Applied Energy 92 (2012) 175–184

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Decentralized cooling in district heating network: System simulation and parametric study

Seksan Udomsri [a,*], Chris Bales [b], Andrew R. Martin [a], Viktoria Martin [a]

[a] Division of Heat and Power Technology, Department of Energy Technology, Royal Institute of Technology (KTH), 100 44 Stockholm, Sweden
[b] Solar Energy Research Center (SERC), Högskolan Dalarna, 781 88 Borlänge, Sweden

ARTICLE INFO

Article history:
Received 17 December 2010
Received in revised form 4 October 2011
Accepted 6 October 2011
Available online 29 November 2011

Keywords:
Thermally driven chiller
Decentralized cooling
District heating network
Simulation study
TRNSYS

ABSTRACT

This paper presents system simulation and parametric study of the demonstration system of decentralized cooling in district heating network. The monitoring results obtained from the demonstration were calibrated and used for parametric studies in order to find improved system design and control. This study concentrates on system simulation studies that aim to: reduce the electricity consumption, to improve the thermal COP's and capacity if possible; and to study how the system would perform with different boundary conditions such as climate and load. The internal pumps inside the thermally driven chiller (TDC) have been removed in the new version TDC and implemented in this study to increase the electrical COP. Results show that replacement of the fourth with the fifth generation TDC increases the system electrical COP from 2.64 to 5.27. The results obtained from parametric studies show that the electrical and thermal COP's, with new realistic boundary conditions, increased from 2.74 to 5.53 and 0.48 to 0.52, respectively for the 4th generation TDC and from 5.01 to 7.46 and 0.33 to 0.43, respectively for the 5th generation TDC. Additionally the delivered cold increased from 2320 to 8670 and 2080 to 7740 kWh for the 4th and 5th generation TDC's, respectively.

1. Introduction

1.1. Background and objectives

A demonstration system (Subproject 1b: SP1b), was one of 11 demonstration systems installed and monitored within the EU-PolySMART project in Sweden. The aim was to design and develop the best system configuration for the combination of district heating and distributed absorption chillers [1]. PolySMART stands for POLYgeneration with advanced Small and Medium Scale thermally driven Air-Condition and Refrigeration Technology. The overall PolySMART project aims were to develop a set of technical solutions for a new market segment of polygeneration, in particular the market for small and medium scale tri-generation systems (combined production of electric power, heat and cooling). The key components of these systems always include the combined heat and power (CHP) plant along with the thermally driven chiller (TDC). There are different approaches of composing the CHP with TDC [1]; (i) centralized CHP and centralized TDC in combination with a heating and cooling network, (ii) centralized CHP and decentralized TDC in combination with a heating network, and (iii) decentralized CHP and decentralized TDC both on the demand side. Each approach can be applied under different conditions depending upon the source of generation, consumption, and applications [1]. However, this article reports on a combination of centralized CHP and decentralized TDC in district heating network. District heating can be described as rational and environmentally friendly method to heat residential and commercial buildings etc. District heating is very common heating method and available throughout Sweden. The system is an example of distributed cooling with centralized combined heat and power (CHP), where the driving heat is delivered via the district heating network. Since the demand for cooling has increased tremendously around the world during the past decades [1–4], the conventional compression chillers share more than 15% of worldwide electricity energy consumption [5]. An absorption chiller is an excellent example of thermally driven cooling technology where the low temperature heat can be utilized for cooling production [6,7].

As part of the project, the aim of subproject 1b was to demonstrate the use of the ClimateWell chiller in distributed cooling with centralized CHP in order to develop the best system configuration for the TDC using a particular form of chemical heat pump [8]. The monitoring results and system calibration of the PolySMART demonstration system (SP1b) has been reported in [8]: monitoring results and calibration of simulation model. The main objective of this work was to calibrate and analyse the monitoring results obtained from the demonstration system and validate against a dynamic simulation model using TRaNsient SYstem Simulation

* Corresponding author. Tel.: +46 8 790 6140; fax: +46 8 20 41 61.
E-mail address: seksan.udomsri@energy.kth.se (S. Udomsri).

0306-2619/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2011.10.009

Nomenclature

CHP	Combined Heating and Power
COP	Coefficient of Performance
Cp	specific heat capacity
E	electricity consumption
Eff	efficiency
HEP	high efficiency pump
LHV	lower heating value of a fuel
$\dot{m}$	mass flow
P	power
PE	Primary Energy
Q	thermal energy flow
RH	Relative Humidity
SP	subproject
T	temperature
TCA	Thermo-Chemical Accumulator
TDC	thermally driven chiller
Tim	time
V	volume flow
dpi	pressure drop in each circuit

Subscript

Air	air
BOP	balance of plant
Cc	chilling circuit of TDC
Cdn	cold distribution system for end-use *N*
Dc	driving circuit of TDC
Dh	district heating
el	electricity
Fl	feed line (considering as the one leaving the heat source, and thus the hottest line)
HEP	high efficiency pump
Hr	heat rejection system
Meas	measurement
OA	outside ambient
Opt	optimization
Pump	pump
Rc	recooling circuit of TDC
Rl	return line (considering as the one returning to the heat source, and thus, the coldest line)
Sim	simulation
Sys	system
Tdc	thermally driven chiller
Th	thermal energy
t_i	time

program (TRNSYS) [9]. The calibration of the base case was made in three stages and the energy performance figures were within 4% of the measured values.

Although a number of weaknesses have been found, it is fair enough to state that the TDC has worked reliably during the whole cooling season that was monitored. The major fault during the cooling season was due to an external electrical component (relay). However the electrical COP for the complete system was relatively low and in fact was lower than that of the main compression chiller. This was due to relatively large electrical energy use in the pumps, the TDC itself as well as the fan for the heat rejection unit (dry cooler). Other principle conclusions from the monitoring period were that the system worked well but at lower capacity than the nominal capacity of the TDC due to the boundary conditions for the system. This also resulted in lower than nominal thermal COP values. For the complete monitoring period during the summer of 2008, the thermal and electrical COPs for the TDC were only 0.41 and 2.1, respectively and the highest values were 0.50 and 4.6, respectively during the hottest period. Additionally, the system COP's were found to be significantly lower than those for the TDC itself. There are a number of other causes of the relatively low thermal and electrical COP values of the entire system such as: (i) Heat exchanger in the driving circuit, causing extra heat losses in the driving circuit of the TDC, (ii) heat exchanger in the chilled water delivery circuit, causing heat gains in the delivery circuit both through normal gains through the insulation and components but also due to thermal energy from the two pumps used, and (iii) the driving temperature available from the district heating network is lower than ideal for the TDC. It is on average 75–80 °C, whereas 80–90 °C would be more ideal. (iv) The operating times of the whole system are relatively short. (v) The TDC cannot deliver at full power with the normal operating conditions of the system.

The main objectives of this simulation study were to: reduce the electricity consumption, and if possible to improve the thermal COP and capacity at the same time; and to study how the system would perform with different boundary conditions such as climate and load. Studies in terms of the replacement of high efficiency pumps, new TDC version and variations in boundary conditions were conducted to further investigate an impact of the system when a new chiller and other parameters change.

1.2. Methodology and the base case

A chemical heat pump or Thermo-Chemical Accumulator (TCA) has been employed and installed in this project as a TDC unit. It has been developed and is sold by a Swedish company ClimateWell AB [10]. It is a three-phase absorption chillers/heat pump that is capable of storing energy internally with high energy density in the form of crystallized salt (LiCl) with water as refrigerant [8,10]. The demonstration system SP1b has been modeled in TRNSYS and calibrated against monitored data; from subsystem level towards a complete system level. TRNSYS is a transient systems simulation program with a modular structure. The TRNSYS library contains many of the components commonly found in thermal and electrical energy systems [9]. Component routines are also included to handle input of weather data or other time-dependent forcing functions and output of simulation results [9]. The modular nature of TRNSYS allows the program tremendous flexibility and facilitates the addition to the program of mathematical models that is not included in the standard library [9]. In order to find improved system design and control, parametric studies have been conducted using TRNSYS. The parameters studied in this work have been derived from different working groups and partners in the project [1], which considers together all those issues relative to the design, commissioning, operation, maintenance, monitoring and evaluation of demonstration plants.

The calibration of the base case was made in three stages: (i) estimation of parameters based on manufacturer data and dimensions of the system; (ii) calibration of each circuit (pipes and heat exchangers) separately using steady state data points; (iii) and finally calibration of the complete model in terms of thermal and electrical energy as well as running times, for a five day time series of data with one minute average data values [8]. In the final stage complete system model was calibrated against a five day dynamic measurement sequence from a hot period [8]. The main criteria for calibration were the thermal and electrical energies of the whole