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OPTIMIZING PIPELINE STATION FUEL EFFICIENCY USING TURBINE SPLIT AND DEGRADATION CALCULATIONS

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Abstract

Current methods for pipeline optimization allow operators to minimize fuel flow for a given set of line conditions. These methods are often overly simplified and make assumptions that can lead to significantly higher fuel consumption. One of these assumptions is to consider each unit of the same type to perform identically. In reality, each unit is delivered to the customer with minimum performance guarantees but due to tolerances in manufacturing, may perform differently (within the manufacturer's acceptable tolerance). Another assumption in these models is that each unit will perform consistently as if new and clean, that is, without any component and performance degradation. Degradation performance loss may be a result of several factors: fouling of the compressor, damage to compressor blade tips, changes in turbine swallowing capacity, and turbine clearance changes, among many others. Degradation can be calculated using a more sophisticated performance model and simulation package such as Liburdi Gas Turbine Analysis Program (GTAP). Degraded performance is calculated by the analysis program by comparing the as built performance information to the current performance using the turbine simulation model. Finally, using real-time information about how the units in the pipeline station are performing, an optimal load split between the units can be calculated which minimizes fuel usage.

1 Introduction

With today's tight energy market margins, it is important for pipeline operators to run as fuel efficiently as possible. Optimization along a pipeline is a complex nonlinear problem that involves many variables. As a result, there are many ways to optimize pipeline operation using different criteria. For example, a typical optimization criterion might be to minimize total fuel consumption along the line for a given set of physical conditions, such as delivery flow rate and pressure. There are several computer software packages available which assist operators to make these decisions.

At the station level, optimization logic is also a very complicated problem. Typically operators must determine the most economical load split between gas turbines. The currently employed methods utilize assumptions which may lead to significantly higher fuel consumption in the long run.

One of these assumptions is the consideration of each unit to perform identically. In reality, each unit at a station is delivered to the customer with minimum performance guarantees. Due to many factors, such as tolerances in manufacturing, each unit may perform differently (within the manufacturer's acceptable tolerance). Another assumption that is employed in optimization models is that each unit will perform consistently as if it is new and clean, that is, without any component and performance degradation. As will be demonstrated, such assumptions can have a significant impact on fuel consumption and cost.

2 Typical Pipeline Optimization Logic

A typical pipeline will use similar logic to optimize a station. For this example, consider a simple two turbine gas compressor station. There are two approaches that are commonly used: equal loading or a fully loaded primary turbine with secondary acting to pick up the excess demand. See Figure 1 for a typical turbine arrangement in a compressor station.

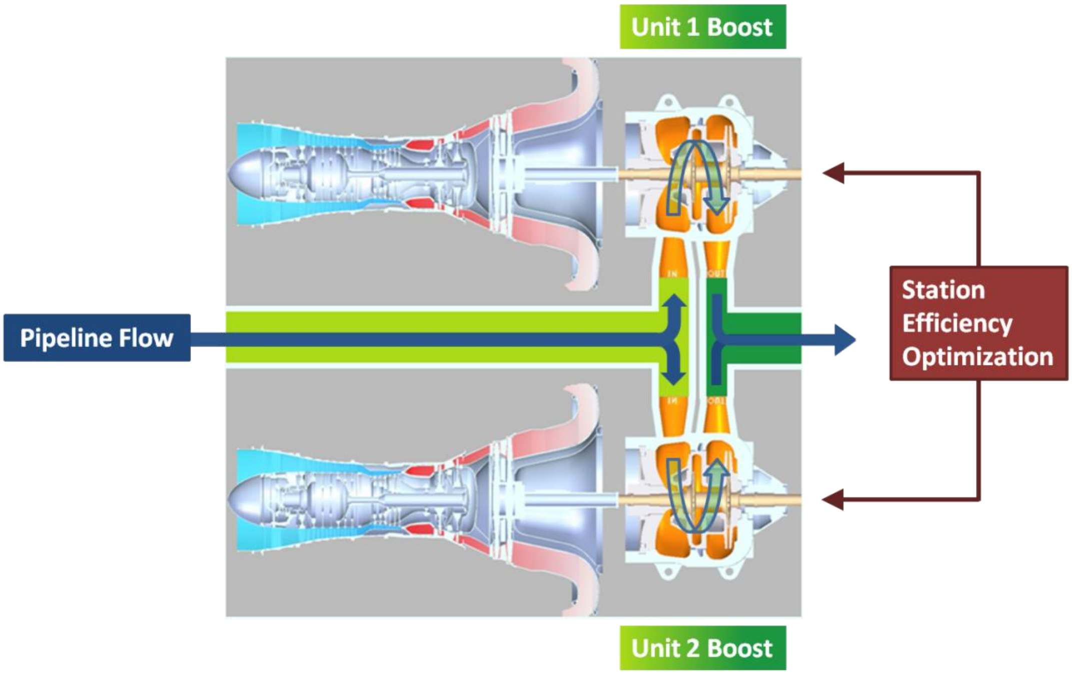

Figure 1 - Typical Pipeline Turbine Arrangement

In an equal load setup, the goal is to run each turbine at the same level. The intent of this strategy is that each of the units is performing an equal share of the work and will have the same power output. Unfortunately, by running both units equally there are times when both units are not running at their optimal design point – which is usually full load. This can lead to inefficient operation and increased specific fuel consumption. Without the aid of a physics model, this strategy also does not consider differences in the unit efficiencies which may also yield suboptimal fuel efficiency.

In the second approach, the objective is to keep one unit running and bring the second one online only as needed. This strategy is only available when the site design permits throttling of the flow rate between the units as the head gained by each unit in parallel must be equal. The primary unit power output is fluctuated to keep up with line demands until it reaches its maximum output. The secondary unit is brought online and output is increased to keep up with any additional demand requirements. This strategy has an advantage that the primary unit will usually reach and maintain its peak efficiency range generally when it reaches full power. However, since the output of the secondary unit varies significantly, this unit is often running out of its most efficient range. Running the turbines in this manner is also challenging from a maintenance perspective. The primary unit will typically will reach its fire-hours limit at a different time than the secondary unit, which will need maintenance due to reaching the limit on start-stop cycles. The plant must also be capable of throttling flow between units otherwise this strategy cannot be employed.

Regardless of strategy, these approaches miss a major fuel-savings opportunity by not considering the individual unit degradation and performance information that is provided by physics based gas turbine simulation tools.

3 What is Degradation?

Degradation is defined as the deterioration in quality, level, or standard of performance of a unit. An increased degradation reduces the heat rate of the turbine. This means that the same unit will require more fuel for a given power output.

The rate of degradation can be categorized as graceful or catastrophic. Catastrophic degradation is usually indicative of a serious event or abrupt change, and will not be discussed here. Graceful degradation is a result of the normal wear and tear a unit experiences over the course of time. It is essential to understand what the long term performance loss is of a unit in order to optimize performance correctly.

There are three main categories of gas turbine degradation which contribute to unit overall performance degradation: turbine efficiency, compressor efficiency, and swallowing capacity.

Turbine efficiency degradation is a result of the gradual change in the components in the hot gas path. Examples of this include: geometry changes due to material loss, tip clearance changes, and accumulation of fused particles (fouling, coking, etc.). Turbine efficiency degradation is a permanent change and can only be corrected by repairing or refurbishing components.

Compressor efficiency degradation is comprised two components. There are both temporary (reversible) and permanent degradation components. Temporary degradation is a result of the compressor becoming dirty by the accumulation of dirt on the flow path and airfoils. This type of compressor degradation can be reversed by a wash which removes the affecting buildup (see Figure 2). The permanent component of compressor degradation is as result of permanent change in the flow path. The typical cause of this change is erosion of the airfoil surfaces due to impact of abrasive particles.

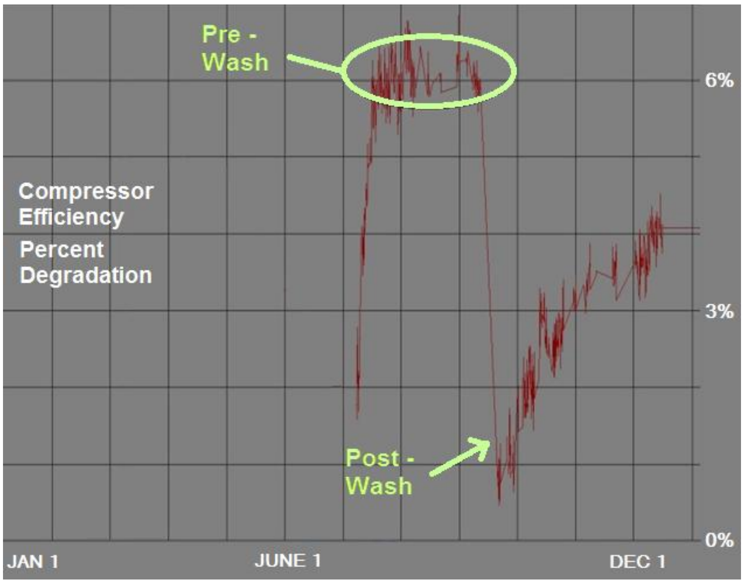

Figure 2 - Effect of Compressor Wash

Finally, the swallowing capacity (sometimes called throat area) is the change in the volumetric capacity of the turbine to accept flow. This is usually caused by creep in the first row stator vanes immediately downstream of the combustion chamber. This creep causes an opening up in flow area which can lead to imbalance and efficiency loss

Even though a change in turbine efficiency has the largest overall effect on total turbine performance, in practice, it generally takes a longer time to reach detrimental levels when compared to the other forms of degradation. Compressor efficiency generally degrades much sooner than the other two types of degradation.

Figure 3, below, shows the typical effect of the individual component degradations and the overall turbine performance degradation.

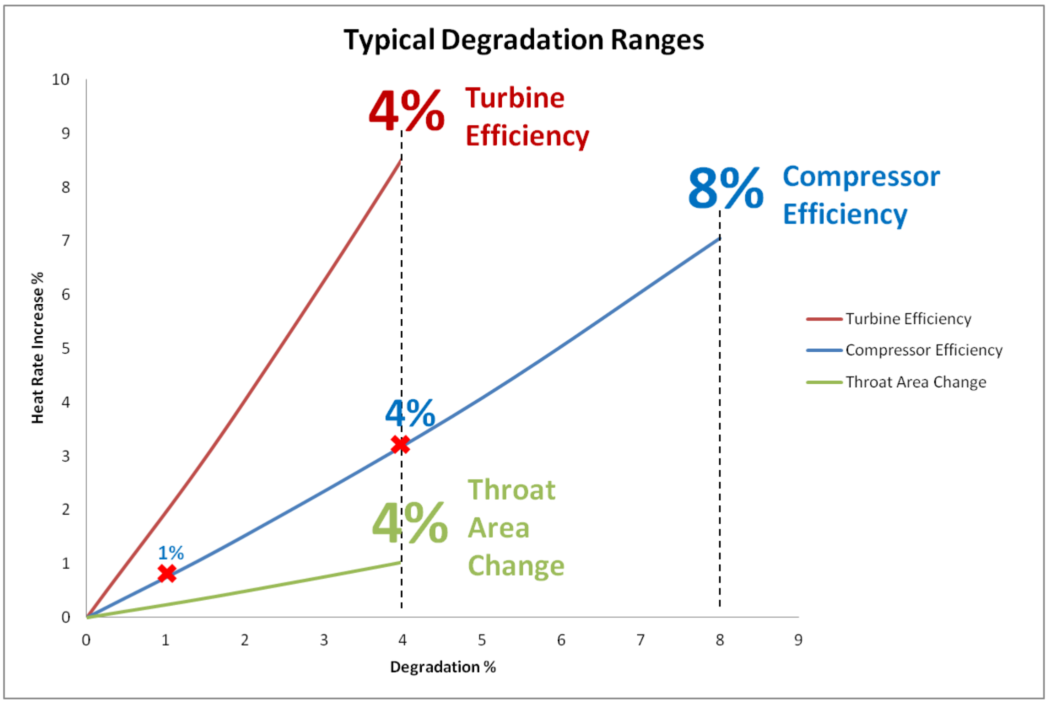

Figure 3 - Increase in heat rate due to gas turbine health degradation

Performance degradation can only be determined using a precise physics based turbine model built specifically for each turbine type. The turbine physics model uses published performance information combined with instrumentation data, which is stored in an historian database, to calculate the expected new and clean (ideal) performance of the machine. Performance degradation is calculated by comparing the actual turbine output with the expected ideal performance. Any difference in performance not directly related to ambient conditions is correlated directly to degradation. Because the turbine model uses real performance characteristics and instrumentation information, it is able to correctly determine exactly the three different degradation components.

4 Optimization Using Degradation Information

With the knowledge of all unit degradations, a more economical optimization strategy can be used. The key to this strategy is to know which units in the fleet consume the most fuel for a given power output in order to prioritize which units are run. The goal is the same as any other strategy - deliver required total flow and station discharge pressure using the least amount of fuel.

The first step for a physics simulator is to determine where on the performance curve the units are running. A typical polytropic head vs. flow rate curve is shown in Figure 4. This chart contains several important pieces of information. The horizontal axis is the volumetric flow rate and the vertical is the polytropic head (which is the amount of energy being added to the fluid for the given flow rate). The two sets of curves on the chart process efficiency and the resulting RPM of the unit. Another important piece of information is the Surge Limit Line (SLL). This is the safe operating limit of the system and running near this line should be avoided to avoid a potential catastrophic surge condition.

These performance curves depend on the degradation condition of the unit and can change depending on a number of factors.

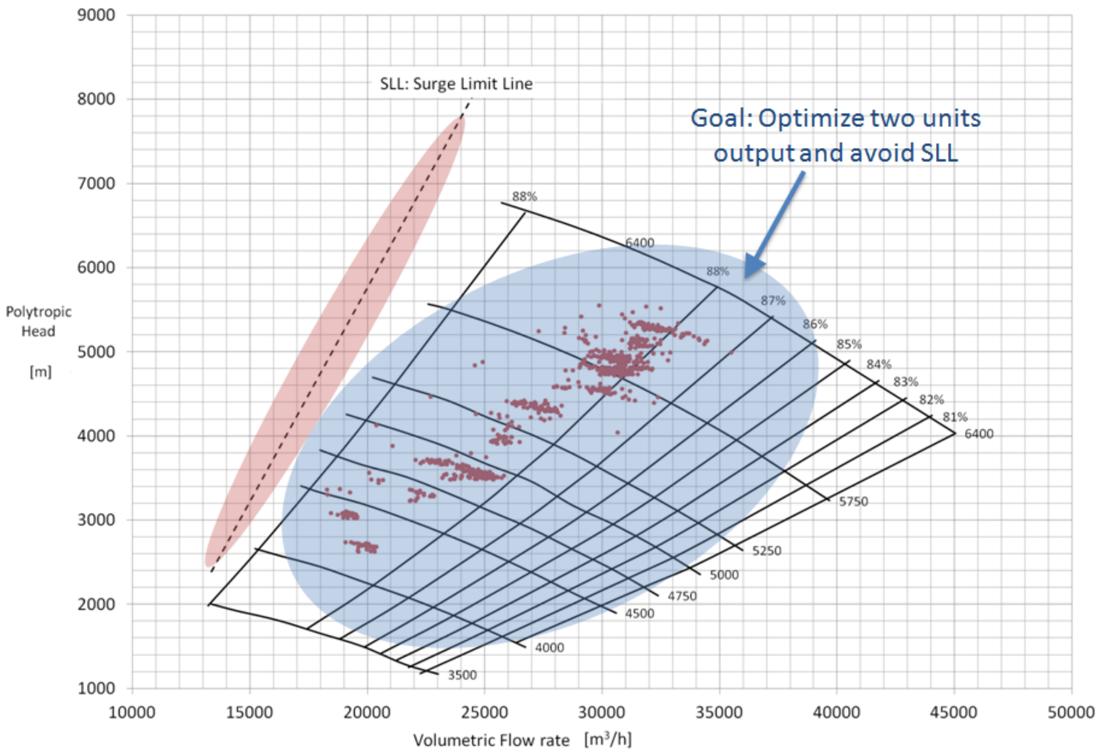

Figure 4 - Typical Pressure vs. Flow Curve

A simple example can illustrate why knowing degradation condition allows operation to be optimized. Assume that there are two identical units connected in parallel at a pipeline station. One is a brand new unit, while the other has been run for 5 years and recently overhauled. It's logical to assume that the new will perform more efficiently than the older unit. Therefore, the best strategy is to use the newer, more efficient, turbine as much as possible while limiting the use of the secondary. The ability to load balance will require the compressor station to have the ability to limit flow to each of the units in order to match the head delivered. If demand is sufficient that both units are at full load, this strategy cannot be employed. However, the physics based model optimization can still utilize great fuel savings.

Using the individual unit degradation information, It is possible to optimize not just the individual station, but the pipeline as a whole, by considering the degradation of each station. Depending on the line requirements, the choice of which stations to run can be determined by choosing amongst the most fuel efficient stations available. Again, this information is only available by running a sophisticated performance and simulation model for each turbine along the pipeline, and knowing the up to the minute performance degradation information.

5 Example of Load Splitting

As a practical example, consider the simple case of a single pipeline station with two identical 27 MW gas turbines driving axial flow compressors to pump compressed gas. The site is equipped with flow restricting valves in order to adjust the flow rate to each unit (in order to balance head between units). The goal is to run this station using the least fuel as possible for the maximum output.

Assume that the physics simulation calculations reveal that one of the two units has a compressor degradation of 2% while the second unit has is performing as-new (0% compressor degradation). According to Figure 3, a compressor degradation of 2% results in an increased heat rate of approximately 1.6%. If the unit with 2% degradation were to run for the entire year instead of the unit with the 0% degradation, the difference in fuel consumption may amount to more than $157,000 USD (using 2014 fuel costs). That is a significant operating cost which could be reduced by simply changing the primary unit. Table 1 works through a sample calculation used to determine the fuel savings.

Table 1 - Cost of Degradation Calculation

Power	27			MW
Thermal Efficiency	37%			
Comp. Degradation	0%	2.00%	5.00%	
Heat Rate Increase	0%	1.64%	4.24%	
Heat Rate	73.0	74.2	76.1	MJ/s
Fuel Price (2014 Market Avg)	$4.39			USD/MMBTU
	$4.16			USD/GJ
Cost Rate	$26,214	$26,644	$27,327	$/d
	$9,568,034	$9,725,223	$9,974,187	$/y
	Cost Savings (per year)			
	$157,189		X	
	X	*$248,964*		
	$406,153			

The savings amplify with higher degradations. Consider the same two units but this time with 5% and 2% compressor degradations, respectively. Running the unit with the higher degradation will consume an estimated $249,000 USD more fuel for the year than the unit with the lower degradation.

Without knowing the health of the station, deciding on which unit to run can be a shot in the dark. These specific examples show a significant cost savings is possible for a single station. When multiple stations are optimized, the potential cost savings can multiply. It is important to note that actual savings will depend on many factors such as demand, line conditions, and the required station and pipeline logic.

6 Conclusions

Operators are faced with many choices on the most economical way to run a pipeline and individual stations. Conventional methods do not consider turbine degradation in the optimization strategies. The best way to determine the degradation information is by using a sophisticated turbine physics simulation platform which has the capability to compare new and clean performance with real-time running performance. With the coupling of simulation software and advanced pipeline optimization logic it is possible to build a strategy to run the pipeline which can save significant fuel cost per year while still meeting all line demands.