IDENTIFICATION AND EVALUATION OF MARKETING OPPORTUNITIES FOR FLEXIBILITY IN LOCAL ENERGY COMMUNITIES

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ABSTRACT

Virtual power plants have been established as a crucial instrument in the course of energy transition in Germany. They help substituting conventional centralized power plants, thus promoting the integration of renewable energy sources.
This paper briefly highlights relevant marketing opportunities for VPPs including short-term energy markets, balancing power auctions and local flexibility markets. The main focus of the paper will be an approach on how to combine all marketing options in an economically optimal way.

INTRODUCTION

The transition of Germany's energy system mainly shows in the rising share of renewable energy sources (RES) regarding the overall power generation, which reached 31.5% in 2016 [1]. Since the majority of those technical units are of small or medium size in terms of absolute power generation (compared to conventional centralized power plants), they are mostly connected to the distribution grid (low or medium voltage level) [2]. Therefore interconnecting a large number of RES as well as flexible consumers may help both taking advantage of synergy effects as well as substituting conventional centralized power plants. Hereby the integration of RES is promoted as well [3].

There are several marketing opportunities for the aggregated flexibility of virtual power plants (VPPs): Since prices for energy at the European Power Exchange EPEX SPOT SE vary throughout the day, a VPP might use its technical units' flexibility to produce and offer electricity at highest prices. Accordingly, power consumption of flexible consumers may be shifted to times of low energy prices within the units' operational constraints.
Furthermore, a VPP might participate in balancing power (BP) auctions that are executed collectively by all four German transmission system operators (TSOs).
As a third marketing option for a VPP's flexibility the so-called local flexibility market is mentioned. This concept depicts a market-based mechanism for distribution system operators (DSOs) to avoid critical network situations using local flexibility as an alternative to conventional grid expansion [3].

This paper presents an approach on identification and evaluation of marketing opportunities for a VPP's aggregated flexibility.
First of all the three marketing options mentioned before are briefly described with respect to their regulatory framework. Thereby some market entry barriers (e.g. minimum offer amounts) are highlighted and first conclusions on requirements for a VPP's portfolio are drawn.
An exemplary VPP portfolio is introduced taking the technical units' operational constraints into account. They are split up in general constraints (e.g. minimum and maximum power consumption or generation) which apply for all units within the portfolio on the one hand side and individual constraints for each technical unit on the other hand side.
Revenue optimization simulations are run on the VPP portfolio using the YALMIP [4] extension for MATLAB. Prior to the implementation of a combined marketing strategy revenue simulations are run for two of the marketing options individually. Even though revenues from these simulations are expected to be lower than those from a combined strategy, they provide information on technical units' possible predestination for a specific marketing opportunity, which results from that units' individual operational constraints.

MARKETING OPTIONS

European Power Exchange EPEX SPOT

The European Power Exchange EPEX SPOT covers most central European countries, providing a trading platform for buying and selling energy. Although the EPEX SPOT offers three different markets for energy (i.e. day-ahead auction, intraday auction and intraday continuous), only two of them are considered in this paper: the day-ahead auction is regarded for previous day optimization as well as the intraday continuous for intraday redispatch. The following paragraphs depict relevant information on these two markets for Germany / Austria taken from the EPEX SPOT homepage [5].

Day-ahead auction

The day-ahead auction takes place every day at 12:00 pm determining a market-clearing price for energy for every hour of the following day. Minimum volume increment is 0.1 MW at a minimum price increment of 0.1 € per MWh.

Intraday continuous
The intraday continuous market offers the opportunity to trade energy for the current day in 1-hour-blocks as well as 15-minute-periods. Minimum volume and price increment are similar to day-ahead market. Starting at 3:00 pm on the previous day for hours (4:00 pm for 15-minute-periods) energy can be traded until 30 minutes before physical delivery (until 5 minutes before delivery within one control zone). Thus, intraday continuous market enables participants to counteract forecast deviations leading to higher accuracy of energy coverage within their balancing group [6].

Balancing Power Auctions

Balancing power is required whenever frequency deviates from 50 Hz due to either a surplus (increase of frequency) or a shortage (decrease of frequency) of power generation within the overall European transmission grid. Providers of negative BP decrease their units' power generation if a generation surplus occurs or they raise power consumption of their loads. Both measures result in a reduction of generation surplus. Accordingly providers of positive BP increase their units' power generation (or reduce their load) thus counteracting the overall shortage. Staggered among time of activation and period of upholding the power, three types of control reserve are defined by ENTSO-E [7]:
Primary control reserve (PCR) is activated automatically to full extent within 30 seconds and is delivered constantly up to 15 minutes. Calls for PCR are announced once a week by the four German TSOs collectively. Providing of PCR is compensated without consideration of activation at highest prices of the three BP types.
Secondary control reserve (SCR) is characterized by an activation time of 5 minutes and is utilized to relieve the primary reserve. SCR auctions are as well announced weekly but in contrast to PCR providing and activation are compensated using two different prices. Therefore two merit-order-lists (MOLs) are established separately, one for auctioning off providing and one for actual activation of SCR.
Secondary control is in turn superseded by tertiary control reserve (TCR) within 15 minutes. TCR auctions take place daily including two prices for providing and activation (as for SCR). The activation call for TCR is carried out electronically and its required upholding time may vary between a quarter hour up to several hours.
On July 12, 2018 regulations for SCR auctions in Germany are modified to the effect of daily auction announcements on 4-hour-blocks for the following day. Furthermore minimum offer amount is decreased from 5 MW to 1 MW [8].

Local Flexibility Markets

So-called local flexibility markets (LFM) are conceptualized as a market-based platform for local flexibility offering DSOs the chance to counteract forecasted network congestions as an economic alternative to conventional grid expansion [9]. Based on the BDEW's traffic light concept (TLC) [10], LFM is determined to avoid the so-called red phase which is characterized by the actual occurrence of a bottleneck in the distribution grid, thus leading to ultima ratio measures executed by the DSO. As a particular characteristic of the LFM, participating units' localizations are meant to be regarded since their sensitivity on the bottleneck's position has a major impact on their qualification to counteract the network congestion.

VPP PORTFOLIO AND CONSTRAINTS

VPP Portfolio

A heterogeneous VPP portfolio has been regarded for investigations in the course of this paper. It comprises of both actual identified technical units within a running research project (which is referred to later on in the acknowledgment section) as well as fictitious units, mostly RES. An overview of the entire VPP portfolio under investigation is given in Table 1.

Table 1: VPP portfolio overview

#	Technical unit	Quantity	Nominal power / kW
1	Combined heat and power unit (CHP)	3	400
2	Wind turbine	2	1000
3	Photovoltaic system	2	50
4	Emergency generator	2	200
5	Pump station	1	260
6	Power-to-Heat unit	1	200
7	Industrial loads (aggregated)	-	2400
8	E-Mobility charging stations (aggregated)	-	200

Technical Units' Operational Constraints

All technical units' flexibility is restricted by both general and individual operational constraints.
General constraints are paid attention to via setting up minimum and maximum power consumption or generation (see Table 2). Values in Table 2 are retrieved either from the actual units operators' information or they are set to nominal power (for maximum power P_{max}) and zero (for minimum power P_{min}).
Each unit's individual operational constraints are, as far as possible, set up using minimum and maximum uptimes and downtimes (see Table 2 as well). They are retrieved from operational constraints such as the size of an affiliated storage unit (e.g. for the pump station) or process-related time limits (e.g. production processes for industrial loads). Constraints in operation times are referred to as:

- min_up: minimum uptime in hours
- max_up: maximum uptime in hours
- max_down: maximum downtime in hours.

In case operation time constraints do not apply to a technical unit, they are simply not defined for it.

Table 2: Power and operation time constraints

#	P_{min}	P_{max}	min_up	max_up	max_down
1	200	400	10	-	-
2	0	1000	-	-	-
3	0	50	-	-	-
4	100	200	1	5	-
5	130	260	5	-	5
6	200	200	-	-	-
7	2400	2400	1	-	1
8	100	200	8	-	-

Additional constraints are set up for specific units individually (e.g. emergency generators are meant to run at least once a month to ensure functionality [11]) as well as for the overall portfolio (e.g. fixed pooling size in order to overcome minimum offer amounts for BP auctions).
Power generation for RES units (i.e. wind turbines and photovoltaic systems) is taken from representative measurements from 2016.
Regarding the technical units' operational constraints, participation in BP auctions is limited to offering SCR. Since regulations for SCR auctions will be modified by the middle of the year, offering SCR is simulated using the new regulations (i.e. daily auctions for time slices of 4 hours of the following day).

REVENUE OPTIMIZATION SIMULATION AND MARKETING STRATEGIES

Revenue Optimization Simulation

Revenue optimization simulations are run using YALMIP extension for MATLAB. Therefore the VPP portfolio including the operational constraints mentioned above is implemented on the basis of time series with a step width of 15 minutes. The VPP portfolio revenue (which is to say the objective of the optimization) is calculated as the difference of flexibility marketing income and power generation costs. Optimization of the VPP portfolio's flexibility commitment leads to a mixed-integer linear programming (MILP) problem which is solved utilizing Gurobi Optimizer. The horizon (i.e. the time period covered by the simulation) is set to one representative month which comprises of one week from each season in 2016 concerning RES power generation and price data.

Investigations on different Marketing Strategies

In the following section marketing strategies for the VPP are described. Table 3 gives an overview of implemented marketing strategies staggered by complexity. Marketing opportunities that are taken into account within the respective simulation run are marked with an "x", those who are neglected with a "-".

Table 3: Marketing strategies under investigation

Simulation run #	EPEX SPOT	SCR	LFM
1	x	-	-
2	-	x	-
3	x	x	-
4	x	x	x

For simulation runs no. 1 and 2 only one single marketing option is taken into account (energy trading at EPEX SPOT and participation in balancing power auctions). LFM as a single marketing opportunity is not mentioned since calls for flexibility auctions at LFM are expected to be infrequent.

Combined marketing strategy
In simulation runs no. 3 and 4 a combined marketing strategy is implemented regarding 2 (for run no. 3) or 3 marketing options. The underlying approach for a combination of marketing opportunities is to predict revenues for each of them, selecting that one most likely leading to the highest revenue. Offering flexibility on different markets results in the necessity to pay attention to all these markets' regulations. Therefore additional constraints are added to the existing MILP problem which apply to the overall marketing of the VPP portfolio's flexibility: Chances to change the currently served market are restrained by that one marketing option with the strictest regulations (i.e. fixed time slices of 4 hours for SCR).

Results

As results suitable for drawing a comparison between the different marketing strategies, the objective of each optimization (i.e. the revenue of one month offering the VPP's flexibility) is regarded.
Figure 1 shows revenue results in € for the different marketing strategies under investigation in this paper.

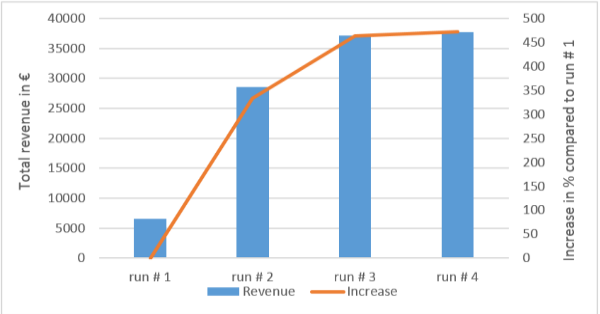

Figure 1: Comparison of total revenues for marketing strategies under investigation

Figure 1 clearly demonstrates that applying a combined marketing strategy for the aggregated flexibility of this VPP pays off in higher revenues than focusing on a single marketing option. Compared among themselves offering SCR as a single marketing strategy leads to more than 3 times higher revenue than trading energy at EPEX SPOT.

The additional increase in revenue for simulation run no. 3 (i.e. combination of EPEX SPOT and SCR) is due to the possibility of serving those two markets simultaneously. For instance regarding a CHP unit the effect of different marketing strategies may be illustrated: For simulation run no. 1 (EPEX SPOT energy trading only) the unit's runtimes are chosen to be those hours of highest energy prices. For offering SCR only (simulation no. 2) total runtime is maximized within operational constraints since SCR income is higher than power generation costs (i.e. fuel costs for natural gas). Applying the combined marketing strategy to the CHP unit leads to both income from EPEX SPOT (selling of energy produced during runtime) and from SCR auctions for offering negative BP.
Increase in revenue for simulation runs no. 3 and 4 (additional participation in LFM) is comparatively low due to several reasons: Traded amounts of energy at LFM are low since LFM auctions take place on low voltage grid level. Additionally calls for flexibility auctions at LFM are simulated infrequent. Their frequency is expected to rise with the share of RES in low voltage grids since their power generation is volatile and few peaks may overstrain the current grid hardware.

CONCLUSION AND OUTLOOK

Three different marketing opportunities for an exemplary VPP have been depicted in this paper: energy trading at EPEX SPOT, providing balancing power for TSOs and participating in local flexibility markets used by DSOs.
Revenue optimization simulations on both single and combined marketing strategies have shown that an added value is achieved by combining marketing options for the VPP portfolio under investigation. The impact of different marketing options on total revenues varies strongly: Participation in BP auctions (i.e. SCR in this case) leads to much higher revenue than focusing on EPEX SPOT only. Providing local flexibility for DSOs at LFM has comparatively minor impact on total revenue since energy amounts are low and calls for LFM infrequent.
Further work may take additional marketing options (e.g. balancing group management) as well as diverse VPP portfolios into account.

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