oil to water heat exchangers and options for replacement/changing over to alternate cooling arrangements.

   ii) Generator Transformers at hydroelectric stations are generally provided with 2x100% oil to water heat exchangers. Condition of the heat exchanger is assessed by visual inspection (corrosion of tube to tube sheet joint) and pressure test on waterside.

iii) Since the river water quality is generally good, solid drawn admiralty brass tubes are generally sufficient and cupronickel tubes can be specified if the water is polluted or too much oxygenated. In Europe double concentric tube (inner concentric cupronickel tube with brass tube sheet for water and outer copper tube with mild steel tube sheet for oil) heat exchangers are mandatory as any tube failure can cause environmental hazard due to oil getting into water islands.

3. The following conclusions can be drawn from the view point of renovation and replacement of coolers: -

i) If space restrictions are not there, tank mounted radiators with cooling fans (ONAN/ONAF) is the best option. Marginal cost increase compared to ODWF will be offset by the savings in auxiliary loss, less maintenance burden and higher reliabiliy.

ii) Wherever space restrictions are there, tank mounted unit coolers (oil to air heat exchangers) with standby coolers is the best choice when compared to OFWF cooling with double tube oil to water heat exchangers.

iii) When there is no alternative other than water cooling (esp. in case of very large rated units or underground power stations), double tube coolers shall be preferred due to the environmental concerns and better safety from water getting into the transformer in the event of a tube failure. Considering the high capitalization of transformer losses being now adopted, manufacturers are now trained to use very low current densities in windings and the advantages once attributed to oil directed water cooling (ODWF) is no longer relevant.

iv) When renovating old transformers, alternate cooler arrangements other than Oil Forced Water Forced (OFWF) are sometimes adopted due to tube failures and to avoid maintenance liability. If in the existing transformer Oil Directed Water Forced (ODWF) is used (i.e. oil directed through the winding) care shall be taken to use Oil Natural Air Natural/ Oil Natural Air Forced (ONAN/ONAF) cooling with the existing transformers to avoid hot spots in the winding. In such cases Oil Natural Air Forced (ON AF) unit coolers will be the best option.

v) However if the water cooling is with non directed oil cooling (OFWF) then separately mounted ONAN/ONAF coolers can be used without difficulty. It is always better to get the advice from the original transformer manufacturer while converting from one cooling method to another in an existing transformer.

4. Condition of a HV bushings /LV bushings should be assessed by proper tests (By capacitance, tan delta & insulation resistance). LV bushings terminal pad shall be assessed for surface condition (pitting, corrosion of silver/tin coating)

**6.5.5 Replacement decision**

Decision for replacement is taken after carefully evaluating techno-economic strategic factors. The flow chart in the proposed CIGRE guide will be a useful tool in taking a repair versus replacement decision. When new transformer is planned as replacement of original generator transformer with or without up-rating the MVA the following shall be considered:

1. It is necessary to match the existing bushings of bus duct termination, cooling water inlet outlet points, HV, LV and HV neutral bushing terminations, matching of bushing determination pads, rail gauge and cooling water quantity is also a must. In many cases, due to higher size and dimensions of active part, it will be difficult to match the LV bushing height to the existing bus duct termination point. On such occasions, it is better to modify the bus duct termination bushing rather than insist for matching of LV bushing terminations since such a course can result in the bushing pockets protrude from transformer sides creating chances for circulating currents between the pockets or pockets and tank.

2. If the up-rated unit is planned, then the rating of bushing connectors, bus duct are to be checked for adequate margins.

3. If the transformer availability is very critical in the overall system, the following online monitoring device are available today for incorporating into transformer: -

   i) Dissolved Gas Analysis (Hydrogen only or Hydrogen plus other combustible gases)
   ii) Fiber optic winding hot spot temperature
   iii) On load tap changer monitoring
   iv) HV bushing tan delta monitors
   v) Partial Discharge monitors

4. However, their selection shall be done only after through techno-economic considerations and evaluating the cost effectiveness. Coordination with transformer manufacturer will be required.

**6.5.6 Uprating of Transformer**

1. Uprating of old transformer can generally be performed by the Original Equipment Manufacturer (OEM) of transformer due to following reasons:

   i) Original electrical design calculations available with manufacture
   ii) Thermal design calculation & test records available with manufacture
   iii) All manufacturing drawings available with manufacturer

2. Following aspects are to be analyzed carefully by the design Engineer of the transformer: -

   i) How much maximum current (load) can be allowed without over heating with the existing winding conductor.
   ii) Do the insulation paper over the conductor experiencing overheating?
   iii) Do the cooling ducts are sufficient for higher load.
   iv) Will there be excessive overheating in the end frame, tank, cover, core or in bus bars.
   v) Are the other accessories like bushings, on/off load changer suitable for higher load.
   vi) Margin in the temperature rise limit.
   vii) Space, available if cooling is to be increased by providing additional cooling fans/ pumps.

viii) To cater for additional cooling control system is to be modified. Can additional relay contacts be accommodated in M. Box.

3. With the advent of improved and latest quality of raw materials, fittings and accessories , computer aided design technology, latest manufacturing and process technology , the size of the present transformers is much smaller compared to a transformer designed and manufactured 15/20 years back. Depending upon existing tank & core it is possible to up rate the transformer capacity by 10 to 50% by redesigning of the transformers. The methodology adopted is summarized below:

i) Removal of tertiary winding: Tertiary winding is one of the weak parts in transformer. Many transformers have failed due to tertiary. It is not mandatory to provide tertiary winding for transformers up-to 100 MVA. This will not only help in increasing the reliability of transformer but will also provide extra space for up rating of transformer capacity.

ii) Redesign windings: The windings are the vital part of the transformers. With the advent of latest type of windings like interleaved disc and partially interleaved disc winding, improved quality of insulating materials and transformer oil, computer aided design techniques for analysis of transformer under transient and power frequency conditions, it is possible to optimize the winding design and provide 10 to 50% more capacity.

**6.6 Electrical systems & Hydro Mechanical equipments**

6.6.1 The intent of the RM&LE study shall be to determine the optimum RMU&LE works, so as to achieve restoration/enhancement of the plant's overall Performance, reliability, availability, safety of operation, life extension for another block of years and updating/ upgrading of outdated equipments/systems wherever beneficial.

6.6.2 The intent of uprating study shall be to determine the potential for uprating the capacity of the affected equipments in line and context with the uprating study for main generating equipments.

6.6.3 The terminal points of studies pertain to the following equipments and areas relating to the station auxiliary/unit auxiliary transformers and other electrical & hydro mechanical equipments as below:-

**a) Electric System**

i) Unit Auxiliary/ Station Service Transformers
ii) Generator bus ducts/Main Power Cables
iii) Power and Control Cables
iv) LT AC/DC Systems, DG Set, Metering System
v) Switchyard equipments
vi) Black start arrangement (DG Set etc.)/ line charging capabilities
viii) Ground resistance etc.

**b) Hydro mechanical equipments**

i) All gates, stop logs, their embedded parts and their operating mechanism
ii) Water conductor system from intake to exit.
iii) Spillway gates and their operating mechanism
iv) Trash racks and their cleaning/operating mechanism at the intake/stop logs
v) Silt excluder gates and their operating mechanism
vi) Under sluice gates and their operating mechanism
vii) Any other gates and valves in the system
viii) Drainage and Dewatering System
ix) A/C and Ventilation System
x) Fire Fighting System

6.6.4 The transformers or reactors of 10 MVA and higher rating or oil filled transformers or reactors with oil capacity of more than 2000 litres shall be provided with automatic high velocity water spray system as per relevant IS or Nitrogen injection based fire protection system. The transformers or reactors of 220kV or higher voltage may be provided with Nitrogen injection based fire protection system is addition to automatic high velocity water spray system.

6.6.5 Power Consumption (wattage) to obtain the same illumination levels is less in case of LED lamps in comparison to Incandescent lamps/ Mercury or Sodium Vapour lamps. It would be beneficial to replace the old lamps to retrofit type energy efficient lamps (LEDs).

## 6.7 Civil Works

6.7.1 The intent of RMU&LE study of the civil engineering elements/components of the hydro plants is to determine optimum works of renovation & 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 generating equipment .

For redevelopment and uprating, first of all, hydrological review needs to be carried out to reassess 90% dependable flow, probable maximum flood, etc. The review of planning and design should attempt to verify the structural adequacy of the existing structure and the modification required in respect of proposed scenario. Adequacy of civil structures due to increased loadings on account of redevelopment and uprating need to be checked. This will also involve re-designing the structure to check the adequacy of earlier design with actual site conditions and appropriate design assumptions. If necessary, geophysical methods, which are powerful tools, can be adopted for subsurface investigation of foundation and other structures. Also LiDAR (Light Detection and Ranging) tests are highly useful for assessment of damage, cracks etc., in civil structures, especially for inaccessible locations.

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

i) Dam (Storage, Diurnal, Diversion), Barrages, Fore Bays, Balancing Reservoirs, De-silting Ponds.

ii) Water Intake and Water Conductor System for the turbines comprising tunnels, de-silting chambers, surface channels, canals, penstocks

iii) Power House and other buildings and yards including equipment for inductions etc.

iv) Any other civil engineering elements and appurtenant forming part of the hydro plant but not specifically mentioned above.

6.7.3 **<u>Inspection, Non-Destructive tests (NDTs) & Destructive Tests (DTs)</u>**

a) **Dam, Weir, Barrage:** Visual Inspection of Dam/Barrage/Diversion Dam/Weir/ spilling in the dam, including upstream water affected faces covering full maximum face (is under drawn down conditions if possible) for detecting any signs of physical defects and structural distress caused by ageing factors namely AAR, ASR subsidence, excessive seepage/leakage under worst conditions of upstream, presence of erosion parts, signs of corrosion in RCC components etc. and examination of records of any physical surveys.

The condition and behavior of the critical civil engineering elements such as dams etc. may also be monitored, if felt necessary using monitoring and recording instruments (e.g. strain gauges, stress gauges. pyrometers, seepage/leakage flow meters etc.)

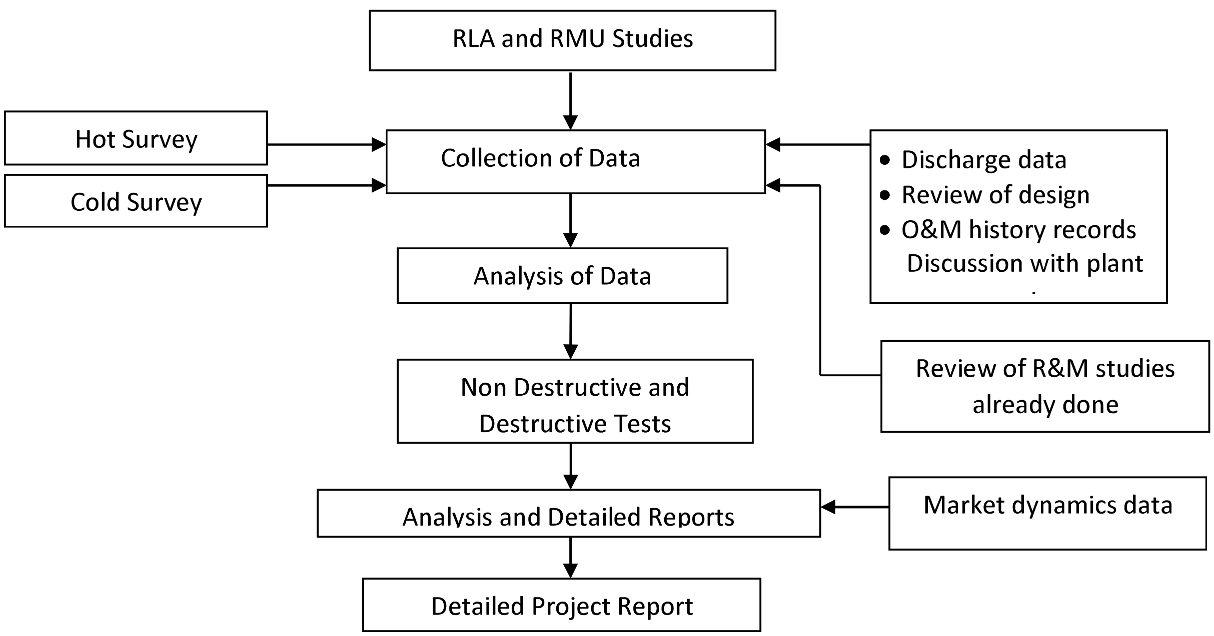
Checking of stability of Darn/Weir structure taking all relevant factors, conditions, forces, later erosions, changes in surroundings etc., into account.

b) **Spillway:** Checking adequacy of spillway Structure & possibility of enhancement of capacity if needed, taking all factors, into account. Inspection of Spillway for any symptoms of distress, collection of design and construction records including records of any past repairs, performing NDT and DT tests for ascertaining strength, integrity and structural performance.

c) **Power House & other structures:** Inspection of power house structure, for any sign of physical and structural distress. Conducting NDT & DT for ascertaining strength, integrity and structural performance of various structural components.

d) **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 of supports structures, analysis of flow capacity of existing WCS 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.




e) **Tests:** NDT and DT type tests shall be conducted on various above mentioned critical concrete structures on the basis of results of visual inspection. In-situ NDT and DT tests shall aim to determine strength of in-situ concrete, integrity of concrete, durability evaluation of concrete and condition/corrosion state of reinforcing bars/structural steel components. In-situ strength should be evaluated using site specific calibration between NDT and core results. Grade of concrete should be evaluated using statistical evaluation of strength results. Integrity of concrete should be evaluated using ultrasonic pulse velocity/pulse echo technique/infrared thermography as per the requirement. Durability evaluation shall require sampling and testing of concrete samples. Tests namely evaluation of chemical makeup and transport properties of concrete should be undertaken. Corrosion evaluation should include measurement of half cell potential, concrete resistivity and rate of corrosion. If any other durability problem is noted during visual inspection then the corresponding in-situ test should be performed

f) **Environmental Aspects:** All proposals of RMU & LE shall be only those that are environmentally friendly.

## 6.8 Cold and Hot Walk survey of Plant

6.8.1 The RLA vendor shall undertake a hot walk down survey(in operation condition) of the Plant and cold walk down survey (in shut down condition) of the plant/equipment.

**a) Hot Survey**

i) Survey/observations of equipments in operation to ascertain their conditions, identification of problem areas for analysis, recording of all problems/deficiencies/abnormalities.

ii) Interacting with O&M authorities regarding general behavior of the plant and problems in operation, any generic problem during initial stage of operation.

**b) Cold Survey**

i) Noting/recording name plate details and general description of all equipment under study.

ii) Inspection of all equipments to be studied, before dismantling for detection of any visible abnormalities.

iii) Inspections of all components of assemblies and sub-assemblies after dismantling

## 6.9 Plant Data and Information

6.9.1 Salient data and information regarding the equipments and their relevant O&M history/ records, major events from first commissioning onwards, breakdowns, repairs, overhauls, main details of any past RMU&LE studies and works carried out original (design parameters) and present parameters of operation, present conditions and problems of operation and the equipments specifically required to be studied are to be listed.

6.9.2 The inspections, checks and tests for RMU&LE studies that require the equipments to be shut down and dismantled shall "be scheduled to be carried out during the period of planned shut down/outages of the main transformers and other equipments in succession as far as possible.

## 7.0 PREPARATION OF HYDRO R&M PROPOSAL (i.e. Detailed Project Report) & CHAPTERS TO BE INCLUDED

### 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/ Uprating/LE works under the following broad heads: -

i) Turbine & auxiliaries

ii) Generator & auxiliaries

iii) Governor and Excitation

iv) Transformer (Main/Station./ Unit Auxiliaries)

v) Station auxiliaries (AC/DC System)

vi) Control & protection and automation etc.

vii) On line monitoring system

viii) Water Availability and Power Optimisation Studies

ix) Hydro mechanical

x) Civil works

xi) Electric & Mechanical accessories

xii) Switchyard Equipment’s

xiii) Misc. works

## 7.2 Prioritizing of activities

The works, which have a shorter 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 .x 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) Technical Particulars of Generating units/transformers/switchgears mentioning their type capacity, supplier/make, 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 I & II.

v) Major failures/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) Need for Renovation- Details of problems experienced, frequency and duration of outages, loss in generation etc. for the last five years

iii) Feasible engineering solutions (The feasible technical solutions to overcome the problems).

iv) The list of R&M works along with estimated cost identified under R&M programmed and covered in the proposal

v) Results of RLA studies carried out, if any.

vi) Abstract of cost estimates of the R&M programme.

vii) Bar chart of work completion programme showing all the main components under R&M

viii) Benefits anticipated in terms of MW/MU after carrying out the R&M/Uprating/Restoration/Life Extension of the generating units. Expected increase in life of generating units/transformers/ switchgears after LE.

ix) Techno-economic evaluation and justification considering various methods like payback period, comparison with the cost of new capacity addition, discounted cash flow etc.

x) Comparative table/chart showing cost benefit analysis with and without uprating.

## 8.0 ESSENTIAL REQUIREMENTS/ APPROACH FOR SUCCESSFUL IMPLEMENTATION OF RMU&LE SCHEME

8.1 In order to ensure close monitoring, coordination, quality assurance and speedy implementation etc. dedicated R&M cell at each power station as well as at the headquarters of the Utility to deal exclusively the R&M/LE schemes may be created.

8.2 A separate high powered committee (Task Force), in each utility with full powers to take decisions in all matters relating to implementation of R&M/LE schemes may be created to avoid administrative delays in placement of order and also execution of the project work if the utility wants for timely completion of R&M/LE

works.

8.3 R&M for Life Extension study may include a comparison on best approach to be suited for a given power station undertaking for R&M/LE

approach one: complete shutdown of power plant & unit wise restoration after undertaking R&M/LE works,

second approach: Unit wise shutdown for R&M/LE works and concurrent generation from other units. The analysis shall deliberate regulatory provisions and benefits of power plant during R&M period to the beneficiaries in both the approaches.

8.4 As far as possible, the overhauls/shut downs of the unit should be planned in such a way that maximum number of R&M works could be executed during overhaul so as to avoid separate shut downs for carrying out R&M works. Proper planning of resources (man and material) should be made to match with the planned shutdown of unit for execution of R&M works also. All the LE works should be executed in one shut down of the unit taken for annual/capital maintenance.

8.5 In case similar R&M activity is implemented at more than one power station of a particular utility, centralized action for procurement of equipment could be taken to reduce the time and cost over runs as well as to avail concessional price for bulk orders, provided the centralized set up is fully equipped to handle the engineering and coordination work. Before Life Extension, RLA study needs to be carried out by reputed RLA agency. It is preferable to have the Life Extension work carried out through turnkey contract wherever possible. since this is a specialized job, the guaranteed performance can be ensured by this way.

8.6 Additional works upon opening of units during work execution after award are unavoidable and may be awarded to the same contractor if price variation on this account is of the order of 10-15% and price to be finalized on negotiation basis after due diligence. However, utilities while doing so may have to consider their own procurement rules since they vary from utility-to-utility. Considering sufficient competition is available domestically, specified skills required for product & services under the works and post-commissioning satisfactory sales-services, product supply may be preferred from such vendors who have manufacturing facilities for major hydro equipment within the country.

8.7 After implementation of the scheme, a feedback system to analyze the modifications carried out, benefits achieved vs. anticipated etc. needs to be introduced. Based on the feedback analysis, remedial steps may be taken up in subsequent implementation.

## 9.0 RECOMMENDED TIME SCHEDULE FOR IMPLEMENTATION OF RMU&LE SCHEMES

The recommended time schedule for implementation of RMU&LE works is as given in Annex-III.

## 10.0 COST ESTIMATES

The estimated cost of the RMU&LE scheme has to be worked out based on the estimated cost of the identified individual works. The estimated cost should be, as far as possible, realistic and should be based on current market rates/budgetary offers of the supplying agencies including all taxes and duties. The import content along with the country from where the equipment is to be imported should be indicated. The source of funding is also to be mentioned. There should not be wide variation between the estimated and actual cost of RMU&LE works. Therefore, the scope of works should be properly identified before estimating the cost of works. The yearly phasing of funds required for implementation of the scheme will have to be given for providing budget allocations and also for monitoring the physical and financial progress of the scheme.

## 11.0 COST BENEFIT ANALYSIS

The RMU&LE scheme should be techno-economically viable. The benefits in term of additional generation and availability, reduction in forced outages, auxiliary power consumption, improvement in plant safety expected to be achieved after implementation of R&M/LE scheme should be clearly brought out.

A Detailed Project Report may be prepared giving complete scope, justification, cost-benefit analysis, estimated life extension from a reference date, financial package, schedule of completion, estimated completion cost including foreign exchange component if any, tariff and labialized tariff and any other relevant parameters to give complete information to beneficiaries about RMU/LE.

The recommended payback period for R&M and LE should be 2-3 years and 4-6 years respectively.

## 12.0 MONITORING THE PROGRESS OF IMPLEMENTATION OF RMU&LE SCHEME

The Utility shall also have a system of close monitoring of the physical and financial progress of various activities with well-defined delegation of powers to the project head executing the work and adequate dedicated term to ensure timely implementation of R&M/LE program.

**Annex-I**

**UNIT WISE PAST PERFORMANCE DATA**
**(For five years)**

Name of the Power House :

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)

Date of Commissioning :

Total operating hours by :
(Date)

| **Sl. No** | **Particulars** | **Past performance Data** | | | | | | **Expected perfor mance data after R&M** | **Remarks** |
|---|---|---|---|---|---|---|---|---|---|
| | | Year-1 | Year-2 | Year-3 | Year-4 | Year-5 | Average | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **1.** | Actual maximum output (MW) | | | | | | | | |
| **2.** | Energy generation (MU) | | | | | | | | |
| **3.** | Plant Availability (%) | | | | | | | | |
| **4.** | Forced outage (%) | | | | | | | | |
| **5.** | Planned outage %) | | | | | | | | |

Note: 1 Major constraints for operating the units at then rated capacity may be given

2 Major reasons for low generation during a year may be given

**Annex-II**

**STATION-WISE PERFORMANCE DATA**
**(For five years)**

Name of the Power Station :

No. of Units :

Total Installed Capacity (MW) :

Total De-rated Capacity (MW)
(As approved by CEA)

Total Uprated Capacity (MW) :
(As approved by CEA)

| **SI. No** | **Particulars** | **Past performance Data** | | | | | | **Expected performance data after R&M** | **Remarks** |
|---|---|---|---|---|---|---|---|---|---|
| | | Year-1 | Year-2 | Year-3 | Year-4 | Year-5 | Average | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| 1 | Energy generation (MU) | | | | | | | | |
| 2 | Auxiliary consumption (%) | | | | | | | | |
| 3 | Cost of generation (Rs. kWh) | | | | | | | | |

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

**Annex-III**

**RECOMMENDED TIME SCHEDULE FOR IMPLEMENTATION OF R&M/LE WORKS**

| SI. No. | Description | Time Schedule |
|---|---|---|
| **For R&M Schemes not involving Life Extension & Uprating works** | | |
| 1. | Carrying out feasibility studies & identification | 1 to 3 months |
| 2. | Preparation of tender document | 1 to 3 months |
| 3. | NIT and placement of orders | 1 to 3 months |
| 4. | Site Measurement of Reverse Engineering (if Required) | 1 to 3 months |
| 5. | Delivery of equipment from the date of order | 6 to 18 months |
| 6. | Erection, testing and commissioning (per Unit) | 3-6 months |
| **For R&M Schemes involving Life Extension & Uprating works** | | |
| 1. | RLA studies | During capital maintenance when approaching end of |
| 2. | Submission of RLA report<br>Approval of RLA Report | Within 1 month from completion of studies |
| 3 | Preparation of DPR and approval of DPR | 1 to 4 months |
| 4. | Preparation of tender document | 1 to 3 months |
| 5. | NIT and placement of orders | 1 to 3 months |
| 6. | Design engineering aspects including Reverse Engineering | 2 to 3 months |
| 7. | Delivery of equipment from the date of order | 9 to 18 months |
| 8. | Works execution on one unit | 3 to 6 months (depending on size of units) |

Note: Common shutdown of 2 to 3 months shall be envisaged while executing multiple units of a power station.