# Renovation, Modernization & Uprating Of Hydro Power Plants- Guidelines For Residual Life Assessment & Life Extension.

*Er. Amrik Singh
**Er. Ashok Thapar

*The installed capacity of hydro power plants in India is 21800 MW ending 3/98. The likely capacity addition during the ninth and tenth plans is 11,194 MW & 16,892 MW. Proper maintenance of these plants is a stupendous task. Depending upon operating environments, manufacturer generally prescribes a useful life of 30-35 years. Replacement or declaring plants unreliable after this period requires huge investment which Indian conditions do not allow.*

*The author had the privilege of working on most of the hydro projects of the BBMB and PSEB in various capacities and found that under the present circumstances, the renovation, refurbishment and uprating of hydro power plants is the cheapest and best technique to get reliable and enhanced service from the existing power plants.*

*In this paper, an attempt has been made to properly dissect and diagnose the health of existing machines and possibilities of their refurbishment and upgradation.*

## 1. NEED AND SCOPE OF RENOVATION, MODERNIZATION & UPRATING

If in a hydro power plant, the machines are properly manufactured, assembled and maintained, these can give trouble free service of 30-35 years or even more except under-water parts of silt effected power plants which may require more extensive repair/early replacement. By refurbishment and modernization i.e. redesigning & retrofitting some of components of these machines, still more enhanced & reliable life of 15 to 20 years and higher capacity & better efficiency can be achieved. It is done before complete replacement of machine and is necessitated due to following reasons:-

i) The cost of new hydro plants or their complete replacement is very high. Some parts of machine like core stampings, rim, spider, poles, shafts, embedded parts etc. have a very long life as compared to parts like AVR, stator and rotor winding etc. Therefore, replacement, refurbishment of only such parts that have out-lived their lives or give frequent trouble costs only about 30-35% of total replacement cost to achieve full/enhanced capacity & life.

ii) Continuous design improvements are also taking place. At some stage after commissioning of machine, it may techno-economically be feasible to get higher output & efficiency by making some major or minor changes due to following reasons:-

a) In older designs, higher safety margines were taken due to limitation of stringent quality control required. These can be usefully exploited to get 10 to 15% enhanced capacity.

b) In old machines, stator & rotor winding is of class B insulation. So if this class B insulation is replaced with 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 and with existing margins in turbine & shaft, the unit capacity increased by 20 to 30% besides new lease of life to machine.

c) On reservoir based power plants, gross available head and quantity of water during monsoons increases. While this is kept in view during designing of power plants, yet some enhanced output may become possible during high head period by replacing some components. Margin in turbine is generally available as it is designed for weighted average head.

d) Sometimes by replacing generator, runner etc. with latest better design and retaining under-water embedded parts; additional capacity upto 50% can be achieved.

iii) Sometimes, refurbishment is necessitated due to non-availability of spare parts, particularly that of excitor and AVR due to obsolescence during which uprating can also be considered.

## 2. FOLLOWING ESSENTIAL STUDIES NEED TO BE CARRIED OUT FOR ASSESSING UPRATING FEASIBILITY OF MACHINES:-

### 2.1. Assessment of existing condition of machine

The first step towards refurbishment is to assess the existing condition of machine & its various components. For this a very detailed study of temperature, vibrations & metallurgy needs to be done. The existing condition can be assessed from the following:-

#### 2.1.1 History Of Machine.

Following data should be collected:-

i) Age of machine & no. of hours it has run & no. of start & stop etc. to calculate residual break down voltage of the insulation.

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* Member/Power, Bhakra Beas Management Board (BBMB), Chandigarh, India
** Dy. Director/P&C and Consultancy Services, BBMB, Chandigarh, India

ii) No. & history of faults and break downs of different components of machine.
iii) History of replacement or modifications of different components already carried out.
iv) Frequency of normal & capital maintenance.

**2.1.2. System Parameters Of Machine**

Record the following and compare with original/design data and latest trend/specification:-

i) Temperature of different components viz. stator, rotor, bearing etc. etc.
ii) Vibration and noise level at different locations.
iv) Load, guide vane opening, servo motor stroke, pressure pulsation.

**2.1.3. Diagnostic Tests On Machine.**

Carry out diagnostic tests on all components of machine viz. Stator, rotor, shaft, runner, head cover, bearings, coolers etc. etc. as described below:-

**2.1.3.1. 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 as per BHEL standard should be 2Ft (2KV+1) at 40$^{o}$C where Ft depends upon life of machine.

ii) **PI –** It indicates dryness of insulation. Minimum value for class F insulation should be 2.

iii) **Over Voltage Power Frequency Test –** It is a destructive test which either passes the insulation or fails it. However is unable to detect over all deterioration of winding. It is a universally recognized acceptance test. The winding of in-service machine should withstand 1.5 Un for 1 min.

iv) **Over Voltage D.C. and 0.1 Hz Test –** As above except that these are not universally acceptance test & stresses produced during test are less that than produced during power frequency tests. However, due to small size of test equipment, these are quite popular and have been recognized by some standards as acceptance test.

v) **Tan Delta And Tip Up Test –** 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 .01 and for class F insulation .006 for 11 KV machine.

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

vii) **Partial Discharge Tests –** It measures inception & extinction voltage i.e. the voltage at which partial discharges commences & extinguishes. It also measure quantity of discharges in pica columns. The minimum inception voltage for an old and in service 11 KV machine should be more than 3.5 KV.

viii) **Dielectric Loss Analyzer –** It measures total losses 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 Un.

ix) **Interlaminar Insulation Test –** It indicates the condition of stator core. Maximum core losses during test should be within 103% of design/commissioning losses. Hot spots, if any should disappear after taking remedial measures.

x) **Impedance Test On Rotor Field Coils –** It indicates poor insulation & short circuit in rotor field winding. Impedance of each field coil should be within $\pm$ 5% of average impedance of each coil.

**2.1.3.2. Metallurgical Studies On Mechanical Equipment Viz. Runner, Guide Vanes Etc.**

Metallurgical tests (like electrical tests for insulation system) reveal existing condition and the rate of deterioration of mechanical parts as mentioned below:-

i) **Visual Inspection** indicate apparent general condition.
ii) **Dye Penetrant Test** detects surface cracks and pitting.
iii) **Magnetic Particle Test** detects sub surface cracks and blow holes.
iv) **Ultrasonic Test** detects existing thickness and by comparison with earlier results can indicate extent of erosion. It also detects deep cracks, blow holes and flaws in the welding.
v) **Hardness Test** indicates hardness.
vi) **Tensile Strength** of a piece from a part, fairly indicates tensile strength of that part.
vii) **Metallographical Examination** indicates the change in micro structure of the part under examination, which in turn indicate deterioration.
viii) **Structural Studies** these indicate matching of resonant frequency of a part of equipment with hydraulic excitation frequency. The comparison of these values with old/original record to effect of ageing on the metal parts can be worked out.

These electrical and mechanical studies indicate the health and residual life of machine and are the main deciding factors for replacement or refurbishment of different components of machines.

**3. GENERAL GUIDE LINES FOR CHECKING FEASIBILITY OF UPRATING**

Broadly following should be kept in view while checking uprating possibilities:-

i) The outer dimensions of major equipment viz. Generator, Rotor, Turbine, Runner, Head cover etc. can undergo no change as these have to fit in existing housings of civil structures

ii) Uprating of Generator also involves improving cooling/ventilation capacity to take away higher heat loss.

iii) Higher out put of turbine would mean more water through the machine which results in increased run away speed, axial thrust speed & back pressure in case of tripping of unit which would require calculation of centrifugal force of rotating parts to check the mechanical strength of rotating parts their fasteners and match the two and to check/redesign/strengthen the bearings and connected brackets, sole plate & foundation for increased axial thrust.

**4. UPRATING AND REFURBISHMENT STUDIES OF GENERATOR**

**4.1 Generator Stator**

**4.1.1 Existing Design Margins :** Check and tabulate following from manufactures data and compare with existing parameters to find out available margins:-

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|---|---|
| i) Any over load capacity of short/long duration provided in these specifications.<br>ii) Ambient temperature<br>iii) Cooling water temperature.<br>iv) Stator winding, stator core and field temperatures. | v) Hot air temperature.<br>vi) Cold air temperature.<br>vii) Excitation current & capacity. |

From above data, some fair conclusions about available margins can be drawn. A margin of about 10% is generally available in old machines. It may increase due to less cooling water temperature of hydro stations than designed figures.

**4.1.2 Stator Core :** Generally stator core is not changed as these are non ageing. However, incidents of repeated faults or saving of time during uprating may require partial or complete replacement. Present day core has losses of 1.1 watt/kg against 3.7 watt/kg of old machines. Therefore, replacement where called shall decrease losses & increase efficiency.

**4.1.3 Ventilation System/Cooling Fans & Generator Air Coolers.**

Higher capacity of generator would cause higher losses requiring more dissipation of heat and hence better ventilation/cooling. This would require modification/redesigning of fan blades, air passages/baffles & change of Generator air coolers etc.

**4.2 Excitation System.**

**4.2.1 Pole Coils :** For increased output from stator winding, the requirement of rotor field flux will change, this would need detailed study of field coils. If found of inadequate capacity, then remedial measures to increase conductor size and or no. of turns and conversion of class of insulation to Class 'F' would have to be taken. Both involve replacement of coils.

**4.2.2 Excitors :** Like above, the capacity of excitors and other connected system would have to be checked for following:-

i) The existing excitor may be sufficient to meet marginal increased requirements.

ii) If the field coils of rotor are being replaced, then the current and turns can be designed to accommodate existing margins of excitor.

iii) The AVR should invariably be changed to new solid stab/digital type as these are more superior and fast acting.

**4.3 Mechanical Parts of Generator.**

**4.3.1 Rotor Pole :** Normally for uprating upto 20%, poles may not need replacement. However, when pole coils are changed with higher weight coils, then for extra centrifugal forces acting on pole, its end plate and keys should be checked. Under some special circumstances, the pole body may also have to be changed. Some examples are given below:-

i) **Pong Power Plant :** At the time of augmentation of machine from 60 to 66 MW, pole body (along with coils) was changed to reduce air gap and to alter profile of pole shoes. This generated extra 17 MVAR.

ii) **Ganguwal & Kotla Power Plants :** During replacement and augmentation of machines after long service, original poles retained but pole keys changed.

iii) **Bhakra Left Bank Power Plant :** At the time of augmentation of Left Bank from 90 to 108 MW by replacing stator winding from class B to F, no change in poles was done.

**4.3.2 Rotor Rim :** Normally no change in Rim is needed but poles/field coils are changed, stresses on Rim increase due to enhanced centrifugal force. This necessitates review/replacement of Rim, keys and studs.

**4.3.3 Thrust Bearing & Guide Bearing :** The load on thrust bearing directly increases with weight of rotor poles and axial thrust. Load on guide bearings would also increase due to greater hydraulic unbalanced forces. This has been discussed in **para 5(iii)(b)** already.

**4.3.4 Stator Frame :** Generally during refurbishment and 10-20% uprating, stator frame is not replaced. However, in case of loosing of stampings and related defects, it is advisable to change the core stampings with latest stamping with lower hysterias loss and higher bearing pressure from 4 kg/cm$^2$ to 12 kg/cm$^2$ for which stronger frame has also to be provided.

**4.3.5 Upper & Lower Brackets :** Since the whole weight of machine along with axial thrusts have to pass to foundations through brackets, their suitability for enhanced load may be checked. Generally these won't need replacement for augmentation upto 20%.

**4.3.6 Shaft & Coupling Bolts** : The mechanical design of shaft & coupling bolts depends on the torque to be transmitted, axial hydraulic thrust, normal speed, run away speed & critical speed. Both torsional & tensile stresses act on the shaft.

**4.3.7 Generator Foundation** : Generally generator is supported on two foundations. While rotating or resting on thrust pads, the whole rotating and stationary weight is passed via thrust bearing, upper bracket and stator frame to sole plate fixed on first foundation. When resting on jacks, the weight or stator frame and upper bracket rest on this foundation but weight of rotor, runner and shaft etc. is passed via jack pads to lower bracket which rests on sole plates of second foundation. The foundation capacity should be got assessed from competent civil engineers with respect to increased weights and thrust bearings and modification if any got done. Some increased load can be met by increasing sole plate area.

**5. UPRATING AND REFURBISHMENT STUDIES OF TURBINE**

Following studies need to be carried out for uprating of turbines:

5.1 **Existing Design Margins** : The decision on different parts of turbine and their replacement/refurbishment is taken after taking action as per para 2. Manufacturer's recommendations for possible higher output by utilizing available margins either by passing more water or utilizing higher available head has also to be considered.

Generally on reservoir based power plants, higher than rated head is available for 4-5 months in a year due to filling of reservoir during monsoons. It may be possible to get more output during this period.

**5.2 Hydraulic Studies**

**5.2.1 Cavitation** : When output more than rated is obtained by either utilizing water or head, turbine's critical coefficient increases. It is therefore necessary to check that sufficient margins from cavitation point of view exists at higher output. This can be ascertained from fresh model test to be carried out from cavitational as well as output point of view. It is worth while to spend a few lacs of Rupees on model testing for getting trouble free service at enhanced output.

**5.2.2** Run Away Speed : It has already been mentioned under para 3 that all rotating parts are designed for centrifugal forces at run away speed which increases on uprating and hence such parts should be checked for it.

**5.2.3 Axial Thrust & Pressure Rise** : Due to higher quantity of water, axial thrust as well as pressure rise would also increase as explained under para 3. Under turbine, check coupling bolts, runner, scroll case etc. for these higher loads and pressure rise.

**5.2.4 Pressure Pulsation** : If the same runner is being retained, then check pressure pulsation at increased output. If it is being replaced, then carry out model testing.

**5.2.5 Vibration & Noise Level** : As per above para.

**5.2.6 Load Throw Off Test** : This test is carried out to check the speed & pressure rise at different load throw offs. In addition, the behavior of governor oil pumps, servo motor & pressure variation in draft tube are also checked during this test with same rotor at higher output or model testing if runner is being changed.

**5.3 Mechanical Studies**.

**5.3.1 Runner** : Mechanical design of runner depends upon maximum head with pressure rise, maximum run away speed & axial hydraulic thrust. There would however be a marginal increase in stresses at higher output due to these factors which should be cross checked.

**5.3.2 Shaft, Coupling Bolts, Guide Vanes & Guide Bearing:** : Same as discussed under Generator

**5.3.3 Shaft Seal** : Pressure on shaft seal depends upon tail race level & leakages through labyrinth. When unit is uprated, generally both increase & the extent of increase howsoever small it may be, should be calculated.

**5.3.4 Pen Stock, Scroll Case, Stay Ring, Draft Tube etc.**

**i) Increase in Pressure Rise** : Extra capacity would also cause extra water pressure rise (on tripping or fast closing of unit) in scroll case & pen stock. If a surge tank exists, its adequacy for this extra pressure rise and mechanical strength of all under water parts for extra pressure rise be checked.

Similarly suitability of other parts like guide vanes, top cover, pivot ring for extra water and pressure rise would need examination.

**ii) Increase in Velocity** : As embedded parts can't be changed, therefore to increase water quantity, water velocity increases. This increase causes extra loss of head in water conductor system and increased erosion in silt affected Power Plant.

**5.3.5 Governor & Servo Motor** : For increased water quantity, guide vanes will have to be opened more requiring higher power from reservoir for which capacity & stroke shall also have to be checked. Along with it, the operating oil pressure of Servo motor may have to be increased and the new governor of latest design provided to replace obsolete sluggish governor with latest state-of-the-art governor,

**5.3.6 Station Crane Capacity** : The crane capacity is dictated by heaviest part which is generator rotor. At enhanced generator output, the rotor weight may increase due to possible increased weight of pole coils. Though this would be insignificant w.r.t. total weight, yet this should be kept in mind.

6. **CONCLUSION:**

- It is worthwhile to implement R,M&U of old hydro Power Stations.
- Pre-RLA Studies should be got conducted from an independent source, other than the manufacturer for an unbiased decision.. For an effective approach, Pre-RLA needs to be conducted for freezing and clarity of the scope of R,M&U. **RLA study may not be required for the parts needing Uprating as these parts are required to be changed.**
- The short listed firms of PFC may be used for getting the RLA conducted. This will shorten the procedure for implementation.
- Independent agencies may be involved for finalizing the Detailed Project Reports.
- Model bid documents as circulated by PFC may be used for quicker implementation.
- Adopting standardized procedures will hasten the project completion.

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