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Application of Alternative Configuration of Cogeneration Plant in order to Meet Power and Water Demand

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Nowadays due to significant increasing in power and water demand, most of the improvement challenging focuses on selecting the optimum cogeneration option and considering technical and economical aspects of the project. This paper provides Thermoeconomic analysis of Qeshm Power and Fresh Water Plant, including typically simple cycle power plant coupling with MED-TVC thermal desalination system. Mentioned plant based on GT-HRSG-MED produces 40 MW electricity and 2 MIGD desalinated water by MED-TVC units. Hence, the aim is to offer a proven alternative for new units for best utilization of GT exhaust gas potential, based on combined gas/steam turbine cycle, which make steam turbine electricity production as a byproduct of delivering steam to desalination process, while meeting the minimum desired market requirement and providing the best return on investment based on the proposed economic assumptions. A thermodynamic modeling based on the energy and exergy analysis is performed while The cost equations for the Purchased Equipment Costs (PEC), Fuel cost (F) and the Operating and Maintenance cost (OM) are derived in order to obtaining the water production cost, capital investment for proposed plant. The results show that an increase in pressure level by 219 % results in a decrease in power production by 7 % and in IRR by 4.5 %, but increase in water production (MIGD) by 20 %. Comparison between configurations indicates lowest pressure for the proposed plant will be as the optimal configuration scheme covers the minimum water generation demands by 3.31 MIGD water productions.

1. Introduction

The scarcity of drinkable water exists in most of the coastal areas due to seepage of seawater into the water table. So, the conversion of brackish/sea water into potable water through desalination technique has been strongly brought into focus. In Persian Gulf countries, dual-purpose power and desalination plant simultaneously producing power and freshwater are very common. Various combinations of power-desalination systems are conceivable in order to satisfy both power and water demands (Deng et. al. (2010)). There are several configurations of gas turbine based cogeneration plants that have been widely studied by Rensonnet et. al. (2007).

Mussati et. al. (2002) designed a combined gas/back-pressure steam turbine cycles coupled to MSF desalination system determining the optimal operating conditions at minimum total annual cost. Another Configuration includes Gas turbine, HRSG and thermal desalination was analysed by Wang and Lior (2006).

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Decreasing the renewable water resources in the south of Iran, supports national planning to add desalination plants to various current and ongoing power plants including simple cycle and combined cycle in tropical coastal regions where Ansari et al. (2010) and Shakib et al. (2012) studied on Thermoeconomic Analysis of MED-TVC which coupled with a gas turbine and a cogeneration cycle respectively. In this regard MAPNA Group is pleased to have the opportunity, to submit a proposal for simultaneous generation of the Electricity and Fresh Water that produces approximately, 40 MW electricity and 3 MIGD desalinated water by Multi Effect desalination plant. For the mentioned plant a thermoeconomic study was done before by Ghelichzadeh et al. (2011). He described the application of hybrid desalination system in the gas turbine based cogeneration plant.

The primary objective of this work is to recommend a different design alternative based on CCGT power plant match the minimum power and water requirements. The aim is the optimum selection of the pressure level for steam exited from the backpressure steam turbine in order to provide the best return on investment, based on the proposed economic assumptions. The performance analysis of the scheme is estimated by THERMOFLOW 20® (2010) (a commercial simulation tool). Take advantage of exergy comparison for determining cycle efficiency leads to optimize the combined water and power cogeneration system.

Optimal selection of cogeneration plant is carried out based on the technoeconomic principles. The economic assessment is done based on the discounted cash flow and payback evaluation techniques.

2. Proposed Alternative

The proposed cogeneration scheme is based on a combined cycle power and water cogeneration plant consisting of a top gas cycle comprising two UGT25000 gas turbines, and a bottom steam cycle with a backpressure steam turbine coupled to the thermal desalination system. Exhaust gases from each UGT25000 gas turbine, with a rated exhaust temperature of 502.5 °C and a rated exhaust mass flow of 608.7 t/h (at site condition and running on natural gas), are used to produce steam from water at a Heat Recovery Steam Generator. In this scheme a dual pressure HRSG has been considered in order to reduce the stack losses. The rated steam production of each HRSG for high pressure level is 63.17 t/h and for intermediate steam depends on its pressure level its flow rate will be changed. The HP steam is expanded in a backpressure steam Turbine and the exhausted steam mix with IP steam (generated in HRSGs), the overall uses as motive steam in first effect of the thermal MED-TVC desalination system. A schematic diagram of this cycle is shown in Figure 1. The desalination system has five effects, which the evaporators are designed for operation at a top brine temperature of 70 °C and last effect temperature of 40 °C. The size of distillers will be chosen to match steam conditions for satisfying a minimum water production of 3 MIGD. A schematic diagram of MED-TVC desalination system is presented in Figure 2.

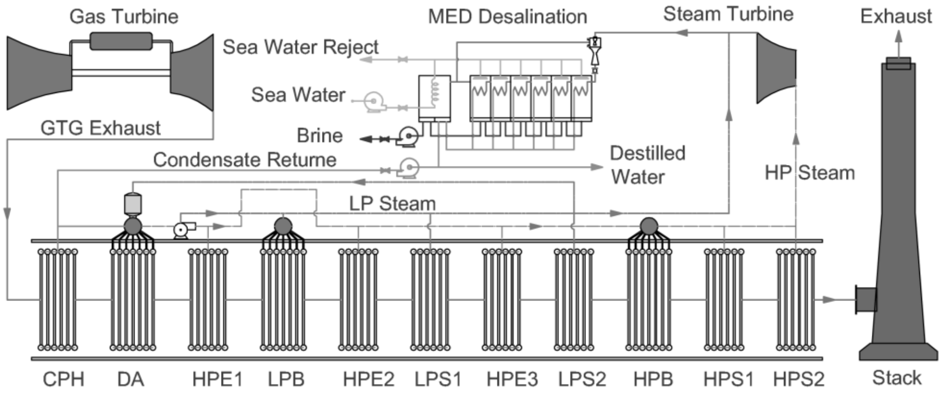


Figure 1: Schematic diagram of the cogeneration power and water plant

3. Alternative analysis

There are many different design alternatives for proposed cogeneration plant due to the large quantity of design parameters that can be taken into consideration. In this analysis the aim is to define an optimum design scheme based on the exhaust pressure level of steam turbine in the proposed combined cycle back-pressure cogeneration system. Basic data given by the steam turbine manufacturer have been used to develop the applicable exhaust pressure level in thermodynamic modelling at design conditions. In this regard, first of all the full simulation of all parts of the plant, including the gas turbines, heat-recovery steam generators, steam turbine and the desalination plant is carried out using THERMOFLOW 20® (2010), a software obtained under license from Thermoflow, Inc.

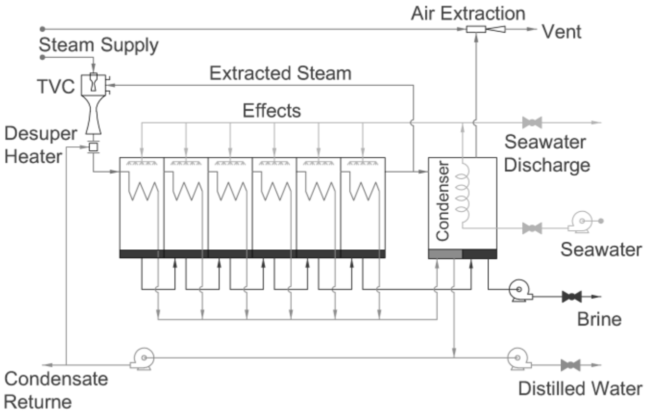


Figure 2: Schematic diagram of the the MED-TVC system

The design philosophy for the complete station including main equipment is based on original manufacturer limitations for commercial units. Secondly in order to achieve the cost optimization of the project, the thermoeconomic method has been applied to define cost function based on the maximum profitability, which depend on the optimization parameter. The economic model takes into account PECs (Purchased Equipment Costs), operating and maintenance cost, and the cost of fuel consumption. It calculates all the costs associated with a project, based on the estimated total capital investment defining amortized capital cost and assumptions for economic, financial, operating, and market input parameters. Table 1 represents the economical constants, parameters and assumptions that are used in economic analysis of this work.

Table 1: Economic constants and assumptions for all alternatives

Parameters	**Unit**	**Value**
Electricity price	USD/kWh	0.04
Fuel gas LHV price	USD/GJ	2.239
Desalinated water price	USD/kMIG	5
Power plant Fix O&M costs (percent of initial cap. Cost)	%	3
Power plant Var. O&M costs	USD/kWh	0.003
Desalination Fix O&M costs (percent of initial cap. Cost)	%	2
Desalination Var. O&M costs	USD/(m^3/d)	0.05
Operating hours per year	h	7884
Project life	y	20
Interest rate	%	8

4. Results

Table 2 shows the total simulation results. It summarizes the effect of exhausted steam pressure level form BP steam turbine on cogeneration plant performance parameters including total power and water production.

It indicates that higher pressure value reveals higher Gain output ratio (G-O-R) and water production for the thermal desalination plant; however play a significant role in reducing power generation rating and efficiency.

Table 2: Cogeneration Power plant performance parameter and cost data

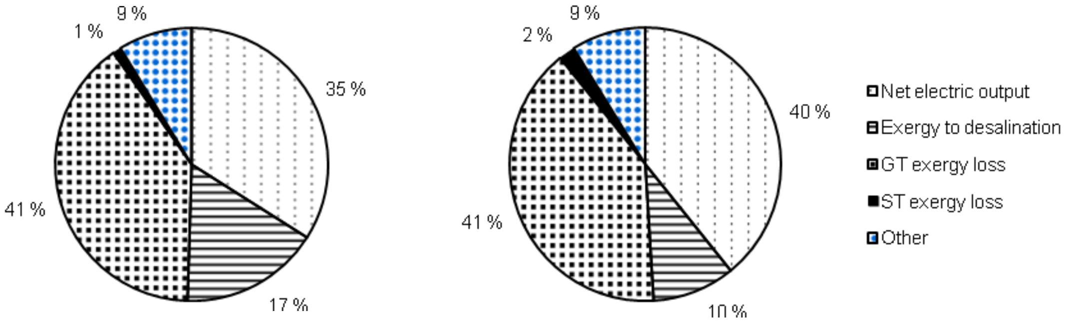
Plant characteristics	**Unit**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
HP steam pressure	Bar	62	62	62	62	62
HP steam temperature	°C	480	480	480	480	480
HP steam flow rate	t/h	63.17	63.17	63.17	63.17	63.17
IP steam pressure	Bar	1.72	5.5	8.25	13.2	18.15
IP steam temperature	°C	116	156	172	192	208
IP steam flow rate	t/h	25.44	24.4	23.02	20.03	17.74
GT gross power output	kW	2 x 21905	2 x 21905	2 x 21905	2 x 21905	2 x 21905
ST gross power output	kW	12,183	8,729	7,427	5,813	4,654
Fuel LHV input	kW	134,642	134,642	134,642	134,642	134,642
Plant gross power	kW	55,992	52,538	51,236	49,622	48,463
Net power output	kW	54,026	50,486	49,151	47,497	46,308
MED aux. power consumption	kW	893	981	1008	1037	1055
GT gross efficiency	%	32.54	32.54	32.54	32.54	32.54
Net elect. eff. LHV	%	40.13	37.50	36.51	35.28	34.39
Water production	MIGD	3.31	3.963	4.167	4.392	4.536
Water production	m^3/d	15,048	18,015	18,945	19,968	20,622
Des. motive steam pressure	Bar	1.5	5	7.5	12	16.5
Des. motive steam temperature	°C	112	152	168	188	203
Des. motive steam flow rate	t/h	88.6	88.6	88.6	88.6	88.6
Gain output ratio (desalinated water / steam flow)		7.055	8.448	8.884	9.362	9.67
Net present value	kUSD	36,056	33,199	32,213	31,174	30,321
Internal rate of return	%	14.01	13.4	13.24	13.09	12.98
Years for equity payback	y	6.619	6.858	6.926	6.985	7.032

It summarizes the effect of exhausted steam pressure level form BP steam turbine on cogeneration plant performance parameters including total power and water production.

It indicates that higher pressure value reveals higher Gain output ratio (G-O-R) and water production for the thermal desalination plant; however play a significant role in reducing power generation rating and efficiency.

Figure 3 shows that higher pressure value result in reduced exergy consumption on steam turbine for power generation section and increased exergy allocation to water generation plant, leads to increasing exergy destruction in MED-TVC plant. It means that with increasing in steam pressure level exited from steam turbine, net exergy plant efficiency will be decreased significantly.

Since backpressure value affect on both power and water production, the total profitability of the plant will be changed. Table 2 also includes the financial internal rate of return, net present value and project payback period for each case.



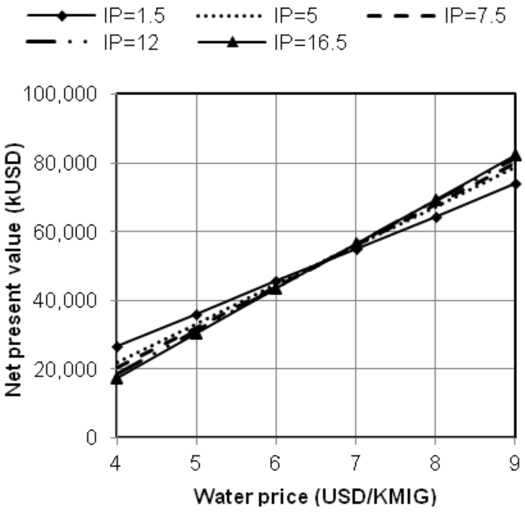
A: IP Pressure = 16.5 Bar

B: IP Pressure = 1.5 Bar

Figure.3: Plant exergy analysis

An increase in pressure level by 219 % results in a decrease in power production by 7 %, and in IRR by 4.5 %, but increase in water production (MIGD) by 20 %. Comparison between configurations indicates case 1 as the optimal configuration scheme satisfying the minimum power and water generation demands also at maximum internal rate of return for the project.

This means that in this configuration a search for a higher water production by increasing steam pressure level from back pressure steam turbine leads to a lower power production for the cogeneration plant, would increase water selling revenues but not as much as reducing electricity revenues. Thus according to the specific economic conditions selected in this work (0.04 \$/kWh electricity and 1.1 \$/m^3 water selling price), it is not worth reducing the benefit of power selling in order to have higher water generation.



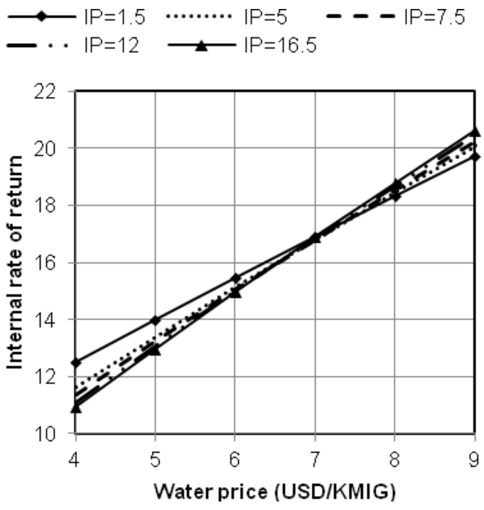


Figure 4: Sensitivity of net present value to water price

Figure 5: Sensitivity of internal rate of return to water price

In this regard in order to take in to account sales policy for water production plants, a Sensitivity analysis has done based on water market price. It shows that for a proposed constant fuel and electricity price, the increase in water price renders a similar increase in NPV and IRR as shown in Figure 4 and Figure 5 respectively. The figures show that the higher steam turbine backpressure, the higher sensitivity of project profitability to water price.

Also this approach shows for a specific water selling price, whether it is worth increasing steam turbine backpressure level (and increasing the plant water production), in order to achieve a higher profitability for the project or not.

5. Conclusions

Thermoeconomic analysis can be successfully applied to the optimization of dual purpose power and water plants. In this study it has been applied for a CCGT cogeneration power plant to set the pressure level of exhausted steam from backpressure steam turbine as design variable that is influencing the supposed economic objective function: internal rate of return.

It has been pointed out that in general choosing the best configuration and optimal design for a supposed configuration strongly depends on economical consideration such as fuel price, sales policy and end product cost.

Particularly, for the proposed project in this work, it is concluded that with increasing the pressure level of exhausted steam from backpressure steam turbine, the exergy cost of electricity produced with steam turbine and water produced with thermal desalination will be significantly increased. Thus from an energy efficiency viewpoint, lower backpressure level for exhausted steam is preferred , however from a profitability viewpoint it is possible to find situations in which higher pressure level seemed to be more interesting depends on the water purchase policy, and even electricity and fuel market price.

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