The feasibility study of a night sky radiative cooling system for cooling the intake air of the gas turbine

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ABSTRACT

The compressor inlet air cooling, especially in hot climates, has significant effect on the power output augmentation of the gas turbines. The water consumption in evaporative cooling and fogging systems and power consumption and investment cost in vapor absorption and compression refrigeration systems are high. So, the purpose of this article is to investigate the possibility of using the night sky radiative cooling system for cooling the intake air of the compressor. In this method, the circulating water used to cool the intake air of the compressor, at night and in the exchange of radiation with the sky, is cooled using glassless flat plate collectors and returns to the storage tank for reuse on the next day. The effect of parameters such as the number and arrangement of collectors in series or parallel on the cooling capacity is investigated. Also, the required storage tank volume for returned water from collectors is calculated. The results show that, the compressor's intake air cooling for six hours a day needs a storage tank with a minimum capacity of 1000 m^3. Also, by using 400 parallel collectors and a 1000 m^3 storage tank, the power production increases by an average of 2 Megawatt hour.

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KEYWORDS

Gas Turbine, Air Intake cooling, Night Sky Radiative Cooling, Passive Cooling, Solar Collector

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1. Introduction

Gas turbine output is a strong function of the ambient air temperature. Increasing ambient temperature has a negative effect on the production capacity of gas turbines with power output dropping by 0.3 percent to 0.5 percent for every $1^{\circ}F$ rise in ambient temperature [1] . The adverse effect of high ambient air temperatures on the power output of a gas turbine is twofold: as the temperature of the air increases, the air density and, consequently, the air mass flow decreases. The reduced air mass flow directly causes the gas turbine to produce less power output. On the other hand, the higher intake-air temperature results in an increase of the specific compressor work and, therefore, in a further reduction of the power output. Depending on the type of the gas turbine, the electric output will decrease by a percentage between 6% and more than 10% for every $10\,^{\circ}C$ of intake-air temperature increase [2]. The night sky as the coolest available heat sink, is a kind of passive cooling systems used to reduce energy consumption [3]. This system has been studied and used in numerous projects in the past century to reduce the energy consumption of traditional cooling systems and improve their efficiency [4].

In this paper, the feasibility study of a night sky radiative cooling system for cooling the suction air of the gas turbine compressor is studied. The aim of study is reducing water consumption and increasing electricity generation at peak consumption hours.

2. Problem Description

The purpose of this study is to investigate the possibility of using a night sky radiative system for cooling the suction air of Bampur powerplant compressor. Bampur power plant (also known as Iranshahr power plant) consists of two 160-megawatt gas-fired units is located in the south of Sistan and Baluchestan province in Iran with hot and arid climate. The inlet air mass flow rate entering to each unit at ambient temperature conditions is approximately 345.6 kg/s. The schematic diagram of proposed cooling system for compressor's suction air cooling is presented in "Figure 1".

In this system, at first, the cool water is pumped from the storage tank into the coils located inside the suction side of the compressor and cools the entering air. The circulating water through the coils, then, returns to the storage tank. During the night, by using the collectors the warmed water exchanges its energy with the sky and is cooled for use on the next day. In this method of cooling, compared to the evaporative and water spray cooling systems, a constant amount of water is used to cool the air. Therefore, this system, which is actually a kind of cold water storage system, considering the water consumption has a high compatibility with hot and arid climate.

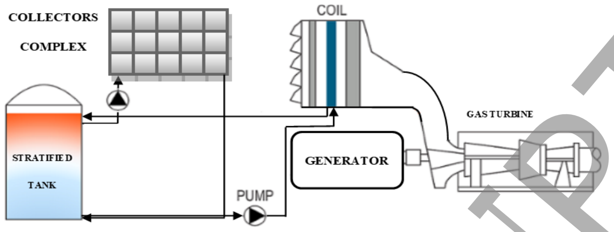

Figure 1. Schematic diagram of proposed cooling system for compressor's suction air cooling

As depicted in "Figure 1", the proposed system consists of three main components: collectors, storage tank and coil. Mathematical models are used to study the effect of these components.

3. Results and Discussion

In order to investigate the possibility of using the night sky radiative cooling system as a compressor inlet air cooling system, the amount of cooling capacity stored during the night and then its efficiency throughout the day must be first considered. So let's look at these issues further. The environmental conditions used in this research, including the temperature and humidity of ambient air, have been extracted from the values recorded by the measuring equipments of the Bampour power plant. The measured values of the temperature and humidity ratio of the environment at night 30 and the morning of July 31, 2018 are presented in "Figure 2".

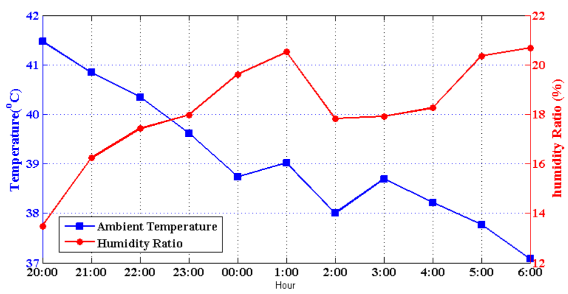

Figure 2. The measured values of the temperature and humidity ratio of the environment at night 30 and the morning of July 31, 2018

The water as the working fluid used in this night sky radiatve cooling system. The system consists of the glassless flat plate collector and water storage tank. Due to the high volume of cooling required for cooling the air entering the gas turbine unit, the collector surface should be large. In practice, it is not possible to build a large-scale collector. Therefore, in order to increase the

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surface exchange of radiation with the night sky, the connection of several small collectors is proposed in series or in parallel. The series and parallel connection of collectors are shown schematically in "Figure 3" and "Figure 4", respectively.

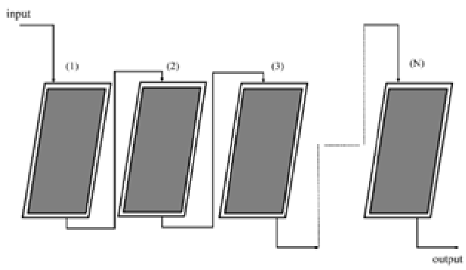

Figure 3. The series connection of collectors

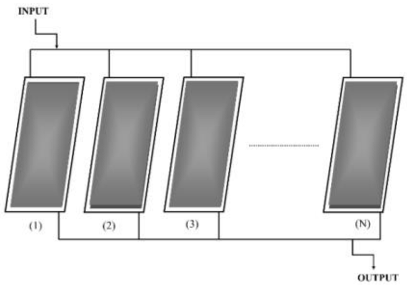

Figure 4. The paralell connection of collectors

High cooling capacity is required for cooling the air entering the gas turbine. Therefore, the number of collectors should be high. Usually, there are spaces in the gas-fired power plants that have no specific application and can be considered as collector's location. Among these spaces can mention to the top of the turbines (turbine roofs). For example, the available space on the top of the turbines in the Bampur power plant is 17 × 87 square meters. With a collector area of 2.94 m^2, about 503 collectors can be placed in this space. Considering some considerations, such as taking into account the space needed to move during the repair and maintenance of collectors, the space required for plumbing, the space necessary to set the framework for the placement of collectors, etc., the number of collectors in the work is considered 400.

The ability of collectors with 400 collectors with parallel and series arrangements are compared and presented in "Figure 5".

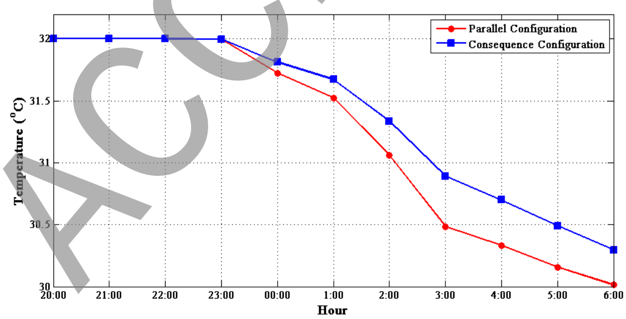

Figure 5. The comparison of cooling effects of 400 collectors in series and parallel configurations

As depicted in "Figure 5", the parallel arrangement is better than series configuration and decrease water temperature more than its counterpart. In the parallel arrangement by dividing cooling water between collectors and reducing the mass flow rate passing through collectors, the water temperature decrease is better than series configuration.

For two cases of with and without the night sky radiative cooling systems, the air temperature of the suction side of compressor are compared in "Figure 6". The results are presented for a storage tank capacity of 1000 m^3.

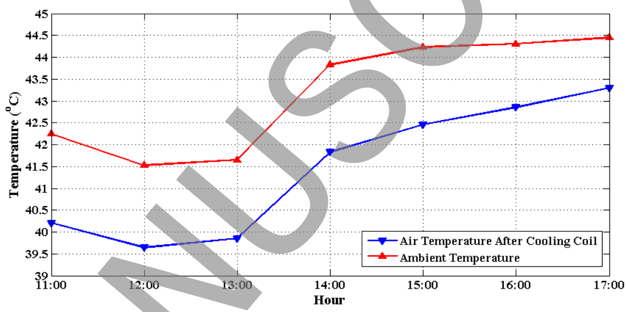

Figure 6. The comparison of the compressor's air suction temperature with and without night cooling system, tank capacity 1000 m^3

As depicted in "Figure 6", the proposed cooling system can decrease the entering air temperature more than $1^\circ C$. Also, the related increased power generation is presented in "Figure 7".

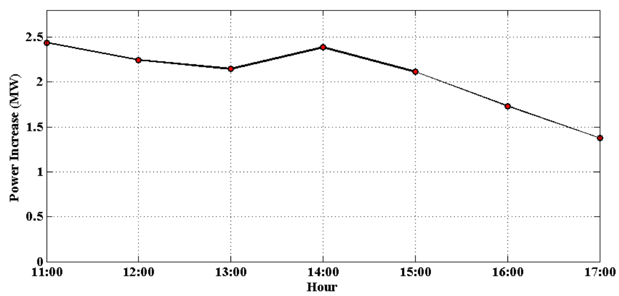

Figure 7. Increased power generation by pre-cooling of the intake air to the compressor with the help of a night radiative cooling system, tank capacity 1000 m^3

4. Conclusions

In this paper, the use of a night sky radiative cooling system as a novel cooling system for cooling the air entering the compressor in a gas turbine unit has been suggested and its feasibility is studied. With respect to the high rate of required cooling the use a large number of collectors are necessary. In this research, the method of collector connections was investigated, which showed that in a very large number of collectors (more

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than 200 collectors), the parallel connection is better for storing the generated cooling. Also, the effect of reservoir storage volume on the cooling storage was investigated. The results show that, to ensure that the stored cooling with 400 parallel collectors can provide the demand for cooling the compressor's suction air, the storage volume of the cooling system should be at least 1000 cubic meters. Finally, the use of this system by pumping water only increases the power consumption at a rate of 9 kilowatt hour, but will increase the amount of electricity generation about 2 megawatts hours at peak consumption times.

5. References

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