Keeping the Wheels of Industry turning efficiently and in an ecologically sound manner:

Gas Turbine multi-fuel capability for Power Generation and Cogeneration

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Abstract

Pipeline quality natural gas is the preferred fuel of choice for power generation on plants varying in scale from a few kiloWatts to hundreds of MegaWatts: it’s clean-burning, with low CO2 and emissions of pollutants, and economical. But what are the alternatives when natural gas is not available, or its supply cannot be guaranteed? In some instances, a town or factory or remote oilfield may rely heavily on a local power plant for its energy supply because of a weak grid system or lack of central generating capacity. So if the gas supply volumes are reduced, or the gas is redirected because of prevailing policy decisions, what happens?

Many power plant adopt dual, or even tri-fuel, capability with liquid fuel considered as a back-up fuel. On modern gas turbines, this is usually a premium liquid fuel, such as aviation grade kerosene or No. 2 diesel. But these are expensive fuels, and if prolonged natural gas outages might occur, will have an adverse impact on plant economics.

In some instances, plant may have access to locally-produced ‘waste’ fuels, such as a process offgas in a refinery or chemical plant, biogas from digestion or landfill gas. These can be used as main or back-up fuels, either on their own or blended with natural gas, to provide fuel gas for the power plant. Another option is to use a lower cost liquid fuel, such as Heavy Fuel Oil (or even crude oil) as the fuel source.

This paper looks at some examples where such solutions have been applied, and looks at other potential ways of replacing or supplementing natural gas, such as mixed fuel operation or use of Natural Gas Liquids.

Introduction

Natural gas is today’s fuel of choice: it’s a relatively low cost fuel, has a low carbon content so produces less carbon dioxide (CO2) per kWh of electricity generated compared to other fossil fuels and emits less combustion pollutants (such as oxides of nitrogen and sulphur, carbon monoxide and particulates) reducing the impact on the local environment.
Future forecasts of energy consumption predict an increase in usage of natural gas in the years to come, both in real terms, and as a share of the overall fuel mix, with an average annual growth forecast of 1.7% per annum between 2010 and 2040, faster than any other major fuel source.

Figure 1: Total Energy consumption by fuel type (quadrillion btus)
Source: ExxonMobil – The Outlook for Energy: A view to 2040

The forecast shown in Figure 1 above suggests that even in 2040, the World will still be dependent on fossil fuels to provide the majority of its energy, but that the role of coal with its high CO2 emissions will decline while growth in oil consumption, another high CO2 emissions fuel, will slow down. This is more clearly shown in Figure 2 below, which looks at the forecast percentage share of the total energy requirement by fuel type.

Figure 2: Percentage of Energy mix by fuel type
Source: ExxonMobil – The Outlook for Energy: A view to 2040
But not all countries can meet gas demand with indigenous resources, and so natural gas has become a globally traded product by pipeline and increasingly in recent years through LNG shipments.

Figure 3: Major gas trade movements 2012
Source: BP Statistical Review of World Energy June 2013

The demand for natural gas, the distribution of resources and the limitations of the gas transmission infrastructure, along with a decoupling of natural gas prices from oil prices in some parts of the World, has led to huge variations in the price paid by natural gas users and transporters. The USA, for example, with the new developments of indigenous shale gas reserves along with offshore production in the Gulf of Mexico and export restrictions, has seen gas prices at the main trading hubs decline over the past 4 or 5 years, whereas Japan which is almost totally dependent on LNG imports to satisfy natural gas consumption has seen prices rise significantly over the same period.
The increased availability of LNG has also led to the development of a spot market, and the ability to ship LNG to wherever the highest price will be paid. This means that sometimes in countries that rely on LNG imports to meet natural gas demand, there may not be a gas shipment available to top-up long-term contracted supplies to meet peak demand, as the cargo has been diverted to a higher price market.

**Dual Fuel Gas Turbines**

While natural gas is the preferred fuel for gas turbine operation in power plant, and in cogeneration facilities installed in industry, commercial and Government buildings etc., the availability of natural gas cannot necessarily be guaranteed.

In the United Kingdom, it was common for operators of cogeneration plant to opt for ‘interruptible’ gas tariffs – an arrangement by which they received a lower gas price but the gas supplier had the right to cut off the gas supply for a given number of days per year as long as advance notice was given of supply disruption. This allowed the gas supplier to ensure gas was supplied to essential users and those on more expensive tariff schemes. The cogeneration plant operators therefore opted to purchase dual fuel gas turbines, with a premium liquid fuel such as #2 diesel or kerosene being used as a back-up fuel in case of non-availability of natural gas. This enabled the operator to continue to provide the heat and power necessary for his processes without shutting down any part of the operation, but when liquid fuel operation was required,
there was an economic impact due to the additional cost of the liquid fuel, even if operation on
liquid fuel was only for a few days.

But what if a natural gas supply is not available for a prolonged period? The alternatives are to
shut down production completely, shut down the gas turbine and rely on the electricity grid for
power and liquid or solid fuel boilers for heat production, or to use a lower cost liquid fuel.

There are lower cost liquid fuel available – either because of the applicable tax regime or
because they are poorer quality fuels than #2 diesel. In some locations, Liquified Petroleum Gas
(LPG) is an economical option to allow continuous gas turbine operation. A by-product fro gas
or oil production, LPG is often readily available, easily transportable and can be used in many
models of gas turbine with relatively simple changes to the fuel system and burners. Naphtha is
another alternative.

Naphtha as a fuel has to be treated with a lot of care. It is very volatile due to the range of
species that can make-up such fuels. Siemens Industrial Turbomachinery Ltd in Lincoln, UK
developed a special variant of the conventional combustion burner for some cogeneration
projects in Turkey, enabling the facilities to operate on what was then a low cost fuel while the
customers were waiting for a natural gas pipeline to be completed. The novel burner design
allowed a small amount of the fuel to “leak” resulting in local vaporisation, and the latent heat of
vaporisation provided cooling to the end of the burner keeping the bulk of the fluid cool and in
liquid phase through to the heart of the burner where controlled vaporisation takes place.
Applying the technology in this way enabled the fuel delivery system to operate at low pressures,
<40bar, a safer alternative than compared to traditional methods of handling naphtha fuels by
operating at very high pressures.
Another option is to use a lower cost refined product, such as Heavy Fuel Oil (HFO) or refinery residual oils. There are varying grades of HFO depending on quality and viscosity, but in general HFO costs around 40% less than a premium refined liquid fuel like #2 diesel. The viscosity of HFO and the contaminants contained within it make it unsuitable for use in most gas turbines, but there are some models, such as the Siemens SGT-500 that, due to their combustor and fuel system design, have the capability to operate on such high viscosity fuels.
The latest order for the Siemens SGT-500 gas turbine is an example where the capability to operate on HFO was the compelling factor when EDO Cement decided to buy 3 x SGT-500 as the power generation solution for their new cement plant in Okpella, Nigeria. The power generation facility, designed to met the whole cement plant need so as to be independent from the power network, is mainly based on using natural gas as the primary fuel, but as pipeline supplied natural gas is unreliable in Africa in general and specifically in Nigeria, availability of a liquid back-up fuel was considered crucial for uninterrupted and profitable cement production. Disturbances on the natural gas supply network are frequent and can in the worst case last for several months, which puts high focus on minimising the cost of operation on the back-up fuel. Prices of premium liquid fuels can often be more than twice the price of residual fuels like HFO, leading to the HFO capability of the gas turbine significantly reducing operational costs during periods when natural gas is not available and operation on a back-up liquid fuel is required.

![Siemens SGT-500 Gas Turbine](image)

Figure 6: Siemens SGT-500 Gas Turbine

**Alternative Gas Fuels**

An alternative to using liquid fuel in gas turbines to compensate for non-availability of natural gas is to source an alternative gas fuel. With gas prices at best volatile and at worst rising rapidly, seeking an alternative gas fuel may be a more attractive long-term economic solution than operating a gas turbine continuously on pipeline quality natural gas.
There are industrial processes which produce waste gases that could be used as gas turbine fuels such as Coke Oven Gas (COG), or high hydrogen refinery off-gases. These gases may be considered sometimes as a zero cost fuel, as often they will just be flared for disposal and so using these gases as a fuel offers both economic and environmental benefits. However, these fuels contain hydrogen and carbon monoxide, and so require special consideration for both the combustion system and for personnel safety reasons.

The Siemens SGT-200 has operated for many years with fuels containing high hydrogen concentrations (up to 85% by volume). This capability was extended to encompass refinery off-gas fuels such as COG from the production of coke for the steel industry. In one example of this application, 2 units in China have been operating on COG for more than 2 years and have accumulated in excess of 25,000 operating hours. Before the COG is provided to the gas turbine, it passes through extensive cleaning processes to ensure much of the known contaminants in such fuels are eliminated, or reduced to a more acceptable level.

Figure 7: An SGT-200 gas turbine in China operating on Coke Oven Gas as the primary fuel.
Other potential gas fuels are those derived from natural decomposition of organic material, such as biogas from anaerobic digesters or landfill gas from municipal waste disposal sites. These methane / carbon dioxide gas mixtures are suitable fuels for gas turbines, and can even be used in Dry Low Emissions (DLE) combustion systems. The development work undertaken by Siemens on their DLE combustion systems to utilise such gaseous fuels has enabled customers to operate Cogeneration plant on low cost, locally available fuels that can displace natural gas, or can be used as alternatives depending on price and gas availability, while also providing environmental benefits by avoiding venting to atmosphere or flaring of these methane-rich gases. Two such projects are discussed in the following sections.

The first example is an industrial facility in China that fuels its gas turbine-based cogeneration plant, providing the power and process steam necessary for operations, on a biogas – a hydrocarbon gas fuel weakened with Carbon Dioxide. Part of an on-site ethanol processing plant produced a waste biogas containing high amounts of inert species, carbon dioxide. A typical fuel composition and analysis is shown in table 1 below.

<table>
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<th>Species</th>
<th>Vol %</th>
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<tr>
<td>O₂</td>
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</tr>
<tr>
<td>H₂S</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table 1: Biogas composition (Sept 2011)

Siemens extended fuels capability on the SGT-400 gas turbine covers fuels as low as 17.5MJ/m³ Wobbe Index (WI), and for this particular application the WI was determined at 21MJ/m³, at a required supply temperature of >50°C. Testing also proved that the unit could be started on the biogas, negating the need for an alternative fuel, so a gas fuel only turbine configuration was
confirmed with order placement July 2012. Installation and commissioning was completed during April and May 2013 (figure 5)

Figure 8: 12.9MW SGT-400 in operation on a weak gas fuel with Wobbe Index circa 21MJ/m³

A second example is that of a tri-generation plant installed at the University of New Hampshire (UNH) in the USA. Here a Siemens SGT-300 gas turbine operates on natural gas, processed landfill gas and distillate fuel.

Originally the contract was to supply a dual fuel (natural gas and distillate) gas turbine for the tri-generation plant at the Durham Campus of University of New Hampshire, providing the power required by the campus, the heat required in winter and cooling in the summer months, while meeting the strict emissions requirements of 15ppmv NOₓ laid down by the local authorities. When a local landfill site made the University aware of the availability of landfill gas as a possible lower cost fuel, the option was evaluated by the engineering teams and it was decided that this fuel was could be accommodated only if the removal of CO₂ could be achieved, leaving nitrogen as the dominant inert species, but would be an economically viable alternative to pipeline natural gas.
Prior to this project, the SGT-300 standard DLE combustion hardware had been proven to have an extended gas fuel capability down to circa 30MJ/m$^3$ Temperature Corrected Wobbe Index (TCWI), with units installed for offshore Oil & Gas applications.

UNH installed the necessary landfill gas treatment system and constructed a delivery pipeline of approximately 20km from landfill site to the university in an additional US$40m investment. Gas turbine operation on the processed landfill gas (PLG) commenced in spring 2009 and continues today. Even when operating on the PLG, this installation was still required to meet the requirements for low emissions to atmosphere and to be compliant with air quality permit at all operating conditions.

![Figure 9: Siemens SGT-300 gas turbine-based tri-generation application at the University of New Hampshire, USA](image)

Operation on PLG sometimes resulted in non-compliance with regard to exhaust emissions, occurring during a combination of part-load GT operation and variability in the PLG fuel composition. To address this issue, ‘intelligent control’ of the gas turbine DLE system was developed. Using the existing instrumentation measuring the normal parameters that are monitored on a gas turbine, a control algorithm was developed which allowed automatic control during periods with changing fuel quality, or load, or ambient conditions. The result is more
accurate control of the pilot fuel schedule within the combustion system in order to achieve the lowest possible emissions signature without compromising gas turbine operability. This control method is now a standard switchable option on all Siemens sub-15MW gas turbines with DLE combustion systems.

The NO\textsubscript{x} emissions data was recorded during a full month, 1 year apart, before and after application of ‘intelligent control’ and the results are shown in the charts below (figure 7). For both August 2010 and September 2010, full emissions compliance was achieved after introducing and applying “intelligent” control.

![Histogram of NO\textsubscript{x} with and w/o Intelligent control](image)

Figure 10: NO\textsubscript{x} data at UNH on an SGT-300 gas turbine before and after the application of intelligent control

**Developments for Remote Oilfield Operations**

Because of the need to produce their own energy in remote locations, Oil & Gas operators have operated gas turbine power plant on a variety of different, non-standard fuels for many years.

In order to produce the power required for operations at the lowest cost, Oil & Gas operators have used locally available fuels with the minimum of processing. These fuels are usually associated gases – hydrocarbon content gases produced along with oil – and can vary from ‘weak’ gases with high inert gas contents through to ‘rich’ gases with high levels of ethane,
propane and butanes, and even higher hydrocarbon species, within the fuel gas. The gases can also contain high concentrations of hydrogen sulphide, H₂S.

Increasingly pressure is being brought to bear on such installations to comply with air emissions legislation, despite the use of non-standard gas fuels of varying composition and quality. Siemens, like most other gas turbine OEMs, has been enhancing the fuel flexibility of the Dry Low Emissions combustion systems fitted on their gas turbines in order to be able to accept this wide range of potential fuel gases, and in recent years have won a number of orders for such systems. These proven capabilities are therefore available for other industrial and utility power applications where such potential fuels are available.

An interesting development on the fuels front has also been driven by the Oil & Gas industry: bi-fuelling, or mixed fuel operation. In some instances, there is insufficient gas available from oil production operations to provide all the fuel for the gas turbines, and so in order to generate the power required without the need to build a gas import pipeline, Siemens have developed the capability on some gas turbine models to ‘top up’ the gas fuel with liquid fuel to provide the required energy input. While the liquid fuel for topping-up would normally be a high quality diesel or kerosene, on the Siemens SGT-500 the produced crude oil itself can be used as the liquid fuel. This capability enables the maximum amount of produced gas to be used and avoids the environmental impact of flaring this otherwise waste product. This capability could also be applied in other industrial applications where a waste or low cost gas fuel is available, but not quite in sufficient enough quantities for full-load gas turbine operation.

**Conclusions**

While pipeline quality natural gas will remain the preferred fuel of choice for gas turbine power plant and cogeneration installations, Siemens’ proven gas turbine experience shows that there alternatives available to compensate for brief interruptions in, or longer term non-availability of a natural gas supply, and that locally available resources can provide low cost alternative fuels to ensure security of energy supplies for both industrial users and utility power providers, while also sometimes providing environmental benefits both locally and globally.