SIMULATION TO QUANTIFY THE REVENUES OF LINKED CHP-DEVICES PROVIDING BALANCE POWER UNDER REALISTIC CONDITIONS

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ABSTRACT

Linking distributed energy resources to a virtual power plant (VPP) makes their electricity output more predictable and controllable. VPPs help integrating and boosting renewables as well as CHP and may reduce grid losses. Furthermore, they open energy markets to individual devices. Linked devices can take part in the wholesale market and provide balance power. Estimates of revenues are usually based on day-ahead forecasts, but they do not draw realistic irregularities (deviation of the thermal load, activation of balance power) into account. Therefore, the simulation developed at the FfE determines in a first step the revenues, based on a load forecast. By simulating deviations of the thermal load and activation of balance power in a second step, the operation of boilers and thermal storages are analyzed. The short-term redispatch and the remaining deviations reduce the revenues of the provided balance power. These ex-post revenues can be quantified within the close-to-reality simulation.

INTRODUCTION

The increase in renewable-based power generation is one of the key factors of reducing greenhouse gases. In Germany, the Federal Government defined the political ambition of increasing the share of the renewables concerning electricity generation from 16 % now to 35 % in 2020 (German Gov., 2010). However, the disadvantage of the renewables is that power generation is dependent on the energy source, e. g. wind and solar radiation are fluctuating sharply and therefore cannot easily be planned with.

Heat-lead CHP plants, which in case of local heat demand generate power, exacerbated this problem as their characteristics of power generation is a fluctuating one as well and therefore difficult to predict. However, most CHP plants have a thermal storage which could be used to temporally separate the thermal demand and electrical generation. CHP schedules can be created based on forecasts of thermal demand and these schedules can be adhered to by a proficient utilization of storages. Fluctuating power generation of CHP plants would become predictable (Arndt et al., 2007). Additionally, the same devices which are required to balance frequency deviations can be used to offer balance power (Henle, 2009). Thus, the integration of the fluctuating energy of the renewables can be improved. Already at nowadays applying price levels for grid services additional revenues can be reached. At favorable boundary conditions, these justify the required additional expenditures concerning information technology and planning.

The aim of the simulation, which has been developed at the FfE and which is presented in this paper, is to examine the quality of schedule compliances and the varying revenues which can be reached in different operational concepts of the CHP plant.

METHOD

The core element of the simulation is a unit commitment plan, which is based on MIP and which is generally used for this kind of problems. (Dentcheva et al, 2005; Hinüber, 2007).
The target of optimization is to economically run the power plants. Fuel costs and activation costs are regarded as expenditures, revenues from power supply or grid services are defined as income. Technical conditions like minimum Up-Time, minimum Down-Time, partial load efficiency and storage losses are considered within the overall boundary conditions.
The heat-lead reference operation is characterized by constant power prices. Thus, the optimization target is to minimize the losses during partial load operation, activation time and thermal storage.
The aim of power trading at the stock exchange is to shift electrical generation to periods of high prices while considering the mentioned losses.
If additional grid services are offered, the provision of positive or negative power reservation is another criterion for optimization.
The output of the optimization is the best possible result at given input parameters. However, some parameters as, for example, the thermal load and the electricity prices of the

following day are based on forecast values and therefore are subject to uncertainties.
Forecast deviations can only be quantified, when actual values are available. At this moment, the schedule of the affected time interval has already been run. These actual values enter the operation planning as updated boundary conditions and the loop of “optimization”, “assessment” and “correction” is being repeated (see figure 1).

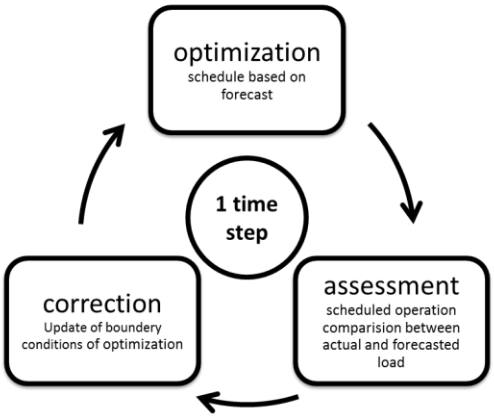

Figure 1: The closed loop of the simulation

As the power trading contract is settled the previous day (stock exchange, grid services), intraday balancing can only be effected by altering the storage operation or using the boiler.
In figure 2 the system constellation is shown. Two CHP plants, two boilers and one storage facility are connected parallel. The thermal load for future time intervals is based on forecast values, for the actual and past intervals the historical values are stated.

Three options for power trading are at the disposal: constant power prices (a), varying power prices (b) and prices for power reservation (c).
The simulation period includes 250 days in which data of forecast and measured thermal load are available and it is covering all of the seasonal temperature ranges. The period is divided into daily intervals. While doing so, an overlap is placed before and after the single daily intervals to realize the day-ahead market, respectively the anticipatory operation of the storage facility (see figure 3).

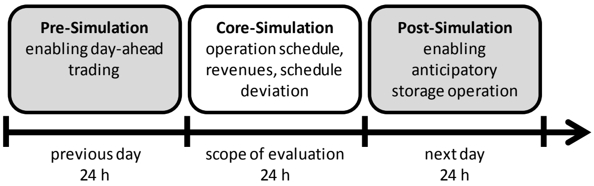

Figure 3 The sections of the simulation cycle

There is an one-hour resolution and calculation time is limited to 180 seconds, the tolerance of the result is at 1 %.
In figure 4 the operation plan of both CHP plants is shown, representing the most economical operation based on the thermal forecast. This early operation plan is determined by power trading, which has to be dispatched the day before.

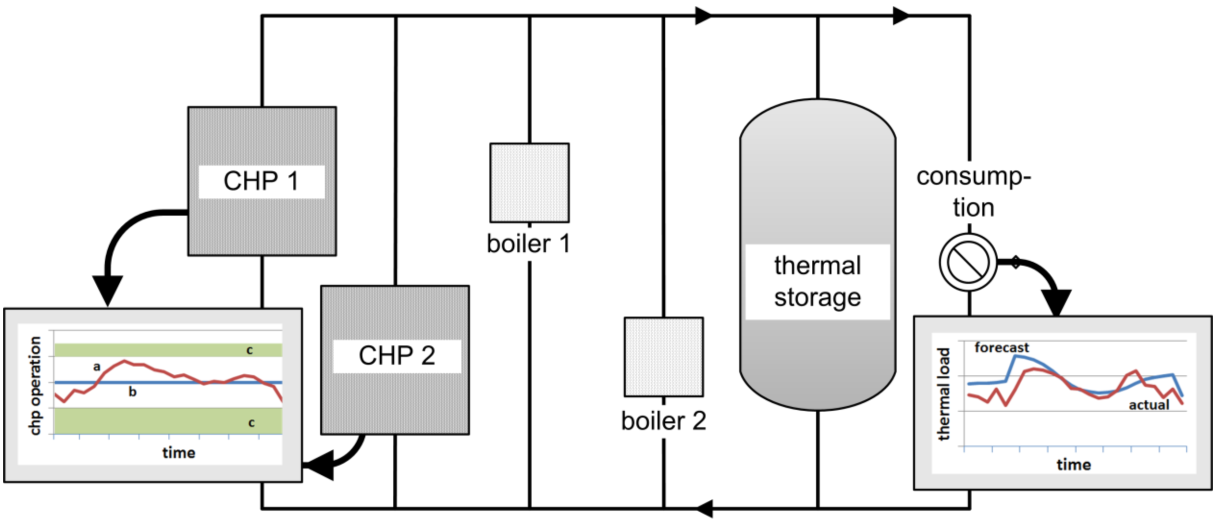

Figure 2 The system constellation

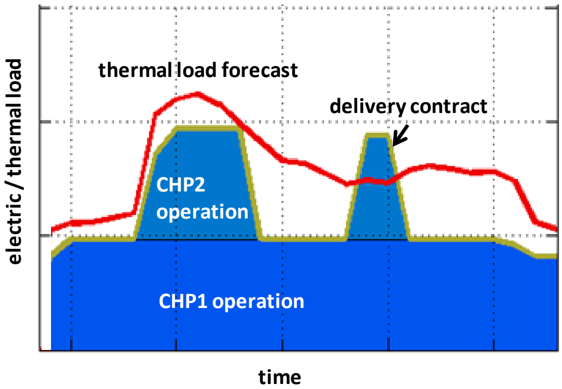

Figure 4: Schedule based on day-ahead forecast

During the looping simulation of the single time intervals of the considered day, the forecast demand is replaced gradually by the historical actual values. In some cases, these forecast deviations can be balanced by an altering utilization of the thermal storage facility or boiler. However, in individual cases this is not successful. The CHP plant has to adjust its operation and causes schedule deviations. In figure 5 the additionally occurred thermal demand is shown, as well as the CHP operation deviation.

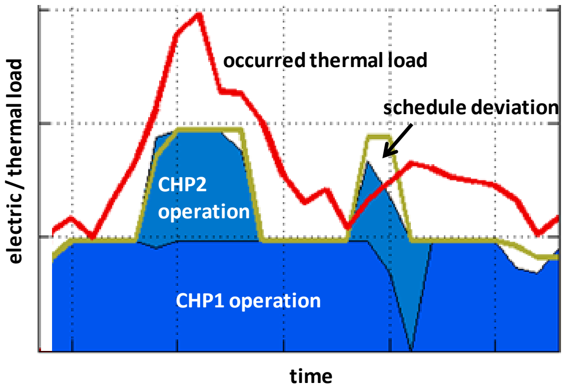

Figure 5: Schedule at the end of the day

When optimizing operation according to forecast values, the utilization of the storage facility is determined already the day before aiming for maximal revenues with these parameters. The storage is used for marketing and therefore will be called market volume in the following. Figure 6 shows that the storage is charged in periods of high power prices and discharged at low price levels.

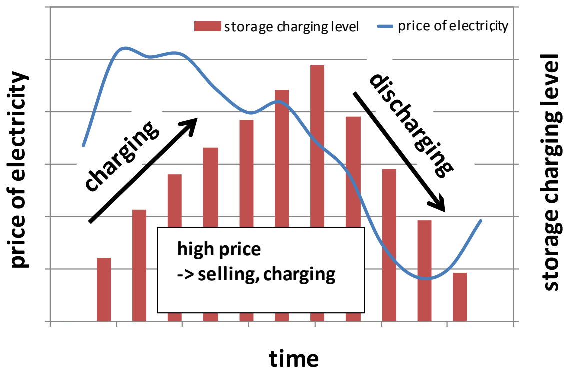

Figure 6: The market volume

The storage facility can also be used to balance short-term forecast deviations. If the CHP plant is – according to the amount contracted at the day before - generating less power than the actual thermal load is requiring (under-production), the storage can be discharged or, vice versa, in case of an overproduction, it can be charged (figure 7). In the following, this kind of storage disposal which is qualified for balancing forecast deviations is called balancing volume.

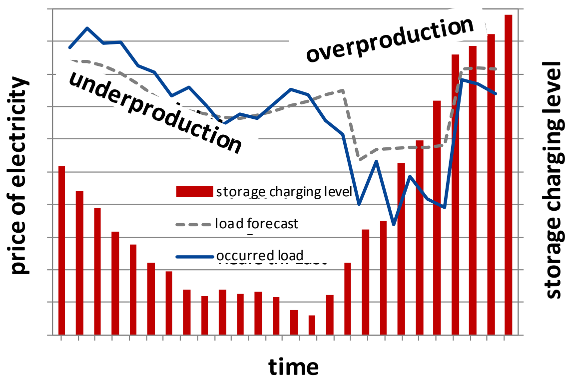

Figure 7: The balancing volume

The capacity of a storage facility can either be used as a market volume or as a balancing volume. The volume of storage, which is available in the model at market closure, is used as market volume. The additional volume which is modeled during the day is defining the balancing volume.

Besides considering the scenario of a market or balancing volume alone, the examination of the model set is also regarding the case of a 50-50 % utilization of both kinds of volume.

Additionally, scenarios of reduced power trading are examined. By this way, just an individually defined part of the possible generated power based on the thermal load forecast is marketed. Thus, the boiler is part of the operation plan already the day before in order to fill the gap between the CHP heat production and thermal load.

The power trading contracts define the schedule which shall neither fall below nor be exceeded during the day. Utilization of the storage facility or an increase in the operation of the boiler for balancing can both prevent the schedule from being deviated. If the actual thermal load is lower than the forecast, there is a danger of falling below the schedule. In this case, there is the possibility of running the CHP plant as scheduled and consequently balancing the overproduction of heat by a reduction in the operation of the boiler or by charging the storage.

Including a reduced power trading into operation planning concludes that the CHP operation might be reduced at the expense of the boiler. However, deviations in the schedule can be reduced this way.

VALIDATION

The target of the simulation is to identify the schedule which is operating most efficiently with these boundary conditions. The schedule is continuously updated if there are any deviations between forecast and actual demand. Therefore, it is not possible to compare it with the operation of a productive plant.

Nevertheless, statements can be made, concerning the adherence of the schedule within the range of the applying parameters of the plant. The schedule is valid as soon as the heat delivered equals the demand in each single time interval. Validation is confirmed after verifying the actual schedule.

The extent of the actual reached revenues which have been calculated depends on the exact power trading of each day. Within the simulation the historical market data of the examined days serve as a basis.

The same applies to the activation and the prices at the balance power market, which is regulated by tendering. The model uses the mean historical values of the price for power reservation which guarantee for a participation. The prices for power activation based on the historical demand for balance power serve as factors for the decision of calling up and therefore are varying in several scenarios.

RESULTS

The utilization of the storage facility is examined in four scenarios with modulating plant operation. The generated power is marketed at the Day-ahead spot market, the forecast revenues are shown as crosses, the actual revenues as columns (figure 8). In the first scenario, the volume of the storage is virtually unlimited available as market and balancing volume and thus identifies the theoretical potential which could be reached by an expansion of the storage facility. In the other scenarios, the so far installed storage volumes of 2 MWh are utilized, whereby 0 MWh (pure market volume), 1 MWh (50 % market volume, 50 % balancing volume) or 2 MWh (pure balancing volume) are reserved for forecast deviations which might occur.

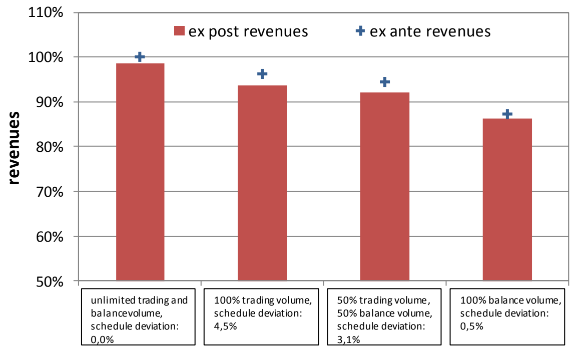

Figure 8: Revenues of different storage operation modes

It is recognizable that revenues decrease depending on declining capacities of the market volume. In turn, violation of the balance group is lower with increasing capacities of the balancing volume. The general monetary assessment of the deviations requires the involvement of all generators and consumers within the balance group and was not part of the simulation referring to the single plant. Initial estimates have shown so far, that risking deviations within the balance group appears economically preferable in order to reach high spot market revenues.

In addition to the examination of the varying utilization of the storage facility the application of reduced power trading is examined.

The revenues in figure 9 are the higher, the larger the capacity of the market volume is.

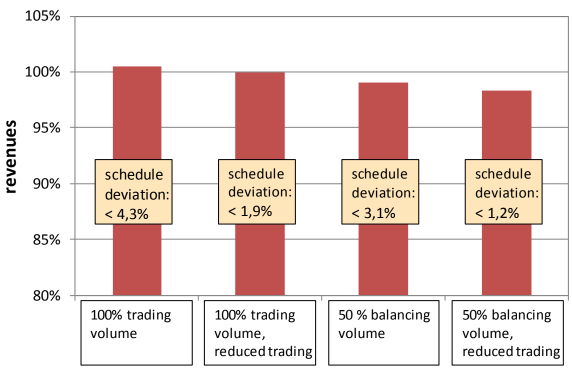

Figure 9: Revenues of different operation and trading modes

Tertiary frequency control is called up rarely and is not predicted. The actually reached revenues range similarly, if the utilization of a pure market volume and average prices for power reservation are provided (columns 1 and 2). Revenues decrease if the market volume is limited (columns 3 and 4). Calling up balance energy contributes to an increase in revenues due to the set price for power activation. However, these effects are limited as the called up amount is quite low.
Balance group deviations are generally lower when utilizing the balancing volume as well, compared to a pure utilization of the storage as market volume. Day-ahead planning with marketing below forecast turns out to be quite efficient referring to reductions in balance group deviations and thus, losses in revenues can be limited. However, the CHP-module is not utilized to capacity with this option but the boiler contributes more. Nevertheless, given the parameters of the plant, this option is a useful compromise regarding revenues from marketing and violation of the balance group.

Compared to the heat-lead operation, additional revenues can be reached by direct marketing. Revenues from power trading can be increased when marketed at high price periods as CHP subsidies and prevention of system utilization are compensated independently. In turn, higher expenditures occur due to additional storage losses and increased usage of the boiler. Costs of investment and operation which appear when linking the plant are not considered.
Revenues which were calculated the day before could be increased by 3.7 % by day-ahead marketing at the spot market. This additional revenue is reduced to 0.2 %, while balancing the deviations during the day (figure 10). This result depends sharply on the quality of the forecast and cannot always be transferred to other cases. Ex-post revenues can be increased by 7 % if direct marketing is done contemporaneously, provided that the plant could realize an average price for power reservation.

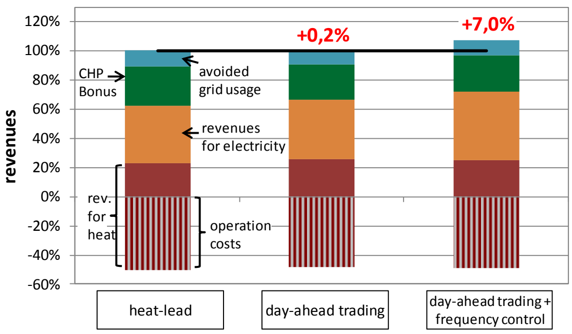

Figure 10: Additional revenues of a CHP-device

CONCLUSION

CHP plants can adhere to a self-defined schedule even if deviations between the forecast and actual load appear. This was shown using an exemplary model with historical load profiles.
There has been identified a conflict of interests regarding adherence to the schedule and maximizing revenues. Unless the maximum possible amount of power is marketed, lower revenues will be reached but forecast deviations will be balanced well by utilizing the boiler contemporaneously. If otherwise the highest possible amount of power is generated, the boiler will be utilized rarely and might not be able to further reduce its output if necessary, which will lead to deviations in the schedule.
The same conflict appears referring to storage utilization. If the volume of the storage is planned with already the day before in order to postpone the generation of power into periods of maximum power revenues (market volume), benefits will increase. However, there might not be enough storage capacity at disposal for balancing forecast deviations on short notice (balancing volume) and the schedule cannot be adhered to.
The best ratio of market and balancing volume as well as the ideal amount of power to be marketed can be identified by calculating scenarios. However, the ratio is specific for each plant, depends on the forecast quality and is determined by the costs set in case of schedule deviations.

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