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BREATHING NEW LIFE INTO AN AERO-DERIVATIVE GAS TURBINE CO-GENERATION PLANT VIA REFURBISHMENT AND MODIFICATIONS

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Abstract

Gas turbine co-generation plants are capable of producing power and thermal energy efficiently. The prime mover in a gas turbine co-generation plant is generally an aero-derivative, light or a heavy-duty industrial gas turbine engine. As economic realities continue to demand increased system efficiency, gas turbine co-generation plants are becoming more common in the power generation industry. Because of various site conditions and an overall market growth trend newly commissioned gas turbine co-generation installations generally consist of new equipment that has been tailored for specific customer requirements.

As part of an overall power plant expansion project a second aero-derivative gas turbine co-generation plant has recently been installed at the London Health Sciences Centre Westminster Power Plant in London, Ontario (Canada). The 3.8 MWe co-generation gas turbine unit originated from a decommissioned plant in California (USA) and was moved, refurbished, and modified to meet the specific site requirements of London Health Sciences Centre by Standard Aero Limited and its contractors. For London Health Sciences Centre, the use of refurbished co-generation plant equipment provided a cost-effective solution for expanding facility electrical and thermal energy needs.

1 Introduction

Gas turbine co-generation plants are capable of producing power and thermal energy efficiently. The prime mover in a gas turbine co-generation plant is generally an aero-derivative, a light or a heavy-duty industrial gas turbine engine. Each engine type generates shaft power (suitable for mechanical or electrical power generation) and exhaust thermal heat that can be recovered for either increased power generation or for district heating and cooling. As economic realities continue to demand increased system efficiency, gas turbine co-generation plants are becoming more common in the power generation industry. Because of various site conditions and an overall market growth trend newly commissioned gas turbine co-generation installations generally consist of new equipment that has been tailored for specific customer requirements. However, in some cases refurbished power plant equipment can offer long term performance and reliability at competitive costs for the end customer.

The recent Westminster Power Plant expansion project at the London Health Sciences Centre (LHSC) in London, Ontario (Canada), is an example where refurbished co-generation power plant equipment provided a cost effective solution for expanding facility electrical and thermal energy needs.

1.1 Project Description

Since 1875 the London Health Sciences Centre (LHSC) has been one of Canada's largest acute care teaching hospitals. LHSC employs approximately 15,000 employees across multiple sites in the London, Ontario area and completes approximately 1 million patient visits each year [1]. LHSC's Westminster Power Plant currently provides both electrical power and steam for district heating & cooling to the LHSC Victoria Hospital and Parkwood Hospital complexes. The power plant allows LHSC to have better control over their utility costs, resulting in over 45% annual savings in electrical power expenditures. Prior to 2013 the Westminster Power Plant housed one 4.9 MW (rated at 0.91 power factor) generator powered by a Rolls-Royce 501-KB7 gas turbine and coupled to a natural circulation heat recovery steam generator, one 2 MW generator (rated at 0.8 power factor) powered by an Elliott back pressure steam turbine, and four conventional boilers. The plant's pre-2013 available saturated steam capacity was 88,904 kg/hr at 724 kPa (196,000 lb/hr at 105 psi).

As part of LHSC's ongoing construction of the new St. Joseph Health Care - Mental Health Care London facility project, the Westminster Power Plant was expanded in 2011 & 2012 in order to provide additional electrical and steam generation capacity associated with the new hospital wing being constructed (see Figure 1). In addition to increased plant capacity, the Westminster Power Plant expansion project sought increased equipment redundancy and reliability for optimal plant operational flexibility and operational costs. The new Westminster Power Plant wing constructed now features a refurbished Foster Wheeler dual fuel conventional boiler, rated for 36,287 kg/kr at 724 kPa (80,000 lb/hr at 105 psi) saturated steam rates, as well as a refurbished Rolls-Royce 501-KB5S gas turbine co-generation unit rated for 3.8 MWe (at 0.92 power factor) and maximum saturated steam rates of 12,927 kg/hr at 724 kPa (28,500 lb/hr at 105 psi).

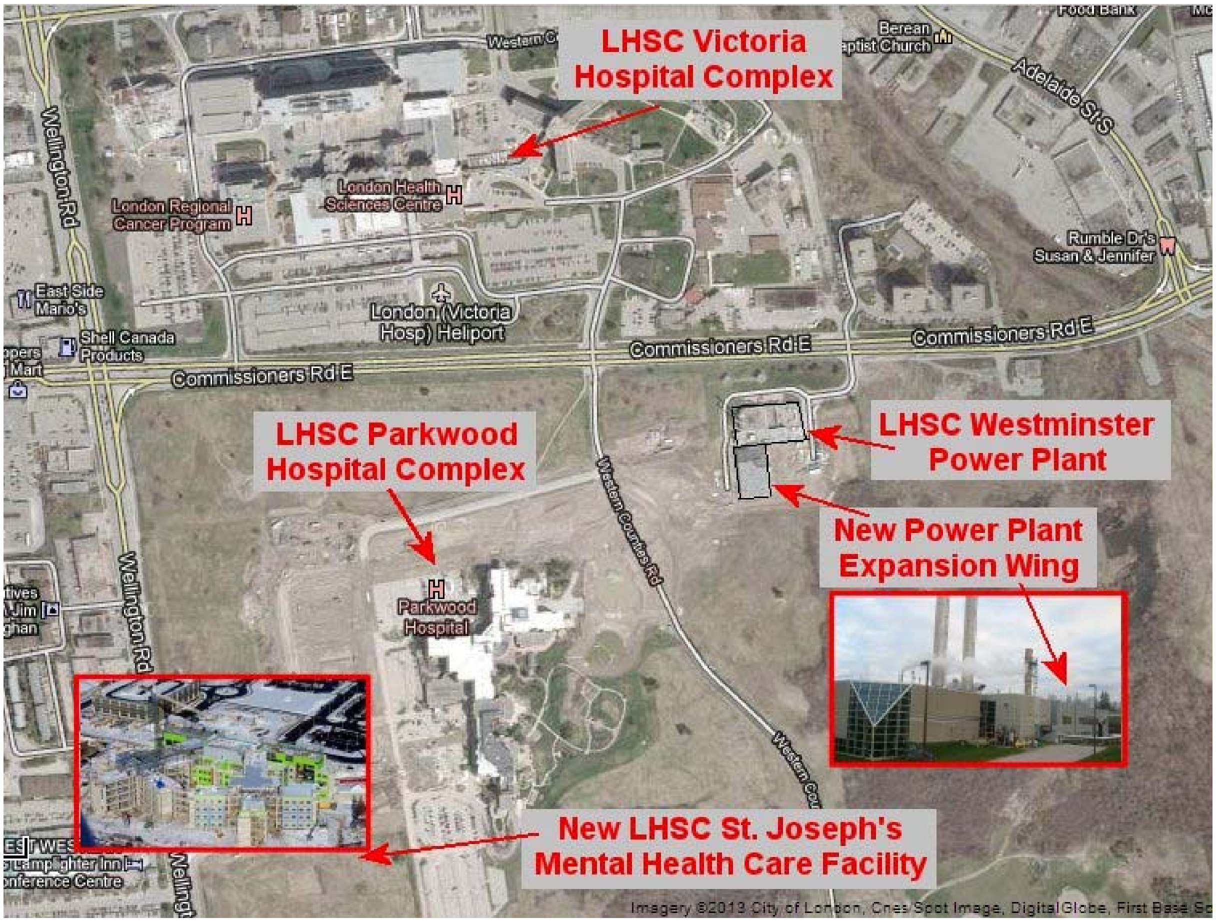

Figure 1: General Layout of LHSC Westminster Power Plant

When identifying possible heat and power solutions for their power plant expansion LHSC sought to source equipment that was both cost effective and was consistent with existing equipment for optimal plant integration and long term maintenance activities. Standard Aero Limited (Energy division) was retained by LHSC to supply the refurbished Rolls-Royce 501-KB5S gas turbine co-generation unit for the Westminster Power Plant expansion project. Standard Aero was also awarded a long-term service contract for the maintenance on the turbine skid following project commissioning. Standard Aero performs gas turbine engine overhaul, component repair, and customized power plant or airframe modification & maintenance projects for industrial gas turbine engines as well as for military & commercial flight operators. The Standard Aero Energy division is located in Winnipeg, Manitoba (Canada) and supports the Rolls-Royce 501K, the General Electric LM1600, and the Vericor TF & ASE engine families as well as performs repairs on a variety of other industrial gas turbine engine components.

1.2 Project Background and Scope

Unlike heavy or light-duty frame gas turbine engines that have been specifically designed for industrial applications, the Rolls-Royce 501K engine family is an aero-derivative due its deep connections with the T56/501 aircraft engine. Introduced in 1954 for the Lockheed C-130 aircraft (see Figure 2) and largely developed using funding from the US Airforce, the Rolls-Royce T56 military turboprop and its 501-D commercial flight version has proven service history and dependability with over 18,000 units produced and 200 million flying hours accumulated in nearly 70 countries worldwide to date [2]. Figure 3 presents the general Rolls-Royce T56 turboprop engine configuration.

Figure 2: Lockheed C-130 Aircraft [3]

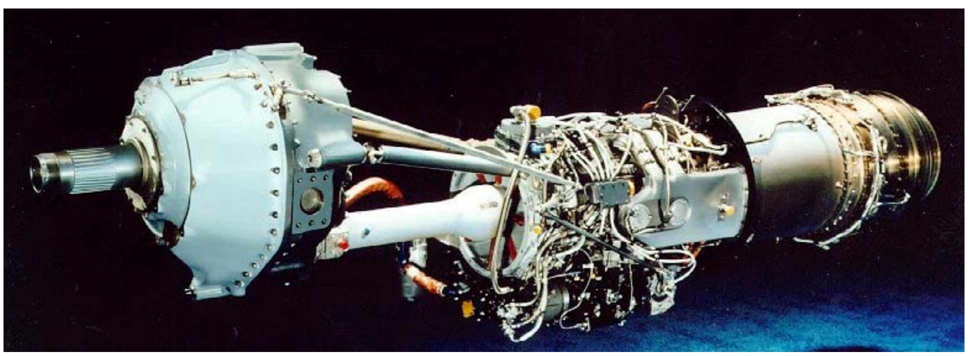

Figure 3: Rolls-Royce T56 Aircraft Turboprop Engine

In 1963 Rolls-Royce (then Allison) leveraged its T56 aircraft engine design and operational experience and adapted the T56 engine for industrial, marine, and electric power generation applications. The result was the 501K engine family, which features a lightweight and modular engine design that has proven both reliable and easy to maintain. An added benefit of adapting the T56 flight engine into the 501K industrial engine was the use of largely similar engine components (a typical feature of aero-derivative gas turbine engines). This then allowed the smaller industrial gas turbine users market to benefit from the high production volumes associated with the aircraft gas turbine industry, which in turn can lead to lower costs of ownership and improved access to spare parts. The 501K engine is offered in either a single or dual shaft configuration and has been updated since its initial 1963 release to reflect changing technologies and application requirements. 501K engines can produce up to 6450 kWe at a gross efficiency between 29 and 40% (simple cycle), can operate on both liquid and gaseous fuels, and is offered with water/steam injection capabilities or a dry low emissions system to reduce exhaust gas emissions [4]. The Rolls-Royce 501-KB5S engine, shown in Figure 4, can supply enough electrical power to supply approximately 400 Canadian homes per year (based on [5]).

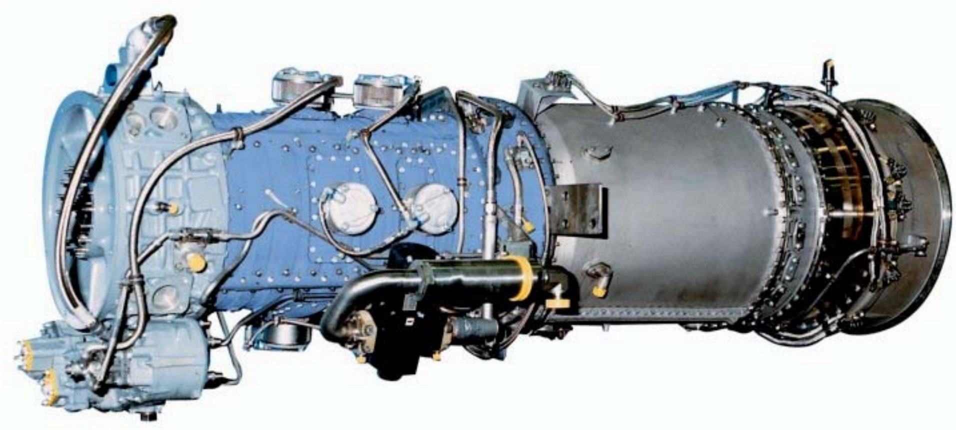

Figure 4: Rolls-Royce 501-KB5S Industrial Gas Turbine Engine (Aero-Derivative)

When considering various options for its Westminster Power Plant expansion project, LHSC found value in the use of refurbished co-generation equipment. Not only would a refurbished co-generation unit provide a 30% reduction in initial project capital costs (compared to an equivalent fully new co-generation plant solution), the equipment would be similar to the existing LHSC Rolls-Royce 501-KB7 co-generation unit, therefore making optimal use of LHSC spare material inventory and overall plant maintenance resources. In addition, having the refurbishment, installation, and commissioning of the additional co-generation unit managed by the same company who will perform long-term maintenance on the unit helped not only reduce project risk but also further developed a mutually beneficial relationship vital to ensuring reliability of the plant in the future.

The refurbished Rolls-Royce 501-KB5S co-generation unit installed at LHSC originated from a shutdown printing company in California, USA. Prior to its shutdown in June 2009, the co-generation unit was continuously operated on natural gas with water injection but also featured black start capabilities and a Selective Catalytic Reduction (SCR) system for additional reductions in exhaust stack emissions. The original unit, which was located outdoors in an industrial area, is shown in Figures 5 & 6 and was commissioned in 1994. The unit originally featured a Rolls-Royce 501-KB5 engine, mated to a 3.8 MWe generator (rated at 0.92 power factor) and a natural circulation Heat Recovery Steam Generator (HRSG) that had a maximum rated steam capacity of 14,969 hg/hr at 3792 kPa and 400^{o}C (33,000 lb/hr at 550 psi and 750^{o}F).

Figure 5: Original Co-Generation Unit (Gas Turbine Enclosure)

Figure 6: Original Co-Generation Unit (HRSG)

Working to the LHSC project requirements for local emissions & noise standards, safety standards, and general plant interfacing, the following general package refurbishment and modification work scope was undertaken:

- Removal of the gas turbine enclosure, HRSG, exhaust stack and air inlet filtration system from the original site (California, USA) and final transport to LHSC Westminster Power Plant in London, Ontario (Canada).
- Permanent removal of the SCR section, the superheater section, the already de-commissioned fresh air duct burner support equipment, and the isolation knife-gate from the HRSG portion of the original co-generation unit.
- Conversion of the turbine enclosure to the 501-KB5S engine configuration (natural gas fuel with water injection) for improved compatibility of the engine with the existing LHSC 501-KB7 turbine unit.

- Modification of the HRSG boiler for 724 kPa (105 psi) saturated steam output pressure and full safety certification of the HRSG with the applicable Canadian regulations for boilers and pressure vessels.
- New generator protection equipment, upgraded generator switchgear, and integration of the 3.8 MWe (at 0.92 power factor) generator with the existing LHSC Westminster Power Plant electrical distribution system (including an existing/spare 4.16kV-to-13.8 kV electrical transformer).
- New control system for the gas turbine unit and for the HRSG.
- Design and manufacture of silencers for the exhaust and turbine enclosure ventilation stacks to meet LHSC local noise emissions requirements.
- Re-certification of the co-generation unit electrical system per the Ontario Electrical Safety Code regulations.
- General integration of the co-generation plant into the new Westminster Power Plant expansion facility (eg: foundation, boiler feedwater support system, steam distribution system, fuel supply system, compressed air supply system, low voltage electrical distribution system, etc…). CEM Engineering performed the balance of the plant engineering design as part of the general LHSC Westminster Power Plant expansion construction project.
- Full site commissioning of all sub-systems of the refurbished Rolls-Royce 501-KB5S co-generation plant and final site performance and emissions qualification testing.

Figure 7 presents the general layout for the refurbished Rolls-Royce 501-KB5S co-generation plant for the LHSC Westminster Power Plant expansion project.

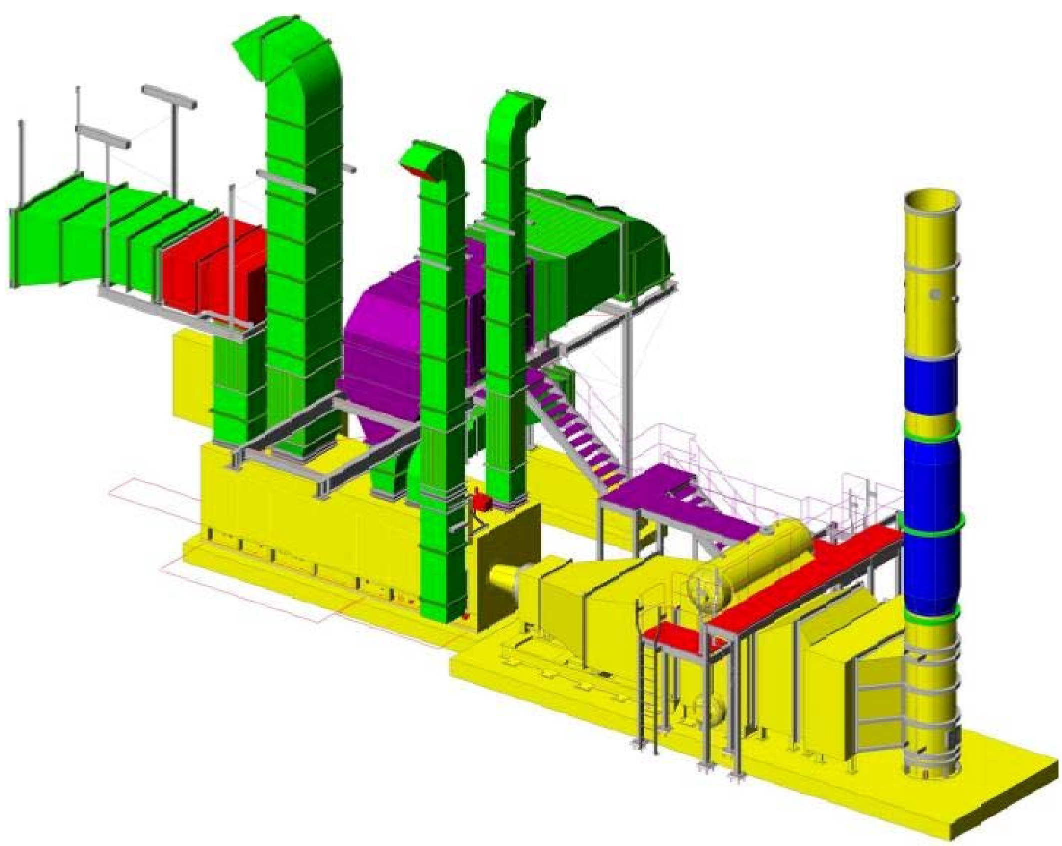

Figure 7: General Layout for the LHSC Refurbished Co-Generation Plant

2 Co-Generation Plant Refurbishment Project Challenges and Highlights

The age of the original co-generation plant equipment, differences in plant operating conditions and the need to re-certify various electrical and mechanical systems with local safety organizations posed significant challenges for the plant refurbishment project. In this section various project challenges and highlights are described.

2.1 Co-Generation Plant Re-Location

The fact that the original co-generation unit was operated outdoors did somewhat complicate the initial plant salvaging operations. In some cases the mounting bolts and studs of various sub-components required cutting using welding torches due to excessive corrosion damage (reference Figure 8). While these findings were expected some of the cuts initially made required that some additional repair work be performed in order for the unit to be properly re-assembled at LHSC. As part of the general unit refurbishment work performed the general corrosion damage was repaired and new surface protection coatings were applied.

Figure 8: Advanced Corrosion on Various Equipment Support Structures.

Since the refurbished co-generation unit would be installed in a new wing of the LHSC Westminster Power Plant, final installation of the co-generation plant had to be coordinated with LHSC's overall construction project activities. Since the co-generation plant salvaging and refurbishment project work was completed prior to the major completion of the new Westminster Power Plant expansion wing temporary storage of the refurbished co-generation unit components was required.

In May 2012, the refurbished co-generation unit began installation at LHSC and major re-commissioning of the unit was completed in November 2012. Figures 9 and 10 present the final configuration of the refurbished co-generation plant installed in the new wing of the LHSC Westminster Power Plant.

Figure 9: Refurbished LHSC Co-Generation Plant Installed (Gas Turbine Enclosure)

Figure 10: Refurbished LHSC Co-Generation Plant Installed (HRSG)

2.2 HRSG Conversion and Re-Certification

Prior to final installation and startup at LHSC the HRSG underwent hydrostatic pressure testing of its economizer and boiler internal tubing sections. Modifications to both the steam drum nozzles and the steam drum pressure relief safety valves were also performed to accommodate the LHSC target 724 kPa (105 psi) saturated steam output pressure. Due to the extensive reconfiguration of the HRSG performed, the entire HRSG was temporarily assembled in a separate staging area to ensure all flanges successfully mated with adjoining components and the baseplate prior to final unit installation at LHSC. Figure 11 presents the HRSG reconfiguration performed per the LHSC project requirements.

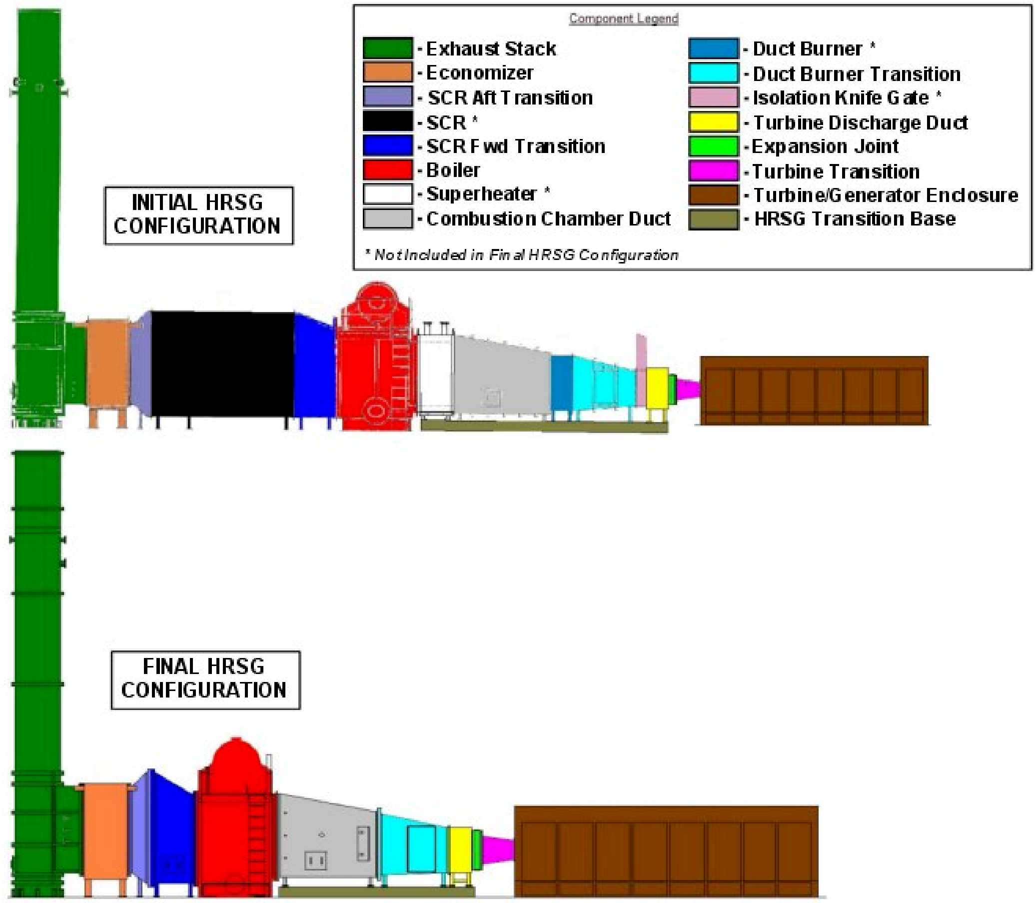

Figure 11: HRSG Reconfiguration Performed for LHSC Co-Generation Plant Refurbishment Project

As well, the HRSG required a full safety certification in order to receive a Canadian Registration Number (CRN) per the Canadian Standards Association (CSA) requirements for boilers and pressure vessels. The HRSG certification was obtained through Ontario's Technical Standards & Safety Authority (TSSA). Since the original HRSG build drawings from Cleaver Brooks were not available, the entire HRSG had to be reversed engineered and new design documentation had to be created in order to receive TSSA approval. The additional work required careful coordination between various engineering consulting groups as well as TSSA representatives in order to obtain the required documentation for final re-certification of the HRSG for use at LHSC.

New boiler trim hardware was also fitted to the refurbished HRSG and new boiler feedwater level controls were integrated with the new gas turbine control system installed with the refurbished co-generation plant at LHSC.

2.3 Co-Generation Plant Electrical Equipment Integration and Certification

Integration of the refurbished co-generation plant electrical equipment with the existing LHSC power plant equipment and the local electrical distribution system, as well as obtaining final electrical system certification from Ontario's Electrical Safety Authority (ESA), required careful planning and coordination throughout the plant refurbishment project.

All original turbine enclosure electrical motors (for pre-lube of the generator and reduction gearbox, for compartment ventilation, etc…) were originally rated for 480VAC/3 phase per the normal American electrical standards. Since the Canadian electrical standard for these components is 575 VAC/3 phase a step-up voltage transformer was added between the new LHSC Motor Control Center (MCC) and the refurbished co-generation plant electrical motors. This option was more cost-effective than fully replacing all original plant motors but additional modifications and re-wiring of various plant electrical components were needed in order to fully comply with the applicable Ontario Electrical Safety Code and associated regulations. In addition, modifications to the gas turbine enclosure, as well some of the components located inside, had to be carried out in order to obtain the required explosion proof electrical safety certification (for a Class I, Division 2, hazardous environment) per the Canadian electrical code requirements.

While the existing LHSC Westminster Power Plant medium voltage system already had provisions for an additional electrical generator, modifications to the local utility electrical distribution system were still required. As an example, upgrades to the LHSC intermediate transformer (4.16kV-to-13.8kV) bus bars were required to safely handle the higher current flows associated with the additional electrical generator being installed at LHSC. As well, because the original generator protection and controls equipment was part of the original turbine control cabinet, which was completely replaced as part of the co-generation plant refurbishment project, installation, commissioning and certification of the new standalone generator controls and original generator switchgear was required. Careful system design and resource coordination was required in order to successfully integrate and commission the new generator controls with both the turbine control system and the LHSC Westminster Power Plant medium voltage system.

Given that the province of Ontario (Canada) has a deregulated electrical market the integration and certification of the additional LHSC 3.8 MWe (at 0.92 power factor), 4.125 MVA, 4160V, 3 phase, 60Hz electrical generator also involved dealing with multiple local and provincial entities. Upgrades to the adjacent Hydro One electrical supply station feeder breaker and the addition of new power metering and monitoring devices were also required to successfully integrate the new LHSC electrical generator with the local electrical distribution interconnection system. The coordination of these activities between various entities proved challenging due to the number of different parties involved as well as because of different delays encountered during the project.

2.4 Water Injection System Modifications due to Site Ambient Conditions

As can be expected with the re-commissioning of used equipment a number of minor issues were found and addressed during the re-commissioning of the refurbished co-generation plant. One such example involved the water injection system.

During re-commissioning of the water injection system at LHSC it was discovered that the original equipment placement of the high pressure portion of the water injection system within the gas turbine enclosure was not suitable for all possible ambient weather conditions seen at the LHSC site. Specifically, during an abnormally cold (-20^{o}C or –4^{o}F) day during the LHSC co-generation plant re-commissioning activities, water freezing was experienced in some sections of the gas turbine water injection system. This problem was never reported by the original plant operator, which operated in California (USA), and appeared to be caused by the fact that the affected water injection components were directly exposed to (cold) ambient temperature air flows created by the turbine enclosure ventilation system. The water freeze event did not cause damage to the gas turbine engine but the event did require that high pressure components of the gas turbine engine water injection system be re-located to prevent re-occurrence. Since the refurbished co-generation plant would be operated in the heated enclosure of the LHSC Westminster Power Plant expansion wing, the affected water injection system components were moved outside of the turbine enclosure where ambient temperatures were maintained above freezing throughout the year.

As part of the refurbished co-generation plant re-commissioning activities, the Rolls-Royce 501-KB5S water injection control system was tuned such that LHSC's local exhaust stack emissions requirements were met. Per LHSC's environmental compliance permit, the gas turbine water injection system was tuned such that the exhaust stack emissions were below 52.9 ppm NOx and 60 ppm CO (dry basis and normalized to 15% oxygen concentrations) at maximum plant rated conditions.

3 Conclusions

In the case of the London Health Sciences Centre Westminster Power Plant expansion project a refurbished Rolls-Royce 501-KB5S co-generation plant was the preferred option to help provide the additional electrical power and district heating steam loads required by adjacent LHSC health care facilities. While the refurbishment and relocation of the original co-generation plant was technically challenging and involved many different entities from different industries, the project helped demonstrate that the use of refurbished power plant equipment can be a cost effective alternative for meeting expanded site electrical and thermal energy requirements. Partnering with comprehensive service providers for both initial commissioning and long-term maintenance of the unit can also lower project risk and ensure long-term reliability of the refurbished equipment.

4 Acknowledgments

The author would like to thank Paran Singam & Brian Dubé (Standard Aero Energy project management & engineering), London Health Sciences, CEM Engineering, Tarco, Dielco, and Power Services for their help in gaining a deeper technical understanding of different aspects of this project.

5 Nomenclature

LHSC	London Health Sciences Centre
HRSG	Heat Recovery Steam Generator
SCR	Selective Catalytic Reduction
CRN	Canadian Registration Number
CSA	Canadian Standards Association
TSSA	Technical Standards & Safety Authority
ESA	Electrical Safety Authority

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