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Dynamic Simulations supporting the Design Process of a real Combined Heat and Power Application in Switzerland

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Abstract

In many European countries the production of combined heat and power based on renewable energies is well established though the efficient and economical operation of such plants remains a challenging task. This also applies to the existing district heating network at Baden-Dättwil (Switzerland) where a conventional gas boiler is substituted by a wood-fired boiler comprising an Organic Rankine Cycle. An overall control strategy that allows fully exploring governmental incentives is therefore of paramount importance. In addition, the highly fluctuating heat demands combined with the thermal inertia of the different plant components impose demanding requirements to the control system to guarantee a stable as well as highly efficient operation.

The overall control concept is successfully tested and verified by means of dynamic simulations of the overall plant with a simplified model for the district heating network. The models are implemented using the object oriented modeling language Modelica. The overall model is based on open source Modelica libraries such as ThermoCycle, Modelica Standard Library and StateGraph2 as well as on own Modelica models.

The overall model is prepared to be coupled to the real plant control system which will allow virtual commissioning in the next step. This allows pre-tuning of control parameters as well as a weakness analysis which again helps to speed up the commissioning process. In General, the dynamic simulations proved to be a useful tool that deepened the insight and understanding of the plant operation at an early project phase and therefore greatly supported the making of design decisions. After commissioning, the calibrated simulation models will be used for monitoring purposes.

Keywords: Organic Rankine Cycle; Dynamic simulation; Combined heat and power; Cogeneration; Modelica; Virtual commissioning

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Nomenclature

DH	District Heating
CHP	Combined Heat and Power
ORC	Organic Rankine Cycle
E_{DH}	Annual thermal energy demand of district heating network [GWh/a]
E_{th}	Annually produced thermal energy [GWh/a]
E_{el}	Annually produced electrical energy [GWh/a]
L	Charge level of thermal storage [%]
L_{set}	Set point of charge level [%]
T_{sup}	Supply temperature (to the DH network) [°C]
T_{supS}	Supply temperature set point [°C]

1. Introduction

The energy provider Regionalwerke AG Baden owns the district heating (DH) network at Baden-Dättwil and is challenged by future decreasing heat demand e.g. due to upcoming energetic renovation of old buildings and climate change. The future operation of the network is economically feasible only when new customers can be acquired and the existing customers be kept [1]. Therefore, the heat prices must be competitive to alternative heat technologies such as solar heating or heat pumps. Also the major portion of the primary energy must come from renewable sources to meet Swiss energy recommendations such as the MINERGIE standard [2]. A preliminary technology screening with economical assessment led to a combined heat and power plant (CHP) using a wood-fired boiler with an Organic Rankine Cycle (ORC) as the most promising plant concept [3]. As will be shown in Section 2.1 greatest importance has to be given to a suitable concept of plant operation, which is in a first step evaluated by means of simulations.

In general, simulations of power plants are commonly applied during an early project phase to evaluate economically optimal configurations. Sartor et al. state the cost of the energy as the most critical and decisive criteria for the development of DH technologies [4]. They present a synthetic way to combine energetic, environmental and economic aspects for the whole operation range of a plant using simple static simulation models from thermodynamic, combustion process, heat transfer and finance. Wischhusen implemented a Modelica library for the dynamic simulation of energy systems and applies it to a complex industrial energy supply system for energetic and economic optimization [5]. Alobaid et al. emphasize the increased requirements of operating flexibility due to the continuing shift towards renewables. Dynamic simulation are mentioned as a cost-efficient tool for improving this flexibility and optimizing control structures [6]. Dynamic simulation model may also be used for virtual commissioning that allows quick and safe testing of complex plants as well as minimizing the use of resources during commissioning [7].

The control concept of the Baden-Dättwil plant is derived from static simulations. The concept is presented in Section 2.2. Subsequent tests and verifications of the control concept are conducted using more elaborated simulation models which are able to predict transient behaviour and also contain pumps, valves and sensors used to control the overall system. The models are implemented in the object-oriented modeling language Modelica, see Section 3.

2. Plant description and operation concept

The plant basically consist of the wood-fired boiler, the ORC module, the thermal storage, the air cooler, the existing gas boiler and some additional gas heat exchangers such as economizer, air pre-heater and gas condenser - a rather conventional setup as also described in [8]. A simplified plant layout is shown in Fig. 1.

During normal operation the heat from the combustion gases is transferred to a thermal oil circuit. From there it enters the ORC module. The heat rejected by the module is discharged to the return water of the district heating network with a maximum thermal output of 2760 kW_{th}. The applied ORC module has a gross electrical power output of 615 kW_{el}. The thermal storage consists of three parallel water tanks with a total capacity of 300 m^3. Heat