Renewable and Sustainable Energy Reviews 79 (2017) 1275–1284

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Large heat pumps in Swedish district heating systems

Helge Averfalk[a,*], Paul Ingvarsson[b], Urban Persson[a], Mei Gong[a], Sven Werner[a]

[a] School of Business, Engineering and Science, Halmstad University, PO BOX 823, SE 30118 Halmstad, Sweden
[b] ÅF, Division Industry, Frösundaleden 2A, SE 16999 Stockholm, Sweden

ARTICLE INFO

Keywords:
Power-to-heat
Heat pumps
District heating
District cooling
Integrated energy system

ABSTRACT

Power-to-heat solutions like heat pumps and electric boilers are foreseen to be possible future tools to stabilise international power markets with high proportions of variable power supply. Temporary low cost electricity can be used for heat generation at times with high availability of wind and solar power through substitution of ordinary heat supply, hence contributing to increased energy system sustainability. Power-to-heat installations in district heating systems are competitive due to low specific investment and installation costs for large electric boilers, heat pumps, and heat storages. Several large-scale heat pumps were installed in Swedish district heating systems during the 1980s, since a national electricity surplus from new nuclear power existed for some years. The aim of this paper is to summarise the accumulated operation experiences from these large Swedish heat pumps to support and facilitate planning of future power-to-heat solutions with heat pumps in district heating systems. Gained experiences consider; installed capacities, capacity utilisation, heat sources used, refrigerant replacements, refrigerant leakages, and wear of mechanical components. The major conclusion is that many of the large thirty-year-old heat pumps are still in operation, but with reduced capacity utilisation due to internal competition from waste and biomass cogeneration plants in the district heating systems.

1. Introduction

A future demand will appear for balancing the electricity supply from increasing variable renewable electric energy sources. In Denmark, the proportion of wind power is already so high that a strategy is required for accommodating the increasing capacities of wind power [1]. This strategy is suggested to contain both supply and demand parts with respect to electricity in conjunction with the Danish district heating systems [2–4]. The connection to the district heating systems is essential since they contain combined heat and power (CHP) plants and they can also increase the electricity demand by using electric boilers and heat pumps [5]. These two latter types of heat supply units that use electricity are defined as power-to-heat installations.

A supply part of a strategy can be CHP plants that are operated to meet both electricity demand and wind power supply variations [6,7]. But when the CHP electricity generation is reduced during windy days, CHP heat generation becomes more expensive. Hence, other heat supply is required for maintaining a low cost level. The demand part of a strategy can be to use power-to-heat installations in order to counteract temporary surpluses of electricity giving low electricity prices. Heat pumps and electric boilers can then supply low cost heat when the CHP plants are expensive [8–10]. Heat storages can be used for storing this low cost heat for later use.

Power-to-heat installations in district heating systems are favourable as they provide flexibility in the electricity system, since they can be operated when electricity prices are low and shut down when prices are high. This is possible since alternative options for heat supply are available in district heating systems. These power-to-heat installations are also competitive because of low specific investment and installation costs for large electric boilers, heat pumps, and heat storages. It has been elaborated in [11,12] that thermal energy storage systems within district heating systems are a robust and conventional technology that can provide a cost-efficient alternative to introduce flexibility in power systems. Moreover, it has been concluded that, the use of heat pumps in combination with CHP and heat storage units shows promising possibilities with regard to system cost-efficiency [13]. Thus, surplus electricity may beneficially be absorbed outside the power system by export to heating systems for heat generation. Hereby, district heating systems can contribute to balancing the future power systems by this higher integration between heat and power markets.

Scientific journal articles about large vapour compression heat pumps in district heating systems have earlier been rare. An early engineering summary was presented in [14]. However, several journal articles have been published during recent years concerning various future expectations from China [15–19], Japan [20], Korea [21],

* Corresponding author.
E-mail address: helge.averfalk@hh.se (H. Averfalk).

http://dx.doi.org/10.1016/j.rser.2017.05.135
Received 23 June 2016; Received in revised form 7 May 2017; Accepted 19 May 2017

Canada [22], the Baltic states [23], and Denmark [24]. In district heating reviews, the usages of large heat pumps are briefly mentioned [25,26]. The typical common denominator for these recent articles is that they have few references to major installations in existing district heating systems and the corresponding operation experiences.

Another variant of heat pumps in district heating systems is the new use of absorption heat pumps in some Chinese CHP plants and district heating systems [27–31]. Cold district heating systems can also use local heat pumps in order to provide appropriate customer temperatures as performed at the University of Bergen [32] or in the Heerlen mine water system [33].

Several large heat pumps with an aggregated heat capacity of more than 1500 MW have been installed in Swedish district heating systems since the 1980s. These large heat pump installations have seldom been mentioned, discussed, or assessed in international literature. Some exception examples are [14,34,35]. The future competitiveness of these installations was also analysed by [36].

The scope of this retrospective review is to compile and disseminate valuable operational experiences about the large heat pump installations in Swedish district heating systems. This information should facilitate planning, modelling, assessments, and implementation of further large heat pumps in other district heating systems. Hence, this paper does not assess future possibilities for large heat pumps.

The purpose is reached by providing answers to the following five research questions:

- What heat pump capacities were installed?
- How have these installed capacities been utilised?
- What heat sources have been utilised?
- What is the operational competitiveness of existing heat pumps?
- Which other operation and maintenance experiences have been important?

The answers to these questions will provide novel information never summarised before for closing the knowledge gap concerning the operating experiences from existing large heat pumps in district heating systems.

2. The power-to-heat context

2.1. Integration between power and district heating systems

District heating systems are expected to play an important role in future renewable energy systems [37,38], as the future European potential for district heating systems to contribute to reduced primary energy supplies, carbon dioxide emissions, and costs in the European Union has been found to be substantial [39]. District heating systems are commonly associated with CHP, based on heat recovery from thermal power stations. This structural heat recovery is part of the basic fundamental idea of district heating [40].

Although a strong association with CHP, district heating systems have high flexibility in heat supply and thus power-to-heat supply alternatives have been explored. The economic value of using heat pumps and electric boilers to accommodate more variable power has been analysed for the Northern European power systems in [41]. For northern Russia, the possibility of supplying heat by wind power has been analysed as the conditions are beneficial, i.e., a long heating season, at the same time as heat demands coincide with high wind intensity [42]. For northeast United States, the use of excess electricity for heating purposes in a district heating system has been analysed in [43] by using heat pumps and heat storages. A trend of increasing short-term commercial interest in new power-to-heat installations can also be noted from articles in recent sector specific periodicals in both Germany [44–47] and Denmark [48–50].

One barrier to introduction of large heat pumps in district heating systems is that different temperature levels are applied in different countries. High distribution temperatures will require more electricity input at same heat output giving lower competitiveness.

2.2. Concept of power-to-heat

The concept of power-to-heat with respect to buildings may be described as the use of heat pumps or electric boilers for covering heat demands in buildings. From a system perspective, there are two main ways to perceive this concept. It could either be large-scale solutions at energy conversion plants or small-scale solutions, i.e. individual heating systems at end-users. To be viable, large-scale solutions require a district heating system for heat distribution. Competitive advantages with large-scale solutions are: (a) fuel flexibility in heat supply, (b) greater reception capability due to large heat storages, (c) possibilities to integrate higher proportions of renewable energy due to power balancing capabilities, (d) absorption of surplus electricity can be implemented at lower costs due to economy-of-size, and (e), in the case of heat pumps, there is a potential to make use of strategically advantageous heat sources.

Previously mentioned advantages are lost with small scale-solutions, somewhat due to the size and static demand of end-users. However, the possibility for small heat pumps with heat storage units, to be used for power balancing capacities at the location of the end-users has been analysed in [51,52].

To be viable, power-to-heat relies heavily on the prevailing price of electricity; and since the price depends on supply and demand, a situation of surplus power is bound to increase the viability of power-to-heat due to lowered electricity prices. The main application area for large-scale solutions would, thus, be in a system with a continuous surplus power situation, whether it be short-term surpluses, i.e. wind and solar power, or a more long-term surplus, i.e. hydro and nuclear power, and limited capabilities of power transmissions. Small-scale solutions like individual heat pumps are generally best implemented in rural or suburban areas, where heat densities are lower and district heat distribution is not feasible [53–55].

2.3. Power-to-heat installations in district heating systems

2.3.1. Historical installations

The power-to-heat concept is not entirely new, since it has been applied several times during the last century. Power-to-heat solutions have been used on different occasions during history although circumstances for the implementation of heat pumps and electric boilers has varied – the common denominator, however, has been a surplus of power in the prevailing situations.

In early power systems, surplus electricity appeared with more of a long-term character, when an initial major hydropower plant was built with a capacity much higher than the current electricity demand. Three examples of this are: (a) the Haby hydropower station built in 1916 which initially, before electricity demand rose, was oversized; the surplus electricity was used for electric heating of the Borås City Hall, Sweden, during several years [56], (b) the use of electric heating in Bergen, Norway, where an entirely new neighbourhood quarter was to be rebuilt with a district heating system after an outbreak of a large fire in 1916, which destroyed 369 houses [57], and (c) the use of surplus hydropower electricity in two small district heating systems in Munich, Germany, in 1927 [58].

The first case of large heat pumps being used within district heating systems was in 1942 in Switzerland. This installation consisted of three units with a total heat capacity output of 5.9 MW [59]. The impetus for this installation was the shortage of fossil fuel supply in Switzerland during the Second World War. Meanwhile, there was potential for using large quantities of hydropower in Switzerland for heating purposes.

In power systems dominated by electricity from hydropower plants, surpluses appears on an annual basis with regard to the variation of