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Methodology for evaluating the transition process dynamics towards 4th generation district heating networks

Anna Volkova*, Vladislav Mašatin, Andres Siirde

Tallinn University of Technology, Department of Energy Technology, Ehitajate tee 5, 19086, Tallinn, Estonia

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ABSTRACT

Currently, the 4th Generation District Heating (4GDH) is an attractive topic in the energy field as it concerns a sustainable and efficient means of delivering heat to houses. The 4GDH concept is characterised by low temperatures, low heat distribution losses, renewable and excess energy utilisation, as well as high efficiency. As a result of implementing the 4GDH concept, existing district heating systems (DHS) are undergoing massive improvement. The barriers faced by existing DHS over the course of the transition process towards the 4th generation are reviewed in the paper; the methodology for the evaluation of the DHS transition process towards the 4th generation is also presented. This methodology allows to assess the transition process dynamics, as well as helps to focus on DHS characteristics, which need to be improved. A large-scale DHS in Tallinn (Estonia) was analysed with the help of the proposed methodology. Supply and return temperatures, the share of renewable energy, and network conditions demonstrated the highest potential for improvement and had the most notable impact on the Tallinn DHS transition process.

1. Introduction

District heating (DH) has been widely used for space heating and in domestic hot water supply for many decades [1]. Nowadays, there appear to be promising possibilities for DH in future energy sector developments; however, DH must be renewed and subjected to major improvements [2].

After summarising the ideas concerning the required improvements for the future sustainable development of DH, a group of researchers proposed the concept of the 4th Generation District Heating (4GDH) in 2014 [3]. According to this concept, future district heating systems (DHS) must be able to:

- supply low temperature for space heating and domestic hot water supply to buildings (i.e., low-temperature space heating and low-temperature hot water heating, intelligent control in buildings, etc.);
- distribute heat over networks with low heat losses (low-temperature network, smaller pipe dimensions, improved insulation, intelligent control and metering);
- enlarge the share of renewable (non-fuel) energy heat sources (solar and geothermal heat) and recycle heat from low-temperature sources (heat from combined heat and power production (CHP) and waste incineration, excess heat, geothermal heat, central solar heat with seasonal thermal energy storage (TES));
- become an integrated part of smart energy systems, including smart electricity, gas, thermal grids and district cooling (CHP coupled with TES, large-scale heat pumps in CHP, with integrated CHP plants involved in securing grid stabilisation tasks);
- ensure proper planning, cost and motivation structures (integrated strategic infrastructure planning, GIS system-based planning, tariffs based on long-term costs).

Despite the fact that the 4GDH concept has already been implemented in European DHS, there are still numerous DHS that can be described as 2nd or 3rd generation networks. The main questions that should be answered are: Why is the transition process so slow? What are the obstacles, as well as possible solutions in transitioning to the 4GDH, and how can the DHS transition process be evaluated? In recent years, existing DHSs have been

* Corresponding author. Tallinn University of Technology, School of Engineering, Department of Energy Technology, Building U06, Room 227, Ehitajate tee 5, 19086, Tallinn, Estonia.
E-mail address: anna.volkova@ttu.ee (A. Volkova).

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Abbreviations

CHP	combined heat and power
TES	thermal energy storage
DH	district heating
DHS	district heating system
DHW	domestic hot water
4GDH	4^{th} generation district heating
KPI	key performance indicator
HRV	heat recovery
EAHP	exhaust air heat pump
C	transition process criterion

Parameters

Q_s	total heat consumed (sold to consumer), MWh
Q	produced energy, MWh
E	fuel based energy generation, MWh
B	fuel amount, kg
H	net calorific value of fuel, Wh/kg
$Q_{th}^{CHP(cond)}$	additional heat, produced on CHP, due to flue gas condenser, MWh
Q_{hl}	heat losses from DH network, MWh
K	network effective average heat transmission coefficient, W/m^2
L	network length of pipes, m
D_a	average pipe inner diameter, m
t_s	annual average network supply temperature, ^oC
t_r	annual average network return temperature, ^oC
t_{amb}	annual average network ambient (soil) temperature, ^oC
V_{CO2}	amount of CO_2 emission for heat generation, kg
γ	fuel CO_2 emission relative value, kg/MWh
γ_e^{nat}	average national CO_2 emission for electricity generation, kg/MWh
a_{4GDH}	objective for KPI_i according to 4th generation DH and evaluation of barrier
a_i	value of KPI_i at the moment
a_o	value of KPI_i at the starting point
Q_{CHP}	CHP heat capacity MW
Q_{TES}	share of short-term TES from CHP heat capacity, %

Subscripts

th	produced heat
e	produced electricity
i	KPI number, i = 1 … 6
j	fuel type, j = 1.m

Superscripts

CHP	produced in CHP plant
H	produced in heat only boilers
NF	produced from renewable (non-fuel) energy
total	total

undergoing massive changes to become more competitive in the energy market and to offer better service to consumers in comparison to local heating. The transition process is slowed down by obstacles, and in most cases, there are ways to overcome these obstacles. Numerous researches have been focused on the challenges faced by existing DHSs in transitioning to the 4GDH. Examples of such obstacles are lower supply temperature levels [4–6] and high return temperatures [7–9]. Other examples include obstacles concerning consumer equipment [10–12], the Legionella bacteria in domestic hot water (DHW) [13,14], heat loss reduction in DH network pipes [15–17], as well as the implementation of renewable energy sources [18–21]. Additionally, there are researches, where the challenges faced by large-scale DHS have been studied [22–24]. Study results on said barriers and ways to overcome them are described in detail in the second section of this paper.

It is important to analyse the transition process towards the 4GDH. A complex multi-perspective model for assessing the transition towards the 4GDH was proposed in [25]. This complex model was designed to evaluate DHS development scenarios and draft various perspectives for the system in the future. In addition, the complex model includes system dynamics model, where the results of applying the model depend on assumptions made by stakeholders (producers, consumers, policymakers). On the other hand, the general method for evaluating the transition towards the 4GDH is required, one that it is not influenced by stakeholders but rather based on the analysis of the clear engineering indicators with input data, available for each DHS. The development of this method should be based on the analysis of the main barriers encountered by the existing DHS during the transition. The method includes DH transition progress monitoring in both past and present, which is essential for future DH development and strategy formulation. The results of this evaluation can help pinpoint weak links in the system that do not allow it to make progress as fast as possible. A detailed description of this method is presented in the third section. The application of this method is demonstrated in the fourth section using the example of the Tallinn DHS evaluation.

2. Barriers for large DH in transition to the 4th generation

In the following section, the main barriers encountered by large DHS during the transition to the 4GDH are described. Despite the fact that the main goal is to find obstacles faced by the large DH networks, most of the described problems are also found in small networks, and the solutions provided are applicable to both large and small DHS. Additionally, it must be kept in mind that all parts of DHS are interconnected and affect each other, and thus, it is not possible to concentrate only on barriers because changes in parameters on one side also lead to changes on the other side.

2.1. Barriers to low-temperature DH for space heating and DHW

A low supply temperature between 50 °C and 60 °C is one of the main characteristics of the 4GDH [3,26]. There appear to be no barriers from the production side, as it is always possible to mix the flow past the heat source with the DH to lower the temperature to the required level [27]. The first barrier arising from the network can be described as follows:the supply temperature is reduced while the return temperature remains the same or is reduced slightly, to the point that the heat is not delivered to all consumers because of hydraulic factors [28]. It is possible to compensate for this to an extent by installing more powerful pumps; however, this requires larger investments, and electricity consumption for pumping is also increased [27].

During the building renovation process, heat consumption may decrease [29], and the supply temperature may be reduced by 5–10 °C without any additional investments. However, a further decrease in temperature may prove to be a challenge, as proposed by Bolonina et al. [6]. Still, the most important barrier here is the consumer. The heating devices are often designed to operate at