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Analysis of Operation of Heat Accumulator in Large–Scale Combined Heat and Power Plant

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Abstract

This work presents analysis of operation of heat accumulator in one of the biggest European CHP plant. It includes basic information about optimization process for combined heat and power plants and cooperation heat accumulators with such a system. The main focus in this work was given to propose general rules of heat accumulator behaviors, which have been developed by optimization software created by Department of Power Engineering Machines at the Institute of Heat Engineering of Warsaw University of Technology. In the experimental part the unique method of accounting cycles was presented. It was assumed that two qualitatively different cycles can be observed during proper operation. The most intensive usage of heat accumulator was observed in spring and autumn seasons. This time of the year was also characterized by the highest speed of charging/discharging process. During summer there were only a few single cycles and operation of whole accumulator was regulated in weekly mode. Finally, validity of optimizer's decision was proven because charging process was always covered with occurrence of the highest spot market prices.

Keywords:	Heat accumulator; Optimisation; CHP

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1. Introduction

Currently, the very common is an application of a heat accumulators integrated with district heating systems [1]. The profitability of this solutions is based on energy production's optimization [2, 3, 4, 5, 6]. It is well known, the CHP plants, which are based on back pressure turbines, generate electricity with close-coupled dependence on the amount of generated heat. In the case of energy sale on power exchange, the electricity price is low during the night, while expensive during the day. The electricity production by CHP plant is an opposite – during the day, when the energy is expensive, the amount of generated electricity is low, while during the night i.e. period when the electricity prices are low, the electricity production by CHP plant is very high. Therefore, the optimization process bases on the shifting of energy production from night period to peak hours. This shift is mainly possible to due to an application of heat accumulators.

In the available literature, there are reported many analysis of a heat accumulator cooperation with a district heating network. Željko et al. [7] reports the influence of heat accumulator on CHP plant's income, on the basis of optimization code – ACOM. The target of the objective function was to select appropriate load coefficient for each devices for minimization the value of costs' function. The electricity price was assumed to be known, however it was split into two separate periods with different values. The application was created especially for one of the Croatian CHP plants. Paper [8] reports an analysis of operation of CHP plant equipped with the heat accumulator. Heat demand was assumed to be known and electricity prices were time depended. The aim of the analysis was to adjust generation to appropriate water inlet temperature and strategy of heat accumulator's management. The main target of objective function was costs minimization, which are covered by district heating network operator.

The problem was solved by using a projected Lagrangian algorithm.

Paper [6] presents an analysis for selection an optimal capacity of CHP plant combined with heat accumulator in the German spot market, competitive energy market. The paper shows an impact of store volume of heat accumulator on generation and their impact on CHP's income. All of the presented analysis, which are based on net present value and simple payback time, were obtained by using a commercial software energyPRO.

In paper [5], it is reported a short–term optimization model for CHP plant equipped with a heat accumulator. The proposed model is based on MILP method. Author considered three different scenarios. Paper [9] report long-term strategy for optimization of power systems equipped with a heat accumulators. The proposed model takes into account nonlinear characteristics curve of CHP plant's operation. The optimization process was solved by MINLP method. The presented papers relates to planning period and assumes the complete use of storage capacity of heat accumulator. However, in reality, the system operation has a lot of constrains and real operation is different than predicted one. Figure 1 presents a real changes for heat consumption and electricity prices.

Figure reveals that the changes of both electricity prices and heat consumption are not clear as well as there are very often far away from the results of simulation forecasts. In addition, CHP plants has some operational limits e.g. failures. Thus, the complete implementation of scheduled operation is not possible. Authors implemented the optimization system of heat accumulator's operation in the CHP plant, which has a highest capacity in the Poland [10]. However, the most interesting point is an analysis of real operation of heat tank and if (how) it is possible to use the total potential of storage tank in operating conditions.

2. CHP PLANT

The all research were done at existing object i.e. Siekierki CHP plant. This plant is one of four main sources, which are supplying the Warsaw district heating network.

The Siekierki CHP plant (see Figure 2), the biggest one in Poland and the second biggest in Europe, is the largest heat source supplying Warsaw Heating System – the most extensive one in European Union.

The Siekierki CHP plant is composed of 9 steam turbosets, two of them extraction-condensing ones (ST1 of power 52, ST8 of power 125 MW). Other turbines are three large counter-pressure units of 100 MW (large power unit with turbines ST7, ST9 and ST10) and three

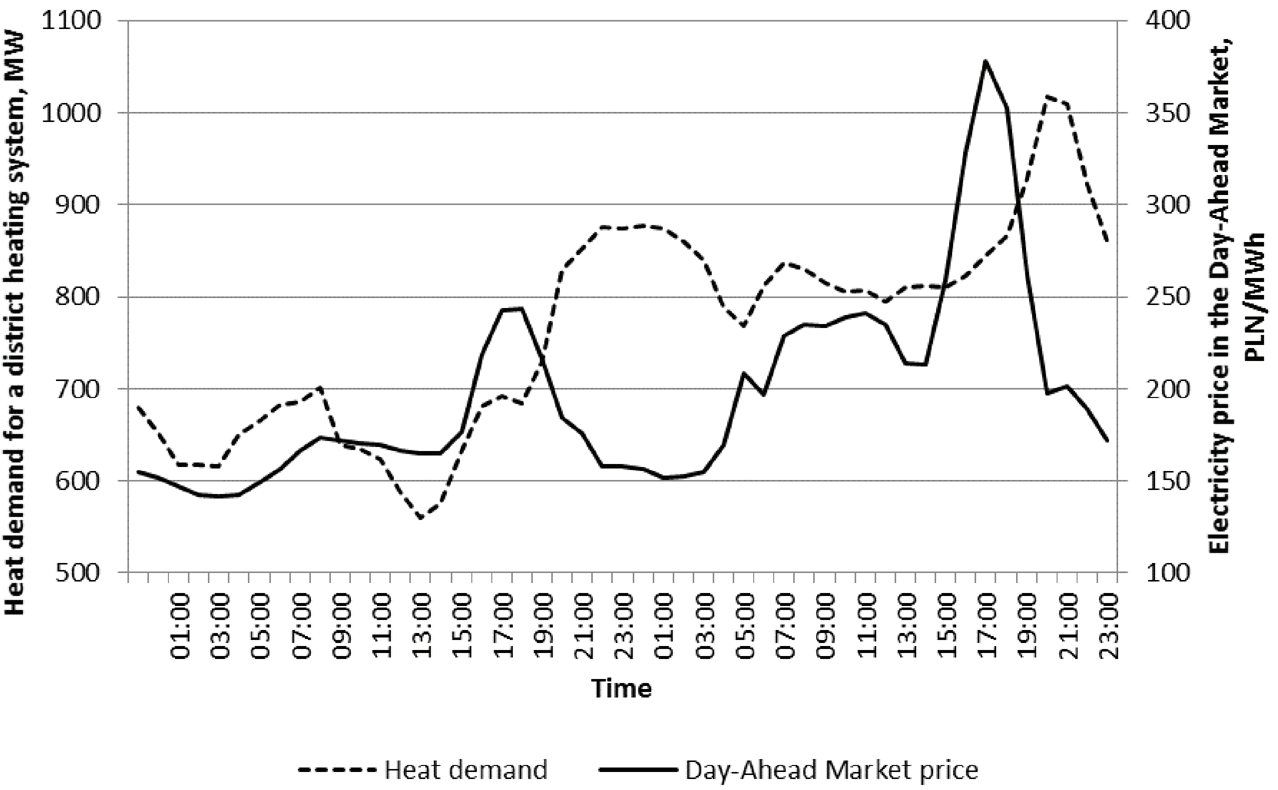

Figure 1: The exemplary heat demand covered by one of the polish CHP plants and electricity prices on stock market

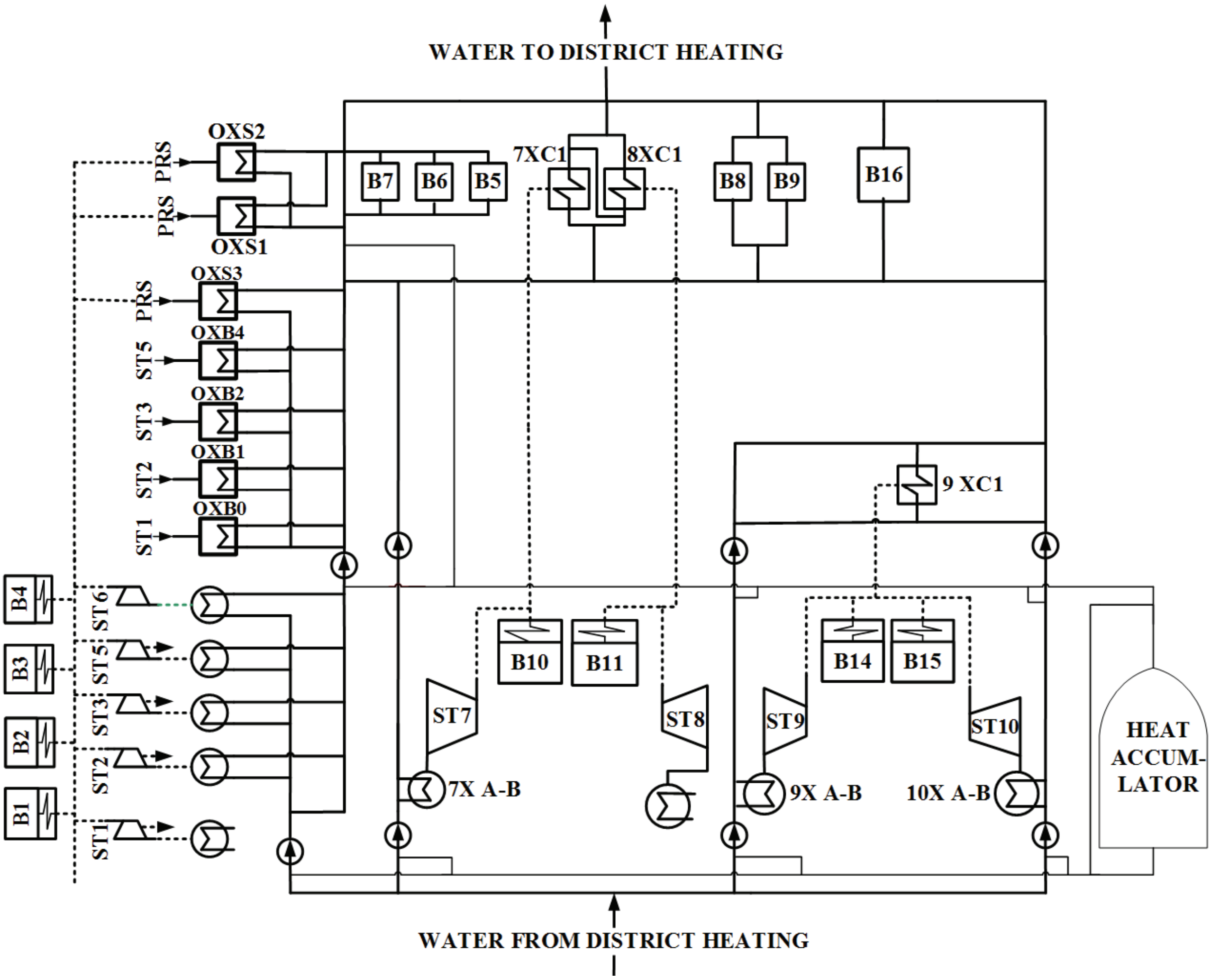

Figure 2: Simplified diagram of heat sources technological system in the Siekierki CHP plant with indicated connections to the heat accumulator.
(B – boiler, ST – steam turbine, PRS – pressure reduction station, X – heat exchanger)

extraction counter-pressure of power 30 MW (turbines ST2, ST3, ST5). The fourth one of power 30 MW (ST6) is not equipped with a controlled steam bleeder, therefore it operates as a counter-pressure turbine. The five turbosets ST1, ST2, ST3, ST5 and ST6 compose the older part of the facility that is supplied with steam by four steam boilers through a header system (header part of CHP). The remaining four units (large power unit) work in the newer part of the boiler house. Six water boilers extend the technological system of the CHP plant. Conspicuously, the configuration of heat sources is complex. The connection of the accumulator and the system enables cooperation with any cogenerating unit (Figure 2). Basic technical data of the accumulator is presented in the Table 1.

The task of the accumulator is to improve flexibility of applied turbosets mainly in order to increase electricity generation in high (peak) demand time of the day. In this case it is more complicated than in case of large accumulators in other countries due to several reasons:

Table 1: Basic parameters of the heat accumulator installed in the Siekierki CHP plant

No.	Parameter	Unit	Value
1	Volume	m^3	30 400
2	Container height	m	47
3	Container diameter	m	30
4	Heat storing capacity	MWh	1600
5	Heating power	MW	300
6	Insulation thickness	mm	500
7	Charging/discharging speed	t/h	4500

- Two counter-pressure turbines are used in the analyzed facility; this type of turbines is not commonly used in plants with accumulators;

- The ratio of heating capacity of the plant to the accumulation capabilities of the accumulator is significantly different from used in other cases (Figure 1);
- The discussed facility is an example of an installation having complex technological structure and high level of heating power;
- The typical load variability is different from observed for most Danish, and even German and Austrian cities due to climate conditions of Warsaw. Climate in Warsaw is relatively harsh what results from location of the city (e.g. long distance from the sea comparing with Danish cities).

3. The analysis of a heat accumulator's operation

The analysis of heat accumulator's operation is based on the data gathered by an electronic acquisition data system (*PI Process Book)*. The examined time period was one year, i.e. since 1st January 2013 to 31th December 2013; with an one hour time interval. The available data consisted of the following parameters: the power of each device, the scheduled production and ambient conditions. Those data ensured possibility to analyze an operation of heat accumulator at different periods.

The first stage of analysis was to determine time periods, when the heat accumulator's behavior is either constant or unique. Poland is situated in the temperature climate with a clear distinction between seasons. Thus, the proposed division of time periods distinguishes the following periods: winter, summer and transition period.

The division into periods was not based on the calendar, but on the basis of detailed analysis of temperatures at each month, therefore:

a) the summer season — June – August
b) the transition season — April – May, September – December
c) the winter season — January – March.

Figure 3 shows an average absolute values of temperatures (temperature to maximum temperature at given time period). It is clearly presented that the highest changes for heat demand occurs during transition period.

The next examined elements was both degree of utilization and types of thermal cycles of heat storage at each month. The detailed analysis of charging status of heat accumulator (expressed in % of maximum capacity) revealed existence of two different cycles. There were denoted as "low cycles" and "high cycles". The main difference between those cycles lays in a three consecutive function extrema's of status of heat accumulator load. In the case, when difference was a two times in a range from 20% to 50% of maximum capacity, the cycles was recognized as "low cycle", while the difference two times was above 50%, the cycles was classified as "high cycle".

This way of analysis allowed to determine the frequency of occurrence of each cycle at every month. As a part of research, the average duration time of each cycle was calculated. The results are depicted in Figure 4. The examination revealed that the storage tank is the most intensively used during the transient period. In the other words, it is characterized by the largest number of cycles, while the duration of the cycles is very short, barely exceed 30 hours. In addition the ratio of "huge cycles" to "small cycles" is the smallest.

During the winter period, the dynamics of accumulator's operation decreases, while the ratio of "huge cycles" to "small cycles" increases. The average time of duration of "huge cycle" is ca. 40 hours. The decreased dynamics of storage tank utilization is a result of constant heat demand, which enables the operation of most of base load power plants with full capacity. In this situation, the optimization of operation of back pressure turbines, which operation is not flexible, does not provide considerable economic benefits. During summer period there are noticeable significant reduction of operation's dynamic of storage tank. In July and August, there are only a few cycles, which duration time is very long. The observed cycles are much different than those in other periods, because the charging of storage tank does not always coincide with the highest prices of electricity at stock market. The observations suggest that during summer period, the operation of heat storage tank is regulated in weekly mode.

Hence, the heat tank operation in July and August, i.e. the period when the average duration of each cycle exceed 150 hours, was scrutinized. This number corresponds to duration of a week, which is consistent with the assumption. It should be noted, that time of use of heat accumulator never reaches 100% during the month, because there are some moments, when the heat accumulator is not operating within tens of hours.

The next examined issue was a dynamic changes of a status of heat accumulator at every day in each period. The first stage was a determination the average % of heat accumulators' charging state at every day. Unfortunately, the specific level of charging is not a meaningful value. Thus, the derivate of the charging status over a time was determined. In order to verify the validity of optimization's decisions, the average prices of electricity in each period was added and presented in the graphs. The results are shown in Figures 5–7.

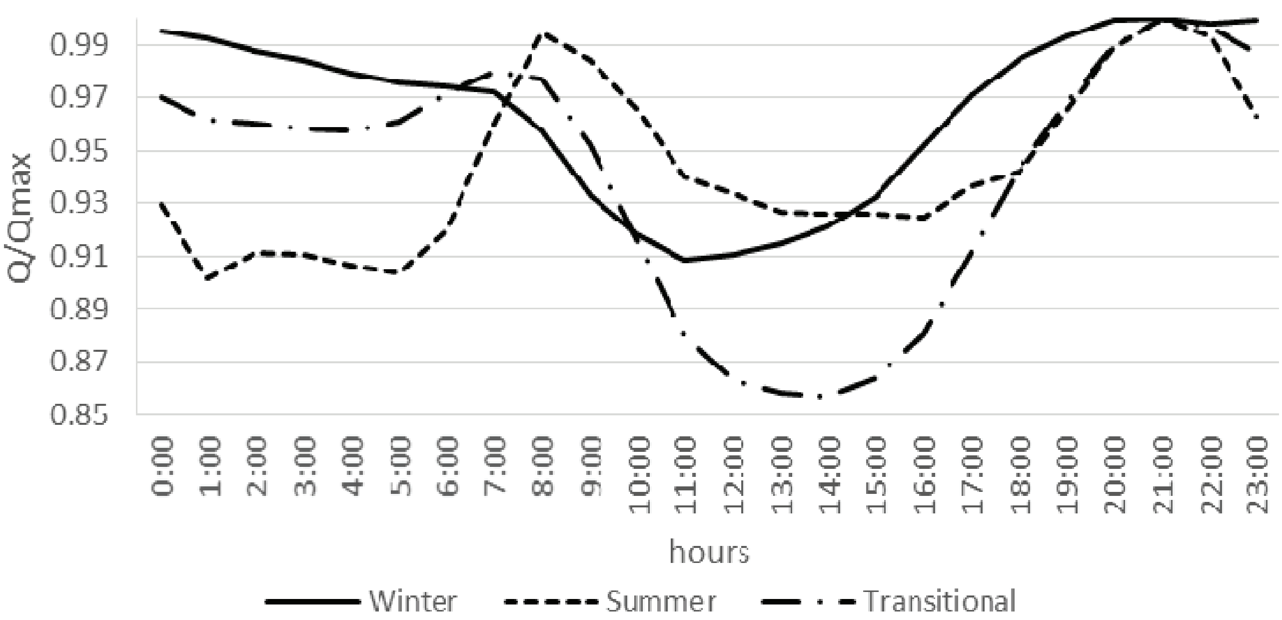

Figure 3: The average days changes of heat demand for three periods in year
(Q – average hourly heat demand at given, Q_{max} – the maximum heat demand at given period)

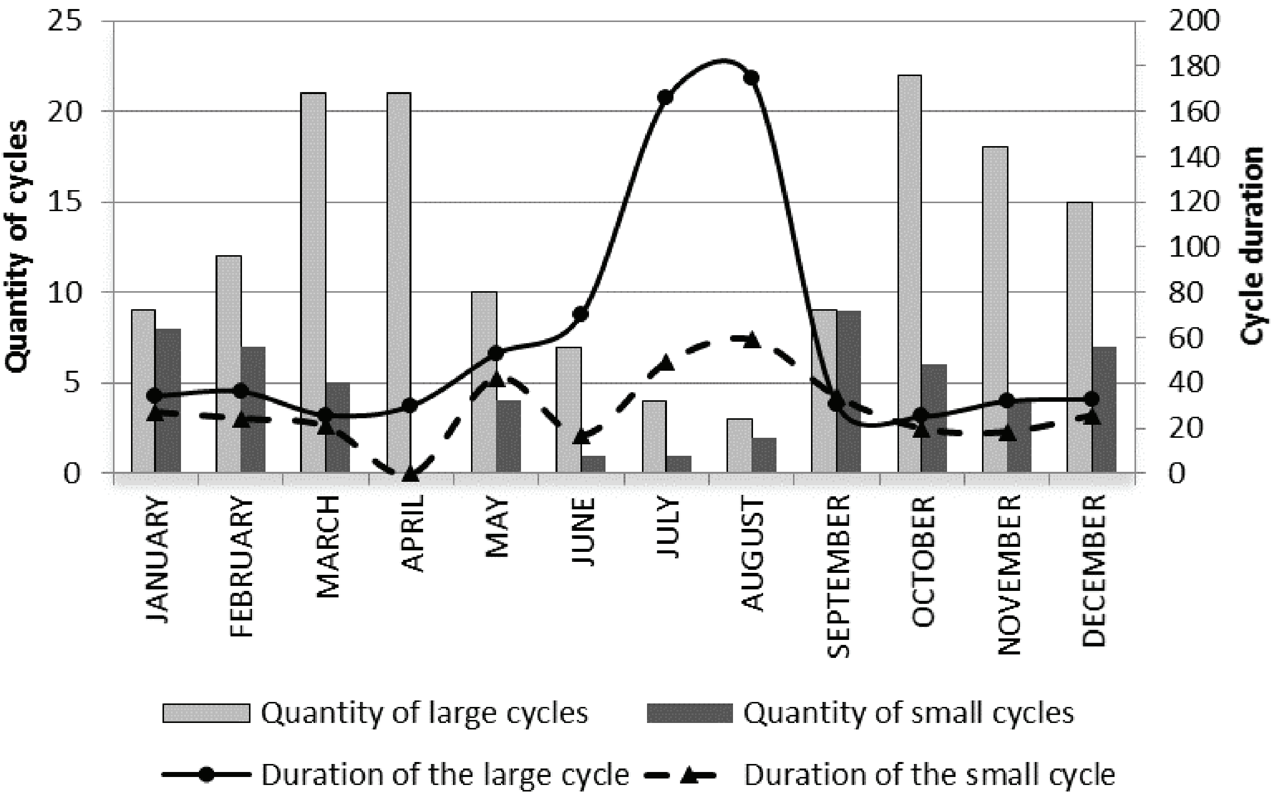

Figure 4: The amount, type and average duration of cycles in 2013

The results confirm the validity of optimizer's selection and conclusions obtained by the method of cycles' calculation. The most dynamic changes are observed in transient period. During the night, the change of tank's charge status reaches – 6.5 %/h. The maximum rate of discharging occurs at 3.00-4.00 a.m., while at this moment, the electricity price at stock market is ca. 27 €/MWh. On the other hand, during the 10:00 a.m. to

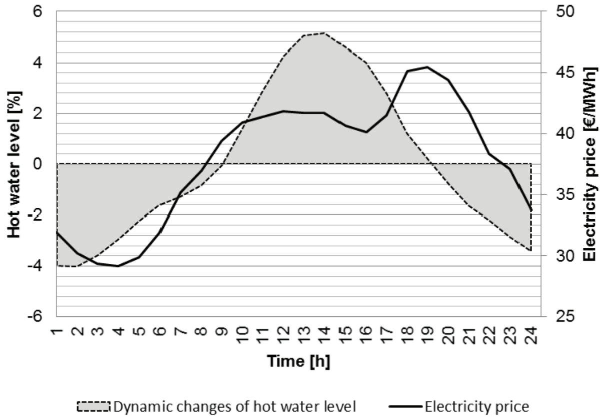

Figure 5: Dynamic changes of an accumulator charging status and electricity prices during winter 2013

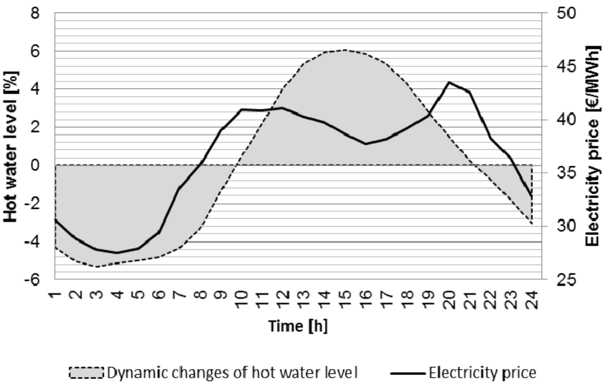

Figure 6: Dynamic changes of an accumulator charging status and electricity prices during transient period 2013

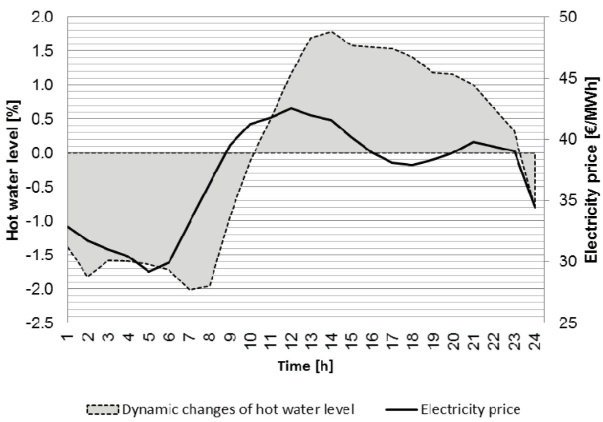

Figure 7: Dynamic changes of an accumulator charging status and electricity prices during transient period 2013

9 p.m., when the electricity price is not lower than 38 €/MWh, the heat accumulator is intensively charge with rate exceeding 6%/h. During the winter period, the charging/discharging dynamics is not so intensive, i.e. the maximum charging/discharging rate is 5.1 and –4%/h respectively. The electricity prices, in the period mentioned above, was not lower than 40 €/MWh during the charging period, while during the period with highest rate of discharging, the electricity price was 29 €/MWh. The summer period is characterized by the smallest dynamic of change of heat accumulator. The extreme speed variations of heat accumulator filling are in range -2% to 1.8%/h. Also, in this case, the maximum speed of charging occurs when the electricity prices is the highest on the stock market.

4. Summary

During the heat accumulator's examination, one of the most difficulties tasks is a correct estimation of storage tank potential after an installation. The proposed analysis allows to qualitatively and quantitatively describe the degree of heat accumulator use. The paper reports an analysis of heat accumulator use and their operation cycles were defined, i.e. "high" and "small" cycles. The "high" cycle denotes the cycle, where the degree of use of heat accumulator is high, i.e. full charging the discharging of heat accumulator. The "low" cycle stands for a cycle, where the potential of heat accumulator was not fully used. The detailed analysis revealed that the highest utilization of heat accumulator occurs during transient period. Thus, the number of "high" cycles increases, while there are only few so called "small cycles". During 30 days in a month, there were ca. 20 "large cycles". The analysis confirmed that during the summer period the heat accumulator was regulated in weekly mode.

The presented results allow to develop a methodology for assessing the actual degree of heat accumulator's utilization in a new constructed CHP plants. It shows that, during the transient period, the accumulator is able to do ca. 20 cycles per one month. In other periods, the number of cycles is significantly lower. Authors will examine other facilities to develop more universal rules.

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