GENERATOR REFURBISHMENT/REPLACEMENT FOR LIFE EXTENSION POINT LEPREAU REFURBISHMENT PROJECT

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Abstract:

Following a decision by New Brunswick Power (NBP) to extend the life of Point Lepreau Nuclear Power Station, a number of refurbishment projects were identified for the various plant equipment and systems. AECL was awarded the contract for the refurbishment of the station of which the generator is one of the tasks included in the overall refurbishment work scope. This paper describes the basis for the various refurbishment/replacement options being considered for extending the life of the generator. Rewinding the stator and the rotor would normally offer an adequate solution; hence this option is included as the reference case. However, other considerations specific to the Point Lepreau station have prompted the development of additional combinations of options with a new stator and a new rotor as well as a complete new generator. How this affects the scope of the project, the relative merits and drawbacks of these options and their impact on the complexity of the project documents are discussed.

Project Outline

In July 2005, NB Power received approval from its Board of Directors and the Province of New Brunswick to refurbish the Point Lepreau Generating Station (PLGS). Over the next 2 years NB Power will proceed with detailed engineering and procurement activities in advance of an eighteen-month shutdown that begins in April 2008. AECL is the main contractor for the project that includes the replacement/refurbishment of the main generator. Refurbishment of the generator and other equipment is necessary to obtain an additional life of thirty years of reliable operation.

Project Activities

Background – The Condition Assessment of the generator, completed in 2000, concluded that the generator would not operate satisfactorily for the additional plant life of 30 years without major refurbishment. In order to continue to produce electrical power at an acceptable risk factor for the proposed extended station life, a number of recommendations were identified. These, along with input from NBP, prospective vendors and AECL, were instrumental in developing the following project documents.

Project Documents - A preliminary design package (PDP) was prepared, which outlined the fundamental design for the refurbishment/replacement of the generator, along with a cost benefit analysis, based on previously received budgetary estimates. The PDP examined the various alternatives from the standpoint of technical content, equipment supply, construction, operations, maintenance and schedule considerations. This allowed NBP to select procurement options on which to base a request for tender to be handled by AECL for the delivery of the complete engineering package. This includes design and commissioning of the refurbished/replaced generator and auxiliary equipment in accordance with the requirements of NBP for an extended life of 30 years.

To ensure the validity of the documentation to be used as input to the design phase, it was necessary to verify an accurate baseline of all existing documents related to the work. Some of the sources included the station records of changes made during the operating life of the generator as well as the examination of databases such as the Field Monitoring System (FMS) at AECL and the Problem Indication and Corrective Action (PICA) at PLGS.

A Request for Tender (RFT) was assembled based on an Engineering Quotation request (EQR), prepared by Engineering. The EQR is accompanied by the Technical Specification and a Technical Documents List (TDL). While the TDL is a tool for tracking changes to project documents, it is also used to record such changes and clarifications with the prospective vendors, from the beginning of the tendering process right through to the final acceptance of the equipment at site. The TDL comprises sections dealing with Certification, Applicable changes to Technical Specifications, Codes and standards, drawings and Bills of materials along with registration and jurisdictional requirements. It also documents technical exceptions in the same categories. It is a controlled document that ensures good connectivity with the prospective vendors during bidding and with the selected vendor during design, build and installation activities.

Schedule - The schedule was prepared to accommodate maximum completed activities with the 4 main options. By encompassing all the options, the schedule would continue to remain in effect without requiring a major revision when the final option is selected. This allows for the costing and resourcing to be conducted well in advance. Furthermore, long lead items can also be considered at an early stage, thereby minimizing the risk of delay to the project.

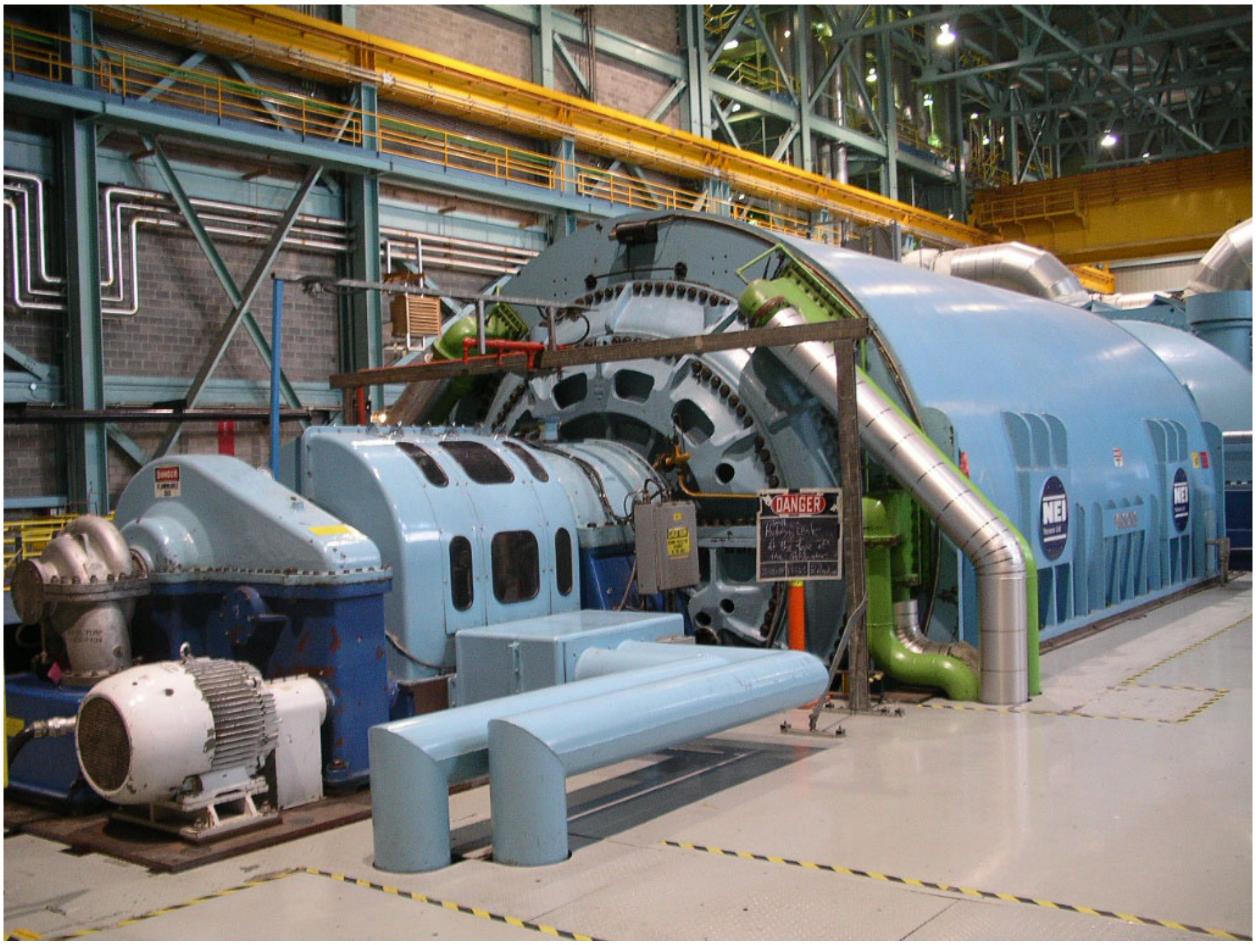
Technical Aspects

Existing Generator

Description – The generator, rated at 680 MW, 800MVA, 0.85 PF, 26kV, 1800 RPM, 60 Hz, was manufactured by C. A. Parsons and began service in 1983. The stator winding is water-cooled while the rotor winding and the stator core are hydrogen cooled.

Operating Experience – The generator has provided reliable service over the years and was shut down for major planned outages in 1984, 1992 and 2000 for inspection and remedial repairs. Moderate amounts of copper oxide deposits in the stator winding were observed during the first two inspections and flushed out, while chemical cleaning of the stator winding was required to remove the extensive deposits of copper oxide found during the 2000 outage inspection. This remains a major concern, as the cause of the winding blockage is not well established; hence incipient blockages have the potential for jeopardizing reliable operation. Age related issues of wear and tear in critical components such as the hydrogen seals and insulation degradation in the stator and rotor are additional concerns. Existing instrumentation in the generator for on-line monitoring of key parameters is rather basic, compared to today’s capabilities, thereby limiting the diagnostic ability for detecting problems in the early stage.

Consequently, reliable service beyond the 23 years (1983-2006) of operation will become more difficult with further aging and on-going concerns of stator winding blockage. Overheating events, identified during outage inspections, may have compromised stator winding insulation life; similar concerns exist regarding the health of the stator core and the rotor winding. Refurbishment or replacement of the stator and the rotor will therefore be required to achieve the goal of extending generator life by an additional thirty years.



Operation of the hydrogen dryer has been problematic and the hydrogen panel is now out of date. The hydrogen cooling system will therefore be upgraded by replacing the hydrogen drier, the hydrogen control panel and associated field devices. Similarly, the stator water-cooling system and the seal oil system will be refurbished where necessary, including changing to individual hose fed cooling of the stator conductor bars.

Existing Exciter

Description –The excitation system comprises a 7.5 MVA power transformer, bridge rectifier, field breaker, dual automatic voltage regulators, dual power system stabilizers and thyristor firing controls. A manual field voltage controller is also provided. The three-phase bridge rectifier has 10 parallel bridges of silicon-controlled rectifiers that convert the AC power to 515 VDC. The excitation system has fast response time and a high ceiling voltage.

Operating Experience – The exciter has provided good overall service with replacement of some components. The spare capacity in the power bridges is ample, although this may be a function of lower duty at close to unity power factor operation of the generator. Some components such as the snubber capacitors and resistors are subject to accelerated aging due to overheating, requiring regular replacements.

Assessment – While the overall reliability of the excitation system has been good, there has been numerous small problems that required significant maintenance (almost 800 work orders). The operating regime of the generator at low reactive power and the ample built-in redundancies of the exciter have allowed sufficient maintenance opportunity to ensure continued operation without major breakdown. The station refurbishment program now presents an opportunity for installing new equipment that will extend the life of the system by thirty years using modern design while also reducing the maintenance requirements.

Proposed Generator Refurbishment

Rewinding with new copper conductors and modern insulation systems can extend the life of the generator stator and the rotor. However, such upgrades are subject to limitations presented by the remaining life that can be expected from the existing rotor forging and the stator core laminations. These components may continue to operate for several more years but are unlikely to last for an additional thirty years without any replacement. These concerns would favour a replacement of the stator and rotor option over the rewind option.

However, the location of the station, restricted railway access or an adequate roadway upgrade and the limited facility and time window for handling large heavy components during the refurbishment program favour a rewind option, where the materials will be of more manageable size. On the other hand, the extensive nature of the entire station refurbishment program may favour off-site construction of large components because of the expected demands on station resources of staff, materials, services and workspace. Another factor that can affect the option selection is the costs associated with sending the rotor off-site for balancing and over-speed testing. This may be offset, to some extent, by ordering a new rotor,

These conflicting issues prompted the development of refurbishment options for the life extension of the generator beyond the reference case option of rewinding the stator and the rotor. It is anticipated that by considering a variety of options, an optimum solution will be found for the refurbishment of the Point Lepreau generator consistent with technical viability, economic value and logistical considerations.

The four main options being considered for the refurbishment of the generator are summarized as follows:

Option 1 – Rewind the stator and rewind the rotor

Stator Winding - This option was chosen as the reference case representing the minimum level of refurbishment. It offers the opportunity of upgrading the present water-box design of the stator winding to a modern all-epoxy hose design. The present conductor bar insulation system is comprised of epoxy in the slot section and bitumen in the end winding section. The softer bitumen insulation allows field adjustment of the bar ends to match the entry holes of the water-boxes that are used to distribute cooling water to the winding.

The water-boxes are made of cast epoxy and are subject to failure from cracks and leaks, which has lead to forced outages at other stations. However, more commonly used stator winding deigns use hoses instead of the water-boxes, such that the end of each conductor bar is connected to a ring manifold using a Teflon hose. This allows the whole conductor bar, including the end winding section, to be insulated with a hard thermosetting epoxy system that is durable and reliable. With simplified connection to the cooling water system, the cracks and leaks associated with the water-box design are therefore eliminated.

The insulation system of the stator winding is particularly crucial at Point Lepreau due to the relatively high terminal voltage of 26kV. This makes any weakened insulation vulnerable to system over-voltage transients. The conversion to all-epoxy insulation system will therefore allow the winding to better withstand the prevailing dielectric stresses.

The conversion to the hose design will require changes to the stator cooling water system and to the stator casing for additional pipes that will feed the new ring manifold for individual cooling of the conductor bars. The new hose design of the stator winding will also facilitate the use of the hose outlet thermocouples that are sensitive to small variations in temperature.

This option of the stator rewind requires the use of the existing stator core. During manufacture, the core plate steel laminations are tightly compressed to stacking pressures of the order of 1500 kPa. This is important for obtaining the required electro-magnetic characteristics and mechanical integrity. This pressure relaxes over time allowing relative movement that can lead to damage to the laminations and the insulation between them. The end sections of the core are more vulnerable as evidenced by localized overheating of the core end sections observed during inspection. The existing instrumentation in the end sections is rather limited for monitoring temperature and vibration.

To improve the reliability of Option 1, the core end sections will be replaced prior to replacing the stator winding. This will require special handling of the core at site to remove the existing end sections, replace with new end sections, apply the required stacking pressure to consolidate the core and secure the end plates to retain the applied pressure. This process will provide an opportunity to improve the diagnostic capabilities of the station. Suitably placed thermocouples will accurately monitor the core end temperatures and accelerometers mounted on the end winding will help detect any increased vibration during service.

Other components such as the high voltage terminal bushings and the current transformers will be reused, subject to prior condition assessment. The ease of handling rewinding components such as stator conductor bars as opposed to a new stator is another advantage of this option.

***Rotor Winding* –** After some 20 years of operation, the rotor winding is showing signs of aging. Reported symptoms include a shorted turn, pitting damage at the ends of slot wedges, wedge migration, excessive slot clearance under the wedges, displaced inter turn insulation, fretting of end winding packings and a crack in the rotor bore insulation. While some of these symptoms may be expected at this stage of service life, they could be indicating overall deterioration in the insulation system. As recommended by the OEM after the 2000 inspection, it will be necessary to rewind the rotor to ensure trouble-free operation in the future.

There is no record of inspection of high stress areas of the rotor forging, such as the rotor teeth and the bayonet lugs for the retaining ring mounting, however an ultrasonic inspection of the rotor bore was carried out in 2000 that showed no defects. Considering the age of the rotor, there is some concern regarding the continued reliability of the forging for another thirty years. A full scope of tests will therefore be performed on the forging prior to accepting it for the new rotor winding in this option.

Rewinding the rotor with new copper conductors will ensure that the material and the brazed joints are sound and the whole winding is restored to design dimensions. In particular, the radial and axial clearances would be optimized to allow the growth and movement expected in service. The new turn insulation will eliminate the concerns about shorted turns and the new slot armour will reduce the probability of ground faults. Alignment of ventilation paths in the copper turns and the insulation between them will provide free flow of cooling gas. New insulation in the rotor bore and over the radial leads would provide the strength required for the duty expected in service.

Option 2 – Replace the stator and rewind the rotor

This option provides all the benefits of the Option 1 (rewind stator and rotor) with the added advantage of a new stator core designed to include modern lamination steel materials; core insulation; and assembled to modern procedures. It would also free up the resources required at the station for the stator rewind work. Depending upon the selected vendor, a significant change to the stator design may be offered. The present “cage” type design has an outer stator casing that carries the hydrogen coolers and an inner stator core and frame assembly that fits into the casing. Most manufacturers offer an integral one-piece design that combines the casing, the core and the frame into one integral stator. This would require special handling on account of being heavier than the individual casing and the inner stator of the present design.

Similar to Option 1, a new rotor winding will be installed in the existing forging. Validation testing will be performed on the forging to provide assurance of its suitability for service for the additional 30 years.

Option 3 – Replace the stator and the rotor

This option has all the advantages of Option 2 (replace stator, rewind rotor) and removes the doubt regarding the longevity of the present rotor forging. A new rotor forging would be machined to fit existing space in relation to the coupling with the low pressure turbine shaft and the interfaces with the bearings, the stator, hydrogen seals, turning gear and the shaft-driven oil pump. It would save resources required at the station to support a rewind effort and avoid the need for shipment of the finished rotor off-site for balancing and over-speed testing. The need for a new rotor forging will result in additional cost with long lead-time and will require special expediting for its procurement in order to meet the project schedule.

Option 4 – New generator

This option not only provides all the advantages of Option 3 (replace stator and rotor) but also gives the manufacturer the freedom to include new design features without the restriction of having to fit to existing dimensions and methods. However, this option involves a significant engineering effort in tying the new generator and the auxiliary systems to existing station equipment and systems such as the foundation block, the isolated phase bus duct, lube oil pump and turning gear. There could also be a greater impact on operating requirements, documentation, training, and impact on spare parts inventory because the new generator would represent about a 40-year advancement in design.

At first glance, the installation of a new generator might appear to be an extreme option as it is not a universally applied solution. However, it merits consideration for the following reasons:

a) The rewind alternatives (Options 1 & 2) may be adequate for extending the life of the generator but they could fall short of the 30-year life extension. Hence, even if these options were less expensive to begin with, the possible need for another rewind in the future would considerably increase the cost of these options.
b) A new stator and a new rotor (Option 3) would provide increased assurance for a 30-year operating life. However, because of the need for a new stator core and a new forging in addition to the new windings, the cost would be significantly higher than the rewind options above. The need to use the existing casing and the difficulty of quoting on the existing 2-part stator design by non-OEM vendors are further disadvantages of this option.
c) Based on budget estimates obtained earlier, the premium to be paid for a new generator over new components (Option 3) is small. This premium may be justified considering the benefits of a proven, modern generator design that is unfettered by the restrictions imposed by the existing design.

Impact of Multiple Options

Technical Specification – The type of refurbishment to be carried out to extend the life of a generator is often decided at the outset. This is due to various reasons such as unit availability requirements, operating duty, vendor recommendation, condition assessment, age of the generator, failure history, operating experience of similar equipment, schedule and cost. After selecting the rewind or the replacement option, a technical specification is written to set out the parameters of the work anticipated. The selection of the refurbishment option beforehand can reduce the engineering effort required to produce and handle the technical specification to a minimum.

Tendering Documents – The technical specification forms part of the tendering documents that were issued for bids to prospective bidders. Considerable amount of work by all the vendors will be required to handle the options involved. The non-OEM bidders face the additional obstacle of lack of equal access to OEM data. This could adversely affect their ability to meet the schedule. When the generator is shut down in 2008, non-OEM vendors will have an opportunity to inspect it for the purpose of engineering the refurbishment.

The number of options being considered makes the tendering package quite complex. The bid request seeks firm prices for 4 generator options, 2 exciter options, 10 component option items and 7 auxiliary system option items subject to condition assessment. In addition, vendors may offer additional equipment and work items they consider to be beneficial to the project.

Hence, while more options can provide for a better match with the requirements of the client, it comes with a cost of additional engineering effort in the early part of the project life cycle.

Conclusions

Generator life extension options beyond the basic rewinding of the stator and the rotor can be beneficial in a competitive bidding environment. Even a new generator could be cost effective and technically more sound, particularly where challenges exist in the removal, handling and shipment of components.
Where numerous options are required to meet the needs of the project they can be effectively managed by ensuring adequate resources for the preliminary engineering stage; including staff, time and a proven and flexible project documentation system. However, careful selection of the refurbishment option beforehand and limiting them to a manageable number would significantly reduce the effort required during pre-order order engineering. This would have positive impact on the project budget and schedule.