System integration as the key to success for cogeneration with sewage digester gas

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Abstract This paper highlights an expected construction of numerous new cogeneration installations in Australia in the near future, due to the newly introduced revenue stream of green commodities. Some of the experiences from the installation at Cronulla STP are used to illustrate the importance of system integration of such units into a sewage treatment plant. The straightforward nature of these examples leads to the conclusion that the key to a successful integration is the proper managing of the multi-disciplinary parties involved during design, construction and operation.

Keywords Biogas; cogeneration; plant optimisation; sewage treatment plant; spark ignition engine; system integration.

INTRODUCTION

Biogas produced from anaerobic digesters and lagoons at sewage treatment plants (STP) presents considerable potential for renewable power production. Although the largest STPs in Australia have already developed this potential, smaller plants are still using the gas for digester heating purposes only, whilst the bulk of gas produced is combusted in flares. A cogeneration scheme, which provides heat from the cogeneration unit to the digester heating circuit, is particularly interesting because it eliminates the need for a gas fired heater, which makes 100% of the produced digester gas available for power production.

At present, most of the cogeneration units at the STPs have an electrical output of about 1 MW or higher. Smaller units were generally not financially viable in the past. Such smaller units were generally only constructed for non-financial reasons. However, the recent introduction of a variety of green commodities in Australia designed to increase development of renewable energy plants such as the NGACs (NSW Greenhouse Abatement Certificates), RECs (Renewable Energy Certificates) and MRET (Mandatory Renewable Energy Target) have significantly improved the potential financial revenue of cogeneration units. As a result, many more STPs can be expected to be considered for biogas cogeneration developments in the near future.

Given the potentially large number of new biogas cogeneration developments in the near future, the involved industry should be vigilant to apply the lessons learned from the past. The technical challenges posed by even these small-scale installations are often overlooked,

WorleyParsons, in a partnership with Sydney Water Corporation and energy efficiency specialists Energetics, became responsible for the operation and maintenance of the 470 kW cogeneration unit at Cronulla STP in 2005. This paper describes some of the challenges encountered operating this small scale cogeneration unit, the impact of these challenges on cogeneration unit performance and how these challenges were overcome. Secondly the paper discusses the importance of system integration as a key to success, what the important issues are and how to tackle these.

INTEGRATION INTERFACES AND PROBLEMS EXPERIENCED

Cogeneration interfaces

A cogeneration unit in a STP interacts with the plant at three interfaces, as illustrated in Figure 1:

(A) The digester gas interface
(B) The digester heating system interface
(C) The power distribution interface

Each of these interfaces needs to be fully understood, accounted for in the design and controlled during operation in order to obtain a satisfactory integration and operation of a cogeneration unit in the STP.

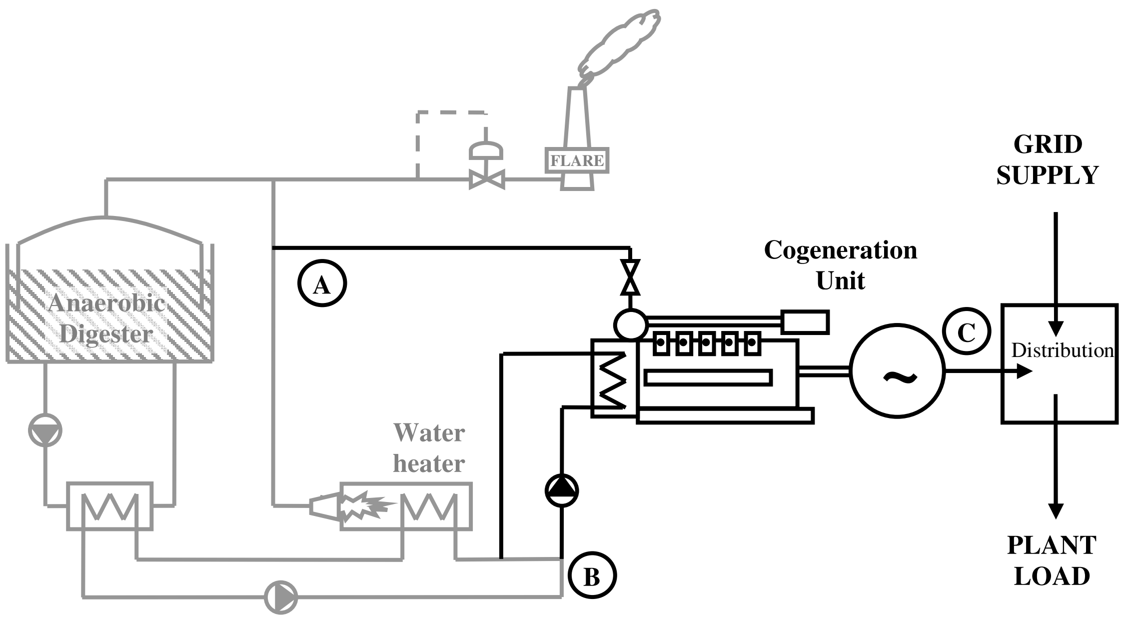

Figure 1. Integration of a cogeneration unit into a sewage treatment plant

The cogeneration unit at Cronulla STP

Cronulla STP treats a sewage flow of approximately 54 ML/day or an equivalent population of 200.000 people. As part of a plant upgrade including the installation of a tertiary treatment system with UV disinfection, a cogeneration unit was commissioned in 2001. The installed internal combustion gas engine is designed to supply up to 470 kW of electricity to the UV installation when fuelled with biogas. As part of the investment case leading to the installation of the plant (desired black-start capability), the electrical distribution system was only designed to supply the UV system. Subsequent export of power to the rest of the plant or the utility mains supply (grid) was not a feature of the designed system. Additionally, the heat from the engine and exhaust gases was made available for digester heating purposes.

The following four examples encountered at Cronulla STP illustrate how basic design flaws impacted on plant performance, resulting in sub-optimal cogeneration unit reliability. These examples highlight the need to consider integration during the design stage to ensure reliable plant operation.

Digester gas interface - fuel-supply driven engine load control
Symptoms. It was observed that the STP supervisory control and data acquisition system (SCADA) frequently tripped the engine due to a low-pressure alarm from the anaerobic digesters.

Diagnostics. Evaluation of the adopted load setting philosophy in the SCADA system showed that the load set-point supplied to the engine management system was demand-side driven, with the load controlled to match electrical demand from the UV-installation. The demand from the UV-installation tends to be constant over a long period of time, whilst digester gas production is variable due to plant operations such as recharging digesters.

The cogeneration plant and digester gas system at Cronulla does not feature any additional gas storage. Gas storage is limited to the floating digester hoods and gas piping system. As a result, the constant electrical demand from the UV-system and subsequent constant gas consumption by the engine would reduce digester gas pressure during lower gas production periods. Consequentially, in order to avoid air leakage into the digesters, the SCADA system would trip the engine on a low gas pressure. At one stage in time, the daily fluctuation in gas production actually resulted in a recurrent daily engine trip (as digesters were unloaded and recharged).

Remedy. The engine loading philosophy was adjusted to include consideration of the digester gas availability. A PID-controller was included in the SCADA system to adjust the engine load as a function of digester gas pressure. As a result the engine gas consumption is matched to the production and "turns down" in the event of gas system pressure reductions and significantly reducing low-pressure related trips.

Digester heating system interface – exhaust gas heat recovery control
Symptoms. The digester heating system was found to overheat when the engine ran at full load.

Diagnostics. The cogeneration unit has two heat exchangers that supply heat to the digester heating system: a jacket water heat exchanger and an exhaust gas heat exchanger. There were found to be two problems with the system.

Firstly, the exhaust gas heat exchanger has a bypass with a motorised butterfly valve on the gas side. This allows controlling the heat of the exhaust gas to the digester heating system and thus the hot water temperature. However, upon closer analysis of the control system, it was found that no automatic valve control was present. The valve was in a closed position at all times, sending all of the exhaust gases through the heat exchanger, hence the potential of overheating the system.

Secondly, the water from the digester heating system is sent through the cogeneration unit by a dedicated fixed speed pump. The original pump could be switched on or off by the SCADA system. However, it was found that after a more recent pump motor failure, this feature was not recommissioned. As a result, the SCADA could no longer control the amount of heat injected into the heating system by the cogeneration unit.

Remedy. The problem has been solved temporarily by opening the bypass valve on the exhaust gas heat exchanger. The digester heating system has not been found to overheat anymore. However, it is proposed to install a PID-control on the exhaust gas valve which will control the water temperature according to a SCADA-controlled set-point. A low-exhaust gas temperature will prevent the exhaust gases to be cooled below 150 °C to avoid any condensation in the exhaust stack.

It is also proposed to connect the water pump to a variable speed drive controlled by the SCADA system. This will allow the SCADA to tailor the heat input from the cogeneration unit to plant needs.

Power distribution interface - engine governing

Symptoms. It is customary on power generation plant start-up to observe transient behaviour. However, in the case of the Cronulla installation, the cogeneration engine was consistently observed to be surging erratically well beyond the start-up period. Evidence of this surging characteristic was observed in oscillations in engine governor movement, irregular power output and acoustic observations. In some cases, the surging behaviour caused the cogeneration protection systems to trip the machine.

Diagnostics. In an attempt to rectify the problem, the optimisation of the internal set points of the load governor controller was unsuccessfully attempted. It was found that the controller was set-up for islanding operation (i.e. disconnected from a power grid) and that there was no feedback signal from the mains supply or the power distribution bus. As a result, the system was susceptible to grid-induced oscillations while trying to match the engine output with the load demand.

Remedy. Because the original controller had no provisions to include a grid input signal, it was decided to replace it with a digital integrated engine controller with bus voltage sensing (Si-TEC Xtend CGC). The bus voltage sensing allows the Si-TEC controller to link changes in measured generator output to variations in the bus voltage, thus making a difference between measured load changes on which to act and those on which not to act. The resulting engine behaviour was found to be much more stable.

Power distribution interface - power metering

Symptoms. It was observed that the SCADA system frequently tripped the engine due to an over-voltage detection.

Diagnostics. The generator could operate normally for hours in parallel with the grid, whilst having the generator voltage within the limits and then, for some unexplained reason, the voltage would rapidly increase above 270 V and oscillate with a 5 s period. The over-voltage protection of the SCADA system would identify this over-voltage and trip the engine. Site personnel also advised that no definite pattern could be established as to the occurrence of the over-voltage condition. The actual cause of the over-voltage is unknown at this stage and would require further investigation. Harmonics, in particular harmonic currents which are generated by non-linear site loads such as variable speed drives, fluoro lights, UPS, etc... all of which are present at Cronulla STP, are suspected as the likely cause.

Remedy. The SCADA control set-points were modified to allow for the occasional over-voltage oscillations, eliminating the consequential engine trips.

RESULTS FROM ADDRESSING INTERFACING ISSUES

Table 1 and Figure 2 illustrate the impact of the improvements made at Cronulla STP. Table 1 gives general plant performance data for 3 comparable months when the cogeneration unit was fully available for power production (i.e. periods with no scheduled or unscheduled maintenance). Figure 2 shows the improvements in generator output as a function of time as a result of addressing the interfacing issues.

The impact of the improvements on the power distribution interface is most visible from the significant reduction in the number of trips which is reduced by more than 70%. Consequentially, the unit produced more power.

The impact of the new fuel-supply driven engine control is most clearly visible in the fluctuation of generator output. The old strategy had a load-driven control, which fixed the generator output at a certain value, while the new control strategy clearly considers the gas production rate at the STP. As a result, rather than tripping on low pressure, the engine reduces output but continues to operate. The net benefit is clear in the increased integrated power production.

It is expected that the improvements on the digester heating system interface will eliminate the need for heat input from the back-up water heaters. Because these are fuelled by digester gas, this amount of gas will then become available for the cogeneration unit to produce more power.

Table 1. Plant performance characteristics before and after cogeneration control improvements

Period	Total Electrical Power (MWh)	Number of trips (-)	Total down time (h)
01/02/2005 – 30/04/2005	545	52	691
01/10/2006 – 28/12/2006	703	15	325

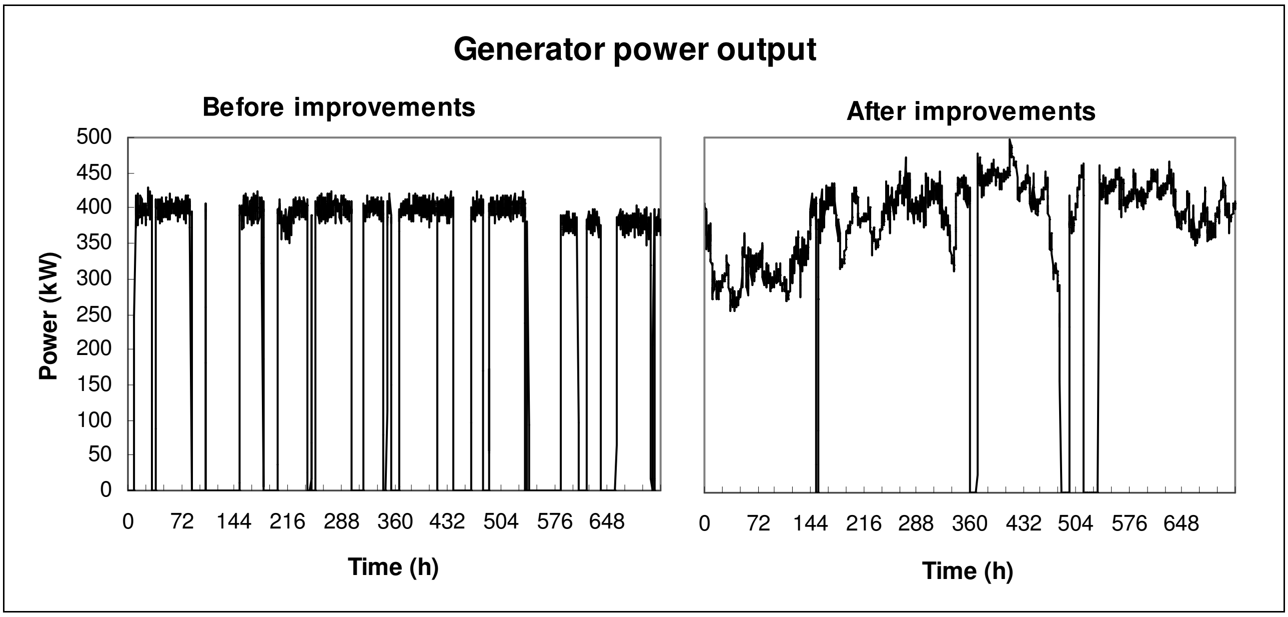

Figure 2. Electrical output of the generator before and after cogeneration control improvements

DISCUSSION

As the examples show above, the reliability of a cogeneration unit is more significantly related to the integration of the unit in the rest of the plant, than caused by the unit itself. Whether the core of the unit is an internal combustion engine, a Stirling engine or a gas turbine, the characteristics of each of these technologies becomes less significant as soon as the integration on any level fails. Although each single aspect of the integration is not cutting edge engineering nor requires complicated solutions, how can it be that these aspects are often the reason behind a sub-optimal installation?

The parties involved in the design, construction and operation of a cogeneration unit are numerous: the STP operator, the design and engineering teams, the different equipment suppliers, the on-site construction teams and occasionally a third party cogeneration unit operator. Often each of these parties is specialised in only one of the interfaces. Whilst STP operators may know everything about the process upstream of the cogeneration unit, they may not be aware of process impacts on the cogeneration performance. Similarly, the contractor who installs the unit is often familiar with power production applications but may not be aware of the problems related to digester heating, digester gas production or even grid parallel power production on a site with large load shifts and complex power system harmonics. Many more examples can be given here, all pointing to the same direction: the complexity of a cogeneration unit on an STP site lies in its multi-disciplinary nature and the requirement for overview from all of the involved parties.

The solution for this problem is as straightforward to identify as it is complex to achieve. The knowledge and specific competences of the different parties involved, need to be combined and managed for the life cycle of the cogeneration unit. The incomplete recommissioning of the water pump as described above, serves as anecdotal evidence for the need of ongoing management of successful system interfaces between the embedded cogeneration facility and the broader STP operations to ensure continued reliable and effective plant performance.

CONCLUSION

Recent introduction of a variety of green commodities can be expected to trigger a wave of new smaller cogeneration units to be installed on sewage treatment plants. Experiences in the past, as discussed in this paper, show that successful integration of such units into existing STPs is dependent upon proactive consideration of the three key interfaces – gas, water and power systems. The key to success for the future installations will be the proper managing of the key interfaces for the entire life cycle of the cogeneration unit including design, construction and operation. Only then the cogeneration units can be expected to operate satisfactorily and assure a healthy reputation to further attract the industry’s attention.