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Achieving low return temperatures from district heating substations

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HIGHLIGHTS

- Fast detection of differential temperature faults in district heating substations by new method.
- Temperature difference faults can be identified within a single day.
- The novel method can also be used in quality assurance of eliminated faults.
- Temperature difference fault frequency in substations is about 5% annually.

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ABSTRACT

District heating systems contribute with low primary energy supply in the energy system by providing heat from heat assets like combined heat and power, waste incineration, geothermal heat, wood waste, and industrial excess heat. These heat assets would otherwise be wasted or not used. Still, there are several reasons to use these assets as efficiently as possible, i.e., ability to compete, further reduced use of primary energy resources, and less environmental impact. Low supply and return temperatures in the distribution networks are important operational factors for obtaining an efficient district heating system. In order to achieve low return temperatures, customer substations and secondary heating systems must perform without temperature faults. In future fourth generation district heating systems, lower distribution temperatures will be required. To be able to have well-performing substations and customer secondary systems, continuous commissioning will be necessary to be able to detect temperature faults without any delays. It is also of great importance to be able to have quality control of eliminated faults. Automatic meter reading systems, recently introduced into district heating systems, have paved the way for developing new methods to be used in continuous commissioning of substations. This paper presents a novel method using the temperature difference signature for temperature difference fault detection and quality assurance of eliminated faults. Annual hourly datasets from 140 substations have been analysed for temperature difference faults. From these 140 substations, 14 were identified with temperature difference appearing or eliminated during the analysed year. Nine appeared during the year, indicating an annual temperature difference fault frequency of more than 6%.
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1. Introduction

District heating systems can substantially contribute to a more efficient energy system. Heat and fuel resources difficult to use individually can be used for heat supply in these systems. Still, there are several reasons to increase efficiency in district heating systems such as: increase in ability to compete, decrease use of primary energy resources and less impact on the environment.

One of the most important factors in running a district heating system with high efficiency is low distribution temperatures. Low supply temperatures have several benefits in a district heating system such as: increased electrical output from CHP-plants, increased heat recovery from industrial excess heat and geothermal heat, and an increased coefficient of performance if heat pumps are used in heat generation. Lower return temperature increase heat recovery from flue gas condensation. Lower distribution temperatures also result in less distribution losses [1]. The economic value of reduced return temperature can vary from 0.05 to 0.5 €/MW h, °C [1]. A decrease in distribution temperatures will be essential for district heating systems to play role in future sustainable energy systems [2]. To achieve decreased supply temperatures, faults increasing return temperatures in substations and customer secondary systems, have to be detected and eliminated. While existing systems, normally referred to as third generation district heating systems, have a supply temperature of 80 °C, future

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systems, fourth generation, will perhaps have a supply temperature of as low as 50 °C [3]. Then it will be necessary to have low return temperatures and to have as large temperature difference as possible. Otherwise the efficiency gains from low supply temperature will not compensate enough for increased cost of pumping and larger network diameters due to increasing distribution water flow. To reach and maintain low distribution temperatures, continuous commission in one way or another will be necessary for substations but also for customer secondary systems. This requires fast fault detection in the district heating substations and the ability to control the quality of fault elimination.

Increased temperature difference and low distribution temperatures in district heating systems have for a long time been a research field of district heating. Publications referred to in this paper have an overrepresentation of Swedish and German origin. This is a result of a unique Swedish continuous district heating research programme since 1975, and the German trade journal Euroheat & Power, earlier named Fernwärme International, that has published research and knowledge about district heating in Germany since 1972.

The optimal supply temperature for a district heating system with CHP is investigated in [4] from 1975. In an article from 1977, the importance of large temperature differences and low supply temperatures in order to be able to increase the generation of high value electricity is being described [5].

Regarding system efficiency it has been shown not only that large temperature differences reduce both energy and exergy losses [6–10], but also that the distribution temperatures, i.e., both supply and return temperature, over all should be decreased from an energy and exergy point of view to increase the total system efficiency [11].

1.1. By-passes

To avoid service pipes to cool off in summer time in district heating networks when there is no heat demand for space heating , by-pass valves are mounted in substations between the supply and return pipes. The resulting by-pass flow decreases the temperature difference, but this is necessary in order for the substation to be able to deliver domestic hot water at the requested temperature. An evaluation to decrease this loss by a new control strategy is developed in [12]. The thought was that the by-pass could be shut off parts of the day when no hot water was used. But the fact was that there was hot water taping all hours of the day. By-pass valves can also be necessary in some parts of the network to prevent freezing, or to keep an entire part of the network with no or low heating demand hot. An evaluation of the cost for by-passes is estimated in [13] where it is concluded that thermostatic by-passes have a payback period of less than 2 months. How to operate by-pass valves to minimize decreased temperature differences is discussed in [14], and the conclusion is that there is not one single solution that fits all.

1.2. System efficiency

Temperature difference in the customer secondary system is a result of both the mass flow chosen and the installed heat transferring areas, but large heat transferring areas result in increased system costs. An evaluation of the system efficiency should also include the customer secondary systems at the customers' end. A distribution temperature optimisation based on the total system including a CHP-plant and customer secondary supply temperature demand dependent on radiator size is presented in [15]. The relation between cost and return temperature in customer secondary systems is discussed in [16] but, on the other hand, two studies indicate that radiators often are oversized and can perform well with lower supply temperatures without decreased thermal comfort [17,18].

1.3. Existing substation technology

It is not new technology that has to be developed to achieve low distribution temperatures, which is well described in [19], but with the existing substation technology a return temperature of 32 °C with a supply temperature of 70 °C is possible. In a technical report from 2005 from the Swedish District Heating Association, old and new substations have been compared resulting in no major differences. The same conclusion can be noticed in a report from 1987 [20]. The only difference that could be observed was in the cases when the heat exchanger was fouled [21], and an evaluation of how ten-year-old district heating substations performed in 2009, showed that they performed well. Only a small increase in return temperature at the hot water preparation could be noticed [22]. Hence, district heating substations have, for decades, been designed for large temperature differences and low distribution temperatures and the existing installed substations are not a problem. But the systems have to work correctly. This is valid both for the substations and the customer secondary systems in the buildings.

1.4. Control

It is not only valves and other components that have to work well but also the control system and the settings. By changing the control of a substation from a traditional reconnected control-loop to an alternative control strategy where the primary flow is determined by calculating the demand, a decrease of up to 10 °C could be possible according to [23]. The supply temperature is in summer normally about 70 °C. When the outdoor temperature decreases the supply temperature is increased to be able to supply increased heat demand in the network. By using multi-agent system described in [24,25], peak load could be decreased and thereby, a possibility exists to decrease the distribution temperatures [26].

1.5. Customer secondary systems

The lower limit for return temperature is determined by the customer secondary systems at the heat users' end. To attain low return temperatures, it is important to control the radiator flow and the supply temperature and different methods are described in [27–33]. One way to decrease the return temperature is to have a cascade coupled secondary system and not only in parallel which is the traditional arrangement [34]. In [35] it is stated that it is important to adjust the radiator flow but there is not one method that is significantly better than another. To have total control of the flow to all parts of the customer secondary system, individually circulating pumps on each heat emitter can be used instead of a centralized pump and thermostatic valves to control the flow in a building which is described in [36]. This solution would also eliminate the need for balancing the radiator distribution system. Normally the supply temperature to the radiators is determined by the outdoor temperature. A possibility to use primary supply temperature instead is presented in [37,38]. The conclusion is that it is possible to maintain comfort by using primary supply temperature instead of outdoor temperature to control radiator supply temperature. Theoretically it would be possible to increase the temperature difference but in practice it turned out to be difficult to realize.

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