LARGE-SCALE HEAT PUMPS – THE KEY TECHNOLOGY IN EFFICIENT URBAN HEATING AND COOLING

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1 SUMMARY

Large-scale heat pumps in the district heating (DH) and district cooling (DC) systems are becoming a key-technology in the energy system, as they integrate three of the four energy carriers. Moreover, due to economy of scale they will normally be connected to heat and cold storages and back-up capacity, which allows it to react on the fluctuating electricity prices. They can use large amounts of electricity for heating in a smart way without over loading the power system.

2 INTRODUCTION

The integrated energy system, including the 4 energy carriers: electricity, DH, DC and gas, is vital for cost-effective and efficient integration of renewable energy. The electric heat pump technology is one of the key-technologies in this energy system, as it integrates three of the energy carriers. Electric chillers for air conditioning, who waste the heat, and electric heat pumps, e.g. geothermal heat pumps, who waste the cooling, are wide spread technologies, mainly in small scale at the building level. Typically, they can-not respond on the fluctuating electricity prices from wind and solar, they are relatively expensive and can be difficult to integrate in the local environment in densely urban areas. Large heat pumps, however, e.g. from 1 MW and above, which can be connected to the campus or to the city-wide DH and DC grids benefit from economy of scale. That includes typically connection to both grids, to hot and cold storages and to aquifer thermal energy storages (ATES). Thereby they can generate heat and cold in co-generation, which is more energy efficient and not least more cost effective, as they generate two useful and valuable products – cooling capacity in summer and heating in winter. Moreover, it will normally be cost effective also to operate them either for heat-only or for cold-only production in case there is no need for both products at the same time. They are flexible and can respond on the market prices in the grids for electricity, heat and cold during the year, as they are integrated with thermal storages and back-up capacity. Like-wise, the absorption heat pump can generate cold and low temperature heat from a high temperature heat source, e.g. boilers or deep geothermal energy in case these sources are available when needed. We will present the state-of the art technology and interesting and spectacular cases, which have been implemented recently or are in the pipe-line.

3 THE ELECTRICAL HEAT PUMP

Electrical heat pumps for heating homes, like ground source heat pumps is a well-known, but expensive technology, which is far more efficient than direct electric heating. However, it can be a problem to eject the cooling in case there is not space for tubes in the ground and in densely urban areas, the noise from fans can be an environmental problem.

Therefore, due to economy of scale it will often be cost effective to interconnect the buildings and establish a centralized heat pump, e.g. one large heat pump in the range of 5-10 MW heat instead of 10-100 small individual heat pumps.

Case: 100 buildings in a district, in total 30,000 MWh/a and 15 MW heat installed capacity at the building level

Baseline:

- 100 heat pumps, in average 150 kW each, total 15 MW heat
- investment in heat pumps 2 mill.Euro/MW heat, in total **30 mill.Euro**

DH system:

- 10 MW max. to the network, 1 heat pump 4x1,5 MW= 6 MW heat
- Back-up from storage and/or peak boiler 4 MW
- Investment in heat pump 1 mill.Euro/MW heat, in total **6 mill.Euro**
- The base load from the heat pump covers at least 95% of the annual production

This reduced investment can justify even large investments in DH network and storages.

The COP is typically 3 for these heat pumps, but it depends on the range from the ambient temperature to the temperature in the heating system. As regards the electricity price the large heat pump could be connected to a transmission grid and avoid distribution fee from the low voltage network.

Moreover, as the large heat pump will normally be combined with a heat storage tank and back-up capacity to allow the heat pump to stop in case of power shortage or high prices. This will reduce the cost of electricity in the market, ant the distribution tariff for electricity should be reduced as the plant can be interrupted. In total, the large plant in the DH system will be more efficient to integrate the fluctuating renewable energy than the small plants.

4 THE DISTRICT COOLING POTENTIAL

According to the UN Climate Panel, IPCC, there is a growing need for cooling capacity, due to the urbanization, the industrialization and the increasing welfare. Moreover, according to IPCC, global warming is expected to increase the need by 25%. In some cities we already can observe load shedding, due to uncontrolled electricity consumption from many small chillers, who overload the power system. Even in a mild and coastal climate like in Scandinavia, there is a need for active cooling in modern commercial buildings to maintain a good indoor climate. This warm summer 2018 there was even a market for active cooling in many new residential buildings.

A district cooling infrastructure in campuses and city districts is the smartest way to solve this problem. Due to economy of scale, simultaneity and the opportunity to store the cold in large scale, DC reduces the need for cooling capacity and opens for demand response, e.g. to generate the cold in off peak hours only.

Campus owners can easily identify this opportunity and coordinate replacement of many small chiller with a DC grid, a cold storage tank and a large chiller. In cities, which are not used to energy planning it is difficult as there are many individual building owners, who have difficulties to co-operate and find the best common solution for all.

Case: A campus has 15 buildings and a total cooling capacity of 10 MW cold.

Baseline:

- 15 chillers, in theory in total 10 MW, but often more, e.g. 15 MW cold
- Total investment 2 mill.Euro/MW cold, in total **20-30 mill. Euro**

DC:

- The total observed capacity demand to the network typically would be reduced to around 7 MW due to simultaneity and as the real total demand of all buildings can be measured and adjusted year by year.
- By installing a chilled water tank to level the daily fluctuations, the maximal capacity demand could be further reduced to around 5 MW
- The cost of one 5 MW chiller plant is only around 1 million USD/MW cold, in total **5 mill.Euro**

Thus, the total investment in chillers can be reduced by at least a factor 4 which will compensate for investments in the DC grid and chilled water storage. Besides, the centralized plant opens for opportunities for ground source cooling, free cooling and not least combined heating and cooling.

5 COMBINING DISTRICT HEATING AND COOLING

There is a strong symbiosis between DH and DC. One of them is that the large heat pumps can generate useful heat and cold, either one or the other or in co-generation.

- In case the baseline is heat production based on ambient heat, e.g. ground water at 10 dgr.C, then the heat pump automatically delivers the cooling capacity in co-generation with the heat, and we can consider the cooling energy as a waste product.

- In case the baseline is cold production from a chiller (or a heat pump), which delivers cold at 10 dgr.C and eject the thermal heat at the ambient temperature in summer of around 30 dgr.C, then we can upgrade this chiller to a useful heat pump, which can generate cold at 10 dgr.C and heat at e.g. 80 dgr.C by adding one more heat pump in serial connection with the first or by installing a two-step heat pump. The additional cost of upgrading the chiller to such a heat pump will only be around **0,3 mill.Euro/MW heat**, and the marginal COP of generating heat at 80 dgr.C compared to a chiller, which waste heat at 30 dgr.C will be around **6.** Thus, compared to a "heat-only" heat pump the investment is reduced by a factor 3 and the efficiency is increased by a factor 2.

Due to this symbiosis between heat and cold it is a good idea for the DH utilities consider DC as a new business.

Case: Grundfos campus and local DH

Fig 1. Heat pump, Grundfos, Gudenådalens Energiselskab

Grundfos has installed a DC grid to supply cooling at the campus. The cooling is generated by heat pumps, which deliver heat to the local district heating system in combination with ground source cooling.

Case: Tårnby DH company in Greater Copenhagen
The DH company establish a heat pump installation to deliver cooling to an urban development area. The heat pump will deliver heat in two steps from 6 dgr.C to around 75 dgr.C to the DH network. The cold side will be connected to a new DC grid, to a chilled water tank, to a ground source cooling (ATES) and to the treated waste water. The max load hours for combined heating and cooling will be around 3,000 max load hours, and the heat only production, "wasting the cooling in the waste water" will be around 4,000 max load hours.

6 DH AND DC TEMPERATURE LEVELS

In case the end-users for heating and cooling have significantly variations in temperature demand we can use decentralized heat pumps or supply the temperatures in steps.

Case. Decentralized additional cooling for ice
In case a DC network is designed for comfort cooling, e.g. supply 6 dgr.C and return 15 dgr.C, the cooling can be used to feed decentralized heat pumps, which reduce the temperature further to e.g. -8 dgr.C or even -20 dgr.C. In case there are several end-users for the ice-water in a district, it could be cost effective to establish a local ice-water network with glycol and supply it from a heat pump which is connected to the DC network. In Carlsberg City in Copenhagen chillers are not allowed for environmental reasons and therefore the refrigerators and freezers in the super market are connected to the DC network in Carlsberg City.

Case: Central production of DH and ice water and end-users in cascade
In Copenhagen Markets, for whole sale of vegetables and flowers, there is installed a DC network to around 70 end users, of which the first group need -8 dgr.C and the rest are supplied from the return pipe of the first group. The centralized heat pump installation, which is established by Høje Taastrup DH company next to Copenhagen Markets, includes three steps going from -8 dgr.C up to 75 dgr.C to the DH network.

Fig.2 Heat pump, Copenhagen Markets, Høje Taastrup Fjernvarme

7 ABSORPTION HEAT PUMPS

In case there is a surplus of high temperature heat available at the same time there is a cooling demand, an absorption heat pump can be an interesting alternative to the electric heat pump or chiller, e.g. in the following cases:

Case Absorption heat pump for district cooling

In case a cheap heat source is available at a temperature of more than around 110 dgr.C or more, e.g. deep geothermal, this heat can be distributed in a DH system for super-heated water, it can be stored in steel tanks and distributed to buildings for heating and for generating cooling by an absorption chiller at the building level. In case the building need low temperature heat e.g. for hot tap water, the return temperature can be used for heating. Such a system is installed to deliver part of the cooling to a new hospital in Aarhus Denmark.

Case 2 Absorption heat pumps for flue gas condensation

For installation of efficient flue gas condensation, e.g. at a waste incinerator, at a biomass boiler or even at a gas boiler, which operates as base load, an absorption heat pump could be an alternative to an electric heat pump. In case the plant is a CHP plant, it has to be taken into account that the steam for the heat pump reduces the power production, which has to be compared with the electricity consumption for an electric heat pump. In case it is a heat only boiler, the absorption heat pump can use the exergy potential in case the boiler is designed for super-heated water, e.g. up to 160 dgr.C. Vestforbrænding in Copenhagen has at one of the waste incinerator CHP units installed an absorption heat pump, which reduces the return temperature to condensate the flue gas and generate around 12 MW heat, which else would be wasted as vapor in the flue gas.

8 CONCLUSION

The heat pump technology will be one of the key technologies in the future energy system in line med CHP plants, as it integrates three of the four energy carriers and has a vital role to make surplus energy sources for heat and cold useful for the end-users.

The technology can be used even in small scale in apartments, but due to economy of scale for the heat pump itself for the related technologies like thermal storages, which are important for integrating fluctuating and low-quality energy sources, heat pumps will also be a driver for more integrated DH and DC systems.

However, due to the technologies of heat pumps there is not much to gain by increasing the capacity from e.g. 20 MW heat to 100 MW heat. Therefore, the heat pumps will be distributed around in the network and located at with respect to the best sources for heat and cold and where it fits into the urban planning.

This complexity opens for many advanced integrated combinations of heating and cooling. We have only presented an appetizer.

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