IEA SHC Task 55: Towards the Integration of Large SHC Systems into DHC Networks

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Abstract

Solar thermal large-scale installations provide less than 1% of heat for DHC networks globally. The interest into solar thermal energy installations increases, but still strong measures are necessary to promote the technology across countries and energy policy frameworks. So how can the share of solar thermal energy be increased in district heating and cooling networks globally? Today, technical, economic, and policy measures still restrict a profound market development and limit the integration of large scale solar systems into different types of energy networks despite the huge potential of the technology to provide heat based on renewable sources. The new IEA SHC Task 55 extends research towards district heating and cooling networks, main system components and hybrid technologies. Additionally, the Task provides a new platform for scientists and industry partners to share their knowledge and solve pressing technical, political, and economic questions.

Key-words: IEA SHC Task 55, solar thermal large-scale installations, solar thermal systems, solar energy, district heating, district cooling

1. Introduction

Renewable energies such as solar provide promising business opportunities for companies. Innovation efforts at the right spot and at the right time can boost business success. Even international stock indices are aware of the economic strength of energy company efforts towards sustainability-oriented measures (Provasnek et al. 2015). However, increasing project dimensions require increasing technical capabilities and business model reliability. The cost competitiveness of solar thermal heating and cooling technologies is defined by several factors. Among these are initial costs of the solar thermal system, proper maintenance, or prices of alternatives. Solar thermal large-scale installations suitable to be integrated into district heating networks face these challenges on a much larger scale than well-established residential solar thermal systems. For decades, countries such as Denmark or Austria have paved a way to upscale solar thermal systems up to GW sizes, with a number of implications due to system sizes.

Several technical design characteristics determine the specific energy output of solar thermal systems, such as collector field losses, low temperature operations, or low return temperatures into solar collectors critical to storage losses. One major specific problem of regions with strong seasons are system and operational losses during winter times. The integration of solar thermal large-scale applications into district heating networks is problematic: Solar radiation is low while temperatures of the district heating networks are high (90°C – 140°C flow temperature). Additionally, the performance of collectors and their performance in field constructions do not correspond to their designated lab test results. Storages, hybrid technologies (industrial waste heat, heat pumps, or storage types) and optimized system components have to be aligned with all-year system requirements of district heating and cooling networks to guarantee a high solar fraction.

The IEA SHC Task 55 is a follow up Task of the successfully terminated IEA SHC Task 45. The former task provided research results on technical-economic parameters of large scale solar thermal plants (TASK 45, 2014). The new task integrates past findings and extends research towards district heating and cooling networks, main system components and hybrid technologies. Additionally, the new Task provides a new platform for scientists and industry partners to share their knowledge and solve pressing technical, political, and economic problems. It aims to provide options on how to best integrate solar thermal large-scale installations in combination with hybrid technologies (such as seasonal heat storages or adsorption heat pumps) into district heating and cooling networks. It is central to focus on the integration of solar thermal systems into network technologies, and on challenges which limit current integration efforts.

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Selection and/or peer review under responsibility of Scientific Committee
doi:10.18086/swc.2017.06.10 Available at http://proceedings.ises.org

2. IEA SHC TASK 55: Structure and Strategy

The international cooperation on the integration of solar thermal large scale installations into district heating and cooling networks is structured into four subtasks, A, B, C, and D. Subtask A focuses on district heating network requirements and options to integrate solar thermal heating or cooling installations. Economic analyses, hybrid technology applications, or control strategy challenges are major points of research. Subtask B elaborates on the specific components of such systems, testing and monitoring projects as well as quality aspects of integrated components. Subtask C emphasize the design of solar thermal systems. Projects elaborate on simulation tools, collector designs or modular conception and construction measures. Finally, Subtask D promotes and disseminates project results and know-how on SDH/SDC systems including hybrid technologies. It contributes business models, market analyses and best practice examples. Experts on Task 55 key research areas exchange their main fields of expertise in half-year cycles between 2016 and 2020, and aim to stimulate the growth and realization of a strong SDH/SDC industry. Strategic steps to reach set objectives are high attendance rates at Task 55 Meetings, active dissemination on most well-known industry platforms, increasing numbers of experts involved into Task 55 project work activities and active participation in the International Energy Agency on local and international levels.

3. Network Analyses and Integration

The overall district heating or cooling network and integration aspects are central as soon as the solar share of a DHC system reaches a level where the operation of the network and the other supply units is influenced significantly.

Best practice examples and case studies of existing, newly integrated and planned SDH and SDC systems with large (>5%) solar fraction (typically of > 0,5MWth up to GWth), including characteristics such as typical network temperatures, summer/winter load ratio, pressure level, collector fields, seasonal storages, hybrid-technology implementation, hydraulics and control strategies are central to analyze the network and integration strategies. Case studies, including potentials and barriers for the integration of solar thermal systems can show possible transition strategies from no to 100% solar thermal supply. System challenges in the network especially affect the hydraulics and the interaction with other supply technologies.

Technical and operational parameters of district heating systems differ across countries. In China, typical water supply temperatures range from 115-130°C, whereas in Denmark 66-115°C apply. In Germany, temperatures range from 90-113°C. Water return temperatures range from 50-80°C in China, 38-67°C in Denmark, and 30-60°C in Germany. Chinese networks show losses of 20-50%, whereas Denmark has 19.8% and Germany on average 13%. The volumes of networks in China have doubled since 2000 with rapid expansions, in Denmark networks are at the age between 24-54 years, whereas in Germany, some networks are close to 100 years old (IRENA, 2017).

The inclusion of solar thermal devices into diverse, complex heat distribution systems is ambitious, but doable. Solar thermal installations are based on renewable heat with minimal environmental impact. Disadvantages of the technology are the irregularity of solar irradiation (on which the heat yield depends) and the typically negative correlation between solar heat supply and heat demand. These disadvantages can be met by the use of storage tanks. Furthermore, heat production can be supported by the use of heat pumps. Complex heat generation and distribution systems incorporate many types of heat sources. The control of both the solar thermal systems and the heat distribution network constitutes a major challenge. Standard strategies of independent linear controllers for individual subsystems are not appropriate for control of transient modes. By disregarding the couplings between the systems, changes in operating conditions in one system can lead to oscillations and suboptimal behavior in others, which again can have repercussions on the first system. Unpredictable behaviors when integrating solar thermal systems into DH networks can be met by subordinate model-predictive control approaches.

Simple linear controllers do not account for dead time (delay), which is unavoidably present in large thermal systems fed by renewable sources. By a model-based approach, dead time can be explicitly taken into account in control strategies. Since the velocity-dependent throughput time corresponds to the heating time in the collector, one has some level of control over the outlet temperature by properly adjusting the mass flow. Adding an electrically operated heat pump to the system allows to decouple (to some extent) outlet temperature and heat flux. With a model-based control approach it is thus possible to independently prescribe target values both for outlet temperature and heat flux (within technical and physical limits). By setting the target values for critical system quantities, a superordinate predictive control system can make best use of all components and avoid unwanted situations, such as loaded storage tanks at a time when considerable solar yields are possible (Lichtenegger, et al. 2015).

Necessary conditions to use these predictive control measures to integrate a solar thermal system into a district heating network are (Lichtenegger, Unterberger, 2015):

- Sufficient knowledge of the system,
- Reliable forecasts for solar irradiation,
- Reliable forecasts for ambient temperature and heat demand,
- Significant device for heat storage,
- The system has non-trivial heat demand characteristics.

International research projects on elementary components of the integration of solar thermal systems are heat portfolio, BiNe2+, UrbanDHExtended, OptENgrid, or BIGSOLAR. A switch to renewable energy sources for district heating and cooling can help meet rising urban energy needs, improve efficiency, reduce emissions and provide cost-effective temperature control. Under calculated conditions, DHC offers a cost-effective and energy efficient option. There is significant potential to upgrade existing systems and create new networks using solar thermal large-scale systems (IRENA, 2017).

4. Components testing, system monitoring and quality assurance

Operational conditions of components in large solar thermal plants usually differ from conditions under which components were originally tested in laboratories. Based on findings of IEA SHC TASK 45 Subtask C - which focused on system configurations, system performance, tools and guidelines for operating strategies, and models for ESCo services – the parameter are scaled up to much bigger sizes (Putz, Provasnek, 2016). Plant-specific characteristics, such as the azimuth, inclination, hydraulic effects, differentiated flow rates of parallel collector arrays, or characteristics of the heat transfer media determine how solar thermal systems operate. To reduce the uncertainty on the performance of solar thermal systems and to increase the planning reliability of systems to be integrated into DHC networks, current test methods have to be scrutinized and the actual operating conditions have to be put into consideration.

One major research project named `MeQuSo´ provides Task 55 with data on In-situ tests of the power output of large collector arrays to assess the thermal performance of the deployed collectors under real operating conditions in the field. By monitoring the performance of different collector types, assessments on the quality of individual products and external influences in the field are possible. Existing measurement data of solar thermal plants are not sufficient to improve current collector test approaches, since the needed quantities might not be measured and the accuracy might not be adequate. This is certainly true for radiation, since precise measurement of radiation is not always mandatory for control systems of solar thermal plants. A solar thermal plant called `Fernheizwerk´ was equipped with high precision measurement equipment to meet the data quality requirements of the project MeQuSo. Test results show that the field performance of a number of collectors differ highly from tests performed in the laboratory. Findings provide more accurate efficiency values under real operating conditions in the field, a higher reliability of the expected solar yield, and will lead to performance improvements of future collectors, collector arrays, and components of the total solar thermal system (Doll, Ohnewein, et. al 2016).

5. Design of the Solar Thermal System and of integrated Hybrid Technologies

The design of solar thermal systems defines their architecture, modules, and interfaces. The data on the design have to focus on the demand of specified requirements. Ideally, theory on system design and product development merge and are transported to the market, leading to innovative large-scale solar installations suitable for SDH. Core steps include the analysis, architecture and engineering of solar thermal components. Hybrid technologies can help to shape the change into DHC solar thermal innovation. Elements from new solar thermal system designs can be combined with technologies of the status quo. Hence, two technologies are combined with one another.

New systems can be based on a first simulation of solar thermal systems and their components, such as storage, piping, and hybrid technologies such as heat pumps. The project at hand elaborates on characteristics of collector array units, large and seasonal storages, hydraulics, and heat pumps within system operations. Large scale collector fields are simulated and compared to related measurements in field tests. Optionally, the simulation tool can be corrected. Next, parameters of seasonal storages are calculated and guidelines for the design and construction of different storage types identified. Hydraulics within systems are sensitive to a variety of parameters. These parameters have to be optimized. Piping within large systems and options for a modular conception and construction of very large systems have to be investigated. The subsequently developed modes provide new findings for performance surveillance, system design, and system control measures.

Steps to evaluate and optimize the design of solar thermal systems include:

- Investigation of measured long-term field performance in relation to standardized collector test information
- Development of tools/models for annual performance predictions at different operating conditions and field designs
- Solar radiation modelling
- Assessment of different collector types for large collector fields
- Investigation of system performance and control for a collector field with series connection of different collector types
- Investigations on influence of the design of the solar collector loop on the thermal performance of solar collector fields
- Analyzing pressure loss and flow distribution in collector components, collectors, and collector fields

Focusing on renewable energy sources, solar thermal energy can be generated by more than one renewable source at a time. Examples are sources of solar, biomass, or geothermal. The hybrid energy generation module of solar and geothermal or solar and waste heat hybrid module are attractive, as they are abundant in nature and from the industry, and are very much environmentally friendly (TASK 55, 2017).

A component critical to solar thermal large-scale systems and their hybrid systems are thermal storages for achieving high penetration levels. It increases the capacity factors or value of such energy systems and are therefore core to any system design (IRENA, 2017).

6. Dissemination of SDH/SDC and of Hybrid Technologies in New Markets

Business activities on solar thermal energy are increasingly important contributors to the energy economy. Current firms on the market are major sources of innovation, business development, and of new jobs. Securing financial success for newly designed large scale solar thermal installations is still a challenge, as they are built upon intellectual capital rather than on physical assets, which are still to be built. However, several companies are willing to `go boldly where no one has gone before´ with solar thermal energy installations. For these companies it is central to identify sources of financing and new business models.

One instrument to assist in the availability of financing are promotion activities for large SHC installations coupled with existing DHC networks. Additionally, including industrial waste heating (and cooling) sources with the other technologies of heat pumps, geothermal heat and thermal energy storages are attractive, innovative combinations. Exemplary business models for these solar thermal and hybrid technologies are to be elaborated, as well as best practice examples of already existing installations.

Besides, promising are also new industrial markets for solar heating and cooling systems, which need training material in order to diffuse the technologies. Most countries could scale up renewable energy substantially in district heating and cooling. In a few countries, such as Denmark and Switzerland, renewable energy already provides more than 40% of district heat supply. Renewable energy such as solar thermal energy and hybrid technologies could theoretically satisfy all DHC demand in 2030. However, a realistic potential for deployment differs from country to country. China could realize a 24% renewable share in district heat generation, split equally between geothermal, bioenergy and solar. In Denmark, the already high renewable share of 42% could reach 73%. The country is and will remain a global leader in large-scale solar energy, which can be expanded to meet 13% of total district heat demand by 2030, complemented by hybrid technologies of geothermal and bioenergy. In Germany, solar heat could reach a share of 6% in DH networks by 2030.

7. Summary and Outlook

IEA SHC TASK 55 focuses on very recent efforts of a number of stakeholders to increase the share of solar thermal large-scale installations in district heating and cooling systems. District heating systems spilt the local production of energy and its consequences (such as CO_2 emissions) from its consumption. Despite already being considers as more environmentally friendly than conventional single energy systems, district heating systems can still increase their environmental performance by integrating renewable sources. Optimizing system operation, achieving economies of scale, integrating large scale storage and holistic system designs are essential to accelerate the deployment of cost-effective solar thermal assisted DHC systems. As the systems of solar thermal and geothermal large scale improve and grow, DHC systems will also offer increasingly attractive synergies.

Mismatches between load patterns and the supply from solar radiation can already be balanced to a great extent with thermal storage facilities. Storages are expected to become integral, with DHC systems coming to play a pivotal role in enabling variable renewable sources. Solar thermal large-scale applications are only used in a few places today but have significant potential. Countries such as China become increasingly dependent on variable renewables due to pollution crises. Next steps have to promote demonstration projects for the new technologies. Due to the limited number of systems already in place (despite in Denmark), the availability and suitability of renewable resources for DHC is often unclear. For solar district cooling technologies, demonstration projects will have a significant positive effect on investors´ and customers´ trust into the technology.

As installations in Denmark have shown for decades, large scale solar thermal systems are a promising technology. However, several challenges are still to be met: Which approaches are most promising in integrating such systems, how should the DHC systems be designed, which components fit best into the system and which business models actually meet most stakeholders´ needs? Examples of already existing installations and elaborations on promising new markets and market developments are much needed fields of expertise. IEA SHC TASK 55 tackles these challenges and will provide answers to all questions by mid-2020.

8. References

Doll, W., Ohnewein, P., Krammer, S., Prem, G., Tschopp, D., Stelzer, R., 2016. PRECISE MEASUREMENT OF LARGE COLLECTOR ARRAYS FOR THE DEVELOPMENT OF IN-SITU TEST METHODS.

IEA SHC TASK 45, http://task45.iea-shc.org/, 09.10.2017.

IEA SHC TASK 55, http://task55.iea-shc.org/, 09.10.2017.

IRENA (2017), Renewable Energy in District Heating and Cooling: A Sector Roadmap for REmap, International Renewable Energy Agency, Abu Dhabi.

Lichtenegger, K., Unterberger, V., Gölles, M., Muschick, D., Höftberger, E., Gerardts, B., Krammer, S., Wöss, D., 2015. Inclusion of solar thermal devices in complex heat distribution systems – a look from the model-predictive control point of view.

Provasnek, A. K., Schmid, E., Geissler, B., & Steiner, G., 2016. Sustainable corporate entrepreneurship: Performance and Strategies toward Innovation. Business Strategy and the Environment. DOI: 10.1002/bse.1934

Putz, S., Provasnek, A.K., 2016. Results of IEA SHC Task 45 Subtask C “Systems - Configurations, Operating Strategies, Financing Issues“. Journal of Energy Procedia. DOI: 10.1016/j.egypro.2016.06.199