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Tårs 10000 m² CSP + flat plate solar collector plant - cost-performance optimization of the design

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Abstract

A novel solar heating plant with Concentrating Solar Power (CSP) collectors and Flat Plate (FP) collectors has been put into operation in Tårs since July 2015. To investigate economic performance of the plant, a TRNSYS-Genopt model, including a solar collector field and thermal storage tank, was established. The optimization showed that there was a synergy in combining CSP and FP collectors. Even though the present cost per m² of the CSP collectors is high, the total energy cost is minimized by installing a combination of collectors in such solar heating plant. It was also found that the CSP collectors could raise flexibility in the control strategy of the plant. The TRNSYS-Genopt model is based on individually validated component models and collector parameters from experiments. Optimization of the cost performance of the plant has been conducted in this paper. The simulation model remains to be validated with annual measured data from the plant.

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1. Introduction

Large solar heating plants have gained great success in Denmark. Most of the collectors used in previous large solar heating systems are Flat Plate (FP) collectors. Parabolic trough collectors are the most mature and prominent solar thermal power technology of all the concentrated solar power (CSP) collector technologies [1]. A novel solar

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heating plant with CSP and FP collectors was designed and built in Tårs, to investigate the advantages and disadvantages in the application of CSP technology for solar district heating.

The Tårs solar heating plant was put into operation in July 2015. The solar plant consists of a 4039 m² CSP collector field and a 5960 m² FP collector field respectively. The cost-performance of the combined solar heating plant was optimized and analyzed to investigate the application of CSP collectors for these plants.

2. Method

To investigate the optimum control and plant design principle, a TRNSYS-Genopt model including conventional natural gas heating plant and storage tank was set up [2]. The CSP collector field performance was modelled based on pilot plant experiences in Thisted 2013 [3]. The TRNSYS-Genopt model was then used to investigate the influence of different component parameters and make a cost optimization of the main design parameters, such as collector fields area mix, tilt of FP collectors and azimuth of CSP collectors. As CSP collectors are still in an early market stage, the influence of the cost level was also investigated. The plant will be monitored to validate the simulation model and analyze the operational performance and control strategy. The same measured district heating load is used in the optimization. New reference year climate data for the Northern Jutland area of Denmark was used [4]. The paper presents a cost optimization of the solar district heating plant.

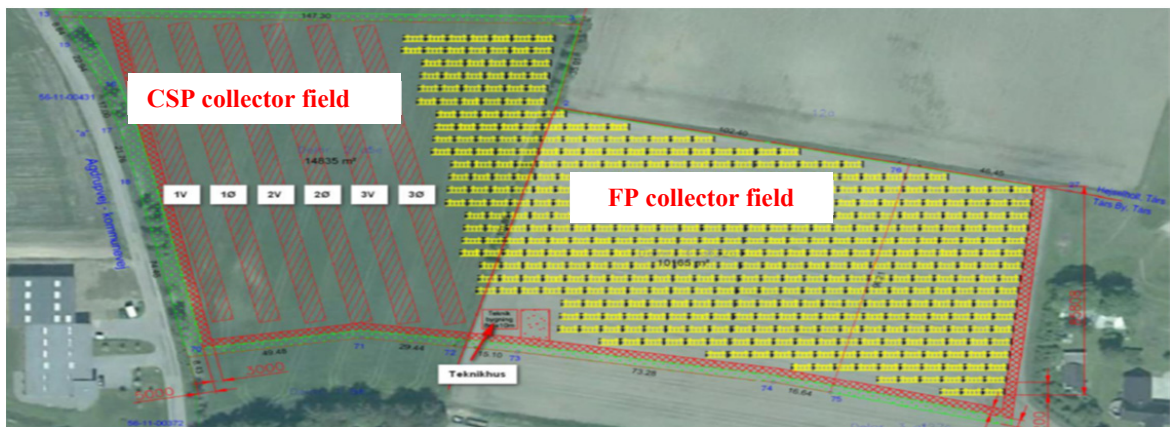


Fig.1. Overview diagram of CSP and FP collector fields.

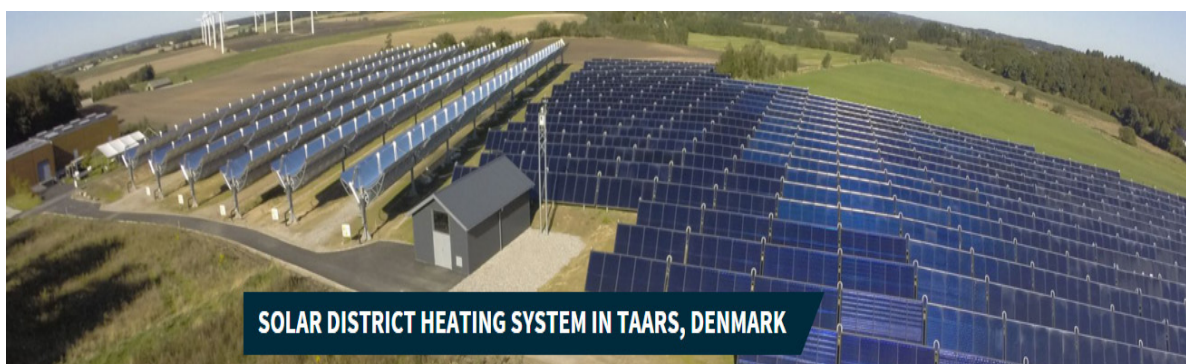


Fig.2. Overview picture of CSP and FP collector fields^[5].

3. Results and discussion

The cost optimization was carried out on the main design parameters of the Tårs solar heating plant, such as total aperture of the solar field, FP share, tilt of FP collectors, thermal energy storage (TES) volume, etc. Two scenarios were discussed in this paper. The first scenario is based on a fuel price of 400 DKK/MWh assuming that the price will not increase in the future. The second scenario is based on a fuel price of 560 DKK/MWh with annual price increase of 2.5% during the entire lifetime of the solar collector fields. The CSP cost level of 0% in both scenarios represents the present situation. Total plant investment costs at different CSP cost levels in scenario 1 and scenario 2 are presented in MDKK in table 1. Seven optimization cases for different CSP collector costs levels were carried out for each scenario.

As too high or low CSP costs may make no sense in the short term, the range of CSP collector price costs is limited by increase or decrease of 50%. A cost-performance optimization was carried out to figure out how other design parameters vary for different CSP cost levels see table 2 and table 3.

Table 1. Total costs of the Tårs plant design for both fuel price scenarios.

| CSP cost | +50% | +25% | +15% | 0 | -15% | -25% | -50% |
|------------------|-------|-------|-------|-------|-------|-------|-------|
| Scenario 1, mDKK | 206.2 | 202.8 | 201.5 | 199.4 | 197.4 | 196.0 | 192.6 |
| Scenario 2, mDKK | 265.1 | 261.7 | 260.3 | 258.3 | 256.3 | 254.9 | 251.5 |

3.1. Scenario 1

It can obviously be seen from table 2 that total aperture area of solar collector field increases steadily as the CSP collectors become cheaper. Within the range of CSP collector prices from highest cost level of +50% to lowest cost of -50%, the total collector field area is more than doubled from 12313 to 25000 m². At the same time, the share of FP collectors reduces from 99.5% to 4%. The main reason is that the CSP collectors with lower price levels can produce heat more cost effectively compared to the FP collectors.

The most cost effective case for Scenario 1 is the half of the present CSP cost level. In this case a total plant cost reduction of -13.9% is achieved compared to the present Tårs plant design. The total solar collector aperture area then amounts to 25000 m² with only 4% FP share and 3500m³ TES volume.

Table 2. Cost optimum for scenario 1.

| CSP cost | Total area, m ² | FP share | β_{FP} | γ_{CSP} | TES, m ³ | Solar Fraction | Total cost, MDKK | Cost reduction |
|----------|----------------------------|----------|--------------|----------------|---------------------|----------------|------------------|----------------|
| 50% | 12313 | 99.5% | 40.6° | 51.9° | 688 | 19% | 197.0 | -4.5% |
| 25% | 14750 | 81.4% | 40° | 60° | 1500 | 24.2% | 198.4 | -2.2% |
| 15% | 16500 | 60.6% | 35° | 87.5° | 2000 | 28.9% | 197.2 | -2.1% |
| 0 | 17250 | 37.7% | 40° | 90° | 2438 | 32.1% | 193.2 | -3.1% |
| -15% | 19000 | 18.4% | 35° | 90° | 3063 | 35.8% | 187.3 | -5.1% |
| -25% | 22000 | 9.1% | 40° | 90° | 3500 | 40% | 181.7 | -7.3% |
| -50% | 25000 | 4.0% | 40° | 90° | 3500 | 43% | 165.7 | -13.9% |

3.2. Scenario 2

The total collector area for all cost levels in scenario 2 is larger than that of scenario 1, especially for higher CSP cost levels. Larger solar collector fields also result in growth of the size of the TES. As fuel price rises by 2.5% every year and the solar heating system has more energy saving potential, the aperture area goes up. Cost and consumption of Natural Gas also decreases dramatically with more heat production of the solar heating plant. The total cost of the plant declines by 11.6% and 16.1% respectively at the CSP cost level of -25% and -50%.

It is also apparent from Table 2 and Table 3 that the plant cost rises with the increase of fuel price. The investment in the plant gets more profitable then. But it should be noted that in these cases no seasonal storage was investigated, so the summer district heating load in Tårs has limited the total solar plant size.

Table 3. Cost optimum for scenario 2.

| CSP cost | Total area,m ² | FP share | β_{FP} | γ_{CSP} | TES,m ³ | Solar Fraction | Total cost, mDKK | Cost reduction |
|----------|---------------------------|----------|--------------|----------------|--------------------|----------------|------------------|----------------|
| 50% | 23000 | 95.7% | 30° | 80° | 2500 | 26.8% | 254.6 | -4% |
| 25% | 22000 | 50% | 35° | 90° | 3500 | 35.2% | 256.9 | -1.8% |
| 15% | 22500 | 42.2% | 37.5° | 90° | 3500 | 36.5% | 252.9 | -2.8% |
| 0 | 25125 | 31.8% | 45° | 90° | 4500 | 39.8% | 246 | -4.8% |
| -15% | 28000 | 21.4% | 40° | 90° | 4500 | 42.4% | 237.9 | -7.1% |
| -25% | 27000 | 14.8% | 40° | 90° | 4500 | 43.1% | 225.3 | -11.6% |
| -50% | 27125 | 14.7% | 40° | 90° | 4500 | 43% | 211 | -16.1% |

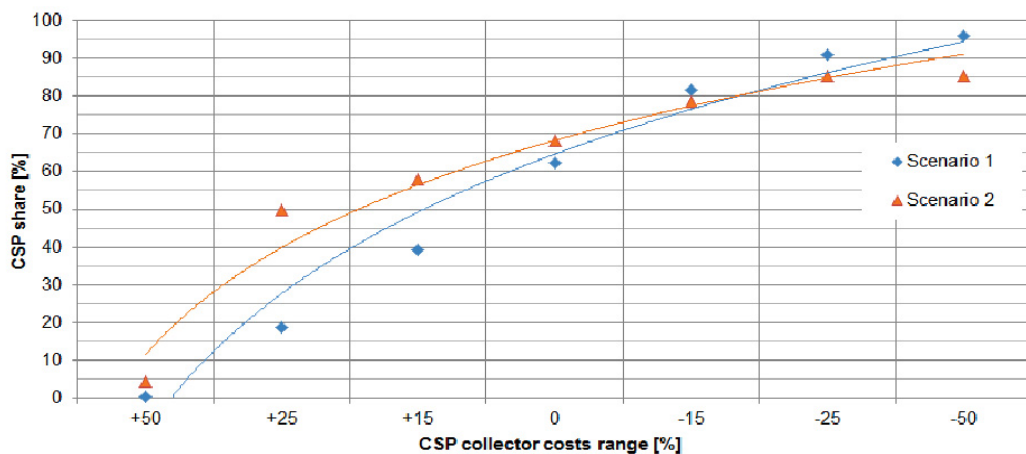


Fig.3. CSP collector share for scenario 1 and 2 versus CSP collector cost.

Notes: FP/CSP share = Percentage of FP/CSP collector in total field; β_{FP} = Tilt of FP collectors; γ_{CSP} = Azimuth of CSP collectors; SF = Solar Fraction

Fig.3 illustrates the CSP collector share in both scenario 1 and scenario 2. The CSP collector share in scenario 2 is larger than that of scenario 1 in most cases of different CSP collector cost levels. With a decrease of the CSP price, the CSP collector share increases steadily in both scenarios. Both scenarios show that a limit is reached when the CSP collector price increases by 50%. Then the application of CSP collectors in a combined plant like in Tårs would make no sense economically, as the CSP share reduces to less than 5% in both scenarios. On the other hand, a decrease by 50% in the CSP collector cost shows exactly the opposite effect since the FP collectors only have lower than 5% and about 15% share, in a cost effective design in scenario 1 and scenario 2 respectively.

4. Conclusions

Simulations and optimizations of the plant have shown that:

- 1) There is a synergy in combining CSP and FP collectors in solar heating plants. CSP collectors are cost effective, even if the cost per m² is higher.

- 2) When the CSP collector price increases by 50%, the application of CSP collectors in a combined plant like Tårs solar heating plant would not make sense economically since the CSP share reduces to less than 5% in both energy cost scenarios.
- 3) Costs of both FP and CSP collector fields are already close to be cost effective compared to present Natural Gas Boiler heat production costs.
- 4) CSP collectors can be applied for large district heating plants also in a high latitude climate like in Denmark, if the installed cost per m² is close to the present cost in the Tårs combined solar plant.

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