White Paper

Use of Compressor Water Wash to Optimise Gas Turbine Performance

Robert J Burke and Alessandro Boursier

Optimising Gas Turbine (GT) performance is a key consideration for plant operators. Such activity returns dividends of improved output and heat rate recovery, benefiting equipment lifecycle and maintenance costs. GTs compress large quantities of air through the compressor stage, consuming up to 60 % of the energy involved in operating the engine. Any compressor efficiency degradation significantly impacts overall efficiency. Contaminants, even in small concentration, can coat or foul working surfaces. Over time, this results in lower efficiency and output. Compressor fouling is almost unavoidable, even with modern air filter treatment. Compressor cleaning is required to maintain overall GT efficiency. A well-designed offline and online water wash system can minimise compressor fouling, maintain higher turbine efficiencies, and significantly improve profitability without impacting the durability of compressor components. This paper reviews methods to optimize a compressor utilizing a water wash program and data that demonstrates an improvement of output and heat rate recovery.

Compressor Wash Design

A compressor wash design is developed by understanding water droplet and compressor blade interactions and controlling this interaction through droplet size, injection location, air to water ratio and water solubility.

Online and offline water wash systems are individually developed for each turbine model employing a design procedure utilising 3D computational fluid dynamics to optimise nozzle location and spray angles. This provides superior offline and online performance with a single set of nozzles and no detrimental erosion from the process.

This globally patented water wash delivery system was uniquely developed to clean aircraft engines and industrial GTs. The wash systems are not high-pressure spray systems, rather they rely on the volume and delivery pressure with full pressure drop across spray nozzles. This provides optimal droplet size, momentum and direction for effective cleaning, while remaining soft to the touch.

The performance of this technology has been recognised by many Original Equipment Manufacturers (OEM) that are applying the system as standard equipment.

Case History: Tenaga Nasional Berhad (Paka, Malaysia) – Gte Wash System Vs. Abrasive Cleaning

For the last 23 years, Tenaga Nasional Berhad (TNB), operating Stesen Janaelektrik Sultan Iskandar (SJSI) Paka power station, has been relying on hand cleaning and a ‘carboblasting’ system for cleaning GT compressor blades. Hand removal of hard deposits was performed semi-annually and during major overhauls. Carboblasting injects a soft grit blasting material into the compressor to remove contaminants such as

Figure 1 : Before andAfter Offline Washing

dust, smog and exhaust deposits.

Located within close proximity to an oil refinery, the compressor was typically fouled with oily contaminants; therefore, carboblasting was inefficient in cleaning the compressor blades. Additionally, problems such as clogging of instrumentation lines, erosion of atomising air cooler tubes and blocking of turbine blade cooling holes have been reported as a result of using the carboblasting technique.

In 2004/2005, SJSI initiated a program to replace the carboblasting with "wet washing" for Block 2, GT2A and GT2B. The system provided offline and online washings for both GTs.

TNB went through painstaking efforts to quantify benefits gained from the implementation of the compressor washing system and to identify the associated risks on the compressor blades as a result of daily online wash.

Performance data was collected for a period of eight weeks preceding installation of the water wash unit and for a period of six months post installation.

Gas Turbine Efficiency's (GTE) 600i-100 water wash system was commissioned on GT2A in May 2007 and GT2B in July 2007. The station adopted a daily online wash schedule using demineralised water on both units.

Performance Evaluation Methodology

Loss in GT performance is normally indicated by a decrease in power output (Pout) and an increase in heat rate (HR). It is well known that in the case of wet washing, most of the GT performance can be recovered through offline washes. Therefore, the main focus of the analysis was determining the improvement in gross Pout and gross HR upon completion of the offline wash. The analysis also reviewed the sustainability of the improved performance as a result of the daily online wash practice adopted by the station upon the commissioning of the 600i-100.

All relevant data was obtained through the Generation Plant Management System historian and sampled every 30 minutes. Due to the unavailability of ambient parameters (temperature, pressure, relative humidity), data was grouped to match the temperature of 32o C as much as possible. Data was compiled for the inlet compressor readings of 32 + 1o C and averaged to generate the daily values. The gross base load and gross heat rate values quoted in the report represent average daily values at the inlet compressor reading of 32 + 1o C.

The calculation to determine the HR was based on the fuel gas Low Heating Value (LHV) whereby the constant fuel gas calorific value (CV) of 35 427.70 kJ/m3 was adopted [2].

Summary Of The Commissioning Activities

Borescope inspections were completed for both units to

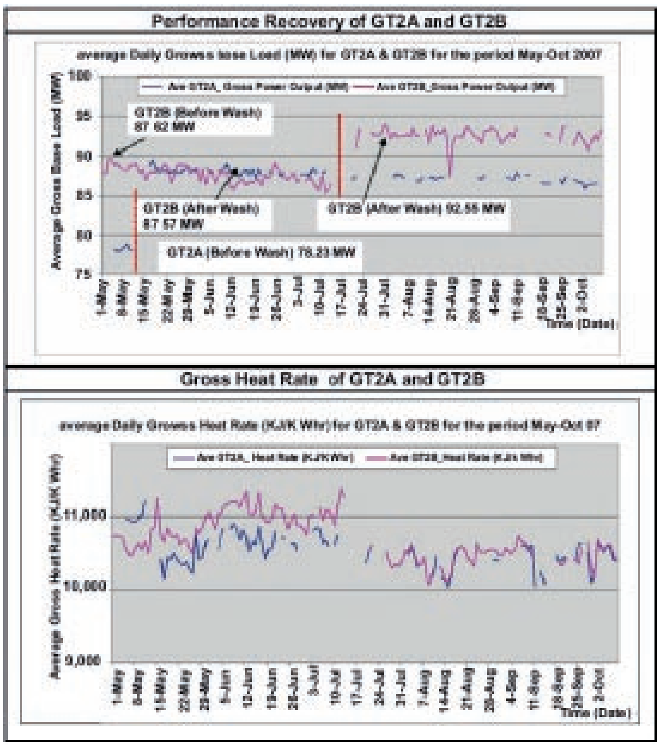

Figure 2: Performance Recovery and Gross Heat Rate of GT2A and GT2B

Before and After Average Gross Heat Rate Values			
GT	Average Gross Heat Rate Before (kJ/KWh)	Average Gross Heat Rate After (kJ/KWh)	Improvement (Percentage of Change) [Efficiency [Eff] Improvement]
GT2A	11 024.83 [Eff: ~ 32.65 percent]	10 508.93 [Eff: ~ 34.61 percent]	515.9 (4.67 percent) [Eff: 1.61 percent]
GT2B	10 909.46 [Eff: ~ 32.99 percent]	10 450.04 [Eff: ~ 34.34 percent]	459.42 (4.11 percent) [Eff: 1.45 percent]
Before and After Average Gross Base Load Values			
GT	Average Gross Base Load Before (MW)	Average Gross Base Load After (MW)	Improvement (MW) [Parcentage of change]
GT2A	78.23	87.57	9.34 [11.93 percent]
GT2B	87.62	92.55	4.93 [5.63 percent]

Table 1: Before and After Gross Heat Rate and Base Load Values

establish the condition of the compressor blades before and after the wash. Manual cleaning of the Inlet Guide Vanes (IGV) were also done as part of the offline washing activities.

GT2A was shut down for a scheduled preventive maintenance outage from the 27 – 28 of October 2007. During this period, the station performed an offline wash and compressor blade assessment for GT2A. The machine was put back on load on the 29 of October 2007 (@ 0130 h).

During the shutdown in May 2007 (11 – 13 of May), three locations were chosen for comparing compressor stator blade surface conditions before and after washing processes. Refer to Figure 1. Each location has four inspection holes. During the shutdown in October 2007 (27 – 29 of October), an additional location was chosen.

Detailed results for every hole were recorded. The condition of the IGV and compressor stator blades was heavily fouled prior to the first offline wash. During the commissioning period of the 600i-100, the IGV required heavy manual cleaning and repeated offline washes due to the ineffectiveness of the prior cleaning practices [3].

Once commissioned and in operation, it was observed during an offline wash of GT2A that the IGV required light manual cleaning only. The station performed one offline wash for one cycle. This is attributed to the station adopting daily online washing which minimised the buildup of deposits in the compressor.

Prior to conducting the offline wash, the actual average gross base loads for GT2A and GT2B were 78.23 MW and 87.62 MW respectively. The average gross heat rates (recorded at 32o C) were 11 024.83 kJ/kWh (~32.65 percent) and 10 909.46 kJ/kWh (~32.99 percent) for GT2A and GT2B respectively.

Figure 2 illustrates the performance recovery (gross base load) and gross heat rate of GT2A and GT2B post implementation of the offline wash. GT2A recovered almost 10 MW in gross base load immediately following the offline wash (14 May 2007).

The primary objective of the online wash is to minimise buildup of deposits in the compressor and reduce the ongoing rate of incremental power losses. This effectiveness was proven since the station adopted the daily online wash and subsequently has managed to maintain the average gross base load of 87.57 MW for the period of 14 July – 6 October 2007.

GT2B recovered almost 5 MW in gross base load and managed to maintain an average gross base load of 92.55 MW for the period of 21 July – 7 October 2007.

The implementation of the offline wash improved the gross heat rate for both GT2A and GT2B. Refer to Table 1. Prior to 14 May 2007, the average gross heat rate of GT2A was 11 024.83 kJ/kWh.

Post offline wash, the aerodynamic surfaces of the compressor blades reduced the compressor work requirement, and reduced the gross heat rate to an average value of 10 508.93 kJ/kWh. This is equivalent to a 1.61 percent improvement in thermal efficiency (i.e. from 32.65 percent to 34.16 percent).

GT2B shows the same results in which the gross heat rate has improved from 10 909.46 kJ/kWh to 10 450.04 kJ/kWh. This corresponds to an improvement in thermal efficiency by 1.45 percent (i.e. from 32.99 percent to 34.34 percent).

Cost Benefit Analysis – Payback Period

The Cost Benefit Analysis of the 600i-100 wash system for Block 2 was conducted to determine the payback period of the system. The analysis of the payback period only considers the following scenarios

- potential savings in fuel cost due to improvement in heat rate
- value for the additional generated capacity
- avoidance of generation cost from open cycle GT

In all three scenarios, the improved base load capacity is assumed to be able to maintain the increase in gross Pout and better HR for a period of one year (which coincides with a combustion inspection).

Risks Of Erosion On Compressor Blades Due To Regular Online Washing

Blade erosion is a phenomenon that can occur with prolonged impingement of water droplets or water columns on rapidly moving blades. The relationship that describes the erosion volume is

$$Vol = (Flux / 2 \times NER) [V/2500]^{4.8} d^{0.67} t$$

Where

- Vol – Volume Eroded (mm)
- Flux – Water Droplet Mass Flow (m2/s)
- NER – Material Parameter (410 SSL equal to 4)
- V – Blade Velocity (m/s)
- d – Droplet Diameter (μm)
- t – Time of Water Flow (3 min/d)

The material type, inlet air velocity, and blade velocity are characteristics of the GT and OEM equipment provider.

An offline wash has no erosion risk. The blades are not moving rapidly enough to cause erosion risk.

Online wash, due to very high velocities of the compressor blade during operation, has the potential to initiate and drive blade erosion. To minimise the risk of compressor blade erosion, the flux, droplet diameter and washing time need to be controlled and optimised.

The design differences between the various types of washing systems, in particular the nozzles, are quite significant and has resulted in a wide range of mass flow rates, operating pressures, spray patterns, droplet size ranges and performance characteristics. Accepting that different design philosophies do exist, there is a fairly common agreement within the industry that online droplet size should be within the range of 50 to 250 micrometre [1].

During online washing it is important for the droplets to be the right size to balance cleaning effectiveness with a reduced erosion rate. Using a high-pressure nozzle system, with a highly atomized spray pattern, results in a statistically tight spray distribution of the desired droplet size that minimizes erosion.

Conclusion

The application of the 600i-100 compressor washing system for Paka Block 2 has improved gross base load of GT2A and GT2B by 9.3 MW (11.9 percent) and 4.9 MW (5.6 percent) respectively and thermal efficiency has improved by 1.61 percent and 1.45 percent respectively.

After a period of five months, GT2A maintained the average gross base load of 87.57 MW compared to 78.23 MW before the application of offline washing. For a period of four months, GT2B maintained the average gross base load of 92.55 MW compared to 87.8 MW previously.

Customer satisfaction with ease of operation, combined with performance improvements achieved, represents a correct application of the GTE water wash system.

The payback period for TNB's combined cycle plant was less than two months. The payback period is dependent upon individual plant operational characteristics, fuel contracts and local dispatch agreements.

References

[1] Meher-Homji, C.B. and Bromley, A.F., 2004. "Gas Turbine Axial Compressor Fouling and Washing". Proceedings of the 33rd Turbomachinery Symposium, September 2004.
[2] REMACO, 2007. "GT2A Performance Test". April 4, 2007.
[3] "SJSI Commissioning Report", 2007. ■

About the Authors:
Robert J. Burke
Applications Engineering Manager, Gas Turbine Efficiency
robert.burke@gtefficiency.com

Alessandro Boursier
Business Development Director, Oil & Gas, Gas Turbine Efficiency
alessandro.boursier@gtefficiency.com

BPCL to Strips Stakes from Oversea Oil and Gas Fields

Mumbai: Bharat Petroleum Corp. Ltd (BPCL), one of the largest state-owned oil and gas company in India, mulls to divest its stake in some overseas oil and gas blocks to free up money for investment in blocks with better potential.

D Rajkumar, Managing Director and Chief Executive of Bharat PetroResources Ltd said, "Some of the overseas blocks explored by the company do not promise much resource potential. So, by divesting our interest in these blocks we can save on the cost of exploring them further, and use it to acquire other blocks with better resource potential." He said BPRL was looking to exit at least one block immediately and more may follow, but it was too early to specify how much money it hoped to save.

S. Radhakrishnan, Chairman and Managing Director- BPCL said, "the company has stakes in many overseas blocks in Australia, Brazil, East Timor, Indonesia, Mozambique and the UK, with a combined acreage of 81,000 sq. km. BPCL has allowed around `7,000 crore to strengthen its exploration and production activities for the next five years. He also stated that although the external environment remained challenging, BPCL had been focused on pursuing an aggressive growth path with the objective of maximizing shareholders value.

Niraj Mansingka, oil and gas sector analyst sang a different tune and said " Giving up blocks may not lead to substantial cost savings for the company. If the blocks have not been found to hold much resources, the valuation they fetch would not be great." He added, despite this, it will help BPCL in freeing up management band width to focus on exploration activities elsewhere.