A Report to
The Board of Commissioners of Public Utilities

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UNIT 1 AND UNIT 2 GENERATOR STATOR REWIND

Holyrood Thermal Generating Station

July 2011
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1 INTRODUCTION

Newfoundland and Labrador Hydro’s (Hydro) Holyrood Thermal Generating Station has a total capacity of 500MW. The Holyrood Thermal Generating Station consists of three oil fuelled generating units which produce approximately 33 percent of the Island Interconnected system’s installed capacity. Units 1, 2 and 3 were commissioned in 1969, 1970, and 1979, respectively. Units 1 and 2 are 175 MW and Unit 3 is rated at 150 MW. Unit 3 has synchronous condensing capability.

Figure 1 - Unit 1 Generator End of Steam Turbine Generator
The generator of each generating unit is approximately five meters in diameter. A generator consists of two main parts: a rotor and a stator. The rotor is connected to a steam turbine and rotates because of the force of high pressure, high temperature steam on the turbine blades. The stator is the stationary part of the generator. As the rotor spins inside the stator, electricity is produced.

The stator is composed of a series of copper wire bars (stator bars) that form the stator winding. Each copper wire bar is mechanically secured into a slot around the perimeter of the stator. This support structure for the winding is the stator core. Along with being mechanically connected, each bar is electrically connected. The generator is three phase and as such has a bar for each of the three phases, with each individual phase being electrically connected together to form the stator winding. For the purposes of nomenclature, the electrical phases are usually represented as A phase, B phase and C phase or in the case of the AMEC condition assessment they are stated as left phase, center phase and right phase.
The stator core is constructed of a series of stacked steel plates each containing slots for the placement of two stacked stator bars. The stator bars are embedded into these slots along the perimeter of the stator to form the stator winding. The copper bars are multi-strand strips of copper and have a packing system that secure the bars in each slot as shown in Figure 3.

![Figure 3 – Stator Bars - Packing System](Photo from GE Turbine-Generator Manual - S.G.E.I. 3025)

The insulation is used to isolate the current carrying copper material from contact with the stator core, which without insulation would produce an electrical fault. As such, the condition of the insulation is a key monitoring component to the health of the stator winding. The insulation material, like all materials, will deteriorate with time and use. This proposal is based on the lifecycle point for the stator bar insulation of Units 1 and 2 having reached their end-of-life.

As the insulation levels are diminished, the occurrences of electrical fault become increasingly more probable which will eventually lead to the complete failure of the generating unit. Ideally, the replacement of the stator windings is completed before a
failure occurs with the generating unit. Failure of a generating unit is unplanned and results in the unavailability of the generating unit with costly repairs and the requirement for additional sources of power to replace the failed unit.

Inspections completed on Units 1 in 2003 and 2 in 2005 by GE Energy Services (GE) provided recommendations on the condition of the stator windings. From the 2005 report, it recommends “that the stator be rewound in near future”\(^1\). Although a precise time of failure cannot be predicted, it is likely the stator windings on Units 1 and 2 will fail prior to the anticipated decommissioning of the facility.

As part of a 2009/10 approved capital project titled “Condition Assessment & Life Extension – Holyrood Generating Station”, Hydro commissioned the engineering consultant AMEC to assess the condition of the existing major plant systems, including the generators and their stator windings, for generating Units 1 through 3 at the Holyrood Generating Station. The AMEC review was based on historical overhaul, inspection, maintenance, and testing data. The intent was to state the present condition of the equipment. AMEC used Robert Jefferys,\(^2\) an independent generator expert to determine these results. Among other items, the AMEC report stated it would be “considered appropriate to proceed with the installation of a new stator winding at the next major outage in 2012”\(^3\). This report is based on a review of all relevant data for these windings and is generally consistent with the GE Energy Services recommendations of 2003 and 2005 for Unit 1 and Unit 2 respectively.

The anticipated mode of operation for Holyrood Generating Station is gradual reduction in the available generation starting in 2017 until 2020 when the plant becomes a synchronous condenser facility. The process of changing a unit to a synchronous condenser involves reversing the rotation of the unit and making the unit a motor rather than a generator. As such the stator windings would be required for each unit as a generating station or a

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\(^1\) GE Energy Services – Steam Turbine Inspection Report, FSR# 20350952, August 9, 2005, Pg 8. (Attached as Appendix C)

\(^2\) See Resume – Appendix A.

\(^3\) AMEC – Condition Assessment & Life Extension Study, 6.4 Actions XI (Attached as Appendix E)
synchronous condenser facility. Thus, this proposal is aligning with the anticipated mode of operation for Holyrood facility for 2020 onward.
2 PROJECT DESCRIPTION

The proposed schedule of replacement is based around planned major unit outages. As such, Hydro’s intention is to replace the stator windings of Unit 2 in 2014 and of Unit 1 in 2015.

The proposal work schedule includes:

I. In 2012, tendering for the procurement and installation of two generator stator windings;
II. In 2013, completing the purchase order for two stator windings for Unit 2 and Unit 1 with delivery in 2014 and 2015 respectively; and
III. The delivery and installation of the stator windings for Unit 2 in 2014 and Unit 1 in 2015 during their summer outage periods coincident with the planned major turbine generator maintenance. The work will also include an upgrade to the generator protection and refurbishment of other generator components to ensure the new windings operate to their full capability.

It should be noted, that changes in the proposed work schedule can occur, including the order of unit installation work. Changes could occur due to the lack of available outage time, emergency work on units or the availability of new technical information on a unit’s parameters.

As part of other work at Holyrood Generating Station in 2012, Unit 1 has a planned generator inspection. This inspection will produce a detailed condition assessment report of Unit 1 generator providing greater analysis into the level of deterioration of this unit since its last condition report in 2003.

As part of the preventative maintenance process, some monitoring equipment is included
with the stator winding. This equipment includes: Resistive Temperature Detectors (RTDs) for temperature monitoring and Partial Discharge (PD) couplers for the measurement of insulation deterioration through the measurement of electrical corona on the insulation. These devices aid in the conditioning monitoring to aid in reducing the probability of an in-service failure.

This proposal also includes an upgrade of the generator protection equipment. The existing generator protection equipment consists of electromechanical relays which are slow to operate in comparison to the newest electronic technologies, which operate ten times faster than the older relaying technology. This improved time performance would provide better response time to protect the generator; as well the newer technologies have improved output response data of a generator fault event. During a fault situation the speed of isolating the generating equipment usually minimizes the level of damage to the equipment and its time and cost to repair.

The ordering of two stator windings is being pursued to mitigate the risk of a Unit 1 failure before a planned installation could be completed. A failure on Unit 1 would create a risk to planned Unit 2 work and would cause budget overruns. In addition, the ordering of two stators for delivery in different years does provide the least cost option for the supply of these items.

Based on the manufacturer manuals for Unit 1 and Unit 2, the manufacturer has stated that asbestos was used during the original installation of these units. Hydro has no record or indication of any asbestos removal on Unit 1 or Unit 2 over the past 40 years. This proposal will include the remediation of asbestos for Unit 1 and Unit 2.
3 EXISTING SYSTEM

The existing windings on Unit 1, and Unit 2, are nearing the end of their useful lives and are in poor condition, consistent with similar units of their design and age. General Energy Services (GE) has produced inspection reports for Unit 1 in 2003 and Unit 2 in 2005.

In 2003, Unit 1 inspections found serious indications of a potential winding failure. The results of the stator winding electrical tests indicate a low dielectric strength of the insulation; Unit 1 winding is closer to failure than the winding of the other generating units.

The electrical testing completed by General Electric included: insulation testing, a polarization index of each phase and a DC high voltage leakage test. The results of the insulation testing and the polarization index were satisfactory. However, the results were considerably lower on two of the three phases. This indicates that considerable deterioration has occurred on the insulation of these two phases. Based on these initial results, General Electric took the unusual step of repeating the insulation test and polarization index testing, to ensure the initial results were accurate.

The results of the second insulation testing showed further reduced insulation dielectric from the previous testing. The results of the second polarization index also showed a reduced insulation level from the previous testing. These results indicate that the winding insulation contains a serious weakness, has excessive dirt and moisture present or is a combination of both conditions.

Due to the known condition of the windings, the DC high potential leakage test was conducted at reduced levels from those recommended by the manufacturer. The stator winding passed the DC high potential leakage test. The results did indicate satisfactory results for the left phase, but the centre and the right phases had high levels of leakage current. This differing result confirms the results of the other testing, that two phases are in significantly poorer condition than the third phase.
From inspection testing in 2003, General Electric concluded that the results of the electrical tests are “a good indication of deteriorated condition of the ground wall insulation”. The report stated that “Based on results of the visual inspection, high-voltage testing, and age of the winding I recommend to plan a full generator stator rewind with new bars in the near future.”

In 2005, General Electric inspected and tested the Unit 2 stator windings and reported they were in very poor condition. The condition reported extensive loosening of the stator bars in their slots, and in the end-winding supports. Oil was found throughout the generator and extensive greasing had developed in the end-windings, and in parts of the slot teeth. Further condition details can be found in the 2005 GE report. (See Appendix C).

The insulation resistance measurements showed that the dielectric strength of the insulation on two of the three phases was significantly weaker. The DC high potential test showed that all three phases had high leakage current and there was a large spread in testing results between one phase and the other two phases. This confirmed the poor condition of the right phase. The polarization index results proved satisfactory indicating dry insulation on the stator windings.

From the results of the visual findings and poor electrical testing, General Electric recommended a replacement of the Unit 1 stator winding and the Unit 2 stator winding as stated in Appendices B and C respectively. As an interim least cost measure, Hydro has installed improved stator ground fault equipment on each generator to indicate the presence of a winding failure condition on a unit. This fault indication is used to minimize stator winding damage.

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4 GE Energy Services – Generator Inspection Report FSR# 20350670 September 18, 2003, Pg. 5.
5 GE Energy Services – Generator Inspection Report FSR# 20350670 September 18, 2003, Pg. 5.
In addition, like the deteriorating stator windings, elements of the existing monitoring equipment on Unit 1 and Unit 2 have also deteriorated and are problematic for preventative maintenance on the stator winding. This equipment includes the RTD thermocouples for temperature detection which are embedded in the stator windings and the Partial Discharge Couplers (PDA) which measure electrical spark or corona activity and provide a condition level of the stator winding insulation also known as dielectric strength.

The General Electric manuals for Unit 1 and Unit 2 have referenced the use of asbestos within the stator winding. Hydro has no record or recount of asbestos removal within the generating units and is considered to be the existing condition of the stator winding until substance testing can be completed during stator winding removal.

The existing stator winding has Class B insulation which was the standard insulation for the late 1960’s. Class B insulation has a temperature level of 133°C and is known to soften as the temperature rises. This can be problematic, as with rising temperature the insulation softens to the point that it liquefies and drips, diminishing the insulation over time. A new stator winding would be of the present insulation standard which is Class F insulation, this insulation has a temperature level of 155°C and remains rigid over its temperature range.

### 3.1 Age of Equipment or System

Generating Units 1 and 2 were installed and commissioned in 1969 and 1970 respectively. Their maximum continuous rating (MCR) output was increased in 1988 and 1989 respectively from 150 MW to 175 MW. This increase to Unit 1 and Unit 2 did not replace the stator winding.

The Unit 1 operating hours to the end of February 2011 were 171,951 which is equivalent to approximately 20 years continuous operation. It is expected to attain approximately 179,000 hours before the next major inspection in 2012. The unit averages about four starts
per year, which should have negligible deteriorating effect on the generator.

The Unit 2 operating hours to the end of February 2011 were 163,732 which is equivalent to approximately 19 years continuous operation. It is expected to attain approximately 179,000 hours before the next major inspection in 2014. The unit averages about thirteen starts per year, which should have negligible deteriorating effect on the generator.

The generating units and in particular the stator windings, have increased forces and loading induced upon them during severe system events, such as storm or lightning conditions where power lines may trip or reclose. Unit 1 and Unit 2 generators are no exception and do encounter numerous system faults and swings in load during system events. During these system events, the increased forces are induced on the stator windings which stress and deteriorate the winding components. In particular, faults on the power system will result in over-current and large mechanical forces on the stator windings. Thus, with the reduced stator winding insulation levels and the possibility of system events on the generator, there is an increased risk of a generator failure.

### Table 1 – Holyrood Unit 1, Unit 2 and Plant Performance

<table>
<thead>
<tr>
<th>Five Year Average 2005-2009</th>
<th>All Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capability Factor (%)</td>
</tr>
<tr>
<td>Holyrood Unit 1</td>
<td>59.24</td>
</tr>
<tr>
<td>Holyrood Unit 2</td>
<td>62.38</td>
</tr>
<tr>
<td>Holyrood Plant</td>
<td>60.04</td>
</tr>
<tr>
<td>CEA</td>
<td>74.74</td>
</tr>
</tbody>
</table>

Capability Factor is defined as unit available time. It is the ratio of the unit’s available time to the total number of unit hours.

DAFOR is defined as Derated Adjusted Forced Outage Rate. It is the ratio of equivalent forced outage time to equivalent forced outage time plus the total equivalent operating time.

Failure Rate is defined as the rate at which the generating unit encounters a forced outage. It is calculated by dividing the number of transitions from an Operating state to a forced outage by the total operating time.
3.2 Major Work and/or Upgrades

Major work and upgrades completed on Units 1 and Unit 2 are shown in Table 2:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Year</th>
<th>Major Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2009</td>
<td>Fast dump of generator hydrogen installed.</td>
</tr>
<tr>
<td>1</td>
<td>2008</td>
<td>Stator winding ground fault protection improved.</td>
</tr>
<tr>
<td>1</td>
<td>2003</td>
<td>Hydrogen dryer and purity meter replaced.</td>
</tr>
<tr>
<td>1</td>
<td>2003</td>
<td>Stator slot wedges replaced and end-winding support system re-tightened;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defective RTD repaired;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Digital multi-functional generator protection relay installed (for improved</td>
</tr>
<tr>
<td></td>
<td></td>
<td>winding ground protection, alarms connected, and sequence of events);</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Four new cold gas RTD’s in stator installed;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Realigned hydrogen seal housing and rotor shaft line.</td>
</tr>
<tr>
<td>1</td>
<td>2000</td>
<td>ABB static exciter and AVR replaced.</td>
</tr>
<tr>
<td>1</td>
<td>1997</td>
<td>New 18 %Mn/18 %Cr retaining rings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial discharge monitoring installed - stator windings.</td>
</tr>
<tr>
<td>1</td>
<td>1988/92</td>
<td>Uprated from 174.160 MVA at 30 psi hydrogen pressure, to 194.445 MVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>at 45 pounds per square inch (psi) hydrogen pressure;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retaining rings polished and NDE inspected in situ.</td>
</tr>
<tr>
<td>2</td>
<td>2005</td>
<td>Fast dump of generator hydrogen added;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Generator hydrogen dryer and purity meter replaced.</td>
</tr>
<tr>
<td>2</td>
<td>2005</td>
<td>Stator slot wedges replaced and slot couplers re-installed;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stator end-winding support system re-tightened;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RTD’s checked - 3 broken and 4 &gt; 20 % inaccurate;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Realigned hydrogen seal housing; hydrogen coolers cleaned;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Installed 4 new cold gas RTD’s in stator;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Digital multi-functional generator protection relay installed, (improved</td>
</tr>
<tr>
<td></td>
<td></td>
<td>winding ground protection, alarms connected, and sequence of events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>monitoring);</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrogen seal rings lapped and clearances re-set to lower limits to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>minimize future oil leaks.</td>
</tr>
<tr>
<td>2</td>
<td>1999</td>
<td>Installed slot couplers for partial discharge monitoring;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ABB excitation system installed;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrogen seal ring segments replaced;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrogen coolers cleaned.</td>
</tr>
<tr>
<td>2</td>
<td>1994</td>
<td>Retaining rings replaced;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stator end-windings and end-wedges re-tightened.</td>
</tr>
<tr>
<td>2</td>
<td>1989/90</td>
<td>Up-rated from 174.160 MVA at 30 psi hydrogen pressure, to 194.445 MVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>at 45 psi hydrogen pressure;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New hydrogen seal set installed;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retaining rings polished and NDE inspected in situ;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PCB excitation transformer drained, cleaned and re-filled.</td>
</tr>
</tbody>
</table>
### 3.3 Anticipated Useful Life

Holyrood’s Unit 1 and Unit 2 stator windings are depreciated over 25 years. However, generator windings typically have an estimated service life of approximately 35 years depending on operating conditions and maintenance. In its 2010 Holyrood Condition Assessment, AMEC stated the following regarding the condition of the Unit 1 and Unit 2 generators “… the visual inspections of the stator windings have shown that they are in a fairly advanced state of deterioration.” AMEC further stated to the remaining life of the units “In view of the next planned outage in 2012 there is little time left to write a specification for a new winding, place the contract for the work, and have new coils delivered ….It is probably more appropriate to proceed planning work for a rewind now, ....”.

The life cycle curves for the Unit 1 and Unit 2 generators from the AMEC report are illustrated below.

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6 AMEC – Condition Assessment & Life Extension Study, 6.1.1.3 Assessment
7 AMEC – Condition Assessment & Life Extension Study, 6.1.1.3 Assessment
3.4 Maintenance History

Since their installation in 1969 and 1970 respectively, the stator windings of Unit 1 and Unit 2 have had regular inspections, which include testing and replacement of faulty or worn components. Typically, the inspections were performed every six to seven years until 2003 when the interval was increased to nine years, consistent with the general direction of the industry. The cost of the typical inspection for the generator portion of a full steam turbine generator is about $1 million. The annual incremental preventive maintenance cost for the Holyrood generators has not been captured but is estimated to be less than $1,000 annually. Due to the deteriorated condition of the existing RTD and PD components on Unit 1 and Unit 2 generators, this portion of preventative maintenance is not monitored.
3.5 Outage Statistics

In the last five years, there have been no outages which were the direct result of the stator windings.

3.6 Industry Experience

The Unit 1 and Unit 2 stator windings were manufactured by General Electric using a proprietary insulation called Micapal, the windings are multi-turn coil. This design was manufactured in the 1960’s and 1970’s and is a common design used in many steam turbine generators built during this period.

Multi-turn coil windings with Micapal insulation have varying service lives, which are highly dependant on operating conditions and regular maintenance. If the stator windings are not overstressed and the manufacturer’s recommended maintenance is performed regularly, the service life of the windings is typically 30 to 40 years. However, this type of winding operating under normal conditions will normally need to be rewound within 40 years. AMEC indicated in its condition assessment report that many generators of this type throughout Canada have already undergone a stator rewind. Although a listing was not provided with the report, its author; Robert Jefferys has provided a partial listing as shown in Appendix G.

3.7 Maintenance or Support Arrangements

All maintenance performed on the stator windings has been supervised since 1986 by GE using contracted staff and experts with the support and supervision by Hydro personnel. GE also provides ongoing support and technical advice under a service contract.
3.8 **Vendor and Third Party Engineer Recommendations**

GE is the original manufacturer of these stator windings and participated in the inspection and testing of the Unit 1 windings in 2003 and Unit 2 windings in 2005. Based on their inspections and the results of the tests performed, GE Energy Services has recommended the rewind of the Unit 1 and Unit 2 stators in the near future. In addition, the condition assessment in 2010 by AMEC determined that the more prudent option is to replace the stator windings of Unit 2 at its next steam turbine generator overhaul in 2014 and in a dedicated Unit 1 generator outage in 2015.

3.9 **Availability of Replacement Parts**

GE halted production of this particular type of winding in the 1970’s. GE as well as the other large generator manufacturers can provide replacement windings designed specifically for the Holyrood units and provide delivery times suitable to meet the schedule outlined in this proposal. Hydro shall solicit bids from qualified vendors of stator windings.

3.10 **Safety Performance**

The generators at the Holyrood Generating Station use hydrogen gas as a coolant. Hydrogen gas is used as its heat transfer properties are better than air. Hydrogen is highly flammable and will burn with a concentration of four percent to 75 percent by volume. As such, careful operating and handling precautions must be followed when operating and working with hydrogen gas. The potential risk of fire to a hydrogen cooled generator is always present, especially in abnormal operating conditions (eg. stator winding failure).

Another area with thermal generating units that could pose a safety concern is the high rotation speeds of these units should a mechanical failure occur. Although the probability of mechanical failure is low the risk would be high and catastrophic if the condition were to happen. Unit 1 and Unit 2 rotate at 3,600 revolutions per minute, at these speeds there is a
large amount of kinetic energy should a failure occur. This energy combined with the energy of hydrogen gas would create a situation that could possibly produce fatalities and injuries from flying shrapnel and falling projectiles.

A third point that cannot be overlooked is the importance of Unit 1 and Unit 2 to the system and the safety of having a reliable energy source. As Unit 1 and Unit 2 in Holyrood are the largest single units on the island interconnected system they each play a pivotal role in establishing an energy balance on this system.

3.11 Environmental Performance

The possible presence of asbestos will be remedied in a safe and prudent manner. There are no other known environmental issues related to this project.

3.12 Operating Regime

Unit 1 and Unit 2 of the Holyrood Generating Station are designed for continuous operation with varying loads. They are typically operated as seasonally loaded in the November to March period to meet system peak winter requirements. The three Holyrood units together can provide about 33 percent of the Island Interconnected System load during the crucial winter peak period. Maintenance outages are typically taken during the summer months when their capacity requirements are less. These units have been operating in this mode, within their design capabilities, since they were commissioned in 1969 and 1970.

The anticipated operational schedule for the Holyrood Thermal Generating Station during the period 2011 to 2041 is:
Table 3: Holyrood Generating Station  
Anticipated Mode of Operation 2011 through 2041

<table>
<thead>
<tr>
<th>Period</th>
<th>Mode of Operation</th>
<th>Capacity Factor</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011 through 2013 - Generation</td>
<td>Capacity factor between 30% and 75%; Availability of 90% to 95%.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014 through 2016 - Generation</td>
<td>Capacity factor between 50% and 100%; Availability of 95%.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017 through 2020 - Generation Standby / Synchronous Condenser Mode</td>
<td>Capacity factor between 30% and 75%; Availability of 90% to 95%.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020 Onward - Synchronous Condenser Mode</td>
<td>Synchronous Condenser Operation – All three units; Capacity factor (MVARs only) 50% to 100%. Availability of 95%.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The three Holyrood Generating Station units continue their current operating regime until sometime after 2016. Units 1 and 2 will be retrofitted to be able to operate as synchronous condensers for system VAR support prior to DC in-feed, similar to Unit 3 which was retrofitted with synchronous condensing capability in 1986. Unit 3 typically provides that support during the summer season.
4 JUSTIFICATION

This proposal is justified to maintain system reliability by replacing the Unit 1 and Unit 2 generator stator windings before a failure occurs. The most appropriate timing would see the Unit 1 stator winding replaced in 2015 and the Unit 2 stator winding at next generator outage in 2014. Should a winding fail while in service, it could cause significant damage to the stator core and the generating unit, thus, impairing Hydro’s ability to provide cost effective power and reliable electrical service to the Island Interconnected System. The emergency replacement time on such equipment could potentially be up to eighteen months.

The life expectancy for Micapal insulated stator windings is approximately 35 years. However, this number varies based on such operating conditions as temperature, number of starts and stops, maintenance and care and unit loading. The windings of Units 1 and 2, and especially Unit 1, have reached the end of their useful service lives, supporting the fact that winding replacements are required.

Two independent condition assessments of the stator windings were completed in 2003 and 2005 by GE Services. GE assessed Unit 1 in 2003 and Unit 2 in 2005. The 2003 report stated “…I recommend to plan a full generator stator rewind…”8 while the 2005 report stated “It is therefore recommended that stator be rewound in the near future.”9

During 2010, the independent AMEC assessment, reviewed the historical test and maintenance data and industry experience and confirmed the GE findings and stated “…there is no doubt that the windings have deteriorated extensively in service. All test results show the right phase is in very weak condition. It has operated for a further 7 years to date, without a failure, but further deterioration can be expected, …it is considered

8 GE Energy Services – Generator Inspection Report FSR# 20350670 September 18, 2003, Pg. 5.
9 GE Energy Services – Generator Inspection Report FSR# 20350952 August 9, 2005, Pg. 8.
appropriate to proceed with the installation of a new stator winding..." The AMEC report considered the mode of operation for the Holyrood Generating Station in its assessment recommendations.

Taking the above recommendations into consideration, the Unit 1 and Unit 2 stator windings have an increased likelihood of failure over the next three years. Hydro has upgraded some of the generator protection systems, but some of the critical temperature monitoring instrumentation is inoperative and repair is not feasible, as these measuring devices are embedded in the stator winding. If a failure was to occur with the current protection in place, the possible damage to the stator core and rotor that could occur would result in possibly costs in the $13 to $20 million range. The generator protection is intended to prevent or reduce damage to the stator core and rotor when a failure occurs by eliminating the fault condition from the system, but with the age and deteriorated state of Unit 1 and Unit 2 the risk of stator damage is high. In order to prevent unnecessary damage to this generating unit and the potential system impacts of a long operational downtime during the winter peak period, the stator windings of Units 1 and Unit 2 must be replaced. The timing of the stator rewind will be reviewed once bids and delivery schedule are received following the tendering process to determine if an earlier rewind would be possible.

4.1 Net Present Value

A net present value calculation was performed in this instance based on the following three options:

1. Base Case: Replace Unit 2 stator winding in 2014 as part of planned steam turbine generator overhaul/testing. Replace Unit 1 stator winding in 2015 as part of dedicated generator stator rewind outage.

---

10 AMEC – Condition Assessment & Life Extension Study, 6.1.1.2 Condition
2. Case 1 - Status Quo: Replace Unit 2 stator winding in 2019 as part of dedicated generator stator winding replacement outage. Replace Unit 1 stator winding in 2018 as part of dedicated generator stator winding replacement outage.

3. Case 2 – Median Option: Replace Unit 2 stator winding in 2017 as part of dedicated generator stator winding replacement outage. Replace Unit 1 stator winding in 2016 as part of dedicated generator stator winding replacement outage.

All cases assume that the Unit 1 generator inspection in 2012 will allow testing to be undertaken to confirm the condition of the balance of the generator and to allow generator vendors to be able to take measurements necessary for rewinds to take place in 2014 for Unit 2 and 2015 for Unit 1.

The assumption is that there would be a 30 percent risk of stator winding failure in the year after the base case rewind date, and growing by ten percent per year to the year of the stator rewind for the option being considered. An in-service failure is assumed to involve substantial damage to the stator and possibly the rotor at a cost of about $10 million (2011 dollars). In addition, the failure probability is applied to increased generation replacement fuel costs from the stand-by simple cycle gas turbine and diesel plants on the Avalon Peninsula (approximately $28,250,000 over the period 2015 through 2019 inclusive). Given the limited stand-by generation capability the analysis indicates a significant amount of unsupplied energy with outages to customers on the Island Interconnected System ranging from 200 to 490 hours over the period 2015 to 2019 inclusive with the loss of Unit 1 or Unit 2 at Holyrood Generating Station. A summary is shown in Table 4.
Table 4 – Summary of Unsupplied Load Implementations

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Gas Turbine Cost ($M CAD)</th>
<th>Unsupplied Load (MWh)</th>
<th>Unsupplied Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>$3.05</td>
<td>10,200</td>
<td>200</td>
</tr>
<tr>
<td>2016</td>
<td>$4.93</td>
<td>19,600</td>
<td>340</td>
</tr>
<tr>
<td>2017</td>
<td>$5.86</td>
<td>24,500</td>
<td>400</td>
</tr>
<tr>
<td>2018</td>
<td>$6.77</td>
<td>30,110</td>
<td>440</td>
</tr>
<tr>
<td>2019</td>
<td>$7.64</td>
<td>36,500</td>
<td>490</td>
</tr>
</tbody>
</table>

Table 5 - Present Value Analysis

<p>| HRD - Rewind Generators Unit 1 |
|---------------------------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Alternative Comparison</th>
<th>Cumulative Net Present Value (CPW)</th>
<th>CPW Difference between Alternative and the Least Cost Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative Net Present Value</td>
<td>To The Year 2041</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unit 1 in 2015</td>
<td>10,119,456</td>
</tr>
<tr>
<td></td>
<td>Unit 1 in 2016</td>
<td>11,793,741</td>
</tr>
<tr>
<td></td>
<td>Unit 1 in 2018</td>
<td>12,922,248</td>
</tr>
</tbody>
</table>
The results of the above table are summarized in Appendix D.

Economically given the costs, the potential system impacts and the required life of the equipment, the base case stator winding replacement scenario is the only reasonably viable alternative.

### 4.2 Levelized Cost of Energy

Levelized Unit Energy Cost (LUEC) is not readily applicable to this proposal, given the fact that a large part of the generator value will be during its role as a synchronous condenser producing reactive power (MVARS) for system support and not electrical energy (MWh).

### 4.3 Cost Benefit Analysis

A cost benefit analysis is not applicable for this proposal, except as may be inferred from the Present Value analysis.
4.4 Legislative or Regulatory Requirements

There are no specific legislative or regulatory requirements which affect this proposal.

4.5 Historical Information

There is no historical information associated with this proposal.

4.6 Forecast Customer Growth

The forecasted customer load on the system has no effect on this proposal. The relevance to both its generation role during peak winter periods in the short term and its synchronous condensing support of generation from Labrador via HVDC transmission in the period 2017 to 2041 is significant.

4.7 Energy Efficiency Benefits

There are no significant energy efficiency benefits anticipated from this proposal; although Hydro will continue to examine all energy efficiencies that are cost effective.

4.8 Losses during Construction

The stator rewind of the units will take about three to four months. The rewind will be done in parallel with the scheduled 2014 steam turbine generator outage for Unit 2 and in 2015 for Unit 1 in a dedicated generator stator rewind outage.

The work would be planned for the late spring through to the early fall, there will be no system loss impacts during the rewind.
4.9 Status Quo

The stator windings of Unit 1 and Unit 2 of the Holyrood Generating Station are operating beyond the expected useful service lives. Inspections and testing in 2003 and 2005 have confirmed that a stator winding failure is increasing more probable. While some protection systems are in place to mitigate the potential for major consequential damage, there is a significant potential for such damage. Further assessment by an independent expert in 2010 confirmed the need to rewind Unit 1 and Unit 2 generators. Therefore the status quo of operating without a replacement plan is not a reasonable option considering the operating regime for these units, their power system role, and the impact of long forced outages.

4.10 Alternatives

See Section 4.1.
5.0 CONCLUSION

Unit 1 and Unit 2 of the Holyrood Generating Station have been in service since their commissioning in 1969 and 1970. The stator windings of these units are now past the end of the useful service lives of approximately 35 years. According to testing and inspections of Unit 1 in 2003 and Unit 2 in 2005, there is a significant potential for winding failures. If the windings for the Units 1 and 2 are left in service and run to failure, it is likely that the machine stator cores and rotor windings and core could be damaged when the stator windings fail. For these reasons, the stator windings of Unit 1 and Unit 2 should be replaced during the planned outage seasons in 2015 and 2014 respectively. This project will see the installation of a new winding in Unit 1 and Unit 2. Proposals for rotor rewinds and Unit 3 rework will be made in future years - Unit 3 being installed 10 years after Unit 1.

The replacement of stator windings on Unit 1 and Unit 2 would improve the reliability of the generating units and ultimately the generating station. The possibility of Unit 1 or Unit 2 failure through system faults or end of useful service life would be minimized or eliminated. The improved reliability would make Unit 1 and Unit 2 available for the anticipated life of the Holyrood Generating Station until 2041.

The replacement of Unit 1 and Unit 2 stator winding and a protection upgrade would minimize the safety risk of fire created from hydrogen cooled generators, as the possibility of a stator winding failure would be minimized.

5.1 Budget Estimate

The estimate for the proposal is $11.9 million. The budget estimate is shown in Table 6.
Table 6: Budget Estimate

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Supply</td>
<td>10.0</td>
<td>850.0</td>
<td>1,650.0</td>
<td>850.0</td>
<td>3,360.0</td>
</tr>
<tr>
<td>Labour</td>
<td>80.0</td>
<td>80.0</td>
<td>85.0</td>
<td>95.0</td>
<td>340.0</td>
</tr>
<tr>
<td>Consultant</td>
<td>9.1</td>
<td>55.3</td>
<td>0.0</td>
<td>0.0</td>
<td>64.4</td>
</tr>
<tr>
<td>Contract Work</td>
<td>0.0</td>
<td>0.0</td>
<td>2,500.0</td>
<td>2,500.0</td>
<td>5,000.0</td>
</tr>
<tr>
<td>Other Direct Costs</td>
<td>5.0</td>
<td>15.0</td>
<td>9.8</td>
<td>14.9</td>
<td>44.7</td>
</tr>
<tr>
<td>Interest and escalation</td>
<td>8.1</td>
<td>107.3</td>
<td>640.9</td>
<td>1,508.9</td>
<td>2,265.2</td>
</tr>
<tr>
<td>Contingency</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>826.9</td>
<td>826.9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>112.2</strong></td>
<td><strong>1,107.6</strong></td>
<td><strong>4,885.7</strong></td>
<td><strong>5,795.7</strong></td>
<td><strong>11,901.2</strong></td>
</tr>
</tbody>
</table>

5.2 Project Schedule

The anticipated schedule for this proposal is shown in Table 7 below.

Table 7: Project Schedule

<table>
<thead>
<tr>
<th>Activity</th>
<th>Start Date</th>
<th>End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Unit 1 Maintenance, Condition Assessment.</td>
<td>April 2012</td>
<td>September 2012</td>
</tr>
<tr>
<td>• Outage Request, Project Planning Unit 2</td>
<td>January 2014</td>
<td>March 2014</td>
</tr>
<tr>
<td>• Outage Request, Project Planning Unit 1</td>
<td>January 2015</td>
<td>March 2015</td>
</tr>
<tr>
<td>Procurement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Tendering and Award for Unit 1 and 2.</td>
<td>November 2012</td>
<td>March 2013</td>
</tr>
<tr>
<td>• Unit 2 Equipment Ordering and Delivery for Unit 2 in 2013</td>
<td>April 2013</td>
<td>November 2013</td>
</tr>
<tr>
<td>• FAT Testing for Unit 2</td>
<td>September 2013</td>
<td>October 2013</td>
</tr>
<tr>
<td>• Unit 1 Equipment Ordering and Delivery for Unit 1 in 2014</td>
<td>April 2014</td>
<td>November 2014</td>
</tr>
<tr>
<td>• FAT Testing for Unit 1</td>
<td>September 2014</td>
<td>October 2014</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Install Stator Winding, Generator Protection on Unit 2</td>
<td>May 2014</td>
<td>October 2014</td>
</tr>
<tr>
<td>• Install Stator Winding, Generator Protection on Unit 1</td>
<td>May 2015</td>
<td>October 2015</td>
</tr>
<tr>
<td>Commissioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Commissioning Unit 2</td>
<td>October 2014</td>
<td>November 2014</td>
</tr>
<tr>
<td>• Commissioning Unit 1</td>
<td>October 2015</td>
<td>November 2015</td>
</tr>
<tr>
<td>Closeout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Unit 2 Closeout</td>
<td>November 2014</td>
<td>December 2014</td>
</tr>
<tr>
<td>• Unit 1 Closeout and Project Completion</td>
<td>November 2015</td>
<td>December 2015</td>
</tr>
</tbody>
</table>
APPENDIX A
Resume – Robert Jeffreys Amec Generator Expert
Robert Jeffreys, P.Eng.
Generator Specialist

Professional summary
Design and manufacture of large turbine generators
Application of generators at new hydraulic, fossil and nuclear plants
Installation, commissioning and performance evaluation of plant
Testing and inspections of generators and auxiliaries
Resolution of operating and maintenance shortcomings
Major repairs, rehabilitations, reliability upgrades, life extension programs

Professional qualifications
Association of Professional Engineers of Ontario (Electrical)
Institution of Electrical Engineers (UK)

Education
Bachelor of Science in Mechanical (and Electrical) Engineering, 1960
University of Durham, England

Memberships/Affiliations
Member of Institution of Mechanical Engineers (UK), 1961-1978
Member and Chairman, Rotating Machines Sub-Committee, CEA, 1970-1987
Convenor of Generator Reliability working group, CIGRE, 1980-1984
Member of Generation Research and Development Committee, CEA, 1980-1984
Co-chairman, hydraulic turbine generator alignment guide, CEA, 1984-1987

Selected Publications, Awards, Presentations
Twelve lectures/seminars on generator and motor topics for EPIC, 1995-2008
  (Electrical equipment, gas turbines, co-generation and combined cycle plants,
  emergency generators, electric motor applications, variable speed drives)
Operation of stator cores, for IRIS generator conference, 2006
New technology award for generator expert monitoring system, for EPRI, 1993
Generator rehabilitation - experience at Lakeview, for CIGRE, 1992
Failure analysis of large motors, CEA research report,1988
Up-rating Bruce B generators, for CEA, 1987
Improving reliability of large generators, for AIM conference, 1985
Canada’s R & D program for large hydraulic plant, for CIGRE, 1983
Mechanical problems of turbo-generators, for CEA, 1979
Languages
English

Employment history
AMEC, Oakville, Ontario (2010 – Present – Contract Basis)
Jeffreys Generator Services, Owner (1994-Present)
Section Head-Power Equipment, Mechanical Engineering Dept, Toronto, ON (1975-1993)
Parsons, England, Generator Design Engineer (1960-1965)

Representative projects

AMEC
Holyrood Condition Assessment and Life Extension Study – Generator condition review and assessment

Jeffreys Generator Services
Detailed major inspections of 60 MW and 150 MW generators at fossil plants
Annual inspections of two 35 MVA generators, now over 60 years old
Inspection of an 18.8 MW hydraulic generator in Newfoundland
Inspection and test of two used 60 MW combustion turbine generators before purchase
Failure analyses of 150 MW and 66 MW generator rotors, with a ground fault
Health assessment of emergency power generators at a nuclear plant
Review of a major power system disturbance (blackout) in Saskatchewan
Review of settings of new generator protection relays at Boundary Dam GS
Study of turbine generator vibration levels and trends over several years
Draft specification for a spare 60 MW combustion turbine generator
Review of failure and repair reports for a 15 MW generator rotor
Conversion studies for 300 MW and 490 MW generators to synchronous condenser duty
Draft generic specifications for rewinding a stator and a rotor
Purchase, installation and inspection of a replacement 300 MW stator

Ontario Hydro
Mechanical Engineering Dept.
Developed generator expertise similar to suppliers, with user focus
Design reviews caught weaknesses and improved features at all plants
Developed reliability measurement and analysis, to justify improvements
Set up regular performance feedback with suppliers, to update quality
Implemented continuous improvement program for Nanticoke generators
Uprated each Bruce B generator by 80 MW, with no adverse reliability
Developed and implemented life extension program at Lakeview, Lambton
Pioneered use of static exciters with stabilizers to enhance stability, output
Pioneered use of EL-CID core inspections, and PDA winding evaluation
Completed EPRI research projects e.g. expert monitor, insulation tests
Led failure investigation of Nanticoke retaining ring, modified other rings
Participated in hydraulic generator monitoring project for EPRI

**Equipment and Materials Dept.**

25/60 Hz frequency conversions of hydro-generators at Abitibi and Beck
Implemented prototype generator designs at new generating stations.
Developed accelerated aging test for new generator insulation systems
Partial rotor rewinds at Lambton. Rebuilt synchronous condenser
Bought spare rotors and stators to facilitate repairs e.g. Lakeview, Pickering
Rewound sixteen 10 MW primary coolant pump motors

**Montreal Engineering Company**

Design of electrical systems and major equipment for a 300 MW thermal power plant at Wabamun, Alberta
Inspected generator and motors during manufacture and test
Provided consulting services on electrical machinery to other projects and to utilities

**Parsons**

Carried out electrical and mechanical designs of generators from 10 to 660 MW
Participated in research and development of features for large generators
Evaluated and improved designs through analysis of factory tests and operating experience
Taught electrical machines and power systems to Higher National Certificate students at local technical college (night classes)
APPENDIX B
GE 2003 Unit 1 Generator Inspection Report Summary
JOB SUMMARY

This report covers test, inspection, and emergency repair activities performed in June 2003 on Unit 1.

Field
1. Visual inspection of the generator field was conducted. The field was found dirty and was cleaned with dry air prior to reassembly.

Stator
1. Visual inspection of the stator was conducted and all information on the findings is included in this report. While CE endwinding was found in good condition TE endwinding was found in very deteriorated condition. Attention needs to be given to the stator winding condition, stator wedges, and ties. Oil was noted on the endwinding and in the stator slots. It is clear that as result of oil spill in the past the bar slot system is saturated with oil and the friction component of the side ripple spring is reduced and its effectiveness is diminished. Deterioration of any part in the bar restraining system may lead to accelerated wear of stator winding insulation. Series loops 9 and 10 on the TE were found covered with thick layer of grease and dust, paint coat on this series loops caps cracked.
2. A complete stator wedge tightness test was performed and numerous wedges were found loose or hollow. The complete wedge map is included in this report. For longer-term reliability a full rewedged with improved-design top ripple spring system was performed.
3. Retorquing of stator axial supports, and hand cleaning of the endwinding on TE was performed. Red eye epoxy was applied to the endwinding ties for additional stiffness.
4. DC leakage tests were performed before and after the rewedged work with similar results. High leakage current was observed in all 3 phases, especially phase T1. This is good indication of deteriorated condition of the ground wall insulation.
5. All repairs performed during this outage will slow process of winding insulation deterioration but can't reverse damage already caused to the winding insulation as result of slot support system looseness, shaky endwinding support and oil ingress. Based on results of the visual inspection, high-voltage testing and age of the winding I recommend to plan a full generator stator rewind with new bars in the near future to correct insulation degradation of the stator winding system and assure long-term reliability.
APPENDIX C

Ge 2005 Unit 2 Generator Inspection Report Summary
RECOMMENDATIONS

SHOULD BE DONE AT THE NEXT OUTAGE...

1. Stator: Winding;

GE recommended AC hipot test voltage for this machine is 24 KV. In case customer decides to perform a DC hipot test then the recommended voltage for this machine is 40.8 KV. These values are based on suitability to service voltage for a reliable operation. A DC hipot test at 34 KV was carried out. Testing at this voltage does not give the level of confidence for reliable operation of the unit for long time. It is therefore recommended that a full AC hipot test at 24 KV AC be performed.

2. Stator: Winding;

Based on units past maintenance history it is quite immanent that condition of the winding and support hardware has deteriorated. Any maintenance that is being performed is to slow the further degradation process in short run. In the long run reliability of the unit is in question. It is therefore recommended that stator be rewound in near future.

3. Instrumentation: Rtd;

Hot and cold gas RTD's needs to be replaced.
APPENDIX D
Amec Unit 1 Generator Condition Report Summary
3.0 CONDITION SUMMARY

Summary:

- Stator core: satisfactory, based on El-cid results.
- Stator Windings: Poor, based on Megger test and DC hipot test.
- Rotor Forging: Not known. (Appears not checked in past 20 years).
- Field Winding: Satisfactory, but few details available (concerns are based on repairs made to similar GE rotors)

**Stator core and Frame:** The stator core and frame are reported to be in good condition, with no loose ness or fretting damage at the bore, or at the outside flexible mounting. GE reported that El-cid readings taken before and after the re-wedging of the stator bars in 2003 show no significant core deterioration, and the stator core is fit to be re-wound.

Excessive greasing of the stand-off insulators, and the flexible line leads to the potential transformers has occurred in the past, which required their replacement. The alignment of the stator was changed in 2003, which is expected to have reduced the vibration and stress on these components.

**Stator Windings:** The stator windings were inspected and tested at the start of the 2003 major outage by GE, and were reported to be in very poor condition. Extensive loosening had occurred of the bars in the slots, and in the end-winding supports. Oil was found throughout the generator and extensive greasing had developed in the end-windings, and in parts of the slot teeth.

The electrical tests, (insulation resistance, polarization index and a DC high potential step voltage of 34 KV confirmed that two of the phases were significantly weaker than the third phase, and had high leakage current and low polarization index, indicating insulation weakness (or wetness). (Further details of these tests and results are given below)

On the basis of the visual findings and poor electrical test results GE recommended that the stator windings be fully replaced. This has not been done to date. Improved stator ground fault protection has been installed, to minimize consequential core damage from a winding failure.

To repair the loose windings, the stator slots were fully re-wedged with an improved support system using top ripple springs. An El-cid test was carried out before and after the re-wedging operation, to show that no core iron damage occurred during the re-wedging operation. The oil, fretting dust and “grease” were cleaned off the end-windings and the loose areas were re-glued with penetrating epoxy. The end-winding support brackets were re-tightened, before the generator was returned to service.

No inspection of the stator windings has been carried out since 2003. It is expected that the ripple springs will provide improved support and retain the support for the stator coils for at least 12 years. However, the end-windings are likely to come loose again during operation, due
to the thermal movement of the windings under daily cyclic load, and the loosening effects of system faults on the windings.

The operating time to the next major inspection in 2012 has been increased from 7 years to 9 years. This does not appear logical, given the poor condition of the stator windings and the progressive nature of the loosening mechanism. It is anticipated that more extensive loosening, fretting, and greasing of the end-windings will be found at the next inspection.

No additional measures were taken in 2003 to prevent the end-windings looseness from re-occurring. If the winding is not to be replaced in 2012 it is recommended that a “bump” test be carried out on the end-winding coils, and extra support blocks be added, to remove any high vibration responses, or resonances near the 120 Hz magnetic force in operation. This has been done on several other units in Canada, with good success.

**Monitoring:** The RTD’s measuring the stator winding temperatures are in poor condition, and the four RTD’s logged in the control room do not read credible temperatures (At half load, they are colder than the cold gas which cools them). When GE measured the 15 RTD’s in 2003, 5 were broken, and the rest had temperature variations of up to 25 %, when measuring the “room temperature”. They are embedded in the windings, and cannot be replaced unless the windings are removed. All four cold gas temperature detectors had failed and new RTD have been installed. The DAS monitoring should be moved to the most accurate RTD’s.

**Rotor and Field Winding:** The condition of the rotor was reported as “dirty” by GE at the 2003 inspection. It was reported that the rotor was inspected visually by GE and “no serious defects were found”. The insulation resistance measurement of the field winding to ground gave a good result of 11.4 Giga-ohms. The collector ring dimensions show there is plenty of wear allowance left. However, the retaining rings were not removed, so there was limited access for inspection.

An examination of the field winding connections, end-windings, and ventilation passages could have been done, using a boroscope, but it is not stated in their report. Some permanent deformation (creep) of the field windings is expected after 34 years. This tends to overstress the flexible coil connections, especially of the longest coil, and of the connections of the windings to the leads, (the flexible interconnections of the longest coil are often replaced every 16 years, per a GE electrical supervisor). GE TIL 1292 recommends inspection of the rotor dovetails and another TIL requires checking the rotor slot wedges for cracks. It is expected that these checks would have been done in 1997 when the retaining rings were replaced. They should be done again in 2012.
APPENDIX E
Amec Unit 2 Generator Condition Report Summary
3.0 CONDITION SUMMARY

Summary:

- Stator core: satisfactory, based on El-cid results.
- Stator Windings: Poor, based on Megger test and DC hipot test.
- Rotor Forging: Not known. (Appears not checked in past 20 years).
- Field Winding: Satisfactory, but few details available (concerns are based on repairs made to similar GE rotors)

**Stator core and Frame:** The stator core and frame are reported to be in good condition, with no loose ness or fretting damage at the bore, or at the outside flexible mounting. GE reported that El-cid readings taken before and after the re-wedging of the stator bars in 2005 show no significant core deterioration, and the stator core is fit to be re-wound.

Excessive greasing of the stand-off insulators, and the flexible line leads to the potential transformers has occurred in the past, which required their replacement. The alignment of the stator was changed in 2005, which is expected to have reduced the vibration and stress on these components.

**Stator Windings:** The stator windings were inspected and tested at the start of the 2005 major outage by GE, and were reported to be in very poor condition. Extensive loosening had occurred of the bars in the slots, and in the end-winding supports. Oil was found throughout the generator and extensive greasing had developed in the end-windings, and in parts of the slot teeth.

The electrical insulation resistance measurements showed that two of the phases were significantly (20 % and 26 %) weaker than the third phase. The DC high potential step voltage of 34 KV showed that all three phases had high leakage current (30, 26 and 48 micro-amps), and the large spread (85%) between phases confirmed the poor condition of the right phase. The polarization index was satisfactory, showing the insulation was dry. However, the high relative humidity of 80% during the High potential test is expected to have contributed to the high leakage current.

On the basis of the visual findings and poor electrical test results GE stated that the stator windings will soon need to be replaced. This has not been done to date. Improved stator ground fault protection has been installed, to minimize consequential core damage from a winding failure. GE recommended an AC high potential test be carried out on the stator windings, but fortunately that was not done, as there is a high risk that the insulation would have failed, due to the aggravating effects of high humidity and dirt and grease, on the weak winding insulation.

To repair the loose windings, the stator slots were fully re-wedged with an improved support system using top ripple springs. An El-cid test was carried out before and after the re-wedging operation, to show that no core iron damage occurred during the re-wedging operation. The oil, fretting dust and “grease” were cleaned off the end-windings and the loose areas were re-glued.
with penetrating epoxy. The end-winding support brackets were re-tightened, before the generator was returned to service.

No inspection of the stator windings has been carried out since 2005. It is expected that the ripple springs will provide improved support and retain the support for the stator coils for at least 12 years. However, the end-windings are likely to come loose again during operation, due to the thermal movement of the windings under daily cyclic load, and the loosening effects of system faults on the windings.

The operating time to the next major inspection in 2014 has been increased from 7 years to 9 years. This does not appear logical, given the poor condition of the stator windings and the progressive nature of the loosening mechanism. It is anticipated that more extensive loosening, fretting, and greasing of the end-windings will be found at the next inspection. The partial discharge readings should be checked annually, to detect excessive greasing, and identify whether the next planned inspection should be brought forward.

No additional measures were taken in 2005 to prevent the end-windings looseness from re-occurring. If the winding is not to be replaced in 2014 it is recommended that a “bump” test be carried out on the end-winding coils, and extra support blocks be added, to remove any high vibration responses, or resonances near the 120 Hz magnetic force in operation. This has been done on several other units in Canada, with good success.

**Monitoring:** The RTD’s measuring the stator winding temperatures are in poor condition. The unit was shut down at the time of the plant visit, but it is expected that the four RTD’s logged in the control room will not read credible temperatures (similar to the finding of unit 1). When GE measured the 15 RTD’s in 2005, 3 were broken, and 4 more had temperature variations of greater than 25 % of the average, when measuring the “room temperature”. They are embedded in the windings, and cannot be replaced unless the windings are removed. All four cold gas temperature detectors had failed and new RTD have been installed. The DAS monitoring should be moved to the most accurate RTD’s remaining, preferably near the centre of the generator where the temperatures are the highest.

**Rotor and Field Winding:** The condition of the rotor was reported as “wet” by GE at the 2005 inspection. The insulation resistance was only 0.042 Giga-ohms and the polarization index was less than 1. Several attempts were made to dry the winding, and after 4 days GE reported that the insulation resistance and polarization index were satisfactory, (although they were still barely acceptable at 0.5 Giga-ohms and 1.3). There is no report or check sheet on the condition of the field windings, the rotor forging, or the collector rings and brushgears. GE stated that considerable corrosion was found on the collector distribution rings, which was cleaned off. The recommendation was made that the rotor should be kept warm and dry during future outages, (which is often considered to be the Contractor’s responsibility!). The impedance measurements showed there are no shorted field turns on the rotor (at standstill!).
It is believed that the retaining rings were not removed, so there was limited access for inspection of the field winding. An examination of the field winding connections, end-windings, and ventilation passages would have been useful. Some permanent deformation (creep) of the field windings is expected after 34 years. This tends to overstress the flexible coil connections, especially of the longest coil, and of the connections of the windings to the leads. (the flexible interconnections of the longest coil are often replaced every 16 years, per a GE electrical supervisor). GE TIL 1292 recommends inspection of the rotor dovetails and another TIL requires checking the rotor slot wedges for cracks. There is no record of this work being done in the GE inspection reports of 1999 or 2005. This work should be done in 2014. The GE report states that the rotor has 18Mn/18Cr non-magnetic retaining rings, but it is not known when they were installed – it is not mentioned in the 1999 or the 2005 reports.
APPENDIX F
Present Value Analysis Details
### HRD - Rewind Generators Unit 1

**Alternative Comparison**

*Cumulative Net Present Value To The Year 2041*

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Cumulative Net Present Value (CPW)</th>
<th>CPW Difference between Alternative and the Least Cost Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1 in 2015</td>
<td>10,119,456</td>
<td>0</td>
</tr>
<tr>
<td>Unit 1 in 2016</td>
<td>11,793,741</td>
<td>1,674,285</td>
</tr>
<tr>
<td>Unit 1 in 2018</td>
<td>12,922,248</td>
<td>2,802,792</td>
</tr>
</tbody>
</table>
Alternative Comparison
Cumulative Net Present Value
Project Title

HRD - Rewind Generators Unit 2

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Cumulative Net Present Value (CPW)</th>
<th>CPW Difference between Alternative and the Least Cost Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 2 in 2014</td>
<td>9,770,913</td>
<td>0</td>
</tr>
<tr>
<td>Unit 2 in 2017</td>
<td>11,238,255</td>
<td>1,467,342</td>
</tr>
<tr>
<td>Unit 2 in 2019</td>
<td>15,323,932</td>
<td>5,553,020</td>
</tr>
</tbody>
</table>
APPENDIX G
Partial Listing Of Rewinds In Canada
## Stator Rewind Work on Generators of Similar Size in Canada

<table>
<thead>
<tr>
<th>Utility</th>
<th>Plant / Unit No.</th>
<th>MW Rating/Manufacturer</th>
<th>In-service/Years</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC Hydro</td>
<td>Burrard #1</td>
<td>150 AEI</td>
<td>1960-2001</td>
<td>Siemens coils, PGE installed.</td>
</tr>
<tr>
<td>BC Hydro</td>
<td>Burrard #2</td>
<td>150 AEI</td>
<td>1961-2002</td>
<td>Planned</td>
</tr>
<tr>
<td>OPG</td>
<td>Hearn #3/4</td>
<td>100 Parsons</td>
<td>1956-1986</td>
<td>Rewound by CGE</td>
</tr>
<tr>
<td>Saskpower</td>
<td>BoundaryDam #1</td>
<td>66 Parsons</td>
<td>1960-1972</td>
<td>Rewound by NEC</td>
</tr>
<tr>
<td>Saskpower</td>
<td>BoundaryDam #2</td>
<td>66 Parsons</td>
<td>1960-1986</td>
<td>Replaced with Hitachi stator</td>
</tr>
<tr>
<td>Saskpower</td>
<td>BoundaryDam #5</td>
<td>150 Hitachi</td>
<td>1973</td>
<td>No rewind. Re-wedged in 2004 with epoxy-glass top ripple springs. Extra end-winding and lead supports added. Core is good</td>
</tr>
<tr>
<td>Transalta</td>
<td>Wabamun #1/2</td>
<td>66 AEI</td>
<td>1956-1990</td>
<td>New coils undersized, loosened</td>
</tr>
<tr>
<td>Transalta</td>
<td>Wabamun #3</td>
<td>150 AEI</td>
<td>1962-1975</td>
<td>Stator core failure, rewind by W</td>
</tr>
<tr>
<td>OPG</td>
<td>Lakeview #1/2</td>
<td>4x150 Parsons</td>
<td>1965-2007</td>
<td>No rewinds, but some winding repairs</td>
</tr>
<tr>
<td>OPG</td>
<td>Atikoken #1</td>
<td>230 ABB</td>
<td>1988-1992</td>
<td>Stator replaced, high winding vibration</td>
</tr>
<tr>
<td>OPG</td>
<td>Thunder Bay #3</td>
<td>100 E-E</td>
<td>1965-1990</td>
<td>Stator rewound (Synch. Cond. conv.)</td>
</tr>
<tr>
<td>DMI</td>
<td>Peace River Pulp Mill</td>
<td>40 Toshiba</td>
<td>1990-1997</td>
<td>Core/winding damage. CGE attempted major repair, not completed. Stator replaced by Toshiba.</td>
</tr>
</tbody>
</table>
General Notes

Canadian General Electric’s (CGE) generators in Canada have performed as well or better than those of other suppliers. Many of CGE’s stator rewind jobs have been associated with generators made by other suppliers.

Some generators made by CGE in the 1970’s and 1980’s were sub-contracts from other manufacturers, e.g, AEI (Wabamun 3 and 4) and English Electric (Rapp). Others were sub-contracts from GE, USA, (Ontario Hydro’s Lambton and Lennox generators). The insulation systems used for the stator windings were similar, but not identical, to the GE Schenectady products (Micapal 1 and Micapal 2); they were geared to the capability of the CGE manufacturing shop in Peterborough.

The Micapal 1 windings were made in Peterborough, Ont. And the later Micapal 2 stator windings were made in USA (Schenectady). The Canadian facilities in Peterborough, Ont, and in Lachine, Que, are capable of making high quality windings for turbo-generators up to 18 KV.

A significant proportion of the rewind work done by CGE and other suppliers, (either partial or full winding repairs/replacement), was the result of stator core failures that proceeded until the stator winding insulation failed.

It is quite common for utilities to replace the whole stator, rather than just to rewind the stator, especially if both the stator core and the windings are in poor condition.

When a stator is rewound by a non-OEM (original equipment manufacturer), there is a significantly increased risk of encountering difficulties, delays, and extra costs, usually when installing the windings, due to variations in core slot dimensions, changes in end-winding support systems, incorrect end-winding involute shape, stator attachments etc. Shipping problems are also common.
Fewer generators have been re-wound in Canada than in the USA, mainly because in USA it is common practice to carry out AC maintenance high-potential tests at 1.5 x rated voltage for 1 minute, or a DC high potential tests at even higher voltage, per the IEEE standards. These pass-fail tests seek out and often destroy weak insulation. In Canada it is more common to use Doble test at up to rated voltage, or DC ramp tests to locate weaknesses, without resulting in insulation failure.

Most units are taken out of service after 40-50 years, due to ageing issues with the boiler or turbine, e.g. OPG’s Hearn and Lakeview units and Transalta’s plant at Wabamun. The generator stator windings, cores and rotors may be capable of longer life. However, it would be a large stretch of the envelope to expect the existing stator windings at Holyrood to perform reliably for 70-80 years.

This list was provided from the discussions with Robert Jefferys.