STANDARDS/MANUALS/ GUIDELINES FOR SMALL HYDRO DEVELOPMENT

1.11
General– Renovation, Modernisation and Uprating

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Lead Organization:

Alternate Hydro Energy Centre
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AHEC-IITR, "1.11 General – Renovation, Modernisation and Uprating", standard/manual/guideline with support from Ministry of New and Renewable Energy, Roorkee, November 2012.

PREAMBLE

There are series of standards, guidelines and manuals on electrical, electromechanical aspects of moving machines and hydro power from Bureau of Indian Standards (BIS), Rural Electrification Corporation Ltd (REC), Central Electricity Authority (CEA), Central Board of Irrigation & Power (CBIP), International Electromechanical Commission (IEC), International Electrical and Electronics Engineers (IEEE), American Society of Mechanical Engineers (ASME) and others. Most of these have been developed keeping in view the large water resources/ hydropower projects. Use of the standards/guidelines/manuals is voluntary at the moment. Small scale hydropower projects are to be developed in a cost effective manner with quality and reliability. Therefore a need to develop and make available the standards and guidelines specifically developed for small scale projects was felt.

Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee initiated an exercise of developing series of standards/guidelines/manuals specifically for small scale hydropower projects with the sponsorship of Ministry of New and Renewable Energy, Government of India in 2006. The available relevant standards / guidelines / manuals were revisited to adapt suitably for small scale hydro projects. These have been prepared by the experts in respective fields. Wide consultations were held with all stake holders covering government agencies, government and private developers, equipment manufacturers, consultants, financial institutions, regulators and others through web, mail and meetings. After taking into consideration the comments received and discussions held with the lead experts, the series of standards/guidelines/manuals are prepared and presented in this publication.

The experts have drawn some text and figures from existing standards, manuals, publications and reports. Attempts have been made to give suitable reference and credit. However, the possibility of some omission due to oversight cannot be ruled out. These can be incorporated in our subsequent editions.

This series of standards / manuals / guidelines are the first edition. We request users to send their views / comments on the contents and utilization to enable us to review for further upgradation.

Standards/ Manuals/Guidelines series for Small Hydropower Development

General	
1.1	Small hydropower definitions and glossary of terms, list and scope of different Indian and international standards/guidelines/manuals
1.2 Part I	Planning of the projects on existing dams, Barrages, Weirs
1.2 Part II	Planning of the Projects on Canal falls and Lock Structures.
1.2 Part III	Planning of the Run-of-River Projects
1.3	Project hydrology and installed capacity
1.4	Reports preparation: reconnaissance, pre-feasibility, feasibility, detailed project report, as built report
1.5	Project cost estimation
1.6	Economic & Financial Analysis and Tariff Determination
1.7	Model Contract for Execution and Supplies of Civil and E&M Works
1.8	Project Management of Small Hydroelectric Projects
1.9	Environment Impact Assessment
1.10	Performance evaluation of Small Hydro Power plants
1.11	Renovation, modernization and uprating
1.12	Site Investigations
Civil works	
2.1	Layouts of SHP projects
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2.4	Maintenance of civil works (including hydro-mechanical)
2.5	Technical specifications for Hydro Mechanical Works
Electro Mechanical works	
3.1	Selection of Turbine and Governing System
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3.8	Technical Specifications for Procurement and Installation of Switchyard Equipment
3.9	Technical Specifications for monitoring, control and protection
3.10	Power Evacuation and Inter connection with Grid
3.11	operation and maintenance of power plant
3.12	Erection Testing and Commissioning

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RENOVATOIN, MODERNISATION AND UPRATING OF SHP

1.0 GENERAL

1.1 Scope

The purpose of this guide is to identify the old power plants needing renovation, modernization, uprating (if possible) and increasing their service life but excluding Capital Maintenance. For this condition assessment, residual life assessment, diagnostic tests of main generating units, associated electrical, mechanical, hydro mechanical and civil works of the plant are necessary which have been covered in this guide.

1.2 References

R1	ASCE-2007	Civil works for Hydroelectric Facility – Guidelines for life extension and upgrade
R2	IEEE-1147-2005	Guide for the rehabilitation of hydroelectric power plant
R3	IEEE: 433-2009	Recommended Practice for Insulation Testing of AC Electric Machinery with High Voltage at Very Low Frequency
R4	IEEE-95-2002	Recommended Practice for Insulation Testing of AC Electric Machinery (2.3kV and Above) With High Direct Voltage
R5	IEEE-286-2000	Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation.
R6	IEEE-1434-2000	Trial-Use Guide to the Measurement of Partial Discharges in Rotating Machinery"
R7	EPRI-CA2001-TR-112350-Vol3-2000	Hydro life extension, modernization Guide (Electro mechanical Equipment)
R8	ASCE-1995	Guidelines for evaluating ageing penstocks
R9	NPTI Pub-2004	Uprating and refurbishment of Hydropower Plants by Naidu B.S.K.
R10	CBIP- Pub-1997	Proceedings of seminar on “up rating and refurbishing of hydro plants”
R11	CEA- Website	Central Electricity Authority, Govt. of India Web Site

Abbreviations:

ASCE: American Society of Civil Engineers, USA
IEEE: Institute of Electrical and Electronics Engineers, USA
EPRI: Electric Power Research Institute, USA
NPTI: National Power Training Institute, Faridabad
CBIP: Central Board of Irrigation and Power, New Delhi

1.3 Introduction

Hydroelectric generation is generally considered environment friendly, non-polluting, renewable and highly reliable source of energy. Apart from construction of new Projects, possibility of up gradation of old hydro units by renovation, modernization and uprating

(RM&U) is considered to be the most cost effective means of capacity addition in short span of time. RM&U and Life Extension (LE) improves reliability and availability of the plant, better efficiency and 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, de-rated or degraded equipment due to which power stations face frequent closure etc. and refurbishment /replacement 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/digital governor, high speed static relays/ multifunction digital relays, multifunction digital meters, data logger, vibration monitoring system and silt content analyser etc.

(iii) Up rating

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 stations 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 gate seals, inlet valve seals, damage to intake gates, draft tube 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.

Once guarantee of up rating by 15% or more is sure, additional generation, thereby additional business is established, the projects can find investment grants from carbon trading.

1.4 Options available for old SHP Stations

(i) Continued upkeep

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

(ii) Renovation, Modernization & Up rating

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.

The decision on the above three 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 component of the hydro sets.

1.5 Categorization of Power Stations for RM& 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 rated 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&U & LE of such plant.

(iv) SHPs (which are not working for various reasons) with station capacity up to 25MW set up in Govt. Sector and commissioned seven years prior to the date of submission of proposal for RM&U to the MNRE,GOI will be eligible for financial support.

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 and other eligible projects as per Para 1.5:

2.1 Condition Monitoring

2.1.1 Collection of Data & Operating Parameters

General Information

(a) Name of Power House.
(b) Name plate rating such as MW, MVAR, kV, PF, Hz etc.
(c) Overload rating, if any.
(d) Date of commissioning.
(e) History of major outages and remedial measures since commissioning.
(f) History of modifications of various components or systems made since commissioning.
(g) Details of faults repeated frequently.
(h) Unit wise annual running hours since commissioning.
(i) Unit wise annual generation since commissioning.
(j) Availability of discharge on daily, weekly, ten daily or monthly basis at least for last five years.
(k) Year wise data of silt (PPM and silt contents) especially during months of Monsoon (May to September) for last few years as far as possible.
(l) Commissioning reports

A. Operational Data

(i) Generator

(a) MW output at different heads & discharges.
(b) Stator winding temperature at maximum load.
(c) Field winding temperature at maximum load.
(d) Hot and cold air temperature.

(e) Excitation current at rated load.
(f) Excitation voltage at rated load.
(g) Guide bearing temperatures at maximum load
(h) Thrust bearing temperatures at maximum load

(ii) Turbine

(a) Guide vane /runner blade/needle and deflector opening at different head and load.
(b) Servomotor stroke
(c) Load throw off test at various loads.
(d) Governor and governor control
(e) OPU system- oil pressure
(f) Working of all turbine auxiliaries and different valves

(iii) Other System

(a) Drainage and dewatering system
(b) Cooling water system
(c) Compressed air system (if provided)
(d) Sealing water system(if provided)
(e) Oil leakage unit
(f) Grease lubrication system
(g) MIV

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(a) Runner
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(c) Shaft seal arrangement.
(d) Turbine guide bearing details.
(e) Guide apparatus and servomotors.
(f) Oil leakage unit.
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(h) Guide vane /needle and deflector/ runner blade combinatory relationship.
(i) Stay ring.
(j) Runner chamber (Kaplan only)
(k) Top cover drainage arrangement.

(l) Governor and OPU system
(m) MIV
(n) Other relevant drawings.

(iii) All civil structure & layout drawings.

(iv) Hydro mechanical equipment including trash racks, trash cleaning machine (if provided), gates with hoisting arrangement, penstock and associated valves – Manufacturer's drawings.

C. Documents

(a) Operation & maintenance manuals.
(b) Commissioning Reports of each unit.
(c) Technical data and description of main unit & various other equipments installed in Power plant.
(d) 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 equipment, penstock, MIV, spiral casing, draft tube, stay ring, guide vanes, runner, top cover, TGB, shaft, guide apparatus, governor, OPU system, Generator Guide Bearings, 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 coolers, rotor fans, ventilation ducts, baffle plates, braking & jacking and speed increaser(gear box, if provided) system needs to be carried out. Besides this, all unit and station auxiliaries are to be inspected and checked in the existing conditions. Obsolete and sluggish items must be identified for replacement with latest versions.

Detailed study of design parameters, operating parameters, history of machines major events, repair works done in past, repeated problems it faced during operation is required. Comparison of operating parameters and design/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 and mechanical tests are required to be carried out before taking up RM&U.

Some pre shutdown and post shutdown checks to assess existing condition are required to be conducted for Pre RLA studies of the Plant which are as under:

2.1.2.1 Pre shutdown Checks

(a) Maximum output of each unit at available head and discharge. In case less output than reasons are to be found out.
(b) Guide vane /runner blade/ needle and deflector opening, servomotor stroke at available head & available discharge & available output.
(c) Wobbling of TGB, coupling & generator guide bearings.
(d) Temperatures of all bearing and stator

(e) Measurement of vibration and noise at various accessible points of machine.
(f) Leakages through accessible points of water conductor & cooling water system inside power house.
(g) Leakage through pressure oil pipe and valves of OPU system.
(h) Excitation current and voltage.
(i) Stator current, system voltage, MVAR output and p.f. etc.
(j) Condition of power transformer, its cooling water system, emulsifier system (if installed) in running condition.
(k) Inspection of switchyard equipment and bus bars in charged condition.
(l) Inspection of all, main & unit control boards, LT boards while power station is generating electricity.
(m) Condition of all station and unit auxiliaries in running condition.
(n) Inspection of complete water conductor system and hydro mechanical equipment while the plant is generating.

2.1.2.2Post shut down checks

(a) Inspection of all underwater parts after dewatering
(b) Dimensional checks of underwater parts.
(c) Inspection of shaft seals, sleeve, TGB housing, pads, shaft guard, coupling, head cover.
(d) Inspection of all generator bearings (housing, pads), thrust bearing, rotor, stator, ventilation system, stator air coolers etc and excitation system.
(e) Measurement of bearing clearances.
(f) Centering of shaft, verticality of shaft, alignment and rotor level are to be checked & recorded.
(g) Inspection of OPU system, running of OPU pumps and quality of oil being used.
(h) Inspection of control, protection & metering system.
(i) Inspection of power & control cables.
(j) Inspection of D.C. System.
(k) Inspection of fire fighting system.
(l) Inspection of power transformers & switchyard equipment.
(m) Inspection of all station and unit auxiliaries.
(n) Inspection of MIV
(o) Inspection of pressure relief valve and other valves of penstock
(p) Inspection of hydro mechanical equipment.
(q) Chemical analysis of water.

2.1.2.3The study of records and observation collected during pre RLA studies:

These studies would give the following information:

(a) Components to be replaced due to their being irreparable or obsolete or sluggish.
(b) Components which need to be refurbished after establishing their remnant life.
(c) Margins for up rating of units.
(d) Components to be got redesigned with latest techniques of precise design and advancement in material science.

2.2 Residual Life Assessment Studies (RLA)

2.2.1 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
  - (a) Visual inspection & critical examination
  - (b) Mechanical
  - (c) Metallurgical
  - (d) Chemical
- (ii) Dynamic Behavior Tests
  - (a) Pressure Pulsation
  - (b) Vibration
  - (c) Noise
  - (d) Load throw off
  - (e) Ventilation and air flow analysis
- (iii) Hydraulic Studies

2.2.1.1 Non Destructive Tests (NDT)

(i) Visual Inspection:
(Take photographs of the components as necessary for illustration and record).

- (a) Accessible areas of turbines, surfaces are examined for swelling, blistering, warping. Amount of swelling, wall thinning is determined by mechanical or ultrasonic methods.
- (b) Thorough examination of possible signs of corrosion or erosion.
- (c) Examination of surfaces to detect misalignment due to warping and disengagement.
- (d) Identification of signs of distress.
- (e) 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:

- (a) 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.
- (b) 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.
- (c) 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 on the inner wall of tubes/surface due to deposition of corrosion product.

- ➢ Subsurface material defects.

(d) 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

(e) 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.

(iii) Metallurgical Tests:

(a) 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.
(b) The location selected is properly polished with portable grinder, sprayed with suitable chemical for examination under portable microscope.
(c) The reverse image replica of metal surface is taken on a plastic replicating film for detailed laboratory examination under optical microscope.
(d) 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:

(a) Chemical examination of small samples taken from components operating at high stress to ascertain their chemical composition and compare the results with the design figures.
(b) Chemical analysis of water.

2.2.1.2 Dynamic Behavior Tests (at 50% and full load)

(i) Measurement and spectrum analysis of bearing vibrations (Turbine/Generator).
(ii) Measurement and spectrum analysis of shaft vibrations alongwith orbit analysis (Turbine/Generator).
(iii) Measurement and spectrum analysis of vibrations at draft tube man holes and in turbine pit at top cover in vertical machines.
(iv) Pressure pulsation measurement and spectrum analysis in the water path at following points:-
- 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.

(v) Vibration measurement in penstocks.
(vi) Speed rise and pressure rise at load throw off.
(vii) Noise signal analysis at turbine pit, draft tube area or any other affected area of unit.

(viii) Pressure test – affected areas are tested, recorded and analysed.

2.2.2 Hydro Generator

2.2.2.1 Visual Inspection and diagnostic testing

(Photographs of the components as necessary for illustration and record be taken.)

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:

(a) Stator

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

(i) Signs of overheating.
(ii) Change in color and texture of coil surfaces.
(iii) Contamination due to grease, oil, brakes dust etc.
(iv) Presence of white powder or any other powders.
(v) Looseness of wedges, spacers and bindings.

In addition to above diagnostic testing like IR, 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.

(b) Stator Core

Stator core is inspected for major external changes such as:

(i) Looseness of core laminations.
(ii) Mechanical damages.
(iii) Locally overheated spots and core burning.
(iv) Deposits in cooling/ventilating ducts.
(v) O.C.C. and S.C.C. tests.

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

(c) Rotor

The rotor is inspected thoroughly for:

(i) Signs of overheating.
(ii) Cracks in shaft end or in body.
(iii) Damages/cracks in coupling system.
(iv) Presence of powdered insulation.
(v) Condition of cooling ducts.
(vi) Condition of fan blades.
(vii) Condition of brake track
(viii) Condition of braking and jacking units
(ix) Condition of high pressure lubrication system (if provided)

(x) IR values and field winding impedance measurement.
(xi) Condition of various weld joints.

(d) Other components

Other components should also be inspected such as:

(i) Stator casing, brackets etc. for cracks and tightness.
(ii) Bearings for wear and tear and contact area.
(iii) Commutators, brushes, brush holders and slip rings for wear and tear and other damages.
(iv) Coolers for deposits, corrosion of tubes and water chambers.
(v) Fan blade surfaces.
(vi) RTD, TSD
(vii) Performance of cooling system and ventilation system

2.2.2.2 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 40^0C where Ft depends upon life of machine.(Refer IEEE: 433-2009)
(ii) PI – It indicates dryness of insulation. Minimum value of class 'F' insulation should be 2. (Refer IEEE: 433-2009)
(iii) High voltage power frequency test (as per IEEE-95-2002) – 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 with stand 1.5 Un for 1 min. (Un=Rated voltage in kV). This test is not for machines generating at low voltage i.e. 415 V.
(iv) High voltage DC and 0.1 Hz test – As above except that this test is 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, this is quite popular and has been recognized by some standards as acceptance test.
(v) Tan Delta and Tip Up test (not below 6.6 kV) – 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 machines.(Refer IEEE-286-2000 for method and VDE-0530 Part 1/1.66 for values)
(vi) Capacitance Test (not below 6.6 kV) – 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.(Use Schering bridge for measurement)
(vii) Partial discharge test (not below 6.6 kV) – It measures inception and extinction voltage i.e. the voltage at which partial discharge commences and extinguishes. It also measures quantity of discharge in Pico Coulomb. The minimum inception voltage for an old in service 11 kV machine should be more than 3.5 kV.(Refer IEEE-1434-2000 for method)

(viii) Dielectric loss analysis (not below 6.6 kV) – 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.. Hot spots, if any should disappear after taking remedial measures.

(x) Impedance test on Rotor Field Coils of salient pole generator with slip rings- It indicates poor insulation & short circuit in rotor field winding. Impedance of field coil should be within $\pm$ 5% of average impedance of each coil.

(xi) ELCID Test: It is a stator core imperfection detection test and establishes healthiness of the core. This test is for assessment of condition of core of old generators.

Note: All above tests are required for unit having capacity more than 1MW (low speed). For smaller units having generation voltage of 415V some of the tests which are very costly may not be required, only condition assessment by visual checks and operating parameters with essential tests at Sl. No i, ii, iv, and xi will give the desired information.

2.2.2.3 Mechanical and metallurgical tests on Generator stator frames, rotor spiders, thrust collars, thrust bearing housing etc.

Metallurgical test 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 & blow holes in welded portion.

(iii) Magnetic Particle Test:
It detects subsurface cracks and blow holes also bonding of white metal of bearing pads.

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

(v) Hardness Test(Bearing pad supports)
It detects hardness.

(vi) Tensile and Shear Strength:
Test on a piece taken from the part, fairly indicates tensile and shear strength of that part. Residual stress in the shafts due to torsional forces should also be checked. This test is to be done wherever applicable

(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.

The recommendations as applicable to SHP plants as given in table 1 may be considered:

Table 1: Recommended Observation/Tests for renovation and modernization of SHP Stations

Para No.	Observation/Tests	SHP Stations Installed capacity		
		Up to 100 kW	**Above 100 kW and up to 5000 kW**	**Above 5000 kW**
2.1.1	Collection of Data & Operating Parameters	As per para2.1.1	As per para2.1.1	As per para2.1.1
2.1.2.1	Pre shutdown Checks	a,b,d,i,j,k,l,m,n	a,b,d,f,h,i,j,k,l,m,n	all
2.1.2.2	Post shut down checks	a,b,d,l,m,p	a,b,c,d,g,h,I,j,l,m,n,p	all
2.2.1	RLA of Hydro Turbine			
2.2.1.1	Non Destructive Tests	(i) All (ii) b,e (iii)none	(i) all (ii) all (iii)all	(i) all (ii) all (iii)all
2.2.1.2	Dynamic Behavior Tests	f	e,f,g,h	all
2.2.2	RLA of Hydro Generator			
2.2.2.1	Visual Inspection and diagnostic testing	(a) All (b)i,ii,iii (c)i,ii,iii,iv,xi (d) i,ii,iii	(a) All (b) All (c) All (d) All	(a) All (b) All (c) All (d) All
2.2.2.2	Electrical Tests:	i,ii	I,ii,upto1 MW .All above 1MW	All
2.2.2.3	Mechanical and metallurgical tests	i,ii	I,ii,upto1 MW .All above 1MW	All

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:

(a) Development of higher efficient runner.
(b) Improved material capable of with standing higher velocity and cavitation.
(c) Computer aided precision design techniques in the field of hydro-dynamic design and stress analysis.

(d) Higher speed rise is now acceptable on rejection of load by any unit of SHP does not affect frequency in the modern day strong power grid.

However, for up rating of plant all the components require rechecking for their suitability under new operating condition and assessment of their residual life expectancy should be made.

3.1.2 Assessment of up rating Potential

Following points make it essential to assess possibility of uprating of old units:

(a) 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.

(b) Ever expanding power systems demand, higher peaking support during limited period of the day.

(c) Availability of better cavitation resistant material capable of with standing stringent hydraulic conditions under the uprated capacity decides the upper limit of rerating. Computer based precision design techniques of course augment the uprating possibilities.

(d) Up rating of plant capacity, where water discharge remains unchanged, enable to generate more in case one unit goes down due to some problem.

3.1.3 Options for up Rating

(a) It is a 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, there by permitting higher discharges.

(b) Hydro turbines are capable of producing higher outputs than their rated capacity at heads higher than the design 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.

(c) The discharge capacity of existing runner can be increased by making some modifications without interfering with its basic design.

(d) As much as 30% uprating is possible by replacement with an efficient runner designed through modern computerized techniques. 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 for up rating

(a) Axial hydraulic thrust

(b) Runner speed:

- Normal

- Runaway

(c) Velocity at:
  - Spiral inlet
  - Runner exit
  - Draft tube exit

(d) 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.

It is preferred to retain guaranteed maximum pressure rise so that the old repaired spiral casing and penstocks may with stand the same. Higher speed rise of the machine is however, now acceptable on load rejection by an individual unit hardly affects modern day strong grid frequency.

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 up Rating

(a) Mechanical strength and material composition of machine components is important as further loading under higher rating can not be ruled out.

(b) Design review of such components, using latest computerized techniques will reveal stress level and also indicate excess safety margin of original design.

(c) During uprating programme following parameters may vary, which have direct bearing on mechanical integrity of various turbine components as mentioned below:
  - (i) 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).
  - (ii) Turbine Discharge – Runner, spiral case, speed ring and guide apparatus.
  - (iii) Velocity of Water – Runner, spiral casing, draft tube.
  - (iv) Torque on Turbine Shaft – Shaft & guide bearing.
  - (v) Axial Hydraulic Thrust – Runner, shaft.
  - (vi) Normal Speed – Shaft, guide bearing, shaft gland.
  - (vii) Runaway Speed – Runner, shaft, guide bearing.
  - (viii) Pressure Rise – Penstock, MIV, 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 with stand changed/increased parameters for longer time.

Previously 13:1/Cr: Ni and 18:8/ Cr: Ni stainless steel were used for hydro turbine runner and guide vanes. Currently 13:4/Cr: Ni stainless steel is used which has following advantages over others.

(a) Improved mechanical properties, especially good impact value, even at low temperature.
(b) Good weldability.
(c) Improved cavitation, erosion resistant.

The opportunity of manufacturing of the runners and guide vanes for uprating purposes with 13:4/Cr: Ni 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. Ranges of transient parameters in case of reaction turbine are as follows:

(a)	Vibration	0 – 100 microns
(b)	Noise level	0 – 100 db
(c)	Shaft run out	0 – Bearing clearance
(d)	Pressure fluctuations	3 to 5% of net head
(e)	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.

Up rating 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 uprate 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.

(a) 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.

(b) Various possibilities of up rating 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.

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

Where class B insulation is proposed to be replaced with class F insulation it should be kept in mind that class F insulation is not as flexible as class B and insertion of winding in the existing slots may not have any adverse effect on stator core.

3.2.2 Field Windings

The original winding can usually carry the increased current associated with uprating as these are liberally designed. But to with stand 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 affect bearings due to change in axial hydraulic thrust, therefore, thrust and guide bearings should 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 temperature 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 temperature, 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 temperature 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 emulsifier protection system for fire protection of power transformers.
(h) Provision of SF6 circuit breakers in switchyard.

4.0 RENOVATION AND MODERNISATION OF OTHER EQUIPMENT

So for renovation, modernization and up rating of MIV, Hydro turbine, speed increaser (if provided) 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:

4.1 Electrical Systems

(i) Unit auxiliary / station auxiliary Transformers.
(ii) Generator bus ducts /Main power cables.
(iii) Power and control cables.
(iv) LT AC/DC Systems
(v) Switchyard equipment viz. circuit breaker, isolators, CTs, PTs, LAs etc.
(vi) D.G. set.
(vii) Grounding and lightning protection systems

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. 4 and transformers in Annex. 3.

4.2 Control, Protection and Metering System

Condition assessment of the existing system, study of various modern options and adopting state of art technology based on financial viability and requirements of site.

4.3 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 pittings, 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). Take photographs of the components as necessary for illustration and record.

5.0 RENOVATION, MODERNIZATION AND LIFE EXTENSION 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, technology, manufacturing and process technology it is possible to up rate (capacity enhancement) 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
- Necessity 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.

Assessment of core losses and winding losses of old transformer and comparing them with original design values is also necessary for condition assessment.

The basic purpose of condition monitoring is:

(a) Minimise / avoid forced outage.
(b) Improve safety of personnel and the environment
(c) Improve equipment or power system availability and reliability
(d) 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:

(a) Main winding
(b) Magnetic circuit
(c) Insulation system

(d) Auxiliary systems such as bushings, transformer cooling system, tap changer etc.

For condition assessment following tests are carried out:

(i) Routine Tests
(ii) Special Tests

Routine Tests:

(a) Visual inspection of transformer and its associated accessories
(b) Dissolved gas analysis (DGA) along with formaldehyde concentration, moisture and acidity measurement is done once a year.
(c) Loss tangent tests on bushings
(d) Insulation resistance to check core & frame earthing is intact
(e) Inspection of tap selector and diverter switch
(f) Functional checking of coolers
(g) Winding resistance to check broken sub conductor and tap changer contact problem.
(h) Frequency response test to detect mechanical distortion of winding, which occurs only after a specific event.
(i) Oil sample testing for BDV value
(j) Working winding temperature and oil temperature indicators
(k) Working of air vent breather
(l) 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.

(a) Frequency response analysis to detect winding mechanical distortion
(b) Loss tangent or power factor tests, as a general indication of insulation quality with some indication of location
(c) 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.
(d) 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.
(e) Radio interference measurements, using a high frequency current transformer.
(f) Magnetizing current and turns ratio, detects electrical problems, useful for confirming that transformer requires repair or replacement but not as sensitive as FRA.
(g) Visual inspection by means of CCTV or endoscope
(h) Infra red thermal survey

5.3 Residual Life Assessment

5.3.1 The factors which determine 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

Ageing mechanical & electrical over stressing and contamination are the main technical factors.

(a) 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 due to transport shocks or resonance phenomena.

(b) Electrical overstress:

Causes of electrical overstress resulting in dielectric break down are as under:

- lightning
- switching over voltages
- internal influences such as winding resonance
- over fluxing due to high voltage or low frequency may cause over heating resulting in failure of insulation.

(c) 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 behaviour 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 CO_2, 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 Extension (LE)

Following information / data are collected and analysed for assessment of LE:

(a) Design specification and details
(b) Service history
(c) Operational problems
(d) 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 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.

(a) Original electrical design calculation available with the manufactures
(b) Thermal design calculations and test records available with the manufactures
(c) All manufacturing drawings
(d) Computer calculations available with manufactures

Following aspects should be analysed carefully by the designer:

(a) Current load to be allowed with out overheating with existing conductor
(b) Check the insulation paper over conductor is overheating
(c) 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
(d) Check suitability of accessories like bushings, on/off load tap changer for higher load
(e) Margin in the temperature rise limit
(f) Availability of space for additional cooling fans / pumps, if required.
(g) 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:

(a) This slows up the ageing of paper insulation, and of the oil as well as improves the electrical and insulating properties of oil.
(b) Keeps humidity of paper insulation at the level of less than 3%.

(c) Improves the short circuit strength (the axial forces pressing the windings are reduced due to ageing process in the solid cellulose parts)
(d) Other general reasons like changing of gaskets, repairing or replacing bushings protective devices, indicators fitted on the transformer.
(e) Inspection testing and repair of on load or off load tap changer, Buchholz relays, air vent breathers etc.
(f) Fitting of new / latest condition monitoring system
(g) De-sludging.
(h) Tightening of various joints
(i) D.P. test of paper insulation
(j) Inspection and cleaning of HV and LV windings, if possible.
(k) If oil parameters are within limits vacuum reconditioning of same is done.
(l) In case oil is found deteriorated beyond possibility of recondition, the same should be changed. This will improve over all insulation characteristic.
(m) Reconditioning or modification of conservator sealing system.
(n) Improve life expectancy and reliability is restored.

5.6.2 Refurbishment Activities

(a) Lifting of active part from the tank and thorough inspection of core, clamping arrangement, insulation of winding, earthing and internal joints.
(b) Chemical analysis and electrical measurements to determine condition of transformer.
(c) Inspection and cleaning of tap changer selector switch
(d) Inspection and cleaning of diverter switch and motor drive unit.
(e) Cleaning of active parts by flushing with oil or in a vapour phase oven.
(f) Oil treatment (filtering and drying)
(g) Drying of transformer with heat and vacuum or vapour phase process (the active parts are dried in its own tank with vacuum less 0.5 m bar)
(h) Tightening of windings
(i) Checking repairing or replacement of protective devices (gas relays, oil thermometers etc.)
(j) Check and inspection of bushings
(k) Replacement of all gaskets.

6.0 RENOVATION, MODERNISATION, UPRATING & LIFE EXTENSION 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:

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

6.2 Inspection, Non-Destructive Tests and Destructive Tests

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 behaviour of the critical civil engineering elements such as dams etc. shall be inspected with the help of any existing condition / behaviour 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.,

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, NDTs and DTs where required, any (excessive)ingress of external water, excessive humidity.

6.2.4 Water Ways (desilting chambers, tunnels, surface channels, canals, fore bay penstocks)

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 up rated 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) Main Inlet Valve (MIV)
(ii) Turbine and auxiliaries.
(iii) Generator and auxiliaries
(iv) Transformer (Main /Stn./Unit Auxiliary transformer)
(v) Station auxiliaries viz. EOT crane, drainage &dewatering and cooling water system
(vi) Control and instrumentations/ automation, etc.
(vii) On-line monitoring system. (if provided)
(viii) Switchyard Equipment
(ix) Civil works,
(x) Hydro mechanical components
(xi) 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 RM&U 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 5 and 6.
(v) Major failure /accidents occurred, major components replaced, generation problems/design deficiencies and possible solutions.
(vi) Details of major RM&U 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 RM&U works
(ii) Results of RLA studies carried out, if any
(iii) The list of RM&U works along with estimated cost identified under RM&U programme and covered in the proposal.
(iv) List of line monitoring system.
(v) Abstract of cost estimate of the RM&U programme.
(vi) Phasing of expenditure.
(vii) Bar-chart showing all the main components under RM&U.
(viii) Implementation schedule.
(ix) Benefits anticipated in terms of MW/MU after carrying out the RM&U /Restoration/Life extension of the generating units.
(x) Expected increase in life of generating units/transformers /switchgears after LE.
(xi) Cost estimation based upon RLA. Some percentage of cost may be kept for unforeseen items.
(xii) Techno-economic evaluation and justification considering various methods like payback period, comparison with the cost of new capacity installation, discounted cash flow etc.

7. 4 Methodology of Implementation of RM&U Programme

(i) Generation Company to identify the RM&U works required to be carried out and prepare or get prepared detailed project report (DPR) for implementation of R&M scheme.
(ii) RLA studies to be conducted on the main equipments/plants, which have completed their normative life of operation.

(iii) 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.

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

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

(vi) Preparation of detailed project report (DPR) for life extension works based on RLA report. The company will tie up for the necessary finances.

(vii) Preparation of technical specifications and bid documents incorporating performance guarantees and penalties for deviations from the guaranteed performance, etc.

(viii) 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.

ANNEXURE 1

TEST RELATING TO TURBINE, GENERATOR, STATOR AND ROTOR

Components/ Location	VI	DIM	DPT	MPI	UT	WTT	HM	RPL	ELCID	DCR	SVT	IR/PI	CT	VT	VAA
Turbine															
Shaft	●		●	●	●		●	●							
Shaft coupling Bolts	●			●	●		●								
Bearing	●				●										
Runner	●	●	●	●	●			●							
Spiral case, stayring suction cone, draft tube	●		●		●										
Main inlet valve/PR valve	●		●					●							
Wicket gates	●		●					●							
Governor, governor pump, compressor	●														
Servomotor	●														
Generator Stator															
Winding	●					●				●	●	●	●		●
Core	●								●						●
Terminal Bushing	●														
Coolers	●														●
Bus duct	●														●
Upper/Lower bracket	●				●			●						●	
TB/GB	●		●		●								●		
TB Support	●				●			●						●	
Generator Rotor															
Shaft	●		●	●	●		●							●	
Winding	●														
Spider	●				●		●								
Fan	●		●		●										
Excitation															
ArmatureWinding	●														
Commutators	●									●		●			
Collector rings	●														
Brush Rings	●														
AVR	●														

ABBREVIATIONS:

VI	Visual inspection	DCR	DC resistance	FFT	Furfural test
DPT	Dye Penertrant test	SVT	HIPOT step voltage test	MCR	Measurement of contact resistance
MPI	Magnetic particle inspection	IR/PI	Insulation resistance/ polarization index	MSR	Measurement of specific gravity
UT	Ultrasonic test	CT	Capacitance test	MV	Measurement of voltage
WTT	Wedge tightness test	RVM	Recovery voltage measurement	MAH	Measurement of ampere hour
DIM	Dimensions	SCT	Surge comparison test	MC	Measurement of capacity
HM	Hardness measurement	CL	Core loss	TVS	Thermo vision scanning
RPL	Replication	BDV	Break down voltage	VAA	Ventilation and air flow analysis
ELCID	Electromagnetic core imperfection detection	DGA	Dissolved gas analysis		

ANNEXURE 2

TEST OF GENERATOR

Test	Purpose	Item	Required Condition
IR and PI	Detects serious flaws, moisture absorption and cleanliness of winding	Stator and field winding	Bus bars and neutral connection has to be isolated
Tan Delta / Power factor	Evaluation of stress grading, dielectric losses and homogeneity of the winding insulation	Stator winding	-do-
DC Winding Resistance	Detects poor connections and conductor shorts	Stator & field winding	-do-
DC HV step voltage / Leakage Current	Detects Insu. Weakness and possibility of warning of breakdown of incipient fault	Stator Winding	-do-
Partial Discharge/ Corona / TVA Probe	Evaluation of stress grading system and location of PD sites	Stator Winding	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.
Computerised Digital ELCID Wedge Tightness Check	Determines healthiness of stator core inter laminar insulation	Stator core insulation	Rotor has to be taken out for this test or at least rotor poles are to be removed
Wedge Tightness Check	Determines wedge tightness	Stator wedges	Rotor has to be taken out
AC Impedance	Detects of presence of short circuit turns	Field Winding	Rotor winding should be isolated from excitation system
Recruitment Surge Oscillograph (RSO)	Detects Inter turn and Earth faults in winding	Field Winding	Rotor winding should be isolated from excitation system
O.C.C.	Detects shorted turns	Field Winding	On-line test
Thermal Sensitivity Test	Detects Vibration cause	Rotor	On-line test
Partial Discharge Analysis(PDA)	To assess delamination, stress control, slot support tightness	Stator Winding	Coupling coils has to be fixed to the machine
Metallurgical Tests on rotor retaining rings i) DP and ii) UT	Detects surface and sub surface cracks	Rotor retaining rings	Rotor has to be taken out

ANNEXURE 3

TEST OF TRANSFORMER

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

ANNEXURE 4

TEST ON OTHER EQUIPMENT

1. TEST ON CIRCUIT BREAKER

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

2. TEST ON POWER CABLES

Test	Purpose	Component	Required Condition
Insulation Resistance	Detects serious flaws, moisture absorption and cleanliness	Overall Insulation System	CB has to be isolated
Dielectric Loss / Tan/Power factor/ Cap. at HV	Shows Insu. Deterioration contamination and phys. Damage	Overall Insulation System	CB has to be isolated
DC Step Voltage test	Determines condition of insulation	Overall Insulation System	CB has to be isolated
Resistance of bolted connections	Determines condition of insulation	Bolted Connections	CB has to be isolated

3. TEST ON SURGE ARRESTORS

Test	Purpose	Component	Required Condition
Insulation Resistance	Detects serious flaws, moisture absorption and cleanliness	Overall Insulation System	Arrestor has to be isolated
Watts loss test	Shows Insu. Deterioration contamination and phys. Damage	Overall Condition	Arrestor has to be isolated
Resistance of bolted connections	Detects poor contacts	Bolted Connections	Arrestor has to be isolated

ANNEXURE 5

UNIT WISE PAST PERFORMANCE DATA
(For last five years)

Name of the Powerhouse :

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

S. No.	Particulars	Past performance Data						Expected performance data after R&M	Remarks
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1.	Actual maximum output (MW)								
2.	Energy Generation (MU)								
3.	Availability (%)								
4.	Forced outage (%)								
5.	Planned outage (%)								

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

ANNEXURE 6

STATION WISE PAST PERFORMANCE DATA
(For last five years)

Name of the Power Station :
No of Units :
Total Installed Capacity (MW) :
Total De-rated Capacity (MW) :
Total Uprated Capacity (MW) :

S. No.	Particulars	Past performance Data						Expected performance data after R&M	Remarks
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1.	Energy Generation (MU)								
2.	Availability consumption (%)								
3.	Cost of generation (Rs./kWh)								

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