SPARK IGNITION CHP
GREAT PERFORMANCE, BUT LOTS TO THINK ABOUT

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Abstract

'Combined Heat and Power' systems have been commonplace on waste water treatment works for decades. The latest engine technology however offers significant gains in terms of efficiency and emissions. The ability to successfully integrate this type of engine, and hence access these benefits, relies upon the careful consideration of some key aspects:

- Sizing/utilisation – High capital cost makes redundancy uneconomic. These engines can 'ramp' to a greater extent, but constraints still apply.
- Gas quality – Spark ignition engines have increased sensitivity to contaminates in the biogas.
- Integrated control – ensuring that the site systems and proprietary engine systems can communicate without compromising network security.
- Load management – The low inertia of this type of engine makes them susceptible to trips in response to load steps. (A particular challenge if the CHPs are going to be used during power outages).

These aspects are discussed herein, with practical examples to illustrate, as required.

Keywords

Biogas; CHP; Efficiency.

Introduction

Asset planners and accountants can sometimes be forgiven for being so excitedly seduced by the prospect of step changes in OPEX opportunities that a high efficiency CHP installation can offer. When assessed simplistically based on the typical engine efficiencies, the numbers speak for themselves:

Table 1: Indicative OPEX Improvements

Engine Technology	Typical Electrical Efficiency	Notional kW/Nm^3 'biogas'	£/year benefit*
Historic compression ignition	30%	1.80	£660k
Modern spark ignition	42%	2.55	£920k
			£260k improvement.

* Based exclusively on energy import offset @ £0.1/kWh for a site generating 10,000 Nm^3/d of 'biogas'. Such a site would likely be at the mid to lower end of the spectrum in terms of CHP viability for municipal wastewater treatment plant applications.

These theoretical improvements can indeed become a reality. In many cases, opportunities to improve heat recovery system performance, and reduce maintenance down-time, means the benefits can be extrapolated further still.

However, any project to upgrade or install a spark ignition CHP engine must be carefully conceived if it is going to deliver successfully, and go on to return the anticipated 'operational expenditure' (OPEX) benefits. Some of the influencing factors are obvious, but others are more subtle. This paper seeks to explore some of the key aspects from a general perspective and is written in laymen's terms as far as is possible. The paper is written in the context of CHP at municipal wastewater treatment plants. This is due to circumstance, with the author's experience arising from projects in this sector. It is however suggested that the same challenges apply to varying degrees in other applications such as landfill or food waste processing.

Sizing/Utilisation Review

A consideration that certainly falls into the 'obvious' category is engine sizing; selecting the correct number and size of engines is by no means a new conundrum. The main difference compared to historic considerations appears to be that of budget provision as it is often the case that asset planners are no longer inclined to approve the inclusion of 'spare' or 'standby' engines. The predominant reason for this, as explained further in 0, is that spark ignition type CHP engines are seldom truly counted as part of a site's 'standby power provision'. As a result, the OPEX case for procuring units basically needs to justify the cost of installation. Even when maintenance outage cover is considered, any installed capacity that is not regularly generating is likely to tip the balance and extend the payback period significantly.

Static engines are generally intended to run at, or close to, 'maximum continuous rating' (MCR). If the gas is available, then of course an operator would want to run engines at MCR continually to maximise revenue. It also makes sense to run an engine at MCR as the maintenance intervals tend to be based on 'hours run'. (This is because your maintenance costs remain the same regardless of how many kWh you manage to generate over a time-based running interval). When operating more than one engine, it is also necessary to consider that ramping CHP engines together will increase the likelihood that they reach service intervals at the same time. This of course should be avoided if possible.

A modern spark ignition CHP is generally more flexible in terms of 'turn down' than an ageing dual fuel engine. The penalty paid in terms of an efficiency drop when running below MCR is certainly likely to be reduced when compared to an older engine. Acknowledging the maintenance cost impact and small efficiency penalty, the ability to better match gas consumption to gas production gives system designers a little wriggle room. However, limits of course apply. For example, the maximum 'turn down' is prescribed by the engine supplier but is typically say MCR x 60%. Also, for old and new engines alike, frequent stop/starts are not desirable. Suppliers often impose warranty linked limits to the number of permissible starts in a 24-hour period. (4 starts per 24-hour period might be considered typical). Therefore, at sites with limited gas storage, even the ability to reduce consumption rates will mean a poorly selected engine will stop and start with undesirable regularity. (Poorly selected in this context suggest the engine or engines are oversized). The compression ignition type engines as previously employed could typically be switched over (when already running on biogas plus a small proportion of 'pilot' diesel fuel) to run exclusively on diesel fuel. Rather than subject an engine to a stop, operators running dual-fuel engines have the option to switch engine(s) to full diesel fuel supply until the biogas supply recovers. As they will not run on diesel, this option is simply not available for spark ignition engine operators.

Losing the option to run CHPs on diesel fuel also has implications for the raising of process heat. In most municipal wastewater applications, the heat recovered off the engines is utilised for sludge treatment (e.g. anaerobic digestion/pasteurisation/thermal hydrolysis etc). Providing these processes with sufficient heat is often the key to overall process compliance. Although sites should theoretically have the means to satisfy this process heat demand using dedicated boilers, it is often the case that a combination of CHP engines and boilers will in fact be required to cater for peak demands. On occasions where the peaks in heat demand (during cold weather periods) coincide with low biogas production, dual fuel engine operators would again have the option to supplement CHP heat output by running engines on diesel fuel. Without this option, spark ignition engine operators will need to rely to a greater extent on any auxiliary boiler capacity to ensure sludge compliance is not compromised.

Fuel Gas Composition

As per the subject of Section 0, ensuring the fuel gas supply is appropriate for the CHP engines is clearly a fundamental consideration, as fuel gas supply pressure is perhaps the most common bugbear for operators of gas engines of any type. Moisture content normally comes in a close second. The presence of contaminates in the fuel gas has a more gradual impact on engine performance and health. None the less, this gradual degradation resulting from fuel gas contaminates can have devastating effects.

From a fuel gas pressure perspective, spark ignition engines are in fact easier to satisfy than compression ignition type engines. The primary difference being that the compression ignition type engines require a much higher supply pressure in order to operate. The capital and operational costs associated with supplying fuel gas at high pressure are significant in the first instance; the operating pressures invariably require that positive displacement compressors are needed. The hazard associated with operating gas equipment and pipelines at (relatively) high pressures is a further unwelcome headache. Generally speaking, systems serving spark ignition engines can utilise centrifugal type blowers. Not only do these blowers use significantly less power, but the system thermodynamics do not necessarily mandate that post-compression gas cooling is required. Booster machinery must still be carefully selected and system design is still highly critical. Fluctuations in fuel gas pressure can and do manifest in issues with spark ignition engine operation.

Spark ignition engines, or moreover, spark ignition engine suppliers, are more prescriptive about the moisture content of fuel gas. It is clear that condensate tends to carry the aggressive and damaging contaminates (discussed below) forward through fuel gas systems. It has hence always been the case that fuel gas systems for engines should be designed to incorporate facilities for collecting and removing condensate. However, apparently conservative relative humidity (%RH) limits are often prescribed by spark ignition engine suppliers, introducing the additional need to assess requirements for ‘drying’ of fuel gas. As a result, it is not uncommon to find gas dryers in modern CHP fuel gas systems. As well as increasing the capital cost of a new spark ignition installation, these active dryers also erode the OPEX benefit as a further ‘parasitic loss’.

When it comes to contaminates in the fuel gas, there are a number of key risks that need to be considered. In wastewater treatment applications, the presence of significant quantities of hydrogen sulphide (H_2S) in the fuel gas has historically been the main concern. Hydrogen sulphide (or sulphuric acid in condensate) can of course cause corrosion both in the gas train and within the engines themselves. This remains the case for spark ignition engines. Typically, the process of drying the gas to the requisite %RH helps to reduce the H_2S concentration (as a quantity drops out in the condensate). By specifying a limit for H_2S, spark ignition engine suppliers further force designers to consider the potential need for scrubbing.

Another clear limit stipulated by most engine suppliers concerns siloxanes. If present in significant quantities in the fuel gas, siloxanes leave a glass-like silica residue on the surfaces of internal engine components. These deposits accelerate wear and necessitate additional maintenance. Whether it is because modern engines are more sensitive to this type of contaminant damage, or whether this type of contaminant is becoming more prevalent in the waste water influent, there is now a clear need for system designers to address the presence of siloxanes and include filtration or absorption stages to protect engines (and comply with engine warranty conditions). Removing siloxanes again comes at a cost and the ongoing (subcontract) OPEX implications are particularly high.

Spark plugs (that are clearly not a problem for compression ignition engines) certainly have been observed to suffer if the fuel gas is not properly conditioned. Although they are essentially consumables, the cost associated with renewing spark plugs on these multi-cylinder engines is significant and should be considered.

Control, Control Integration & System Security

The main reason modern engines can offer such an efficiency increase is the sophistication of the engine control systems. These control systems are monitoring thousands of parameters in real time and adjusting the combustion to suit. Every CHP engine will have an ‘engine control unit’ (ECU), just like a modern car. Typically, CHP units also have a programmable controller that takes care of the ancillary items (such as the heat recovery systems and enclose ventilation etc). In tandem, these controllers will work to optimise and protect each engine. In most cases, the programmable controllers (rather than the ECUs) offer the control interface for site systems. It is ordinarily via this interface that the engine/engines are given information regarding the availability of fuel gas or site heat demands. (Some pertinent exceptions are discussed in Section 0).

As well as managing engine operation locally, it is common for both the engine ECU and engine controller to have the means to communicate via modem to the supplier’s technical service teams. If either it detects a problem, or the site operator reports an issue, the supplier’s off-site technical teams can interrogate and potentially rectify issues quickly and efficiently. Whilst this is a valuable feature, there are two significant aspects that need to be considered; safety and network security.

From a safety perspective, the implications of a remote team having the ability to start/stop/trim/adjust these large machines are clearly significant. Operators will admittedly be used to the fact that these engines are operated in an automatic mode. They might for example be automatically ramping up in response to a high digester gas level on site. However, under remote control, there is a possibility that the engines will operate in a way that is contrary to the local operator’s expectations. Although there should be operational safeguards to prevent this from leading to a situation that might result in damage or harm, a residual risk remains. Further to such operational safeguards, system designers might consider the option to disable remote control functionality whilst the engines are running in regular ‘auto’ mode. It would then be necessary for the operational team on site to enable this functionality should the engine supplier’s service team need to make changes. If agreed to be a requirement during design development, collaboration will be required in order to facilitate this type of discretionary access. The additional complexity of the solution is likely to attract additional cost.

With their modem connections, the ECU and/or the engine controllers are potential access points for malicious attempts to breach network security. As noted above, and it is certainly probable in the context of municipal wastewater installations, the engine controllers are likely to be connected to site systems for data transfer in some capacity. The specific arrangements for these connections are critical to ensure the engine modem/modems do not indeed become access points for malicious attacks.

If the engine controller/controllers are simply monitoring site field instruments or communicating with items like site alarm outstations via ‘hard wired’ signals, then there is no risk of a beach. However, if it is proposed that the engine controllers will be communicating with other networked controllers on site via a true communications network, the risk is very real. Dependant on the existing site systems, there may well be the need for a communications protocol conversion in order that the engine controllers can communicate with the site network. If such a protocol conversion is required, then this is the logical place to configure a firewall to protect against the possibility of a breach. If a protocol conversion is not required, then a dedicated firewall may need to be included. Again, the cost resulting from the added complexity must be factored in during the feasibility assessment.

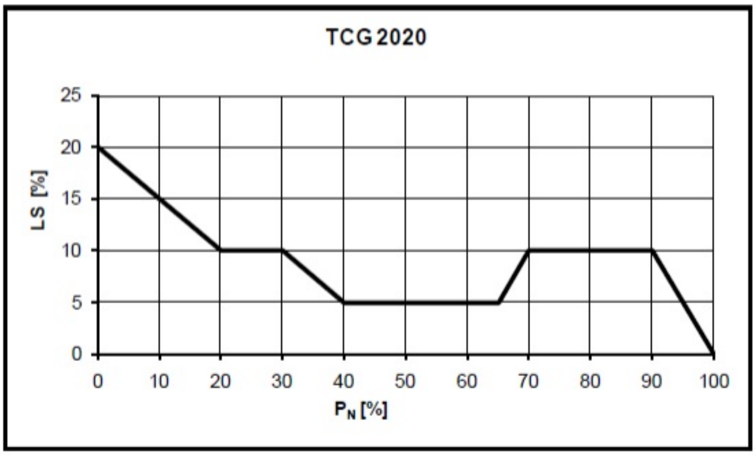
Engine Stability and Load Management

The ‘active load’ on a generating engine is imparted by its alternator. As the active load increases or decreases, the engine governor and ‘automatic voltage regulator’ (AVR) react accordingly. All engines have limits with respect to the load steps that they are able to tolerate. Too great a step, and the protection on the engines will trip them to prevent damage due to stalling/over-speeding. When operating engines in parallel with a grid connection, such under or overloads are largely attenuated. When operating in ‘island mode’, engines are exposed to changes in site load resulting when electrical equipment is started or stopped.

Compression ignition type engines tend to have a high rotational inertia. They also tend to operate at high compression ratios. These features give them a robust nature. It is hence conceivable that a compression ignition engine will withstand reasonable over, or underload, whilst the engine governor and AVR adjust to suit. As such, these engines are relatively stable and can often be run in island mode operation to provide generation capacity (or supplementary generation capacity) should a site lose its grid connection. As noted in Section 0, compression ignition type engines can also typically be switched over to run on diesel fuel if required. Operating on diesel further improves the compression ignition type engine’s ability to withstand load steps and perform in a stable way in island mode.

Spark ignition engine design seeks to maximise efficiency. The rotating inertia is reduced, allowing the engines to rev to a higher speed. They are also running ‘leaner’ at significantly lower compression ratios. These features tend to give them a more sensitive nature with respect to load steps. The protection settings for the engines need to be much tighter, limiting their ability to accept or reject load quickly. Again, when operating in parallel with a grid connection, this limitation is not a significant drawback. However, the option to run spark ignition type CHPs when a site is operating in island mode needs special consideration. It is certainly the case that spark ignition type engines should only be run in conjunction with regular diesel generators to support island mode operation. It is probable that, even if the CHP engines were running at the time, a loss of the grid connection would necessitate a ‘black start’ for the site. This black start must be managed with diesel engines. Only once the site is running again on the diesel generators might the option to run the CHPs be considered. Depending on the nature of the site load, the diesel generator capacity and the CHP capacity, it may still not be possible to run spark ignition CHPs due to their intolerance of load steps.

The manual management of island mode operation with CHPs would require detailed knowledge of the site load characteristics and engine performance criteria. At sites with an automated power management system (that will automatically start and stop generators ahead of permitting electrical load to change), there is an improved probability that CHPs can be run in conjunction with diesel generators in island mode. It should be possible to programme the power management system to recognise the limitations of the CHP engines, exposing them only to load steps that they are known to tolerate. Figure 1 is an example of permissible load steps for a 20 cylinder 2MW TCG2020 CHP supplied by MWM GmbH.



P_N	Active load	$t_{r,In}$	Recovery time
LS	Load step	n	Speed drop

P_N [%]	$t_{r,In}$ [s]	n [%]	P_N [%]	$t_{r,In}$ [s]	n [%]
0 - 20	15	11	55 - 60	15	7
20 - 30	15	10	60 - 65	15	7
30 - 40	15	9	65 - 70	12	7
40 - 45	15	9	70 - 80	12	7
45 - 50	15	8	80 - 90	12	7
50 - 55	15	7	90 - 100	12	7

Figure 1: MWM TCG 2020 : Permissible Load Step Data

If spark ignition engines are replacing compression ignition engines, the standby power provision for the site needs to be reviewed. If the compression ignition engines had formed part of the standby provision, then an assessment of the practicality of counting the replacement engines in that provision needs to be made. Once again, the complexity and cost of making it possible to run CHPs during island mode operation and making said CHP installation resilient enough to be considered dependable in the event of an outage needs to be understood at feasibility stage.

Conclusions

In the main, the conclusions drawn below are pertinent for asset planners or teams tasked with feasibility assessments for new or upgraded CHP installations.

1. Designers should not be tempted to simply oversize CHP engines in an attempt to cater for current uncertainty or future increases in gas make.
2. When planning a CHP installation or upgrade, review the capacity and condition of the site's auxiliary boilers to ensure that the ability to meet process heat demands is not compromised.
3. A means to control the %RH of the fuel gas is likely to be required for a spark ignition system. The capital cost and OPEX impact of this aspect needs to be assessed.
4. A means to reduce contaminant levels in the fuel gas is likely to be required for a spark ignition system. Siloxanes are of particular concern. The capital cost and OPEX impact of this aspect needs to be assessed.
5. Remote (third party) control of CHP engine systems potentially constitute a H&S risk. Supplementary mitigation may be required.
6. Remote (third party) modem access to CHP controllers potentially constitutes a security risk. Additional security features may be required.
7. Spark ignition CHPs are significantly less tolerant of load steps when compared to compression ignition units. This compromise is required to access the improved efficiencies on offer.

8. If spark ignition engines are replacing compression ignition engines, the standby power provision for the site needs to be reviewed. If the compression ignition engines had formed part of the standby provision, then an assessment of the practicality of counting the replacement engines in that provision needs to be made.