Performance and Optimization of a Novel Combined Solar Heating Plant with Flat Plate Collectors and Parabolic Trough Collectors in Series for District Heating

Zhiyong Tian, Bengt Perers, Simon and Jianhua Fan

Department of Civil Engineering, Technical University of Denmark, Brovej Building 118, Lyngby, 2800, Denmark

Abstract

More than 1.3 million m^2 solar heating plants are in operation in Denmark by the end of 2016. Most existing collectors in the solar heating plant are flat plate collectors. To maximize the advantages of flat plate collectors and parabolic trough collectors in large solar heating plants for a district heating network, a novel combined solar collector field with 5960 m^2 flat plate collectors (FPC) and 4039 m^2 parabolic trough collectors (PTC) in series has been constructed in Taars, Denmark. The design domain variables of the combined solar heating plant require to be considered in the optimization routine to get the optimal performance of such plant. A validated TRNSYS-Genopt model was set up to optimize key design parameters and investigate the potential performance of the combined solar heating plant. It is found that the design concept of hybrid solar heating plants with flat plate collectors and parabolic trough collectors in series can be feasible in Denmark. The results of optimal design parameters could guide engineers and designers in the design, construction and control of large-scale combined solar heating plants.

Keywords: combined solar district heating plants, flat plate collectors, parabolic trough collectors, LCOH.

1. Introduction

Large scale solar district heating plants have gained great success in Europe, particularly in Denmark. Denmark is the frontrunner country in the large scale solar district heating plants. Most solar collectors in the existing solar heating plants in Denmark are ground mounted flat plate collectors. A hybrid solar heating plant with flat plate collectors and parabolic trough collectors was put into operation in August of 2015. The aim of this study is to optimize the hybrid solar heating plant based on the Levelised Cost Of Heat (LCOH).

2. Case study

The Taars solar heating plant was put into operation in August of 2015, consisting of a 5960 m^2 flat plate collector field and a 4039 m^2 parabolic trough collector field in series [1]. Figure 1 briefly illustrates the basic principle of the plant. The solar collector fluid of the parabolic trough collectors is water, while that of FPC is a 35% glycol/water mixture. The return water from the district heating network is heated up to 70°C by the heat exchanger connected to the flat plate collector field. Then the water from the flat plate collector field is heated to the required temperature by going through the parabolic trough collector field. The orientation of parabolic trough collector axes is 13.4° towards west from south. The parabolic trough collectors track the sun rays from east to west when the collectors work during the daytime. There are six rows of parabolic trough collectors and the row distance is 12.6 m. The length of each row is about 120 m. The parabolic trough collectors were delivered by Aalborg CSP A/S. The orientation of the flat plate collectors is south and the collector row distance between flat plate collectors is 5.67 m. The tilt of flat plate collectors is 50°. The flat plate collectors consist of two types of flat plate collectors, namely HTHEATboost 35/10 and HTHEATstore 35/10, delivered by Arcon-Sunmark A/S. Half of flat plate collectors are HTHEATboost 35/10, while the other half is HTHEATstore 35/10. The backup heat resource is two natural gas boilers. Two tanks with a total volume of 2430 m^3 are used as heat storage for several days in the summer. The lessons from the operation are that the parabolic trough collectors have to be defocused in several sunny days in summer because of limited heat storages and heat demand. A validated TRNSYS model was developed to optimize the hybrid solar heating plant to reach the minimum nLCOH [2]. The yearly DNI and global

doi:10.18086/swc.2017.06.14 Available at http://proceedings.ises.org

radiation in the Design Reference Year are 1150 and 1030 kWh/m^2 respectively. The typical heat demand is 20167 MWh per year.

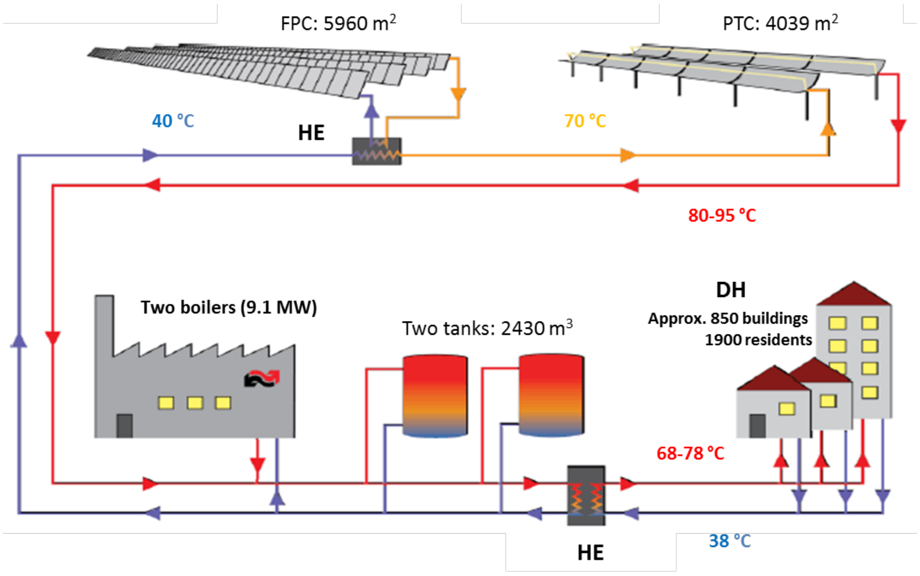

Fig.1.Illustration of the Taars solar heating plant [3]**.**

3. Method

LCOH definition has two boundary conditions for the solar district heating network in this study. One boundary condition is elaborated only for the solar collector field and heat storage. Other boundary condition not only includes the solar collector field and heat storage, but also takes conventional heat supply into consideration. The former is called by net LCOH (nLCOH). nLCOH is used in this study and can be expressed as equation below: I_s is the initial cost, DKK; T is the lifetime, 30 years; r is the discount rate, 3%; P_s is the operation and maintenance cost, SE is the energy produced, kWh. The operation and maintenance cost of the flat plate collector field every year is assumed as follows: a) 2 DKK/MWh heat produced for maintenance fee; b) 1.5 kWh electricity/100kWh heat produced for operation (2.3 DKK/kWh electricity). The operation and maintenance cost of the parabolic trough collector field every year is assumed to be 0.8% of the initial cost. The initial cost of the flat plate collector field without foil was assumed as 2180-2400 DKK/m^2 (500-10000m^2). The cost of the flat plate collector field with foil was assumed as 7.6% higher than that of the flat plate collector field without foil. The cost of the parabolic trough collector field is 40-70% higher than that of the flat plate collector field. Detail information is shown in the reference [4].

$$nLCOH = \frac{I_s + \sum_{t=1}^{T} P_s \cdot (1+r)^{-t}}{\sum_{t=1}^{T} SE \cdot (1+r)^{-t}} \quad (1)$$

4. Results and conclusions

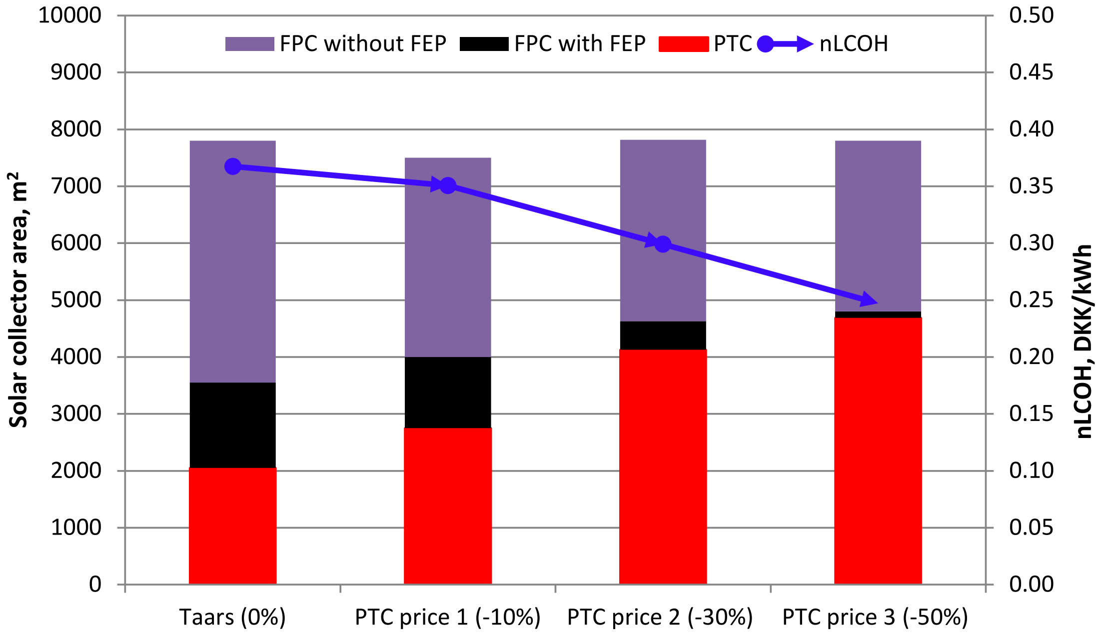

Fig.2. Minimum LCOH and optimal parameters based on different prices of the PTC [4].

Fig.2 shows the optimal solar collector area for different scenarios. The Taars bar shows optimal solar collector area for the reference case. Different scenarios for different parabolic trough collector price levels are also investigated, if the the price of the parabolic trough collector field decreases by 10%, 30% and 50% in the future. All the scenarios show that the design concept that the hybrid heating plant with flat plate collectors and parabolic trough collectors can be feasible in Denmark. Further information please find in the published papers.

5. Acknowledgements

The first author really appreciates the China Scholarship Council (No.201506120074) for the financial support for the PhD study at the Technical University of Denmark. Special thanks are expressed to Aalborg CSP A/S (Andreas Zourellis, Jan Holst Rothman, Steffen Rovsing Møller and Per Aasted) for the information provided. This work is a part of an EUDP project financed by the Danish Energy Agency and the IEA-SHC Task 55 "Towards the Integration of Large SHC Systems into DHC Networks".

6. References

[1] Aalborg CSP A/S, "Aalborg CSP," *http://www.aalborgcsp.com/*, 2017. [Online]. Available: July.2017.

[2] Z. Tian, B. Perers, S. Furbo, and J. Fan, "Analysis and validation of a quasi-dynamic model for a solar collector field with flat plate collectors and parabolic trough collectors in series for district heating," *Energy*, Sep. 2017.

[3] Z. Tian, B. Perers, S. Furbo, and J. Fan, "Annual measured and simulated thermal performance analysis of a hybrid solar district heating plant with flat plate collectors and parabolic trough collectors in series," *Appl. Energy*, vol. 205, pp. 417–427, 2017.

[4] Z. Tian, B. Perers, S. Furbo, and J. Fan, "Thermo-economic optimization of a hybrid solar district heating plant with flat plate collectors and parabolic trough collectors in series," *Manuscript*, 2017.