Technical Memo

To	Johan van Niekerk	**Date**	6 July 2011
From	Andrew Marshall	**Project No**	WP04268
Copy			
Subject	**Impact of generation capacity augmentation options on the MRCP calculation**		

1. Introduction

Sinclair Knight Merz (SKM) have been commissioned by Western Australian (WA) Independent Market Operator (IMO) to analyse the impact of power generation capacity augmentation options on the 2010 Market Reserve Capacity Price (MRCP) calculation, for nominal 160MW capacity simple cycle gas turbine generator (GTG) power plant equipment.

This work was undertaken using the Thermoflow suite of proprietary software, specifically the GTPro and PEACE add-on packages. This process did not include the industry cross checking and project references that are undertaken in the MRCP calculation.

2. Assumptions & Methodology

The GTG performance modelling was conducted using GTPro on a simple cycle gas turbine plant with a nominal capacity of approximately 160 MW, under ISO conditions.

The GTG performance modelling was conducted with the following atmospheric reference conditions:

- Ambient temperature = 41°C
- Relative humidity = 30%
- Site elevation = 25 m

The following typical GTG machines are representative for this investigation, as they are of suitable capacity and are currently installed and operational within the South West Interconnected System (SWIS) of Western Australia:

- Siemens SGT5-2000E (ISO generator rating 167.7 MW)
- Alstom GT13E2 (ISO generator rating 185.7 MW)

For costing evaluation purposes the Siemens machine was selected as the generator rated capacity is closest to the nominated 160 MW rating. Note that the net power output, at the base case reference conditions, is significantly lower than the ISO rating of the unit, due to the impact of the higher ambient temperature. The selection of the machine should not have a significant impact the change in net power and capital cost of each of the power augmentation cases.

The reference baseline GTG plant scope and configuration is consistent with the plant defined and presented in the SKM "Review of the Maximum Reserve Capacity Price 2010 – Power Station Elements" report. This plant is based on a nominal single unit, 160MW simple cycle GTG with distillate fuel oil only firing capability.

As described in this report, this reference plant configuration includes demineralised water injection for NO_x emission abatement, with provisions include for the demineralised water treatment, processing and supply equipment included within the overall balance of plant systems. Operation of the GTG with water injection for NO_x emission abatement provides some power augmentation capacity in comparison to an unabated GTG unit. To provide the baseline performance, against which further power augmentation measures considered will be evaluated, SKM set up a base reference performance model with a water injection water to fuel mass flow ratio of 0.7 (which is typical for NO_x emission control).

GTPro provides power plant estimated capital costs through the PEACE add-on feature. The standard PEACE generated estimated capital costs are corrected to reflect specific plant / project conditions. In this application the PEACE outputs were corrected to reflect and match the estimated capital costs described in the "Review of the Maximum Reserve Capacity Price 2010 – Power Station Elements" report. In doing so, the following adjustments were made to the PEACE output for the base model:

- Removed 'Contingency' and 'Bonds and Insurance' in contractors soft and miscellaneous costs.
- Removed Owner's 'soft and miscellaneous costs'.
- Scale the Contractor's soft costs to 9.8% of Contractor's Internal Costs in line with the CAPEX Costs in previous reporting.
- Apply a global scaling figure for EPC CAPEX cost to match the previously presented 160MW OCGT capital cost estimate of AUD$121.8million.

The above derived scaling factors were then applied to the modelling conducted with the various alternative power augmentation systems put in place.

The estimated costs presented are to be considered as 'order of magnitude' estimate levels to compare and assess the relative impact of the inclusion of the alternative power augmentation systems considered.

3. Modelling Cases

SKM evaluated the various alternative power augmentation systems, in comparison to the base reference case, which are described in Table 1.

- **Table 1 Description of power augmentations**

Name	Description
Evaporative Cooling	Evaporative cooler installed within the GT combustion air intake with a typical 90% effectiveness, operating with suitable potable quality water.
Water Spray “Fogging”	Evaporative type cooling, using a pressurised water spray “Fogging” system mounted within the GT combustion ait intake system, with 90% effectiveness, but operating with demineralised quality water.
Wet Compression Cooling	Evaporative cooler and high pressure overspray “fogging” wet compression cooling, injected at the GT compressor inlet, with approximately 5 times the water required to typically achieve saturated air conditions.
Refrigerative Cooling	Water-cooled electric chiller, installed within the GT combustion air intake system, with a 15°C inlet temperature reduction capability.
Water injection for power augmentation	Water injection with mass (water) / mass (fuel) ratio of 1.1 (which exceeds the ratio of 0.7 typically required for NO_x emission abatement).

Note that the base case performance is modelled with water injection for NO_x control (water to fuel mass flow ratio of 0.7). The water injection described in Table 1 is additional water injected for power augmentation purposes which exceeds that required for NO_x control.

SKM produced a total of 10 models in GTPro to analyse the impact of various combination of power augmentation on capital cost and net plant output. Table 2 summarises the power augmentation methodologies applied for each model.

- **Table 2 Summary of power augmentation models**

Case	Description	Evap. Cooling	Fogging	Wet Compression	Refrig. Cooling	Water Inj. for Power Aug.
1	Base Case					
2	Evaporative Cooling	♦				
3	Water Spray Fogging		♦			
4	Wet Compression Cooling	♦		♦		
5	Refrigerative Cooling				♦	
6	Base Case with water injection for power augmentation					♦
7	Evaporative Cooling with water injection for power augmentation	♦				♦
8	Fogging with water injection for power augmentation		♦			♦
9	Wet Compression Cooling with water injection for power augmentation	♦		♦		♦
10	Refrigerative Cooling with water injection for power augmentation				♦	♦

4. Summary of Results

Table 3 summarises the net power and estimated capital cost for each of the modelling cases considered, with and without water injection for power augmentation.

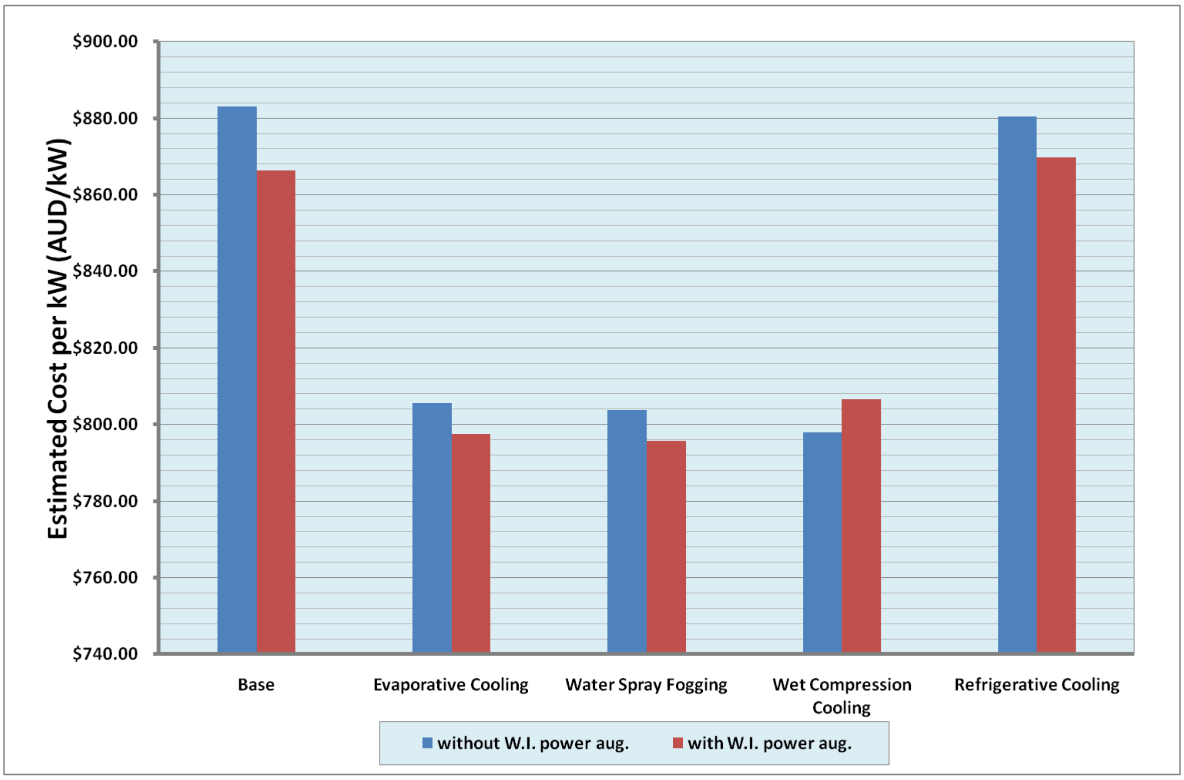
- **Table 3 Summary of results**

Modelling description	Net Power (MW)		Capital Cost AUD(million)		Capital Cost per kW Net Power AUD (thousands)	
	without W.I for power aug.	with W.I. for power aug.	without W.I for power aug.	with W.I. for power aug.	without W.I for power aug.	with W.I. for power aug.
Base	137.9	142.9	$121.8	$123.8	$ 883.0	$ 866.3
Evaporative Cooling	154.8	160.0	$124.7	$127.6	$ 805.6	$ 797.5
Water Spray Fogging	154.7	159.9	$124.4	$127.3	$ 803.8	$ 795.8
Wet Compression	165.4	165.3	$132.0	$133.4	$ 797.9	$ 806.6
Refrig. Cooling	153.0	158.2	$134.7	$137.6	$ 880.5	$ 869.9

Note: W.I. – Water Injection

Figure 1 provides a summary of the Table 3 results in a capital cost per kW net power basis.

- **Figure 1 Estimated Cost per kW of cases considered**



5. Impact on Maintenance Costs

Given that a demineralised plant exists in the base case; for a generator operated in a peaking mode the incremental maintenance cost of the capacity fogging and evaporative cooling augmentation options (above the base case) is not considered material in the context of other operation and maintenance costs.

It is noted the wet compression capacity augmentation option and high levels of water injection may increase the frequency of maintenance activities and this may have a material incremental impact on maintenance costs.

6. Discussion of Results

The following conclusions have been drawn from the results:

The estimated additional costs presented are Capital Costs and exclude any additional “Owner’s” cost provisions.

Fogging and evaporative cooling provide approximately the same additional net power. The additional power produced by fogging or evaporative cooling is directly impacted by the ambient relative humidity conditions, with lower capacity improvement as relative humidity increases. The other alternative power augmentation systems considered are independent of relative humidity effects.

- Fogging provides the lowest cost per kW compared to the base case, closely followed by evaporative cooling. These options produce a cost per MW **approximately 10% below the base case.**
- If water injection for NO_x control was not included, and hence there was no demineralised water supply system within the base case, then the incremental cost of the Fogging system would increase. However, the cost of the evaporative cooling power augmentation would not be impacted as such systems typically require only suitable potable quality water for operation. That is, the 10% reduction in capital cost per kW capacity would still be available if there were no demineralised water supply available (i.e. if NOx emissions were not required to be abated).
- Wet compression cooling would provide significantly more power than evaporative cooling and fogging alone, but the cost per kW is also greater. Wet compression cooling is typically installed in combination with evaporative cooling or fogging, as performance is improved when operated in conjunction with a pre-saturated air flow.
- Refrigerative cooling provides less additional power compared to evaporative cooling and fogging, while having the greatest capital cost, under the specific set of environmental conditions considered. SKM would suggest that refrigerative cooling is unlikely to be an economically viable power augmentation option for this type of peaking plant, operating under the conditions considered in this study.
- The 10% reduction in capital cost per kW capacity available through the fogging and evaporative cooling options can be achieved with minimal impact on maintenance costs.
- Water injection and wet compression have a direct adverse impact on plant efficiency (heat rate) and may increase plant maintenance requirements.
- Water injection for power augmentation will provide additional power output for all power augmentation cases, excluding wet compression cooling. Greater quantities of water may be able to be injected for power augmentation than analysed in this study, to

provide an even greater additional power capacity. This limit depends on the specific gas turbine unit selected and typically involves a trade off with increased maintenance costs.

Regards,

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