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An applicable method for gas turbine efficiency improvement. Case study: Montazar Ghaem power plant, Iran

Afsaneh Noroozian, Mokhtar Bidi*

Faculty of Mechanical and Energy Engineering, Shahid Beheshti University, A.C., Tehran, Iran

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ABSTRACT

Compressor inlet air cooling is one of the most well-known methods to improve gas turbine power plant performance. In this study, pressure reduction valve in natural gas pressure reduction station is replaced by a turbo-expander to use the potential energy of the compressed gas. The turbo-expander shaft is connected to a mechanical chiller to produce refrigeration; the produced refrigeration is used to decrease the compressor inlet air temperature. Moreover, thermodynamic and exergetic analyses are carried out and the effect of compressor air cooling on the performance of the plant is studied. To do so, Montazer Ghaem power plant is considered as the case study. Results showed that using cooling system causes 3.2% temperature drop which leads to 1.138% increment in both thermal efficiency and net output power in the warmest month. Exergetic analysis reveals that using the cooling system leads to a higher exergy efficiency and hence lower exergy destruction. Also combustion chamber with 81.26 MW has the highest amount of exergy destruction which decreases to 77.36 MW after implementation of the cooling system. In January, exergetic efficiency of total plant has 1.86% enhancement and exergy destruction reduces about 3.8 MW.

1. Introduction

The optimization and reduction of energy consumption has an important role in the contemporary world. Increasing the efficiency of various devices and decreasing their consumed energy is preferred. Gas turbine is a device which has various applications such as producing electricity in power plants, especially those which require less commissioning time. The efficiency and output power of gas turbines are related to many different parameters. The aim of this study is to investigate the influence of ambient temperature on gas turbine plants output power. One Celsius degree temperature increment leads to approximately one percent reduction of the gas turbine rated capacity (Mohanty and Paloso, 1995). There are as many methods to reduce compressor inlet air temperature so as to improve the gas turbine performance. The most important ones are as follows (Kakaras et al., 2006; Hosseini et al., 2007; Chacartegui et al., 2008; Ehyaei et al., 2011):

a) Mechanical chiller or absorption chiller: mechanical chiller cools the inlet air so its temperature drops to below the wet bulb temperature. Mechanical chillers are driven by electric motors, steam turbines or engines. These type of chillers use a classical mechanical compression cycle. The inlet air is passed across the cooling coils, through which intermediate refrigerant fluid is circulated. Absorption chillers require steam or hot water as the basic source of energy and they use absorption refrigeration cycle with the working fluids of water/ammonia or lithium bromide/water. Absorption chillers also require less electric energy than mechanical chillers. The main difference of these two types of chillers is in the way that the refrigerant is changed into liquid. This is the reason why absorption chillers do not have any moving parts.
b) Chilled water storage or ice harvesting: chilled water storage and ice storage, store sensible and latent heat energy respectively. Ice storage is mostly profitable for small storage capacity.
c) Media evaporative cooling and Fogging: the evaporative cooler is a wetted rigid media. As the water distributes from the top, hot air passes through the media and cause water evaporation. So, the air is cooled during the process and then enters the compressor. Fogging is another evaporative cooling technology in which the fine droplets of water are added to the inlet air by

* Corresponding author.
E-mail address: m_bidi@sbu.ac.ir (M. Bidi).

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means of high pressure nozzles. Water consumption in fogging system is more than that of evaporative cooling, but fogging system has higher effectiveness.

In a method suggested by Mohanty and Paloso (1995), the heat of flue gas was directly used by an absorption chiller to provide cooling system. Therefore the gas turbine output power increases, the waste heat is recovered and the environmental impacts are decreased. They also concluded that 11% increase in plant's energy output could be achieved. M. De Lucia et al. (1995) discussed differences between absorption and evaporative cooling systems. They concluded that, although evaporative cooling systems have a lower cost, but absorption ones are much more effective especially for base load production plants. Combination of these two cooling systems which has the highest benefit was likewise. Badran (1999) worked on the influence of parameters which could affect the gas turbine performance, such as compressor inlet temperature and turbine inlet temperature. He emphasized that as the compressor inlet air temperature increases, thermal efficiency decreases and also ambient condition would have less effect on efficiency by choosing the best location for power stations. M. Chaker et al. (2003) have studied available direct evaporative cooling hours of 122 locations in the U.S.A with inlet fogging system for gas turbines. Their focus was mostly on climate conditions. Ameri and Hejazi (2004) suggested an air cooling system that uses a steam absorption chiller in Chabahar (Iran) power plant. They concluded that this system with payback period of 4.2 years, would have led to 11.3% increase in average output power. Kakaras et al. (2006) have compared different air cooling methods and their integration. They mentioned that investment costs of evaporative cooling technology are lower than other methods, while absorption chiller system has much higher capacity for increasing electricity generation.

Hosseini et al. (2007) evaluated the influence of media evaporative cooling system on gas turbines performance in a combined cycle power plant. Their results showed that this cooling method causes 19 °C reduction in inlet air temperature which leads to 11 MW growth in gas turbine output power with a payback period of about 4 years. Shi et al. (2010) performed a research aimed at improvement of combined cycle power plant. They demonstrated that with integration of inlet air cooling, inter cooling and LNG gasification within a combined cycle power station, there would be an increment in net electrical efficiency and output power. De Sa and Al Zubaidy (2011) focused on the relation between ambient temperature and gas turbine efficiency and output power. They mentioned that with increase of temperature, efficiency and output power are reduced. They also established an empirical relationship between ambient humidity and system performance. In addition to conventional cooling methods, there are modern cooling technologies such as ceramic tubes membrane (Zeitoun et al., 2014). Zeitoum et al. worked on an experimental sample and demonstrated that by having both latent and sensible heat transfer, in this model the air passes over the ceramic tube matrix and the water runs through the ceramic tubes. So the ambient temperature decreases and the relative humidity increases with no erosion in compressor blades. There are other methods for gas turbine performance enhancement. Using liquid nitrogen spray is one way to reduce turbine inlet air temperature in Integrated Gasification Combined Cycles (Morini et al., 2015). Some advantages of this method are that it does not need a large amount of water despite common thermal storage systems and there won't be pressure losses at the compressor inlet. Oyedepo and Kilanko (2012) used evaporative cooler for performance enhancement of a gas turbine power plant. They mentioned that 5 °C drop in compressor inlet air temperature, causes 5–10% increment in net output power and 2–5% thermal efficiency enhancement. They also showed the positive effect of pressure ratio on their results. Ibrahim et al. (2011) showed that if compressor inlet air temperature increase 1 °C, the gas turbine power output drop about 1%. They also showed that by increasing ambient air temperature, air mass flow rate reduces and finally cycle efficiency decreases. Gas turbine power plants performance in warm and relatively dry climate is very important, so cooling compressor inlet air in these conditions is the topic of many researches (Tobi, 2009; Abam et al., 2012; Jarzębowski et al., 2012). Zaki et al. (2011) demonstrated that by the use of evaporative cooler in hot humid climate, there would be limitation in gas turbine capacity improvement (not more than 5%–7%). Because compressor inlet air temperature should not be less than wet bulb temperature.

Farzaneh-Gord and Deymi-Dashtebayaz (2009, 2011) used a similar method for inlet air cooling system to enhance the output power, but they directly used expansion turbine outlet flow for cooling the compressor inlet air by the use of a heat exchanger. Implementation of their model is not possible for a constructed power plant, because their method causes fundamental changes in fuel supply system. As a result, installing of this model needs a long overhaul of power plant and this is against the power plant owners' expectations. On the other hand, because of long distance between pressure reduction station and gas turbine power plant, there would be a possibility to phase change, so this project is very hard to execute. Moreover there were two fundamental shortcomings in their thermodynamic modeling which leads to less accurate results. The first one is that they did not correctly relate the inlet air cooling to output power, another problem is that they used ideal Brayton assumption in their calculations, therefore there will be miscalculations and it could not be used in real industrial decisions.

For example Fig. 1 shows differences between the results of simulation procedure with ideal Brayton cycle in comparison with real data for a 134.140 MW gas turbine model (GE, model MS9001E with 34.6% efficiency at shaft output). There is a 7.92% discrepancy between efficiency of ideal Brayton cycle with the catalogue data, while there is no considerable error in the proposed method.

In the present study an applicable method for an installed power plant is provided. In the proposed model, a mechanical chiller is used for reducing compressor inlet air temperature which its required power is obtained from a turbo-expander. The turbo-expander is replaced in pressure reduction station with a pressure reduction valve. Using a turbo-expander is an appropriate way to recover pressure energy of natural gas in pressure reduction stations (Farzaneh-Gord et al., 2015). Fuel pressure must be reduced from 5–7 MPa to 1.5–4.0 MPa, in the natural gas pressure reduction station (Poživil, 2004). Andrei et al. (2014) demonstrated that by the use of turbo-expanders instead of throttle valves or pressure reducing valves in pressure reducing stations of the whole country, the sum of power generation could be significant. In this study a preheater is used before the expansion turbine to prevent from production of liquid or solid phase at the discharging of the station. This article compares basic model with proposed model, from the viewpoints of thermodynamics and exergy. As discussed earlier, in previous studies ideal Brayton cycle was used for simulation which caused miscalculations as mentioned in Fig. 1. So in this paper a real cycle is simulated for more accuracy. The proposed model is an applicable method to use potential energy of natural gas unlike previous studies which were impracticable. It is for the first time that exergetic analysis of each component and whole cycle is done for a real gas cycle with cooling system. Exergy destruction rate and exergy efficiency of different points in the cycle are also calculated.

Other power plants can use the methodology of the proposed model to enhance the plant power and efficiency, because this model is applicable and does not involve executive problems unlike previous models. Effect of different amounts of *COP* on net output