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Thermodynamic Investigation of Iran LNG Cogeneration Power Plant

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In this paper the basic design of cogeneration power plant for Iran LNG unit is investigated as thermodynamic view of point. Due to reliability consideration, power plant shall be able to generate power and steam required for whole plant even in case of one gas turbine and one HRSG failure. According to this condition the combined cycle is employed to meet power and steam required by the worst ambient condition while one complete unit failure does not affect the LNG production. Two scenarios have been studied: 1. Design based on extraction steam turbine 2. Design based on condensing steam turbine. For both scenarios best layout and design for relevant HRSG will be presented and the ability of designs during one unit trip condition has been investigated.

1. Introduction

According to the power and steam demand for whole LNG process in one hand and plant availability on the other hand, it is inevitable to employ heavy duty combined heat and power plant. Iran LNG project which will produce approximately 10 MMTA Liquefied Natural Gas (LNG) is located in Tombak region 60km away from Assaluye. According to the liquefaction process, 684MW electrical power is necessary for heavy duty refrigeration compressors. It should be noted that heavy duty variable speed electrical motors will drive refrigeration compressors. One reason for substituting gas turbines driver with electrical motors is increasing the reliability of plant. However, in addition to power requirements, the desulphurization process needs steam into many pressure levels. In this plant it is required to produce high pressure steam in addition to huge amount of low pressure steam.

In this paper, basic design for combined heat and power generation unit for Iran LNG plant has been discussed. According to process demand of whole plant (steam and power) and reliability consideration the best power plant will be presented. Due to power to cost ratio of gas turbines and the simple operation and improved efficiency of new heavy duty gas turbines, power and heat generation units based on gas turbine are so attractive. In addition, the gas turbine based power plants (specially combined cycles) have faster response during load transition which is very important for LNG units. New

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advanced combined cycles thanks to GE9001H gas turbine and excellent heat recovery in advanced HRSGs have more than 60% efficiency.
In combined cycle or combined heat and power plants the only equipment which there is enough freedom to change the design is HRSG. So, many works are carried out to optimize the thermo economic design of whole plant and HRSG recently [1], [2], [3], [4]. In this paper the sensitivity of two layouts for optimum plant design will be simulate and investigated.

2. Combined Heat and Power Plant Simulation

Demand of Iran LNG plant is shown in table (1). To meet the demand two combined cycles with and without extraction in steam turbine proposed. In the first the appropriate HRSG will be designed in such a way that about 50% of MP steam is produced in HRSG and remaining would be extracted from the steam turbine. In the second method whole MP steam will be generated in MP section of HRSG. The gas turbines which have been used in the simulation are Siemens V94.2 type with 159 MW (ISO Rate). As stated before, for reliability consideration the plant must be able to generate whole plant demand even when one HRSG and GT failed. According to climate condition the worst case for design is considered 43°C and 35% relative humidity. The site ambient pressure is 1 bar. 4 gas turbines can generate necessary power and supply flue gases for 4 HRSG to produce steam and required power in bottom cycle. But for reliability consideration we will design the power plant using 5 GTs and HRSGs.

Table1. Iran LNG Plant Power and Steam Demand

Power	692 MW (Gross)	684 MW (Net)	8MW internal consumption
HHHP Steam	16.75 Kg/Sec	100.5 (bar)	523.3 (°C)
MP Steam	111.1 Kg/Sec	10.34 (bar)	261 (°C)

2.1 Design with extraction turbine

Basically combined heat and power plant utilizing extraction steam turbines planned to generate required power and steam using 5 GT and 5 HRSG in design point while gas turbines are operating in part load mode. In addition this design shall be able to generate whole plant demand using 4 GT and 4 HRSG while gas turbines operate in full load mode. The proposed layout for HRSG is shown in Fig 1. This is double pressure waste heat boiler with 3 part high pressure economizer. It revealed that such a layout brings better heat recovery in HRSG.
The related T-Q diagram is shown in Fig 2. As depicted the high pressure section has been closed to hot gas line. In Fig 2 the dash line represent high pressure water section and numbers address heat exchangers in Fig 1. For instance number 8 in the Fig 2 addresses HHHP super heater heat exchanger. Based on abovementioned layout, design parameters for demand satisfaction are show in tables (2), (3) and (4).

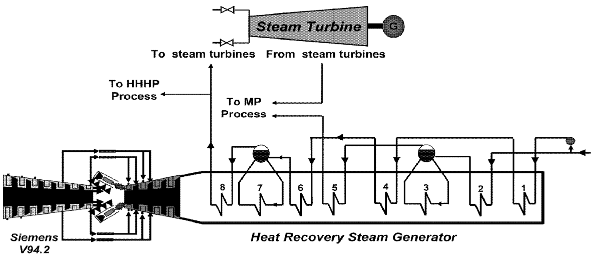

Fig1. Flow diagram of Iran LNG heat and power plant with extraction steam turbine

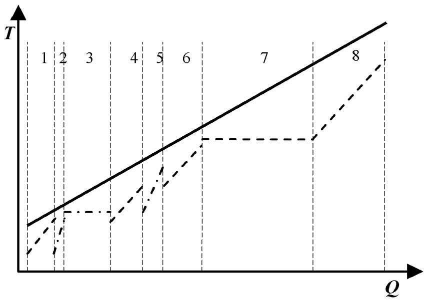

Fig2. T-Q diagram of HRSG

Table2. Siemens V94.2 Performance in Power Plant Design Point

Design variable	Load (%)	Net Power(KW)	Gross Power(KW)	Exhaust flow(Kg/Sec)	Exhaust temperature(C)
value	77.15	97200	99100	394.1	563.1

Table3. Delivered Steam from 5 HRSG in Design Point

	High pressure	Medium pressure
Pinch Point DT (C)	19	15
Pressure (bar)	102.34	11.44
Temperature(C)	523.2	262
Mass flow(Kg/Sec)	233.4+16.75	57.44

Table4. One Steam Turbine Performance in Design Point

	Inlet steam	**Extracted steam**	Exhaust steam
Pressure (bar)	100.5	**12.16**	0.21
Temperature(C)	523.3	**257.2**	61.1
Mass flow(kg/sec)	116.7	**26.83**	89.9
Gross power(kW)	**102000**		

According to these results, it can be concluded that required power and steam has been provided and above configuration can meet the requirement of the plant. In the next step

the plant production in emergency condition (4GT + 4 HRSG) has been investigated. In this case it is assumed that (1GT + 1HRSG) are out of order and the 4 available gas turbines would work in full load condition. TET (Turbine Exhaust Temperature) remains constant until 75% of load while exhaust mass flow is increased. The slope of lines in T-Q diagram is the inverse of total heat capacity (specific heat capacity × mass flow). So by gas flow increasing the slope of gas line will be decreased. Important observation is both of MP and HHHP pinch point difference temperatures have been increased.
In site climate condition we have the following results:

Table5. Siemens V94.2 performance in power plant in trip mode

Design variable	Load (%)	Net Power(kW)	**Gross Power(kW)**	Exhaust flow(kg/sec)	Exhaust temperature(C)
value	100	126030	**128130**	454.8	563.1

Table6. Delivered Steam from 4 HRSG in trip mode

	High pressure	Medium pressure
Pinch point DT (C)	19.02	14.99
Pressure (bar)	**102.24**	**11.44**
Temperature(C)	**523**	**262**
Mass flow(kg/sec)	**214.8+16.75**	**53.06**

Table7. One Steam Turbine Performance in trip mode

	Inlet steam	**Extracted steam**	Exhaust steam
Pressure (bar)	100.63	**12.18**	0.1876
Temperature(C)	522.2	**257.3**	58.7
Mass flow(kg/sec)	107.4	**29.02**	78.39
Gross power(kW)	**92410**		

2.2 Design with condensing turbine

In this section it is assumed that there is no extraction for Steam turbine, so it would be a deficiency in supplying MP, for compensation two alternatives have been considered:

1. Producing MP through let down station which converts HHHP to MP.
   In this scenario HHHP steam produced in HRSG leaded to let down station to provide required MP steam. Obviously this method brings waste of energy and therefore ignored.
2. Using a double pressure HRSG which is able to produce whole MP steam required for the plant in MP section. This method examined as follows:

Assuming that there is no extraction and steam turbine is condensing type, without any quantitative analysis we can predict decreasing in MP pinch point, difference temperature and increasing in HP pinch point. The best layout for this reason is shown in Fig 3. Second part of HP economizer is eliminated in order to provide more opportunity for MP section to generate steam. Fig 4 shows heat transfer between hot gas and water. Results are shown in tables 8, 9.

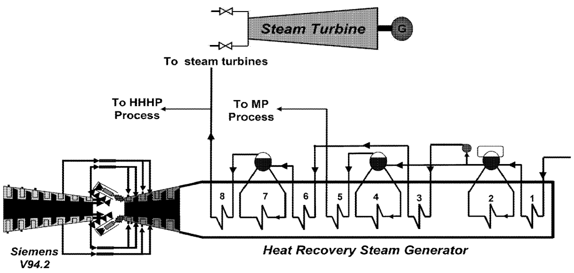

Fig3. Flow diagram of Iran LNG heat and power plant with condensing steam turbine

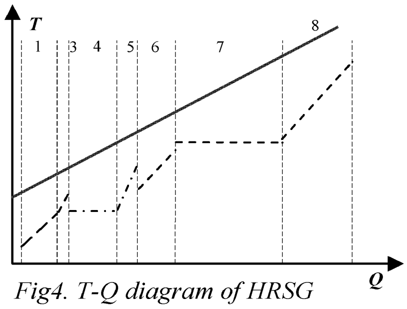

Fig4. T-Q diagram of HRSG

Table8. Delivered steam from 4 HRSG in design point

	High pressure	Medium pressure
Pinch point DT ©	53.5	11
Pressure (bar)	**102.3**	**11.65**
Temperature©	**524**	**262**
Mass flow(Kg/Sec)	**118.12+16.75**	**111.2**

Table9. One Steam Turbine Performance in design point

	Inlet steam	**Extracted steam**	Exhaust steam
Pressure (bar)	100.5	**0**	0.21
Temperature©	523.2	**0**	61
Mass flow(Kg/Sec)	99.06	**0**	99.06
Gross power(KW)		**101960**	

Table 8 shows using proposed HRSG layout and 11°C for MP pinch point and 53.5°C for HP pinch point whole MP steam required for plant can be produced and also required HP flow rate for process and power generation in steam turbine has been provided. It is noticeable that while MP pinch point has been lowered about 4°C, remarkable increasing in HP pinch point occurred. Table 9 shows steam turbine performance which implies there is no extraction in steam turbine. Results show recent design is more cost effective than first design because the HP section area has been reduced but this layout shall be examined for trip scenario. At the following performance of recent design with 4GT and 4 HRSG has been investigated.

The gas turbine outlets are same as table 5. Considering exhaust mass and temperature and proposed layout the following results are obtained. By increasing exhaust mass flow the slope of gas line in T-Q diagram increases. So, both of MP and HP pinch points will increase. By these new pinch points power plant productions are shown in table 10. Results shows in the emergency condition (4GT+4HRSG) whole demands are not satisfied. While enough HP steam for process is produced, total power is 2.5MW lower than demand and MP steam flow is 4.5kg/sec lower than demand. As a solution, HRSG shall be equipped by duct burners so in this way it is possible to meet requirement of the plant.

Table10. Delivered steam from 4 HRSG in trip mode

	High pressure	Medium pressure
Pinch point DT ©	58.81	13.67
Pressure (bar)	**102.3**	**11.4**
Temperature©	**522.3**	**261.5**
Mass flow(kg/sec)	**188.22+16.75**	**106.6**

Table11. One steam turbine performance in trip mode

	Inlet steam	**Extracted steam**	Exhaust steam
Pressure (bar)	90.25	**0**	0.1933
Temperature©	516.8	**0**	59.4
Mass flow(kg/sec)	89.11	**0**	89.11
Gross power(kW)		**91261**	

3. Results and discussion

In this paper two scenarios for design of combined heat and power plant for Iran LNG plant are investigated: a) with extraction steam turbine b) with condensing steam turbine. For each of scenarios the best layout for HRSG is proposed and the basic design for HRSGs is presented as thermodynamic view of point. Results implied that:

- MP pinch points difference temperature for first and second scenarios are 15 and 11 respectively. So, the MP section of second scenario is a little larger than the first.
- HHHP pinch points difference temperature for first and second scenarios are 19 and 53.5 respectively. So, the HHHP section of first scenario is larger than the second.
- The first design successfully meets the requirement of the plant in both normal and trip mode.
- The second design shall be equipped with duct burners to be able to meet the power and heat requirement of the plant.

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