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Research paper

Renovating thermal power plant to trigeneration system for district heating/cooling: Evaluation of performance variation

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HIGHLIGHTS

- Two new performance parameters are defined for renovated power plants.
- The first parameter is named "The comprehensive thermal efficiency".
- The second parameter is named "coefficient of performance for heating/cooling".
- According to analysis all examined power plants can be converted to co-tri generation plant.

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ABSTRACT

This paper presents performance assessments of thermal power plant-based co/tri-generation systems for district heating/cooling system. The power plants were originally designed exclusively for the generation of electricity. With respect to the renovation of power plants to co/tri-generation systems, the analysis of performance variations in the systems has been undertaken. For the purpose of simulation analysis, thermodynamic models of the eight thermal power plants have been developed. The performance variations have been evaluated with different performance criteria, including electrical power output, classical thermal efficiency, coefficient of performance and comprehensive thermal efficiency. The comprehensive thermal efficiency takes into account all products (electricity, heating and cooling energy) generated from the power plant-based tri-generation system. The results of analysis show that the comprehensive thermal efficiencies of the eight considered systems range from 49% to 61% in the heating mode, although their generated electrical power amounts decrease slightly. As a result, this type of modification for an existing power plant can greatly benefit the cause of energy efficiency and sustainable development.

1. Introduction

Thermal power plants (TPPs) are used globally for the generation of electricity. Statistically, 40% of the global electricity production is provided by coal-fueled power plants, and that percentage is projected to rise in the near future [1,2]. Thus the development of methods to increase the efficiency of fuel conversion is crucial, due to the limitations of fossil-fuel sources and the growing pressure for a cleaner environment. From the perspective of sustainable development, the design of new TPPs as co/tri-generation systems that can produce both electricity and district heating/cooling energy would be a significant step toward the greater utilization efficiency of domestic fossil fuels. Indeed, many power plants were originally designed to produce electricity and district heating/cooling [3–5]. In these types of plants, the extracted steam used for feed-water heating was widely employed for district heating/cooling. Naturally, at the design stage it is possible to specify the most convenient point and amount of steam extraction without negatively affecting plant performance.

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Nomenclature

COP	coefficient of performance (−)
$\dot{W}$	power input/output rate (kW)
$\dot{W}_{Net}$	net rate of power output (kW)
$\dot{Q}$	heat transfer rate (kW)
h	specific enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
r	extracted steam rate (%)

Subscripts

A	auxiliary machines
C	cooling mode
DC	district cooling
DH	district heating
H	heating mode
M	machine used in residential zone for heating/cooling
T	turbine
th	thermal
si	steam inlet
so	steam outlet
s	steam
ds	extracted steam
c	condenser
f	fuel

Greek letter

Δ	difference
η	efficiency

Given this context, the ultimate conversion from the existing TPPs to co/tri-generation systems for the supply of district heating/cooling energy could be very beneficial in terms of energy efficiency. However, the open literature provides relatively little information about upgrading an existing TPP to a co/tri-generation system and its effects on plant performance. In the cited study [6], some experience with the coal-fired power plant converted to a cogeneration system for the supply of district heating to the city of Kozani, Greece, was given. However, performance analysis was not given for the converted plant in that study.

A nationwide research project called TSAD (Utilization of Thermal Power Plant Surplus Heat) was, however, conducted by the authors of this paper during the period of 2006 through 2011 in Turkey. In that project, we systematically examined the question of how the existing power plants generating only electricity could be transformed for district heating/cooling applications [7,8]. Initially, the performance of TPPs under the control of governmental bodies in Turkey were modeled, simulated and analyzed from the energetic and exergetic viewpoints [9]. Then, waste-heat potentials and other heat-extraction capabilities in the power plants were methodically evaluated with respect to co/tri-generation conversion [10,11]. The most effective steam-extraction point for district heating/cooling system was identified [12]. As a result of the detailed technical and economical assessments, the Soma thermal power plant was selected for a pilot application. The conversion process was successfully implemented to compensate the heating requirement of Soma district in Manisa, Turkey [13]. It should be emphasized that if the renovation plans can be applied for all TPPs under government control in Turkey, it will be possible to save annually 7–27 million MWth energy. Each of the TPPs in the project scope has 15,000–140,000 housing district heating potential. The economic potential of heating the residences from the power plants ranges from US$ 100 to $550 million annually. Moreover, the hazardous emissions can be reduced considerably by means of the district heating system. It can provide annually the reduction for 1.5 million to 6 million tons of CO_2 and 37,000 to 150,000 tons of SO_2. Moreover, it is possible to reduce water consumption by approximately 4 million to 17 million tons/year in the renovated power plants.

Some technical conversions in the existing TPPs designed for electricity generation are necessary to use in the district heating application. These conversions will affect the power plant performance. Performing analysis through classical performance criteria (power output and thermal efficiency) considering only electricity generation may lead to wrong evaluations. The effects of converting to trigeneration system should be taken into account in the analyses. Therefore, in order to evaluate correctly the performance of power plant-based cogeneration system producing simultaneously both electricity and heat energy, a criterion should be expressed [14–16].

An evaluation of the open literature pertaining to co/tri-generation systems also involved energy–exergy analyses and different objective function-based optimization studies for various regional, commercial, industrial and micro-cogeneration systems [18–26]. In the scope of our study, the conversion of coal-fired thermal power plants (designed to generate only electricity) to co/tri-generation systems was considered for the purpose of district heating and cooling. In the case of such a conversion, the performance indicators have been discussed. There is an important difference in this type power plant conversion study by comparison to the co/tri-generation studies in the cited literature. This difference is that the extracted steam from the turbine, in the case of conversion, is used for a different purpose in place of electricity production, which is the main purpose of the plant. However, the second product (heating or cooling energy) for the co/tri-generation systems considered in the literature is only produced from the energy discharged through the generation of electrical power. This situation does not affect the electricity production in such systems. Therefore, in our study the performance parameters have been defined, taking into account the aforementioned circumstance, and used to analyze the considered thermal power plants.

Thus, in this study the changes in performance of the TPPs converted to trigeneration systems to meet the heating/cooling demand in residential areas have been investigated with respect to different criteria. From that perspective, thermodynamic-based simulation models of the eight TPPs under government control were developed. The effects of the energy taken from the specified location of the power plant for the achievement of district heating/cooling on the performance of trigeneration were analyzed through simulations. The variations in net electrical power output, classical thermal efficiency, utilization factor and comprehensive thermal efficiency considered in this study were analyzed as performance criteria.

2. Renovating existing power plants for district heating applications

The authors of this paper have conducted a nationwide project for the purpose of designing a district heating/cooling system using