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Assessment of gas turbine inlet air cooling in a combined cycle power plant to improve efficiency

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Abstract: An analysis was made to assess the potential enhancement of a fleet of 14 small gas turbines' power output by employing an inlet air cooling scheme at a gas process plant. Various gas turbine (GT) inlet air cooling schemes were reviewed. The inlet fogging scheme was selected for detailed studies due to its low installation capital costs. The results indicate a potential of 10% enhancement in power output on a warm, dry day, a 5% enhancement in a typical summer day, but only a 1% enhancement in a hot humid day. It is shown that the relative humidity is the most important factor that affects the impact of inlet fogging. Therefore, the inlet fogging can enhance GT power output not only in the hot summer, but also in other dry days during the year. An annual analysis was also conducted based on New Orleans's annual weather conditions. The results indicate a potential of increased power of 2.34% with inlet fogging to saturated state and additional 5% increased power with 0.5 %(wt) overspray. In this study, the gas turbines of Boshehr new combined cycle power plant which located in a west of Iran are considered. The highest and lowest improvement in output power (14.3% and 6.88%) occurs by using water cooled chiller system and media system, respectively. At the end, the most suitable turbine inlet air cooling system has been selected according to technical and economic point of view. Sensitivity analysis shows that the candidate system doesn't have economic justification for a price less than 80 dollars per megawatt.

Key words: *Gas turbine; Power plant; Efficiency*

1. Introduction

Using gas turbines to generate power in order to plentiful natural gas resources in Iran has been considered in recent years. Other feature of the gas turbine generators in the power industry is their faster installation and connection to the national grid in comparison with others generators like steam turbine power plants (Ameri et al., 2006). The gas turbines design is based on International Standards Organization (ISO) conditions which specify the following air inlet conditions: air temperature 15˚C (59F), relative humidity 60%, and absolute pressure (sea level) 101.325 kPa (14.7 psia). In theory gas turbines are capable to achieve 65 percent efficiency, but in operation they have less efficiency. Some factors which lead to their low efficiency or in other words some technologies which improve gas turbines performance are reducing internal losses, heat recovery in combined cycle or cogeneration plants and also reducing the inlet air temperature of compressor to ISO condition or even fewer (Abdulrahman and Abdulhadi, 2010). According to a survey, there are more than 170 gas turbine units in Iran. The total capacity of these units is around 9500 MW. However, the power output of the units is about 80% of their rated capacity in the summer. This means that around 1900 MW are lost during the hot seasons (Ameri and Hejazi, 2004). These data are estimated in 2007 and they are obviously increased so far. Select the optimal type of gas turbine inlet air cooling system for a particular plant, requires consideration of various parameters, including the plant's region (weather station location), characteristic of gas turbines, energy prices in the commercial market, etc. So, this issue will be analyzed in this paper.

2. Overview of inlet cooling

Gas turbine inlet cooling is extremely effective in counteracting the decreasing GT performance during hot and humid summer when the power demand reaches maximum. South Louisiana's summer is especially hot and humid; inlet cooling is an option that must be evaluated. The capital cost for an inlet-cooling device is cheaper than installing a stand-by unit only for peak load needs. There are a number of technologies which can be deployed to accomplish the lowering of the inlet air temperature into the compressor inlet, which in turn, increases the density of that air and the corresponding mass flow through the GT, allowing increased power output during warm or hot ambient conditions. The options to improve GT performance/output through inlet cooling are numerous including both indirect evaporative "pre-cooling" systems, active "chiller" refrigeration based systems (both electrically driven and thermally driven), desiccant cooling systems,

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and a number of water spray/fogging options. Caution needs to be taken to avoid frosting when the static pressure reduces during flow's acceleration through the inlet converging duct. This inlet cooling option will be evaluated by both investment economics as well as viability of this generation enhancement to the anticipated load profile of the GT plant in question. Evaporative cooling and refrigeration are two common methods for providing inlet cooling. Evaporative cooling can be achieved either by mixed or non-mixed method. In the mixed evaporation, water will be evaporated and mixed with air before enter the compressor. Small water droplets (mist) less than 5μm can be injected into the GT inlet to reach cooling effect as well as increase the mass flow rate. Selections of appropriate cooling technologies depend on site environment and load characteristics.

3. Power plant description

The power plant under study is located in the southwest of Iran, in Boshehr , next to the Fars state. Boshehr power plant exploited in 1994 with two gas turbine units. In 2004, three other gas turbines added to the existing units, and finally in 2006 three steam turbines and six heat recovery boilers added to above system that developed a combined cycle power plant with overall capacity of 1373 MW which is the biggest power generation station in Fars state, and also it is one of the most important centers of electricity production in Iran. By neglecting the older combined units which consist of older gas turbines, the rested two combined cycle is considered in this study. Each combined cycle composed of these units: two Siemens gas turbines; model V94.2 with nominal capacity of 159 MWe, two Doosan heat recovery boilers and a Doosan steam turbine with nominal capacity of 160 MWe .

According to meteorological data, average weather conditions in Boshehr plant site is at 22 ° C and relative humidity 55%, so these basic conditions considered as a design point. In this study, simulation of the power plant is done by Thrmoflow package software, version 18. The result of plant simulation in design point is presented in Table 1.

Table 1: Result of each combined cycle simulation in design point

parameter	unit	temp=22 C
		RH=55%
Fuel mass flow	Kg/s	8.2
HRSG efficiency	%	71
HRSG gas inlet Temperature	°C	558
HRSG gas inlet mass flow	Kg/s	443
Stack gas exit temperature	°C	143
Duct burner Flow	Kg/s	0
GT Power	MW	2*133.2
ST Power	MW	136.4
GT efficiency	%	33.5
ST elect efficiency	%	26.4
HP Steam flow(@ 90 bar & 520°C)	Kg/s	114.3
LP Steam flow(@ 8.5 bar & 228°C)	Kg/s	13.68
Condenser pressure	Bar	0.092

4. Economic considerations of the analysis

The main assumptions of economic analysis are discussed in this section. For economic assessment of the introduced systems, two criterions are considered; Net Present Value (NPV), and Internal Rate of Return (IRR).The quantity of NPV is given by Eq. (1):

$$NPV = \frac{R_1 - C_1}{1+r} + \frac{R_2 - C_2}{(1+r)^2} + \frac{R_3 - C_3}{(1+r)^3} + \cdots + \frac{R_n - C_n}{(1+r)^n} \qquad (1)$$

In this correlation, i is related to specific year which is under study, R, i and Ci, is the income and cost of a same pointed year, r is a discount rate and finally n is a life plan. If the financing process of the project during N years of its life composed of inflow (Rt) and outflow (Ct), solving Eq.(2) will determined r or IRR.

$$NPV = \sum_{t=0}^{N} \frac{R_t - C_t}{(1+r)^t} = 0 \qquad (2)$$

According to Fig.1 and Fig.2, based on NPV criterion the most appropriate method would be water cooled mechanical chiller and the latter one would be one stage absorption chiller, but based on the IRR criterion the Fog system has higher economic justification and the second one would be Media system. Therefore, in order to selection of the best economic method through these four options, the extra investment analysis has been considered. In this method, the differences in initial investment and revenues of each system should be compared at first. Secondly, according to the differences in investments and incomes costs, the internal rate of revenue (ΔIRR) must be calculated. If the calculated ΔIRR is larger than the considered discount rate, the system with more investment cost would be a better one. The calculation procedure was done for each four superior methods and the following results were obtained.

ΔIRR (water cooled Mech.chiller, Fog) = 29% > 10%

ΔIRR (water cooled Mech.chiller, Media) = 39% > 10%

ΔIRR (water cooled Mech.chiller, one stage abs. chiller) = 951% > 10%

In comparison of water cooled mechanical chiller and Fog system, water cooled mechanical chiller and Media system and water cooled mechanical chiller and one stage absorption chiller, ΔIRR obtained 29%,39% and 951% respectively. Sensitivity analysis of water cooled mechanical chiller system to electricity price changes based on payback period and net present value is shown in Fig 3 and Fig 4 respectively. As seen in Fig. 4, it doesn't have economic justification for a price less than 80 dollars per megawatt.

5. Conclusion

In this paper, the feasibility of different turbine inlet air cooling systems investigated and the best case selected by both technical and economic consideration. The following result obtained in this study. Technically, the most power augmentation achieved by water cooled mechanical chiller, two stage absorption chiller, and one stage absorption chiller, air cooled mechanical chiller, Fog and Media system correspondingly.

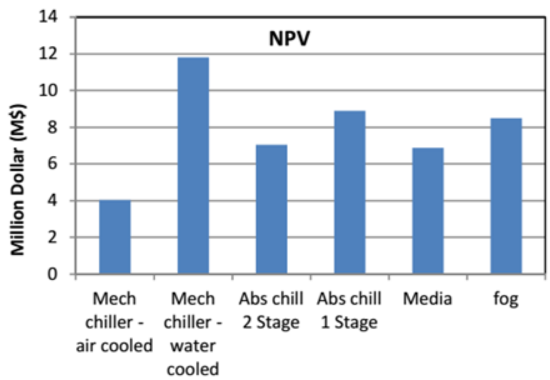

Fig. 1: Net present value for every TIAC system

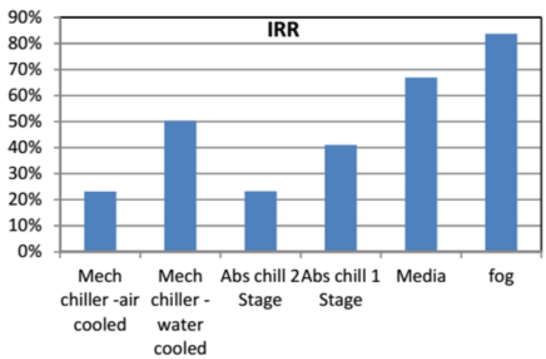

Fig. 2: Internal Rate of Return for every TIAC system

Practical use of each system leads to reducing both annual fuel consumption and emissions, but some issues like availability of water resources for each system should examine precisely. Economically, the most initial investment are for two stage absorption chiller, air cooled mechanical chiller, water cooled mechanical chiller, one stage absorption chiller, Media and Fog system respectively. Based on the economic consideration, water cooled mechanical chiller is the most appropriate method for TIAC in Boshehr combined cycle power plant. The payback period for this technique calculated three years. Using this system in comparison to add a new gas turbine unit for the same power augmentation is more economical. Sensitivity analysis shows that this system doesn’t have economic justification for a price less than 80 dollars per megawatt.

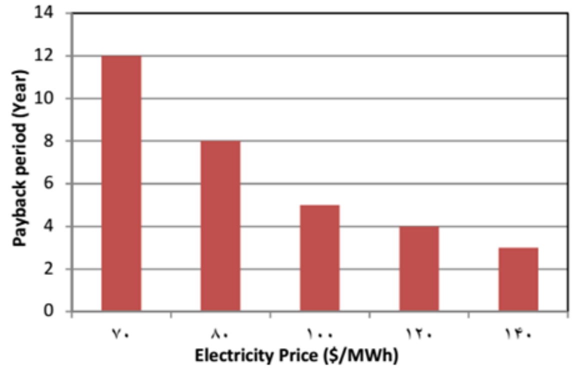

Fig. 3: Sensitivity analysis of water cooled mechanical chiller system to electricity price changes based on payback period

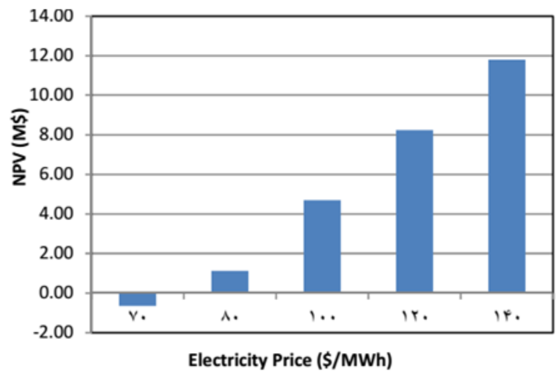

Fig. 4: Sensitivity analysis of water cooled mechanical chiller system to electricity price changes based on net present value

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