MULTI-MARKET OPTIMIZATION OF INDUSTRIAL FLEXIBILITY – MARKET COMPARISON AND FIELD TEST RESULTS

Jan MEESE
Wuppertal University - Germany
meese@uni-wuppertal.de

Tobias KORNRUMPF
Wuppertal University - Germany
kornrumpf@uni-wuppertal.de

Benedikt DAHLMANN
Wuppertal University - Germany
benedikt.dahlmann@uni-wuppertal.de

Andy VÖLSCHOW
WSW Energie & Wasser AG - Germany
andy.voelschow@wsw-online.de

Tobias MARQUARDT
Wuppertal University - Germany
1322340@uni-wuppertal.de

Markus ZDRALLEK
Wuppertal University - Germany
zdrallek@uni-wuppertal.de

ABSTRACT

Most industrial customers use electricity tariffs with static prices until now and therefore cannot benefit from volatile prices at the short term markets for electrical energy. In this paper the relevant short term markets applicable for demand response and three resulting trading strategies will be presented. In a case study, these strategies will be applied to three real industrial customers and their processes.

INTRODUCTION

Due to the volatility of spot market prices, the increasing volume in the short-term trading of electrical energy and the raising share of highly automated industrial processes, the possibilities of demand response are raising. This paper will give an overview of the relevant short-term markets for electrical energy in Germany and will describe different trading strategies. The developed simulation tool will be presented and tested in a case study based on data of real industrial processes, which was gained from field tests of a demand response project [1].

CONSIDERED MARKETPLACES

In Germany, different marketplaces have been established to trade electrical energy. They can be distinguished into long-term and short-term marketplaces. Currently, most industrial customers procure electrical energy by long-term contracts and static prices. However, one opportunity to profit from flexibility of industrial processes is the price-optimized procurement of electrical energy at the short-term markets with dynamic prices. The following section describes the short-term marketplaces from the European power exchange EPEXSpot.

Day-ahead auction

The *day-ahead auction* was the marketplace with the highest trading volume (302 TWh) in 2015 [2]. The marketplace offers electricity trading for delivery at the following day in 1-hour intervals. The daily auctions take place at 12:00 pm and yield to a uniform price for every hour for all market participants. In 2015, 203 EPEXSpot participants were registered for day-ahead auction.

Intraday auction

The *intraday auction*, established in 2014, is a fairly new marketplace and was especially created for trading shorter intervals. The marketplace is useful for market participants like direct marketer who have to handle solar ramps or operators who have to balance the ramps of their power plants. At the intraday auction, electrical energy is traded in 15 minute intervals for the following day. The daily auction takes place at 3:00 pm. 94 EPEXSpot participants were registered for the intraday auction in 2015.

Intraday continuous

The *intraday continuous* market provides the possibility of continuous trading of 15 min and 1 hour blocks until 30 min before delivery. The trading of 1 hour blocks for the following day begins at 3:00 pm. The trading start of the 15 min blocks is one hour later at 4:00 pm. The major advantage of the *continuous intraday* trading of 15 min or 1 hour blocks is the opportunity to compensate forecast errors or other schedule deviations. 199 of the EPEXSpot participants' trade at the *intraday continuous*.
The sequence of the different trading deadlines relative to the time of delivery is illustrated in Figure 1.

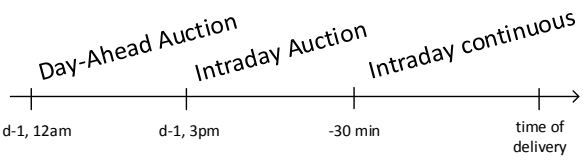

Figure 1: Timings of the considered marketplaces

TRADING STRATEGIES

Different trading strategies may be applied in order to maximize revenue respectively minimize costs on the presented short-term markets. Three trading strategies will be compared in the case study. They will be presented in the following section.

Day-Ahead and Intraday Auction only

The first trading strategy considers trading only at the *day-ahead auction* and the *intraday auction*. The advantages are the relatively simple management of the strategy – only one auction deadline for trading the predicted schedule per day – and the reduction of risk, because of

advanced prognosis possibilities, fixed prices one day in advance, and the participation at the most solvent short term market.

Continuous Intraday Trading only

The second trading strategy focusses solely on the *continuous intraday* market. This entails bigger risks because of the market volume, which is small compared to the day-ahead market. The prices are more volatile than on the other market places – this is a risk and a chance at the same time. If the considered industrial process is very flexible this might be the right otherwise the risk of being forced to buy during an expensive trading period is quite high.

Day-Ahead Trading with Intraday Redispatch

A more advanced way is *the intraday-redispatch* strategy. In the first step, the whole amount of required energy will be traded at the *day-ahead* market. Considering the individual restrictions, the industrial process will be shifted to the cheapest hours, as it is shown in Figure 2. For this example it is assumed, that the process requires an operating time of 3 hours and can be placed between 8 am and 1 pm.

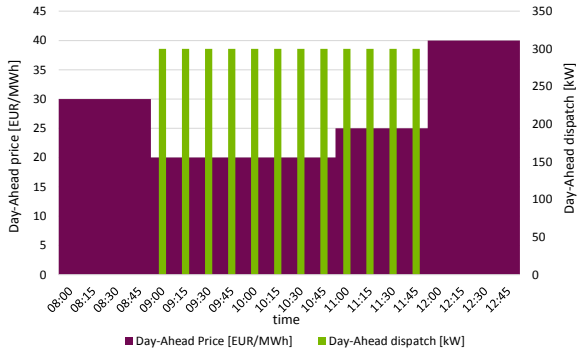

Figure 2: Step 1 - Day-Ahead Dispatch

The second step may be repeated several times during the day, just until 30 minutes before the process should start. Considering the continuous intraday prices, the industrial process is redispatched.

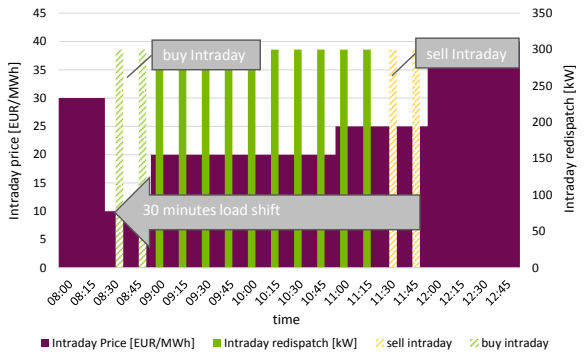

Figure 3: Step 2 - Intraday Redispatch

In the example shown in Figure 3 the intraday prices between 8:30 am and 9 am is significantly lower than the day-ahead price during this time span. The industrial process should be shifted and start 30 minutes earlier than it was scheduled day-ahead. The missing amount of energy for the time span from 8:30 am to 9 am will be bought at the *continuous intraday* market. The amount of energy that is not needed anymore between 11:30 am and 12 am will be sold at the *continuous intraday* market.
This optimization can be executed several times during the day, every time when the price spread before and after the scheduled operation time of the industrial process is high enough to cover additional handling costs and transaction fees.

SIMULATION OF TRADING STRATEGIES

The main focus of the simulation is the comparison of different trading strategies on short term markets. Therefore a simulation tool was developed and will be further explained.
The initial step in the application of the simulation tool is the definition of the process, which should be analysed. This includes the specification of the degrees of freedom and the restrictions of the process. Afterwards a three-step selection of time periods, which should be considered, is executed. In the primary step the user may choose long term periods such as specific seasons, months, and weeks. Secondly, a short term period can be selected, e.g. weekdays or holidays. Finally, a suitable time span is selected according to the restrictions of the process.
Based upon the user given instructions, an algorithm starts which will determine the minimal costs of the process. For each day of the selected period, the tool calculates the energy costs depending on different starting points. As a major part of the simulation, various trading strategies will be applied. The algorithm distinguishes hourly and quarter-hourly costs and determines the best combination. The optimal trading strategy may differ from day to day.
The steps of the simulation process are shown in Figure 4.

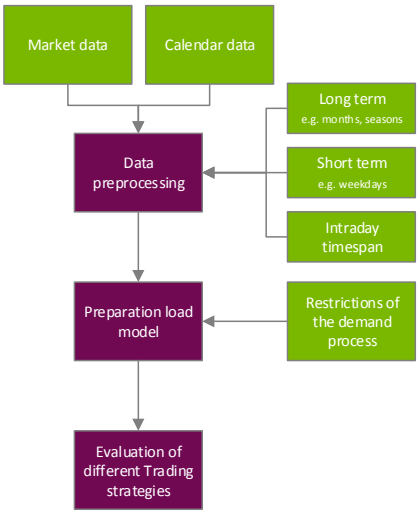

Figure 4: Flow chart of the simulation

In order to obtain a wholesale comparison, index prices for the continuous intraday market are considered. Taxes, surcharges, network charges or additional fees are neglected.

CASE STUDY

The presented trading strategies have been investigated by the presented simulation framework. The following case study is based upon results of an accomplished field test of a demand response research project.
For this case study the prices of 2015 for the considered short term markets were used [2]. For all trading strategies a perfect price prognosis was implied.

Industrial Processes

Three real processes including their individual restrictions and technical data will be used for the case study in a simplified form.

Annealing Furnace in a hardening shop

One of the steps in the hardening process within a metal tool production is the annealing. The process within the regarded company has a peak load of 200 kW, an operation time of 3.5 hours and can be shifted within 12 hours.

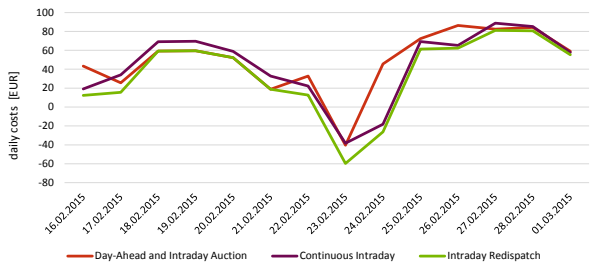

Figure 5: Results for a two week timespan of the annealing furnace

As it can be seen in the two week extract of the simulation in Figure 5 the trading strategy intraday redispatch, which combines all considered marketplaces, is the cheapest. During the whole simulated timespan of one year, this trading strategy is the cheapest at 209 days.

Combined heat and power plant with gas storage on wastewater treatment plants

Most large and medium sized wastewater treatment plants are equipped with combined heat and power plants (CHP) and cover a significant amount of the thermal and electrical energy demand by conversion of sewage gas into electricity and heat. The gas storage provides the flexibility to profit from dynamic tariffs and different short term trading strategies.
During expensive periods, the electric demand is mainly covered by the CHP, whereas during cheap hours the sewage gas is stored in the gas storage and the energy is bought on the different short term markets. In this case study the electricity is sold in expensive time steps – the CHP can instead be used to replace purchase of electricity from the grid.
The flexibility of this process is only restricted by the minimal and maximal state-of-charge of the gas storage and therefore comparatively easy to handle. The CHP must be operated 8 hours a day with a feed-in of 365 kW to process the produced gas.

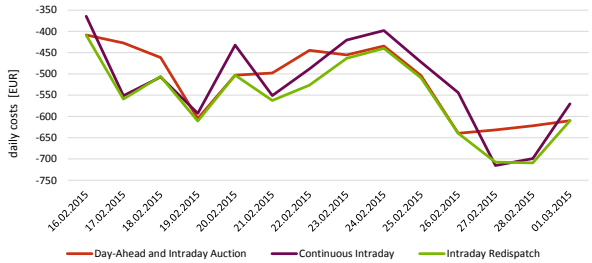

Figure 6: Results for a two week timespan for the combined heat and power plant

Understanding the achievable revenues as negative costs Figure 6 shows the revenues of the three described trading strategies in a two week timespan as an example. The *intraday redispatch* strategy is the best at almost all days. Considering the whole simulated year, this trading strategy is the best at about 50 % of all days.

Cooling system for plastic extruder

Within the production of special cables the plastic sheathing is applied. The plastic extruder as well as the cable after leaving the machine have to be cooled down. The water cooling system includes a 120 kW electrical power aggregate. The cold water is stored in a 20,000 l storage tank. The wide band of tolerable water temperature and the large volume of the storage tank allow a flexible operation of the cooling system.

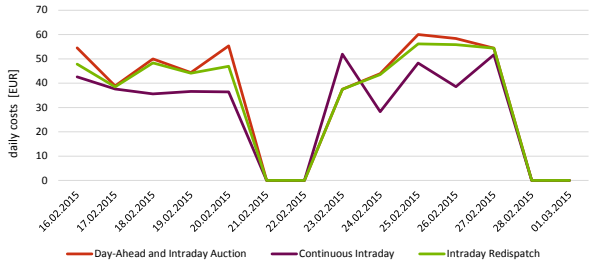

Figure 7: Results for a two week timespan of the cooling system

In contrast to the other shown processes the cooling system has lower load shifting capabilities and the operating time is restricted to the time between 8 am and 1 pm on workdays. This leads to the situation shown in Figure 7, where the continuous intraday strategy is the best in most time steps. Considering the whole simulated year this strategy is the best at 57.85 % of all days.

Results

The simulation of one year shows, that the *day-ahead only* trading strategy is the most expensive one considering the whole year. Nevertheless, by trading day-ahead only, the

risk of short-term price fluctuations can be reduced. In contrast the prognosis of price patterns on the continuous intraday market with a high accuracy is more challenging than for the *day-ahead* auctions. To achieve the same level of risk avoidance, a combination of the day-ahead and the continuous intraday market should be carried out. Figure 8 shows, that this trading strategy is additionally the most successful one on most of the days.

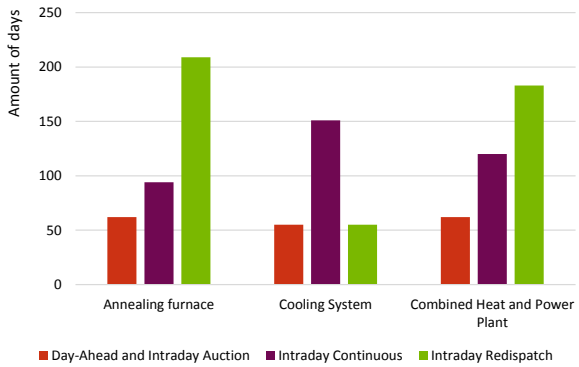

Figure 8: Amount of days with best trading strategy

As it is shown in Figure 9 the simulation of one year revealed that the costs for the both loads can be reduced by considering a trading strategy including the *continuous intraday* market up to 21 % and the revenues for the feed-in of the CHP can be raised up to 6 %.

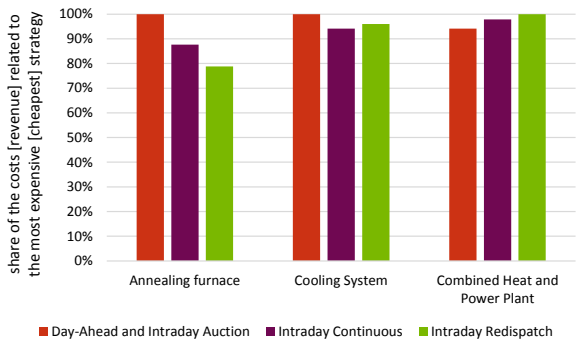

Figure 9: Costs [revenues] per trading strategy in relation to the most expensive [least beneficial] trading strategy

CONCLUSION & OUTLOOK

Until now most industrial customers use tariffs with fixed prices for the whole year and therefore cannot benefit from volatile prices at the different short term markets for electrical energy. Analysing processes regarding their load shifting potential and adding automation hardware and communication links enables the industrial customer to optimize their energy procurement.

The results of the case study show that flexible industrial processes can be used to benefit from volatile prices on different short-term markets for electrical energy. Depending on the needed investment in additional automation hardware savings might be achieved within a short period of time and therefore help the industrial customer to reduce production costs.

Due to the presupposed hardware setup, the required communication infrastructure and challenges in managing the balancing groups an implementation in the medium-sized industry is preferred instead of focussing on private households like other approaches do [3]-[4].

If there are congestions in the distribution grid or additional problems caused by an extensive use of demand response, additional requirements or incentives can be set by the distribution grid operator, too. One possibility is the implementation of regional flexibility markets on which flexible industrial processes could also participate [5]-[7]. Additional to the balancing market, other trading options for flexibilities could arise in the future– e.g. supporting the active management of a balancing groups. Due to the fast development of new marketplaces and frequent changes of the regulatory conditions, new trading strategies for flexible industrial processes should analysed on a regular basis.

REFERENCES

[1] J. Meese, N. Neusel-Lange, M. Zdrallek, A. Völschow, U. Neuhaus, 2015, "Optimal use of Demand Response Potentials in Medium-Sized Industry using dynamic Electricity Tariffs", *Proceedings of the 23rd International Conference on Electricity Distribution (CIRED 2015)*, Lyon (France)

[2] Data Source: European Power Exchange (EPEX), www.epexspot.com, 2015

[3] J. L. Mathieu, M. Kamgarpour, J. Lygeros, G. Andersson, D. S. Callaway, 2015, "Arbitraging Intraday Wholesale Energy Market Prices With Aggregations of Thermostatic Loads", *IEEE Transactions on Power Systems* vol. 30, no.2, 763-772.

[4] G. Methenitis, M. Kaisers, H. La Poutré, 2015, "A Multi-Scale Energy Demand Model suggests sharing Market Risks with Intelligent Energy Cooperatives", *Proceedings of the 2015 IEEE Innovative Smart Grid Technologies – Asia (ISGT Asia), Bangkok (Thailand)*

[5] C. Wissing, H.-J. Appelrath, 2013, "ReFlex: Market-Based Redispatch in Distribution Grids – Incentivizing Flexible Behaviour of Distributed Energy Resources", *Environmental Informatics and Renewable Energies*

[6] E. Goutard, J. C. Passelergue, D. Sun, 2013, "Flexibility Marketplace to foster use of distributed energy resources", Proceedings of the 22nd International Conference on Electricity Distribution (CIRED 2013), Stockholm (Sweden)

[7] T. Kornrumpf, J. Meese, M. Zdrallek, N. Neusel-Lange, M. Roch, "Economic Dispatch of Flexibility Options for Grid Services on Distribution Level", Proceedings of the 19th Power System Computation Conference (PSCC 2016), Genoa (Italy)

ACKNOWLEDGMENTS

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds
für regionale Entwicklung

This work was supported by the program "EFRE", funded by the European Union under the grant EU-1-1-007A within the EFRE-program "European Regional Development Fund" – an investment in our future.