THE ECONOMIC FEASIBILITY OF A HIGH EFFICIENCY GAS TURBINE COGENERATION OPTION WITH A HYBRID MSF/RO DESALINATION

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Contents

Summary

The most common configuration used for seawater desalting is a distillation system bottoming a power generation system for the cogeneration of power and water. The configuration is much more efficient and cost effective than stand alone distillation. However, two factors affect efficiency and cost of this configuration negatively:

- The power/water ratio needed is different from what the plant offers
- The power demand is variable and not a base-load demand

When more water is needed than power, the power/water ratio can be adjusted by adding a power-driven desalting process such as SWRO. The addition also tends to improve efficiency by contributing to the base-load part of the power demand profile. One option is created and studied in detail. A unique advantage of SWRO is its easier adaptation to variable water demand since the process does not involve heating and cooling. This creates an option that can meet variable power demand while operating at constant power profile but with variable water production. The high cogeneration efficiency is preserved and variable water production is of much lower storage cost than

energy storage. In this paper the cost effectiveness of this option is investigated and the results indicate that the power and water cost for this option is substantially lower than the conventional one (without SWRO).

1. Introduction

In the Gulf countries, electrical power is generated in cogeneration systems in which power generation is actually produced in association with desalination plants that produce fresh water from seawater. Distillation and reverse osmosis (SWRO) processes are the two primary methods utilized for seawater desalting. The most common distillation process is the multi-stage flash (MSF), where fresh water is obtained by applying thermal energy to the seawater feed in multiple stages creating a distillate stream for fresh water uses, and a concentrate (brine) stream that is returned to the sea. Different technological efforts have been concentrated on reducing the capital, operation, maintenance, and above all, energy costs. Energy saving and cost reduction for fresh water production could be significantly achieved when hybrid MSF/SWRO system is used. Hybrid SWRO-MSF desalination systems combines the advantages of the high desalting performance of distillation processes and lower energy requirement of the membrane processes. It allows better match between power and water requirements and enables better utilization of the power generated from the cogeneration plant. The most common configuration used for seawater desalting is a distillation system bottoming a power generation system for the cogeneration of power and water. The configuration is much more efficient and cost effective than stand alone distillation.

However, two factors affect efficiency and cost negatively:

- The power/water ratio needed is different from what the plant Offers,
- The power demand is variable and not a base-load demand.

When more water is needed than power, the power/water ratio can be adjusted by adding a power-driven desalting process such as SWRO and VC. The addition also tends to improve efficiency by contributing to the base load part of the power demand profile. In references one option is created and studied in detail. A SWRO process beside the distillation by MSF is introduced. Another created option is use the power to produce water in an all-water system. In this option (internal cogeneration) the variable power demand is avoided completely. This option allows a much smaller cogeneration system for a given water demand. Either SWRO or VC can be used. However the VC allows an all distillation technology of simpler pretreatment and low operating pressure.

A unique advantage of SWRO is its easier adaptation to variable water demand since the process does not involve heating and cooling. This creates a third option that can meet variable power demand while operating at constant power profile but with variable water production. The high cogeneration efficiency is preserved and variable water production is of much lower storage cost than energy storage. The cost effectiveness of this option is now investigated. The objective of this paper is to quantify the economic and environmental benefits of the use of hybrid MSF/SWRO process in simple gas-turbine cogeneration systems that satisfy a given consumer electrical demand which has profile similar to that in Gulf countries. Two configurations are compared, both use a simple cycle gas turbine having the same rated capacity. The first configuration is a conventional one consisting of a gas turbine (GT), heat recovery steam generator (HRSG), auxiliary boiler (AB) and MSF plant.

The second configuration uses the same gas turbine, heat recovery steam generator, but instead of an MSF plant that uses steam produced by the HRSG and AB, it uses a hybrid MSF/ SWRO plant and no auxiliary boiler. Both configurations are required to satisfy a given electrical load profile that is highly convex similar to that in the Gulf region. The GT in the first configuration operates in part-load mode following the consumer load profile while in the second configuration, it operates at full-load throughout the year with the spare power delivered to the SWRO plant for extra water production.

2. The Conventional Cogeneration System (System 1)

A conventional cogeneration system frequently found in the Gulf region of the Middle East consists of a simple cycle gas turbine, GT, a heat recovery steam generator, HRSG, a multistage flash, MSF, desalination unit and an auxiliary boiler, AB. This system is shown schematically in Figure 1.

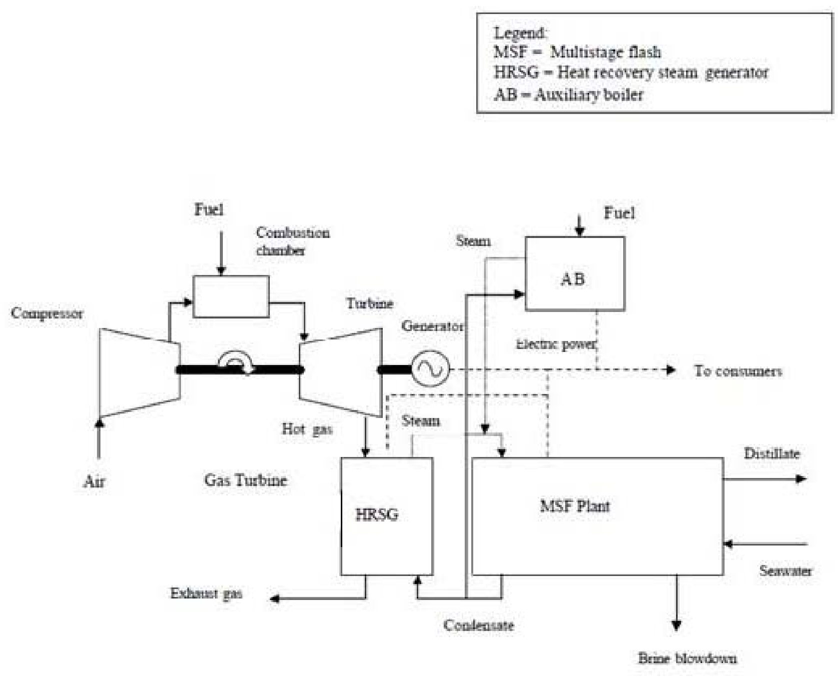

Figure 1 A conventional GT/HRSG/AB/MSF cogeneration plant (System 1)

The HRSG produces MP steam using the heat content of the hot gas discharged from the gas turbine. The MSF plant has a design capacity such that its distillate production is maximum when the GT is operating at full- load which corresponds to the maximum heat content of the hot gas discharge. When the GT operates at part-load as is usually the case during most of the winter months, the amount of steam produced is lower than the design production. An auxiliary boiler is therefore added to the cogeneration system so that it can produce the shortfall in steam demand required by the MSF plant when the GT operates at part load. The AB normally operates at part- load mode most of the year except during periods of very low GT loads. Figure 2 shows how the GT load ratio affects the steam production ratio of the HRSG and the AB. The steam production ratio is defined as the steam flow rate at a certain GT load ratio divided by the design flow rate.

The figure also shows the constant amount of steam supply to the MSF unit which is independent of the GT load. Therefore, the water production for the first configuration is maintained essentially constant throughout the year while for the second configuration it varies throughout the year.

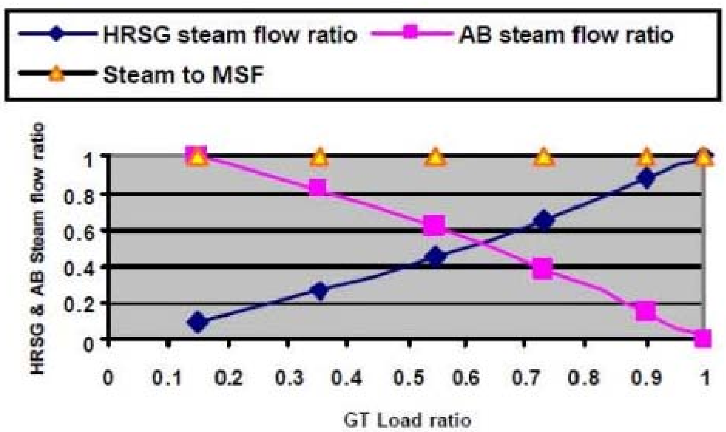

Figure 2 HRSG and AB steam flow ratios for various GT load ratios

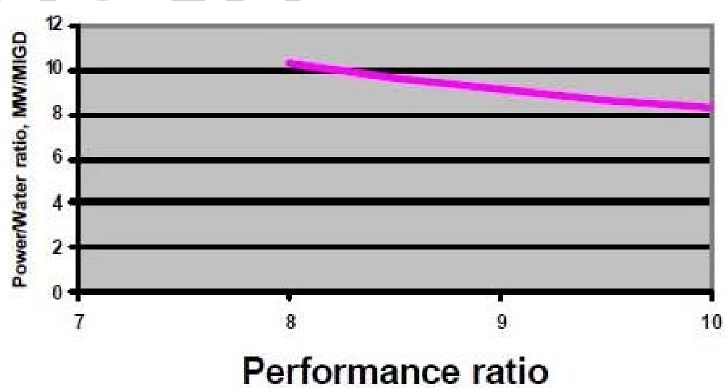

Figure 3 Power to water ratio and design capacity of MSF unit associated with a GT having a capacity of 100 MW

Figure 3 shows the influence of the performance ratio, PR, of the MSF unit on the power-to-water ratio of a typical cogeneration system of the GT/HRSG/AB/MSF type.

3. An Improved Hybrid MSF-SWRO Cogeneration System (System 2)

Figure 4 shows a schematic diagram of the proposed improved cogeneration system (System 2) that consists of a simple cycle GT, HRSG, MSF and SWRO. The MSF and SWRO plants have common seawater intake and outfall. The GT and HRSG operate at full load throughout the year while the SWRO plant operate at part-load and make use of the surplus electrical energy which is available during the winter months in the Gulf region. Maximum surplus power will be available in this region during the months of January and December and minimum surplus power will be available during the month of August. A typical consumer load curve for Sharjah City in the UAE is shown in Figure 5. The figure shows the monthly minimum and maximum load ratios for a typical year and indicates the substantial amount of surplus power available throughout most of the year. This surplus power can be used as energy input to the SWRO plant which can provide additional amount of fresh water.

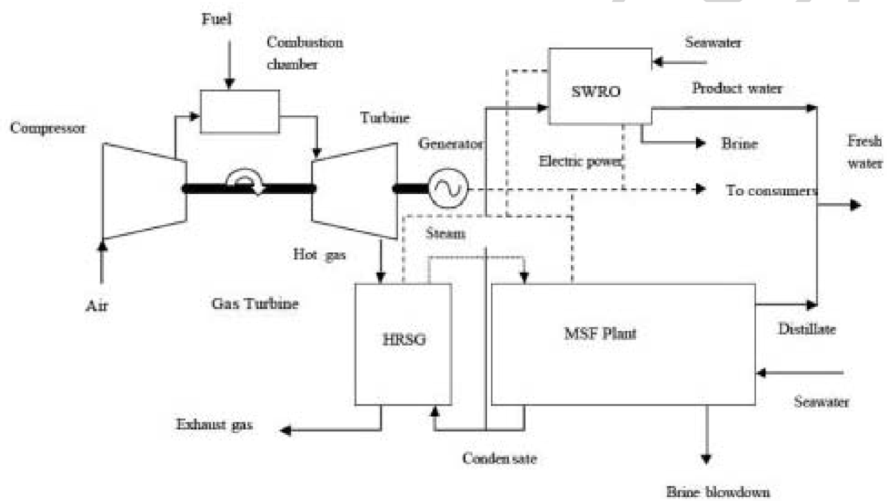

Figure 4 Improved GT/HRSG/MSF/RO hybrid cogeneration system (System 2)

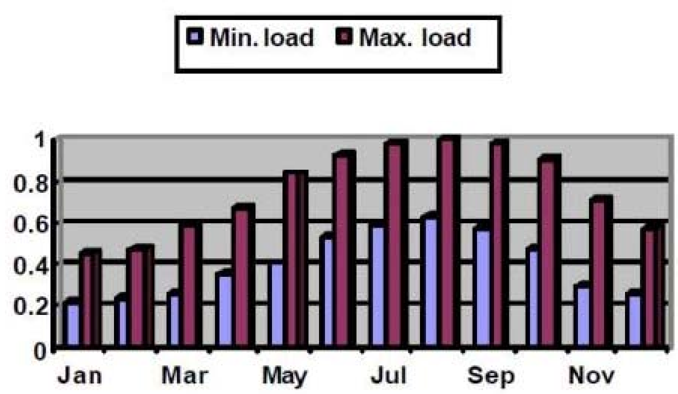

Figure 5 Monthly load variation for the City of Sharjah, UAE

4. A Case Study

A cogeneration plant with a configuration identical to System 1 is selected in order to evaluate the benefits in modifying the design configuration to System 2. An electrical load profile typical to that of Sharjah City, UAE (see Figure 5) was used in this case study. The technical and cost parameters used in the economic evaluation is shown in Table **1**. The GT used in this case study is a GE model 9171E with a full-load heat rate of 3.39 kWht/kWhe (which corresponds to 11,562 Btu/kWh HHV).

The variation of the heat rate with load ratio for this GT is shown in Figure 6. The HRSG produces steam at 24 bar and 227^{o}C and has a design steam flow rate is 261 t/h which represents the amount of steam produced at GT full-load condition. The steam flow rate at part -load conditions is as shown in Figure 7.

	Value
Gas Turbine (GT + HRSG)	
GT type	GE model 9171E
Design capacity of GT	118 MW @ 20^{o}C ambient temp.
Design capacity of HRSG	262 t/hr
Steam conditions of HRSG	24 bar and 227^{o}C
Specific capital cost	500 $/kWht
Cost of primary fuel	0.03 $/kWht
Auxiliary load (% of full-load)	2
Operating hours per year	8000
Fixed O&M expenses	13.1 $/kW-year
Variable O&M expenses	5.5 $/MWh-year
MSF Plant	
Plant design capacity	10.8 MIGD
Specific capital cost	1500 $/(M^{3}/day)
Performance ratio	8.0
Specific chemicals cost	0.024 $/m^{3} dist.
Specific electrical energy consumption	3.5 kWh/m^{3}
Specific spares cost	0.082 $/m^{3} dist.
Specific labor cost	0.1 $/m^{3} dist.
Capital recovery factor	0.1 $/$ year
Operating hours per year	8000
SWRO Plant	
Plant design capacity	57 MIGD
Specific energy consumption	6.0 kWh/m^{3}
Specific capital cost	1000 $/(m^{3}/day)
Capital recovery factor	0.1 $/$ year
Membrane replacement cost	0.13 $/m^{3} prod.
Chemical treatment cost	0.018 $/m^{3} prod.
Spares cost	0.067 $/m^{3} prod.
Labor cost	0.059 $/m^{3} prod.
Operating hours per year	8000
Auxiliary Boiler (AB)	
Specific design capacity	220 t/hr
Specific capital cost	130 $/kWt
Specific electric energy consumption	4 kW/(t/h)
Full-load efficiency	89%

Table 1 Technical and economic parameters of system components

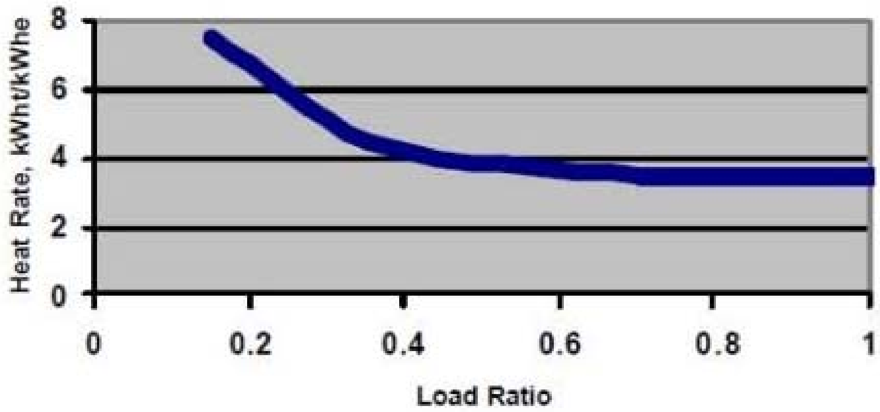

Figure 6 Heat rate versus load ratio for GT model 9171E gas turbine (ambient Temperature = 20^{o}C)

The auxiliary boiler has a design capacity of 240 t/h corresponding to a lowest GT part-load of 15%. The AB steam production at various GT load ratio is also shown in 7. The MSF plant is a cross -flow brine recycle type and has a design capacity of 10.8 MIGD and a performance ratio of 8.0. It has a top brine temperature (TBT) of 110oC. The pumping power requirement is taken as 3.5 kWh/m^3. The SWRO plant has two stages and is designed to operate on seawater having a salinity of 42,000 ppm TDS and a product having 500 ppm TDS. The pumping power requirement for the SWRO is assumed to be 6.0 kWh/m^3.

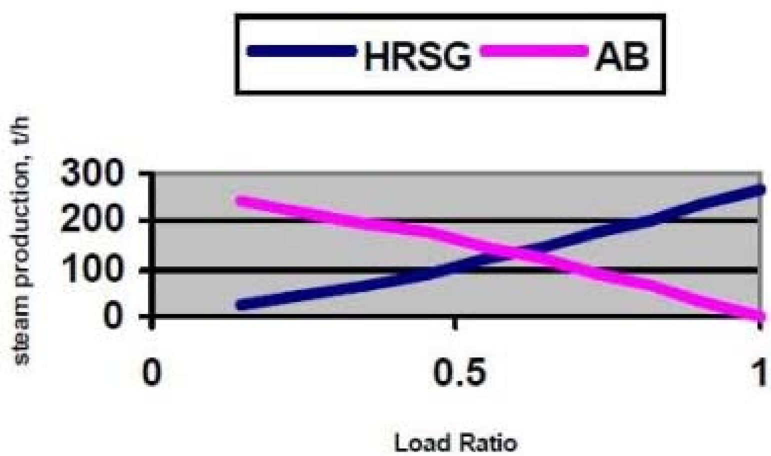

Figure 7 HRSG and AB steam productions at various GT load ratios

The technical and economic parameters of the main devices used in the two systems are shown in Table 1. It should be noted that both system have identical GT and MSF plants having the same rated capacity and the same performance whereas the GT of System 2 operates at full-load throughout the year. The MSF plant in both systems operates at full-load and produce 10.8 MIGD and have a Performance Ratio of 8.0.

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Biographical Sketches

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