Recent Generator Uprate Case Studies

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Abstract. With deregulation of the energy sector, reduction in the number of thermal and nuclear units being installed, the emphasis on improvement in the output and reliability of hydroelectric plants has increased the number of stations being refurbished. Some recent projects are discussed, and observations on the variety of specification requirements seen in the industry. Some of the factors affecting ouptut are: the magnitude of change in rating, modifications required in the generator, affect of a design study on the responsibilities of the supplier, source of design information, and the design process for uprate.

I. INTRODUCTION

The hydroelectric generation industry faces two related challenges: increasing the output and reliability of these aging facilities. Uprating existing generators is often used to provide the increased revenue to offset the cost of rewinding and mechanical modifications.

Increased output may be achieved with or without mechanical modifications to the generator. Starting with the turbine output, if it is being increased, torque, short circuit, and over-speed requirements may require careful analysis of the complete generator to assure that safe operating standards are maintained. The legal responsibility of the owner and the supplier is a factor in determining the scope of any project. Replacement of some or all of the generator components is considered by the owner and his consultant, along with a cost survey prior to the specification stage.

Until the last few decades, technology for turbine output, depth setting of the distributor, efficiency and cavitation were less because designs were extrapolations of existing units. Modern finite element analysis has allowed significant performance improvements that may be matched by the generator and auxiliary equipment. Optimum turbine output may also require a change in unit speed to achieve best efficiency, or to satisfy a new set of operating head requirements. Typically, turbine output may be increased from 15 to 20%, with a maximum of 36 to 40%, to justify the station modifications and the capitol expenditure.

It is considered that this type of plant has an indefinite life.

Station	Original Rating	New Rating	Percent Increase
Abitibi Canyon Ontario Hydro	48.5 MVA 25 Hz	70 MVA 60 Hz	44.3 %
Sir Adam Beck Ontario Hydro	54 MVA 25 Hz	63.5 MVA 60 Hz	17.6%
Sharavathi India	99 MVA	133.65 MVA	35%
Hoover Dam USBR A5, N7	82.5 MVA	130.26 MVA	57.9%
Hoover Dam USBR N3, N4, A7, A6, Al, A2, N8	82.5 MVA	133.3 MVA	61.6%
Shasta USBR	75 MVA	128.87 MVA	71%
Bersimis II Hydro–Quebec Units 24, 25	120 MVA	168 MVA	40%
Yates Alabama Power Units 1,2	19 MVA	24.97 MVA	31.4%
Glen Canyon USBR Unit 8	125 MVA	174 MVA	39.2%

TABLE 1

RECENT UPRATES BY GE/GE CANADA

II. INCREASE IN OUTPUT WITHOUT GENERATOR MODIFICATIONS

Justification from the original contract and rating:

i. Existing margins in the generator may typically allow a 15% overload capability with reduced insulation life. Conducting heat runs will verify the temperatures of the windings, with consultation of insulation experts, to allow safe electrical margins for that class of insulation system. Mechanical ratings and overspeed require verification from the original contract documents or design verification

ii. Increase the power factor. Many designs were specified to have low power factors, i.e. 0.8, 0.85 or 0.9 to provide reactive power needed on the system at the time the units were installed. Such may not now be the case. Larger, newer units can provide additional VARS. Units designed for lower power factor should be designed for the maximum MVA limit at 1.0 pf, increasing the

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base load MW capacity. Increased torque, over-speed, and hydraulic thrust should be reviewed with a consultant or manufacturer.

iii. Increase the temperature rise of stator and rotor to near the maximum allowed by the temperature class of the windings. Verify the mechanical rating and temperature margins, recognizing reduction in insulation life and reliability

iv. Improve ventilation efficiency by reduction in parasitic air flow. Consider using a higher than standard ambient temperature on the coolers in warmer climates. Or increase the cooler capacity in colder climates with lower water temperatures. Higher than design temperature rise is a calculated risk. Cleaning stator ducts and cooler tubes will improve stator temperatures. Flow and fouling redundancy in coolers may be exploited .

These uprates require knowledge and some risk taking. They should be carried out after a joint study by the owner and an experienced generator design consultant or manufacturer.

III. INCREASED OUTPUT WITH GENERATOR DESIGN MODIFICATIONS.

For a significant increase in output, some design changes may be required to maintain safe operating limits or factors of safety. The energy to be dissipated from catastrophic failure of rotating machinery can result in loss of life or outage of the complete plant. The liability for such safety must be addressed in each specification. Some options would be:

i. a new stator winding with updated insulation (possibly Roebel bars, changes in parallel circuits and series turns, increased copper–cross section).

ii. new or re-insulated field windings.

iii. inspection, test, or replacement of the armature core.

iv. new rotor pole design to satisfy stress limits or change in flux density, amortisseur rating.

v. new rotor rim if stress analysis or inertia changes dictate the need.

vi. new generator on existing or modified foundation.

vii. new excitation, monitoring, and control equipment.

IV. DETERMINING THE LIMITS OF UPRATE

The owner and consultant should consider:

i. Owner preferences regarding operating temperatures and limits, including IEEE or IEC Standards.

ii. Present operating temperatures under load, determined by test.

iii. Original design information and margins included.

iv. Original test information, with extrapolation where possible.

v. Station operating and maintenance records, including uprate data.

vi. Computer simulation of electrical and mechanical design.

vii. Independent design studies by the original supplier or others.

V. EFFECTS OF UNIT UPRATING ON GENERATOR COMPONENTS

Increased winding temperatures will accelerate deterioration of the insulation system and increased thermal stresses of both the electrical and mechanical parts. A computer model of the design is required to compare the design with new machine standards and verification to its test calculations. Preferences for Roebel windings may dictate changes in the number of winding circuits and flux levels. Field winding performance may allow increased copper within the stress limits of the pole and rim.

Losses in the magnetic path of the core and poles may change significantly with the load. The open and short circuit losses are major components in the efficiency and temperature rise calculations. A new armature core may allow optimizing the number of stator slots, air ducts, and designs of the new winding configuration to increase efficiency or reduce magnetic noise problems with the design. Typically, refurbished or new cores are assembled without splits, and may allow modification of the electrical characteristics and reactance.

Ventilation losses may account for 20 to 40% of the total design loss, and is a major contributor to temperature rise for all designs. Reducing windage loss should be a prime consideration of any design modification, but is not often considered. Parasitic air flow, re-circulation of rotor air, or bypassing of the stator core were common on older designs.

Mechanical components subject to torque and fault loads require that stress margins, over-speed limits, and material analysis be verified. This must be specified as part of uprate, or it may be assumed an electrical uprate only. If a new mechanical nameplate is to be applied by the supplier, justification that the design meets specified standards is required.

Rapid thermal cycling during peak or rapidly changing load constitute more severe duty on the generator.

Friction and stirring losses in the bearings are usually extracted by a separate cooling system, and are not usually a problem when uprating.

A. Magnetic components - core, rim and poles

Higher output means higher flux densities in the core and poles. Modern designs use higher values of flux densities in these areas. Therefore, if the stator core and poles are in good condition, or can be put in good condition, they usually do not have to be replaced.

A new core does, however, allow a change in the number of slots which may help to optimize the use of a single turn bar winding. Also better grades of core steel and enamel are now available to further improve efficiency. The uncertainty of shorted laminations and increased losses due to aging are also eliminated with a new core.

The air gap can also be modified if a new core or new poles are supplied. Alternatively, the poles may be shimmed outward to the stator bore, as in the case of Bersimis II to optimize the overall generator performance.

B. Mechanical components - stator frame, rotor, and shaft

Although stator frames, sole plates, etc. have traditionally been designed conservatively from an operating stress perspective, these components need to be evaluated for increased unit output. Adding radial freedom sole plates can relieve additional thermal stresses, but a thorough examination of the frame stiffness is needed to avoid air gap collapse.

The rotating parts of the generator have been designed for the original runaway speed stress levels. If the new hydraulic or turbine design increases the unit over speed, or the weight of new poles or field coils is increased, a comprehensive analysis is required to restore traditional factors of safety. Finite element mechanical analysis or higher strength materials may be required.

Since torque increases with load, the torque drive keys, spider coupling, shaft and coupling bolts must be checked. The stator frame and sole plate forces are governed by short circuit which may not change unless the voltage and winding pattern is altered.

C. Ventilation

Air flow per KW of loss in older designs was 40-60% higher due to difficulty in predicting temperature rise and flow capability, adding friction loss. The bidder must know accurate air flow to give confidence in the calculations. This area promises the best increase in unit efficiency, but is seldom approached thoroughly in specifications.

D. Bearings

If the turbine hydraulic thrust or unit maximum over speed are increased, the bearing design including the cooler effectiveness should be verified. As well, the outage associated with an uprate can often be used to improve bearing instrumentation, add high pressure oil injection, or refurbish seals and bearing surfaces.

E. Auxiliary systems

Since reactances in per unit increase with an increasing output (on the new base), the short circuit currents will not change appreciably when a generator is uprated. These will have to be calculated on the new base, as will the reactive capability and the characteristic curves. They will change if the generator circuitry or the air gap length changes.

VI. IMPORTANT ELEMENTS IN A SPECIFICATION

i. Clear evaluation factors in comparison of bidders.
ii. Penalty factors for delays, performance and efficiency
iii. Method of testing.
iv. Definition of whether a mechanical or electrical uprate is considered. If mechanical calculations are required to support a new mechanical nameplate, dimensions and materials must be provided.
v. Clear listing of the drawings, calculations, and manuals involved with the work.
vi. Experience or pre-qualification factors, including personnel and manufacturing facilities.
vii. A review of specification by experienced consultant prior to issue.
viii. Specification may be performance oriented or very detailed.
ix. Clear technical specifications representing the state of the art in the industry.
x. Opportunity to provide value added changed to the contract when accepted by the owner.

VII.CONCLUSION

Cooperation and team work between the owner, generator equipment supplier, and other powerhouse equipment suppliers, is necessary to ensure the eventual success of any RMU project.

In the tendering stages, a wide range of pricing and recommended modifications is usual and should be expected. The evaluation and technical comparison can be more complicated than for a new machine but be optimally resolved through focused negotiation of the parties.

VII.REFERENCES

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