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Performance of Hybrid Solar-Gas Turbine Power Plants Modified with Humidification-Dehumidification Desalination Process

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Abstract

The performance of hybrid solar-gas turbine power plants modified with humidification-dehumidification (HD) desalination process was simulated with TRNSYS software for the first time. The system included a 4.6 MW gas turbine, solar tower and an HD process with an air heater and open water and air cycle. The results showed that solar power managed to supply about 35-45% of required energy, hence, declining fossil fuel consumption. About 40% reduction was also achieved in CO_2 emission. The electric power and efficiency of hybrid system was slightly lower than gas turbine only due to the pressure losses in piping and solar system. The results of HD desalination indicated that the increase in the temperature and relative humidity of the inlet air enhanced the amount of fresh water production; while a rise in the temperature of saline water declined its production. Moreover, the amount of fresh water production had an optimum value relative to the air mass flow rate. In addition, if the mass flow rate ratio of saline water to dry air was equal to 1.8, the GOR had a maximum value of 2. Variation of GOR in terms of returned air was explained at different inlet air temperatures.

Keywords: Hybrid power plants, Solar tower, Fossil fuels, Desalination, TRNSYS.

1. Introduction

Reduction of fossil fuel resources to generate electricity and the need to reduce the environmental impact of these resources has led to increasing interest in the use of renewable energy, especially solar energy. The main problem of using solar energy for electricity generation is the high initial investment costs and also the impossibility of continuous production of electricity [1,2]. The solar-fossil hybrid power plants could be an appropriate method to resolve these problems as they can offer increased efficiency at reduced investment costs and the possibility of electricity dispatching [3,4]. Among various types of thermal power plants, gas power plants are the best option for the solar-fossil hybrid power plants due to their advantages such as short time for construction and commissioning, reliability, fast start and shut down process, the possibility of complete energy dispatching and, most importantly no water consumption [5].

Regarding population growth, technological advances, and the limited and declining freshwater resources, many parts of the world, especially developing countries, are suffering from water shortages [6]. Given that the oceans and seas are the vast sources of water, the use of desalination plants can be a good option to deal with this crisis. Among the various desalination methods, multistage distillation (MED), multistage flash (MSF), and reverse osmosis (RO) have found increasing applications. The main problem with these methods is the use of fossil fuels or other valuable sources of energy and these methods are suitable for high capacities and require high investment and operation costs [7,8]. Humidification-dehumidification (HD) process is one of the relatively new and cost-effective methods for producing fresh water at low capacities [9].

In this research and for the first time, the hybrid solar-gas turbine power plant with HD desalination process is simulated using TRNSYS software to heat the compressed air leaving the compressor before its entrance to the combustion chamber. Also, the energy of the exhaust from the gas turbine was used to produce fresh water in the HD process.

2. Method

The simulated gas turbine in this research is a Mercury 50 gas turbine with a capacity of 4.6 MW, efficiency of 38.5%, and pressure ratio of 9.9. Gas turbine efficiency is defined based on the input energy to the turbine regardless of its type (energy from fossil fuels or solar energy) according to the following equation:

$$\eta_{GT} = \frac{P_{GT}}{Q_{in}} \times 100 \qquad (1)$$

where P_{GT} is the electric power of the gas turbine and Q_{in} denotes the sum of the fossil fuel energy and solar energy:

$$Q_{in} = Q_{fuel} + Q_{solar} \qquad (2)$$

Q_{fuel} shows fossil fuels energy and Q_{solar} is solar energy.

Using the definition of the solar fraction parameter (SF), the proportion of solar energy in the energy input to the gas turbine can be calculated by:

$$SF = \frac{Q_{Solar}}{Q_{in}} \times 100 \qquad (3)$$

To use solar energy to heat the air exiting the compressor, a solar tower was selected, which has 150 heliostats, each with an area of 120 m^2. The height of the receiving tower was also considered to be 175 m.

HD desalination process with air heating and open water and air flow was also used. The gain output ratio (GOR) is a dimensionless indicator of the amount of freshwater produced per unit of input heat to the system. The GOR is one of the most common performance indicators for thermal desalination devices, which is defined as the ratio of the product of latent heat of vaporization in the mass flow of freshwater produced to the amount of heat entering the system as follows:

$$GOR = \frac{\dot{m}_d h_{fg}}{Q} \quad (4)$$

where $\dot{m}_d$ shows the mass flow rate of freshwater, h_{fg} is the latent heat of vaporization and Q represents the amount of heat.

It should be noted that all three parts of the gas turbine, solar tower, and HD desalination process were simulated by TRNSYS software. The city of Yazd is located in the center of Iran and has high solar energy potential. Therefore, meteorological information of Yazd city was used.

3. Results and Discussion

The performance of a hybrid solar-gas turbine power plant including Mercury 50 gas turbine with a nominal capacity of 4.6 MW, solar tower, and HD desalination system was simulated by TRNSYS software for the first time. The effect of solar energy on fuel consumption, efficiency, power plant production, the ratio of solar energy to total energy, and carbon dioxide emissions was investigated. Also, the performance of the HD desalination system which used the energy of the exhaust of a hybrid solar-gas turbine power plant was studied.

The simulation results showed a 35-45% reduction in fossil fuel consumption of the hybrid solar-gas turbine power plant as the required energy was supplied by solar energy. In addition, the use of a hybrid solar-gas turbine reduced carbon dioxide emissions by about 40%. Also, the power production and efficiency were lower in the hybrid mode as compared with the mode of gas turbine only (Figure 1 and 2), which is due to pressure drop caused by increasing piping length as a result of the presence of solar receiver. In the hottest hours of summer, power and efficiency decreased by 0.2 MW and 4.4%, respectively. These values are lower in winter and the power and efficiency were declined by 0.1 MW and 2.8%, respectively.

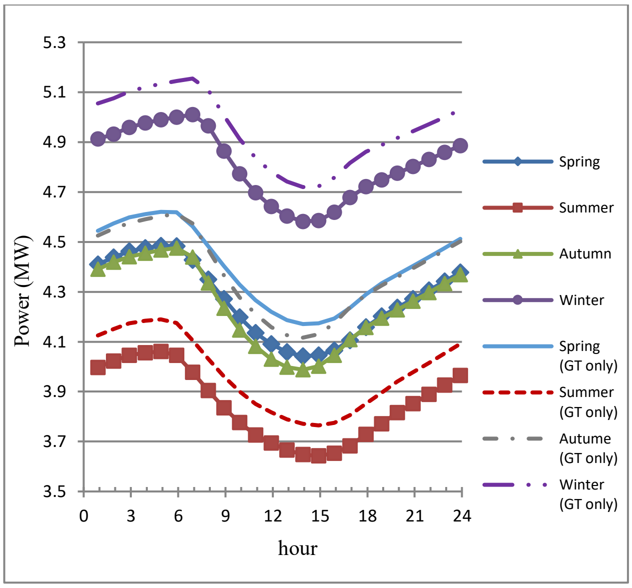

Figure 1. Hourly gas turbine electric power for each season.

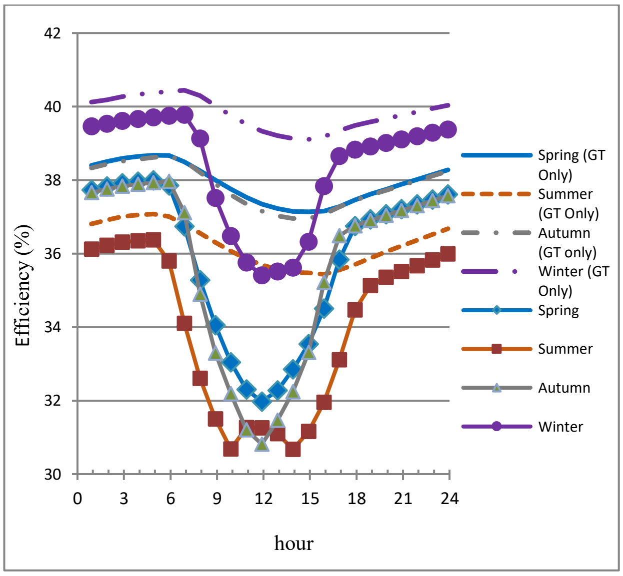

Figure 2. Hourly gas turbine electric efficiency for each season.

The results of the HD desalination system also revealed that an increase in the temperature and humidity of the air entering the desalination system can enhance the amount of freshwater produced while raising the temperature of the inlet saline water reduced that. In addition, the amount of freshwater production based on air mass flow has an optimal value, as with increasing air flow to 18 kg/s, the amount of freshwater production first increased followed by a decrease. Also, at the ratio of incoming saline water flow rate to dry air mass flow rate of 1.8, the GOR of the desalination water reached the maximum value of 2. Examination of the changes in GOR vs. return air (F) at different inlet air temperatures showed different trends of GOR changes at various temperatures.

4. References

[1] A. Shahsavari, M. Akbari, Potential of solar energy in developing countries for reducing energy-related emissions, *Renewable and Sustainable Energy Reviews,* Vol. 90, pp. 275-291, 2018.

[2] J. Peng, L. Lu, H. Yang, Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems, *Renewable and Sustainable Energy Reviews*, Vol. 19, pp. 255-274, 2-13.

[3] A. Giglio, A. Lanzini, P. Leone, M. M. R. García, E. Z. Moya, Direct steam generation in parabolic-trough collectors: A review about the technology and a thermo-economic analysis of a hybrid system, *Renewable and Sustainable Energy Reviews,* Vol. 74, pp. 453-473, 2017.

[4] O. Behar, Solar thermal power plants-A review of configurations and performance comparison, *Renewable and Sustainable Energy Reviews,* Vol. 92, pp. 608-627, 2018.

[5] D. O- León, A. Medina, A. C. Hernández, Thermodynamic modeling of a hybrid solar gas-turbine power plant, *Energy Conversion and Management,* Vol. 93, pp. 435-447, 2015.

[6] N. Lior, Advances in water desalination, pp. 1.3-1.5, First Edition, New York, USA, Wiley, 2012.

[7] A. Ali, R. A. Tufa, F. Macedonio, E. Curcio, E. Drioli, Membrane technology in renewable-energy-driven desalination, *Renewable and Sustainable Energy Reviews,* Vol. 81, pp. 1-21, 2018.

[8] S. Liyanaarachchi, L. Shu, S. Muthukumaran, V. Jegatheesan, K. Baskaran, Problems in seawater industrial desalination processes and potential sustainable solutions: a review, *Reviews in Environmental Science and Biotechnology,* Vol. 13, pp. 203-214, 2014.

[9] Z. R. Ahar, M. S. Hatamipour, L.R. Ahar, Air humidification-dehumidification process for desalination: A review, *Progress in Energy and Combustion Science*, Vol. 80, pp. 100850, 2020.