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Intelligent management of the heat storage tank for production of electricity on demand usingCHP units

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Abstract

The paper illustrates the status quo of a research project for the development of a control system enabling CHP units for a demand-oriented electricity production by an intelligent management of the heat storage tank. Thereby the focus of the project is twofold. One is the compensation of the fluctuating power production by the renewable energies solar and wind. Secondly, a reduction of the load on the power grid is intended by a better match of local electricity demand and production.
In detail, the general control strategy is outlined, the method utilized for forecasting heat and electricity demand is illustrated as well as a correlation method for the temperature distribution in the heat storage tank based on a Sigmoid function is proposed. Moreover, the simulation model for verification and optimization of the control system and the two field test sites for implementing and testing the system are introduced.

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*Keywords:*CHP; control strategy; demand-oriented; electricity production; heat storage tank

1. Introduction

The increasing renewable power generation requires efforts to cope with the fluctuations in power supply and the associated distribution problems. A decentralized electricity generation using combined heat and power plants (CHP units) can contribute significantly to the compensation of these fluctuations and to the relief of the electricity networks. For this purpose, however, a control system for the CHP units is necessary, which ensures both the coverage of the heat demand of the building as well as the exact timing of the electrical energy production with

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respect to the times when it is needed. The decoupling of electricity generation and coverage of the heat demand is achieved by the existing heat storage tank. This device therefore constitutes the central element of the control system.

The development of an appropriate control system is in the scope of a 3-year research project at the Reutlingen Research Institute (RRI) of Reutlingen University funded by the State of Baden-Württemberg within the program BWPLUS. Hereby, the control system should on the one hand assure that the storage tank is emptied in terms of its heat content before an electricity demand is calling the CHP unit into operation. On the other hand a proper heat supply of the building must be guaranteed. Moreover, the demands of the CHP unit in terms of maintenance and lifetime need to be taken into account by limiting the number of starts per unit time and by maintaining a certain minimum length of the operating intervals. Since the project is running until the end of 2015 some intermediate results regarding basic layout of the control system, simulation, determination of the energy content in the heat storage tank and characteristics of the field test facilities will be presented in the following.

2. Basic layout of the control system

As mentioned above, the major constraint of the control system is the utilization of the heat produced by the CHP unit and by this means fulfilling the heat demand of the building as best as possible. However, the thermal capacity of the heat storage tank serves as a buffer providing the degree of freedom needed to decouple the operation of the CHP unit and the associated production of electricity from covering the heat demand. This is illustrated in Figure 1 showing the limiting curves of accumulated heat demand at a fully loaded (red) and a mainly emptied (blue) heat storage tank. Obviously, the CHP unit is free to operate between these two lines and the scheduling can be shifted from the usually implemented heat driven mode (orange) to a mode, which provides a better match of the operating times of the CHP unit to the electrical load (green).

Evidently, the scheduling of the CHP unit between the two limiting curves of heat demand needs to consider the technical limitations of the CHP unit such as minimum length of operating periods, minimum idle times between the periods of operation and the maximum number of starts per day acceptable with respect to maintenance and lifetime.

Moreover, for describing the limiting curves of heat demand and for electrical load proper forecasts for these measures are needed. In order to cope with any deficiencies of the load forecast, it is necessary to implement an additional routine for instantly adjusting the operating schedule of the CHP unit. This routine is also useful to handle any unforeseen electrical load, because it would be valuable to additionally cover these loads from the electricity produced by the CHP unit as best as possible.

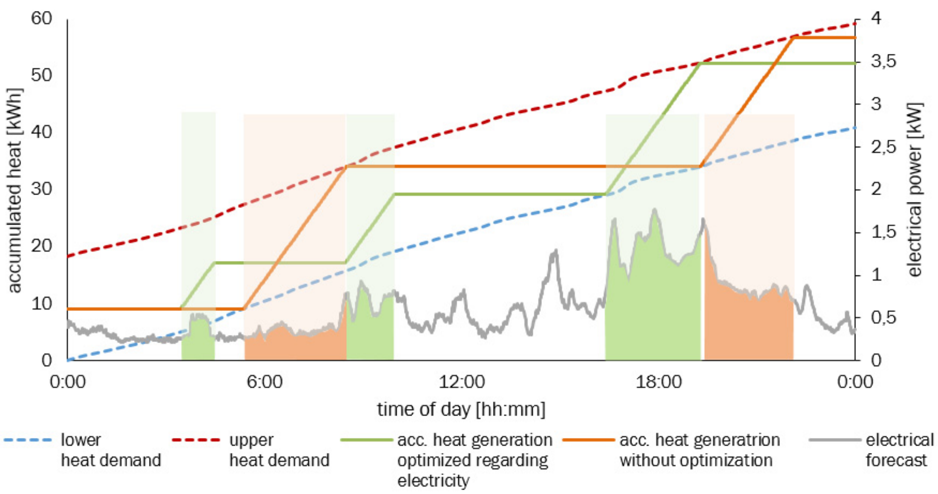

Fig.1: Optimized scheduling of the CHP unit with respect to electrical load

3. Demand forecast

Within the project various forecasting strategies have been analyzed. This work was possible, since the measured data for heat, hot water and electricity demand of 6 single and double family houses was available for a period of one year in a 1-minute resolution. After analyzing this data, it turned out that the individual behavior of the people living in the houses by far overwhelms any other effect attributed to the external conditions such as season of the year, day of the week, ambient temperature or intensity of sunshine, which is in coincidence to the findings of Tzscheutschler [1] and McLoughlin et al. [2]. Even the elaboration of a forecast strategy based on neural networks did not yield more accurate results. For that reason, the so called naive forecast is used to predict heat and electricity demand within the control system. Here, the load profiles forecasted are based on the profiles of the previous day or a weighted average of the profiles of the last couple of days. Obviously, this implies a higher rate of uncertainty in the forecasted data and by this means an additional method within the control strategy is required to cope with deviating and unforeseeable thermal or electrical loads, as already stated in the previous paragraph.

4. Evaluation of the energy content in the heat storage tank

The energy content in the heat storage tank is evaluated from the temperatures of the water within the tank. Here, it would be best to have an appropriate number of temperature sensors along the height of the tank. However, for economic reasons heat storage tanks of CHP systems are generally equipped with sensors at three different heights, only. For that reason a mathematical method is needed for correlating the temperature distribution in the tank based on the data of these sensors. Studies on stratified heat storage tanks have shown that the temperatures form a so called S-curve as a function of tank height, which can be expressed by the group of Sigmoid functions [3]. Out of this group the Gomperz function (see eq. 1) has been selected for correlating the temperatures in the heat storage tank.

$$y = A_{1+}a * \ e^{(-e^{k_1*(x-x_c)})} \tag{1}$$

It can be seen that the function selected carries four parameters A_1, a, k_1 and x_c. Hence, it is not possible to derive all parameters directly from the data of the temperature sensors, since there is a number of three sensors, only. However, by applying appropriate boundary conditions, this problem can be solved by an iterative procedure, as shown in Figure 2. The Gomperz function plotted in Fig. 2 (blue) correlates the three data points from the temperature sensors (depicted by red squares). For validation, additional sensors have been installed, and it can be seen that the Gomperz function fits well to the additional data (shown by green circles). This proves the capability of the Gomperzfunction for correlating the temperature distribution in heat storage tanks in general, and it confirms that the four parameters of the Gomperz function can be found by three data points for temperature, only.

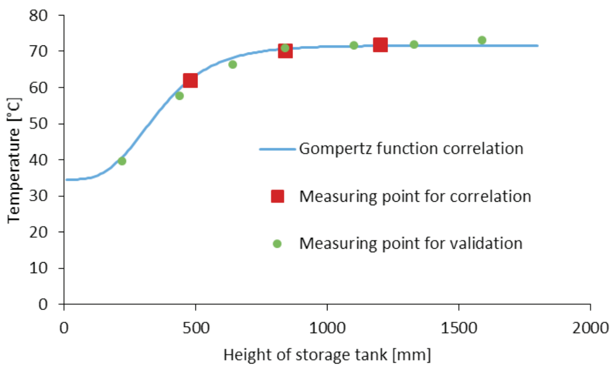

Fig. 2: Sigmoidal Curve Fitting using the Gompertz Function

5. Field test units

For approving the system under relevant conditions in a practical environment two existing CHP plants have been upgraded with the required hardware to measure the system data and hereafter to implement, test and optimize the developed control system. Table 1 summarizes the equipment installed at the two field test sites.

Table 1: Characteristics of the two field sites

	Field test site 1 – Reutlingen	Field test site 2 - Ofterdingen
Building	1 Unit of a double family house	Single family house comprising two small manufacturing units
CHP unit	VaillantecoPower 1.0	SenertecDachs SE G5.5
Electrical power	1 kW	5,5 kW
Thermal power	2,5 kW	14,8 kW (incl. condensing-HX)
Heat storage tank	750 Liters	900 Liters
Peak load boiler	20 kW	Not in operation
Control device	WAGO PFC-200	WAGO PFC-200
Network router	eWonCosy VPN-Router	Innominate mGuard RS2000
Heat meter	4 Meters (M-Bus)	3 Meters (M-Bus)
Electricity meter	2 Unidirectional meters (M-Bus), 1 Bidirectional Meter (M-Bus),	2 Bidirectional meters (M-Bus)
Gas meter	2 Gas meters (converting S0 signal to M-Bus)	None
Additional temperature sensors	7 sensors along the height of the heat storage tank	7 sensors along the height of the heat storage tank

6. Simulation

For the testing, verification and optimization of the control system a simulation model based on MATLAB Simulink has been elaborated. The model consists of major modules for CHP unit, peak load boiler, heat storage tank, heating circuit and hot water tank. The energy demands for heat, hot water and electricity are fed into the program as input data, and the operation of peak load boiler and especially CHP unit can be studied based on the control system implemented. It turned out that the heat storage tank is the crucial module in terms of accurately describing the heat rates and temperatures measured in existing CHP plants. Even though the basic model is well understood and available from the CARNOT-Toolbox of the MATLAB-Software [4], it still takes efforts to find proper parameters to simulate an existing heat storage tank with respect to e.g. heat losses and internal flow pattern at the feeding ports.

Fig. 3 compares the data from the simulation to measured data from the 2nd field test unit over a period of 6 days. The upper diagram shows the curves for heat demand and heat production by the CHP unit. Obviously, the latter refers to the operating phases of the CHP unit. It can be seen that there is a little drift between the operating phases derived from the simulation and the measured data, especially from the 3rd day on. These deviations can be attributed to the simulation of the heat storage temperatures, which are plotted in the lower diagram. Even though the basic pattern of the calculated temperature variations as well as the absolute values for minimum and maximum temperature within each variation matchthe measured data quite well, deviations especially for the lower temperature occur due to inevitable simplifications of the storage tank model.

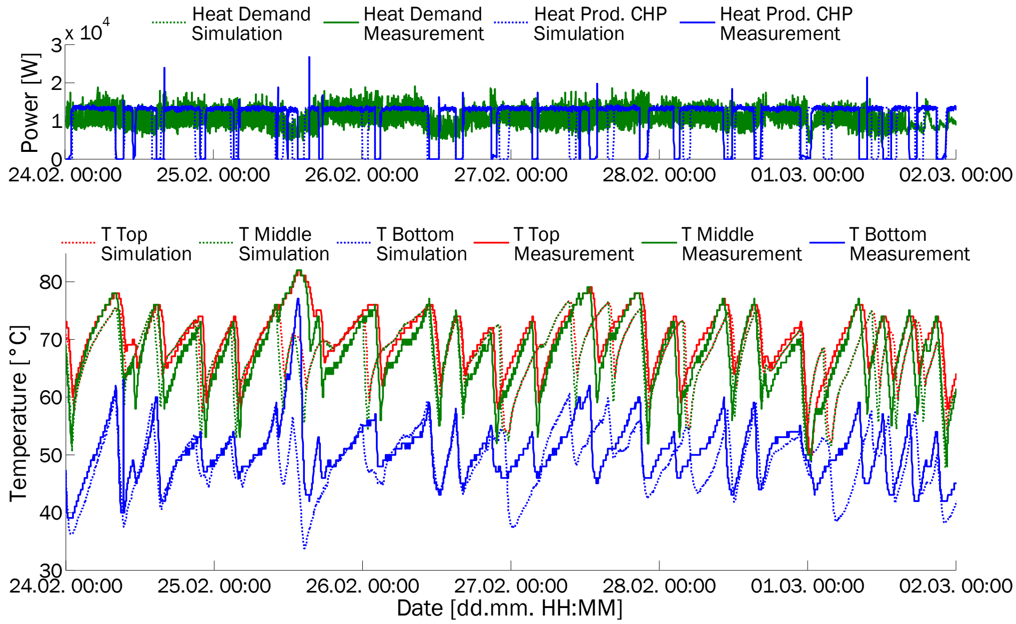

Fig.3: Comparison of simulation and measurement data for field test unitsNo. 2

7. Conclusion

Within the last year left of the 3-year project the control system needs to be tested and optimized with respect to the simulation model. After this task has been completed successfully, the control system will be implemented on each of the two field test units. It is intended to run the first tests at the field test sites during spring 2015, since at this time of the year CHP units generally offer the most flexibility. This, evidently, enables the project team to study the performance of the control system under various conditions and it will allow a good perspective about its benefits in terms of a demand-oriented electricity production.

8. Acknowledgement

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