DO WIND-FARM/GAS TURBINE GENERATORS EMIT MORE CARBON DIOXIDE THAN COAL GENERATORS?

Abstract
Wind-farm/Gas generators (WFGT) base-load power generation is a major emitter of carbon dioxide. In the extreme cases, which may be not uncommon, such as remote high carbon dioxide gas from central Australia and possibly CSG, carbon emissions from gas-turbine generators may be higher than coal-fired generators. The wind-farm portion of the generator serves to reduce the greenhouse gas emissions resulting in significant savings relative to coal. However, this rosy picture may not hold for photo-voltaic/gas-turbine combinations where very low PV efficiencies demand high load factors from the gas-turbine generator.

Background
A previous paper discussed wind-farm generation in the context that each farm is in effect aligned with an open-cycle gas turbine operation which is able to ensure a constant power supply when the output from the wind-farm fluctuates due to change in wind strength. The paper showed that when wind farm efficiencies (load factor) falls below about 32%, carbon saving would result if the wind-farm is decommissioned and the associated turbine facility up-graded to a combined cycle operation.

The combination of wind-farm and gas turbine (WFGT) generator effectively supplies base-load power to the grid[1]. A similar situation occurs with solar generation with gas turbines providing power in times of cloud cover and darkness. The development of these combination generators for base-load power is driven by the Renewable Energy Target (RET) scheme. This scheme aims to deliver 20% of base-load power from renewable sources by 2020. Because of this combination, generating costs are dependent on the availability and price of gas for the turbine (the major portion) of the generator. This issue was addressed in the second paper which showed that WFGT generators could see a significant rise in generating cost driven by the high price and gas demand by LNG exporters.

Because the WFGT is dependent for the major portion of the power generation on gas-turbine power there is a significant emission of carbon dioxide from burning the gas in the turbine. Furthermore, the gas-turbine system is low in efficiency and this was the subject of the first paper. In this paper we tackle the total quantum of emissions from the WFGT generator and include an estimate for the emissions from producing and delivering gas to the turbine generator. This is compared to the emission of carbon dioxide from coal fired power stations.

Carbon Dioxide Content of Gas
The carbon dioxide content of natural gas various according to source. For example the established gas fields of the Bass Strait and those off the North West of Australia contain low quantities of carbon dioxide (typically <5% vol/vol). Newer fields being developed in these provinces tend to have higher carbon dioxide content gas (typically 10% for Gorgon and Kipper). However the important gas fields of central Australia contain large quantities of carbon dioxide (typically 20% to more than

[1] G. King (Origin Energy), Interview with Alan Kohler ABC “Inside Business” 21 July 2013.

30% carbon dioxide). Note that gas analysis is on a volume basis, converting to mass significantly increases the quantum of carbon dioxide present.

Prior to transmission, the carbon dioxide present in the raw gas is removed so that the final gas is below 2% (vol.) carbon dioxide. This is performed in gas-plant operations such as those at Longford in Victoria and Moomba in central Australia; this carbon dioxide is emitted to atmosphere.

Transmission of gas is via pipeline or pipeline networks at pressure (typically 100-200 bar). Since gas is compressible, maximum throughput of gas is achieved by regular recompression of the gas, typically at 50 to 80km intervals for a fully loaded pipeline system. Gas turbine compressors are mostly used for this duty which requires taking some of the gas from the line. For long compressed pipelines, five percent of the transmitted can be used in recompression duty. Furthermore, there is a far amount of fugitive emission (leakage) from the pipeline systems which is a function of the pipeline length. Gas supplied to Sydney and Newcastle from Moomba in central Australia is over 2000km long and the Moomba-Adelaide pipeline is over 1000km long.

From this it can be seen that for some natural gas supplies, the carbon dioxide emission from production to delivery can be significant (e.g. 30%) of the gas used in the gas-turbine system. Gas supplied from low carbon dioxide fields such as the older fields in Bass Strait and delivered by short length pipelines to gas-turbine generators would have much lower production and delivery emissions but is still likely to be in the region of 5% of the gas used.

New Gas Sources

New sources of gas such as shale or coal seam gas (CSG) are unlikely to have lower associated production and delivery emissions. Most of the shale gas provinces being explored are in central Australia and it is likely that these gas reserves, if discovered and developed, would have similar characteristics to the conventional gas reserves in the region, that is high carbon dioxide gas for the Cooper and Eromanga shales. There is little data available for other frontier areas such as the Galilee Basin in Queensland.

Coal seam gas is very low in carbon dioxide (typically less than 5%) but development requires many wells of low productivity which will result in higher fugitive emissions, further exacerbated by methane which has a Greenhouse Warming Potential (GWP) of 21 times that of carbon dioxide. Also it is not clear how the associated water in the CSG reservoir will be disposed and the subsequent emissions from this activity are likely to be significant. Furthermore CSG is produced at low pressure and this is gathered in a pipeline network of HDPE pipelines as opposed to steel. The fugitive emissions of these networks are unknown but probably higher than a steel system. Compression to gas from near ambient pressure to a suitable delivery pressure (50 bar say) for delivery to a gas turbine generator will be significant. In passing I note that in order to maximise gas delivery, some of the CSG systems delivering gas for LNG may use grid-electricity for compression (i.e. coal is being used for the compression rather than gas).

Analysis

Table 1 gives an estimate for the GWP of emissions from the gas to drive a gas turbine generator (500MW nominal capacity) from a carbon dioxide rich field (though not excessive) in central Australia and its delivery via a 1500km pipeline. Note that the calculation assumes that gas recompression is required which will consumed 2.5% of the gas to be delivered to the generator. The

GWP is calculated with methane being 21 as effective as carbon dioxide and nitrous oxide 310 times as effective.

Table 2 gives compares the carbon dioxide emission for a gas –turbine generator with gas supplied as detailed in Table 1 and a generator from a nearby field (200km) with gas containing only 5% carbon dioxide. For this second case no recompression is assumed on the pipeline. These two cases are compared with a coal-fired generator.

Table 1: Estimation of emissions for production and distribution of a high carbon dioxide natural gas for power generation, after Picard[2].

			CH_4	CO_2	N_2O
			000t/y	000t/y	000t/y
Gas to be used (LHV)	PJ	38.23			
Recompression gas	%	2.50%			
Gross gas required	PJ	39.18			
	Mm^3	1104.768			
Gas plant emissions	Mm^3	1104.768	7.84E-01	4.31E+00	5.08E-05
CO_2 in raw gas	vol%	30%			
CO_2 emitted	Mm^3	473.114		9.29E+02	
Gross gas production	Mm^3	1577.883	4.89E+00	3.00E+00	3.47E-05
Gas well annual servicing	No of wells	20	1.28E-03	9.60E-06	0.00E+00
Pipeline fugitive emissions	km	1500	5.10E+00		
TOTALS			1.07E+01	9.37E+02	8.55E-05
TOTAL GWP	tCO2e/y	1162983			
	MtCO2/y	1.162983			

Table 2: Comparison of emission from 500MW generators – gas-turbine and coal.

		GT (1)	GT (2)	COAL
Fuel used (LHV basis)	PJ/y	38.23	38.23	32.34
Thermal Efficiency	%	33.0%	33.0%	39.00%
Carbon Dioxide/TJ	tCO2e/TJ	51.3	51.3	90
Carbon dioxide emissions from fuel	Mt/y	1.960	1.960	2.911
Production and delivery from fuel	Mt/y	1.162	0.211	0.020[3]
TOTAL GWP	MtCO2e/y	3.123	2.172	2.930

From Table 2 it can be seen that the total emissions (GWP) for gas-turbines using the remote, high carbon dioxide content field can have over 30% of the emissions assigned to production and delivery of the gas. This is a similar impact to the 25% reported by Spath and Mann[4] in a US study of gas

[2] D. Picard, http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_6_Fugitive_Emissions_from_Oil_and_Natural_Gas.pdf

[3] Coal fugitive emission estimated after A. Saghafi, "*Estimation of fugitive emissions from open cut coal mining and measurable gas content*", 13th Coal Operators' Conference, University of Wollongong, The Australasian Institute of Mining and Metallurgy & Mine Managers Association of Australia, 2013, 306-313.

[4] P. L. Spath and M. K. Mann, "*Life Cycle Assessment of a Natural Gas Combined Cycle Power Generation System,*" NREL/TP-570-27715

based gas generation. By contrast delivery from a nearby, low carbon dioxide content field has a significantly lower GWP. On these figures the remote case has a higher GWP than a coal based operation where coal is cut from an open pit to be immediately fed into the generator.

Of course for WFGT systems the wind farm is intended to provide 33% of the generation capacity so that GWP is reduced by this amount thereby saving approximately 1Mt/y of carbon dioxide emissions even using remote high carbon dioxide gas.

However, this situation may not be applicable to PVGT generators. Load factors are much lower for PV systems with even industrial systems (optimum position and orientation, good house-keeping) delivering load factors of typically 15%. Residential roof-top solar may be much lower than this. If domestic roof-top solar is backed-up by gas-turbine generators using remote high carbon dioxide gas then efficiencies below 5% (which is entirely possible) will produce no net carbon dioxide savings.

Comments

This analysis shows that WFGT base-load power generation is a major emitter of carbon dioxide. In the extreme cases, which may be not uncommon, such as remote high carbon dioxide gas from central Australia and possibly CSG, carbon emissions from gas-turbine generators may be higher than coal-fired generators. The wind-farm portion of the generator serves to reduce the greenhouse gas emissions resulting in significant savings relative to coal. However, this rosy picture may not hold for PVGT base-load where very low PV efficiencies demand high load factors from the gas-turbine generator.

Because WFGT base-load power generators emit large volumes of greenhouse gases, generation cost will inevitably rise upon application of a carbon tax or similar emissions charge. This means that with the advent of carbon pricing generation cost from WFGT will inevitably rise to exacerbate increase in costs due to rises in the gas price (see PAPER 2).

The use of WFGT base-load power stations is set to continue to increase as a consequent of the currently widely supported RET initiative. This work shows that as the RET progresses, there will be an inevitable and relative large rise in greenhouse emissions. This will continue unless and until WFGT generators are decoupled by an increase in other forms of low GWP used to plug the swinging supply from wind-farms. On present performance data this is likely to mean hydro or nuclear, however, these solutions would appear to be politically unacceptable.

A further observation is that if the installation of WFGT generators continues apace to deliver the 20% renewable target by 2020, then this will require approximately one hundred 100MW wind farms (operating at 33% efficiency) and a similar generation capacity of gas-turbines as back-up. From the data provided in PAPER 2, this will require $35 billion in capital expenditure and 700PJ/year of gas. At this stage, these estimates are in contradiction to the capital and gas available to achieve this outcome.

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October 2nd 2013