CONCRETE DESIGN OF LOCAL FLEXIBILITY MARKETS USING THE TRAFFIC LIGHT APPROACH

Kevin KOTTHAUS, Jessica HERMANNS, Frederik PAULAT, Sven PACK, Jan MEESE, Markus ZDRALLEK
University of Wuppertal – Germany
Kevin.Kotthaus@uni-wuppertal.de

Nils NEUSEL-LANGE, Torben BRAJE
SPIE SAG GmbH – Germany
Nils.Neusel-Lange@spie.com

Fritz SCHWEIGER, Robert SCHWEIGER
E-Werk Schweiger oHG – Germany
Fritz@ew-schweiger.de

ABSTRACT

The progressing expansion of decentralized renewable energy conversion systems in low and medium voltage grids is accompanied with upcoming congestion problems that will occur more often in the near future. This paper presents a specific concept of much discussed local flexibility markets (LFM) as an emerging role in present smart grid solutions. Determinations of all market participants and their mandatory data exchange are followed by the concrete design of tradable flexibility products and the auction timetable. Furthermore, the BDEW traffic light concept (TLC) is focused and implemented by using defined green and yellow phases for predicted congestion. The results demonstrate the benefits of the characterized LFM and identify unique procedures based on the TLC.

INTRODUCTION

The continuous development of the installed capacity of renewable energy systems leads to a conversion of the conservative supply task even for Distribution System Operators (DSO). The increasing integration of electric vehicles, storage systems and new consumption patterns, e.g. based on price signals, could intensify those issues in the near future, but also provide a possible solution in the form of enhanced flexibility. In that regard, flexibility is the ability of energy conversion systems to temporarily alter their local electrical power consumption or generation [1]. In most of the current distribution grids the grid capacity is exceeded only a few hours per year. Innovative grid services provide reasonable solutions to reduce or postpone conventional enhancement of the grid. Active grid users (prosumer) which offer different flexibility options can support their DSO to solve voltage boundary violations and overloads [2] in an economic and ecological manner. Meanwhile established real-time control like curtailment of PV-generation as an ultima ratio option yields no prevention of limit violations and is based on bilateral contracts. Related compensation payments are cost-intensive and increase the grid fees.

This paper will present the concrete design of a LFM that enables the participation of fragmented flexibility by lowering technical obstacles and allow simplified market access for system owners. The focus will be on the characterized market structure divided in two essential parts with defined timetables, marketed products and the remuneration model for accepted auction offers. While recent publications [3][4] investigate various approaches of the BDEW TLC [5], in this paper especially the green and yellow traffic light phase as well as the change trigger will be directly addressed. In addition, the method of predicting congestions using Grid State Forecast (GSF) algorithm and its functionality in the overall LFM process will be introduced. The traffic light module (TLM) as an indispensable supplementary component evaluates the GSF outcome and checks the DSO's options for action. The TLM regulation concept is a key factor in the LFM procedure and will be discussed in the classification of the green phase.

LOCAL FLEXIBILITY MARKET DESIGN

Market Actors and Roles

The main actor in the environment of discussed LFM approaches is the DSO as an exclusive consumer of flexibility products offered at the LFM online trading platform. Local congestion problems affect always just the relevant concession holder. In this regard, the DSO is automatically forced into the role of a sole buyer so called monopsonist at the specific marketplace. In this case the service provider who manages the LFM is another market actor than possible buyers (DSO) for particular marketplaces placed on the online trading platform.

The already mentioned LFM service provider administrates several marketplaces pooled at one online trading platform. In the future development and establishment of LFM multiple service providers in one superordinate grid territory are conceivable. Beyond the task of managing and visualizing all submitted offers, to determine the cost-optimized combination of offered flexibilities to fix predicted congestions is a key task. This optimization process and the accessible online trading platform are spatial detached from each other so that sensitive data are always subject to comprehensive data protection.

Third market actor is the flexibility provider who submits his offers via password-protected internet access. This access will be allowed after a previous pre-qualification procedure. Private system owners can participate in the LFM as well as intermediary companies like aggregators [6] that are pooling private clients.

Aggregators could assume commercial and technical administration at the LFM and other power markets for them. In both cases bids as standardized products can be offered over a defined longer period between market opening of the affected marketplace and the market auction. The selection of the contract award and different approved call procedures grant nearly unlimited conditions of participation with low obstacles.

Data Exchange

As soon as several market actors are involved in LFM concepts provided and shared information is a critical point to be clarified for all parties. Before flexibility providers get full access to the online trading platform necessary registration and system data, that are required from the LFM service provider, have to be indicated. Personal data like the address, owner name or account password are queried by the one-time user registration. Permanent system data are also mandatory for the LFM registration process and include the control type, optional control stages and the call procedure. Details of the precise location via street name and house number are needed to identify the grid connection point. After all system data is confirmed in the pre-qualification process standardized offers including minimal and maximal power output as well as variable price components and a possible fixed capitalized lump sum can be submitted for advertised time-slices. Figure 1 illustrates this data exchange as one part of the general LFM interface. restrictions for the optimization framework. The amount of compulsory grid parameters depends on the type of used matching algorithm which is an interchangeable element in the presented LFM design. The optimization toolbox is constructed modularly and is under the control of the LFM service provider.

LFM Course of Time

Contrary to other recent approaches [7] this concept does not consider long-term commitment and bilateral agreements an expedient solution to acquire primarily small flexibilities and those which are not always available on distribution network level. Especially with regard to increased private use of e-mobility short-term solutions seem more favourable. Furthermore, the forecast quality increases with decreasing forecast horizon based on more accurate input data so that the flexibility needs assessment has minor variance. The concrete course of time of the designed LFM is displayed in Figure 2. The whole sequence starts with the first 24 hours rolling forecast and is repeated every hour for the next 24 hours. The yellow traffic light phase triggers the LFM market opening for affected marketplaces at the earliest six hours before predicted congestion. During this period of six hours a market opening is possible every time when the GSF module calculates a new grid state and the TLM identifies a probable voltage boundary violation or a cable overload. The flexibility schedule will be optimized exactly 45 minutes before the predicted congestion occurs and notifications about accepted as well as rejected offers will be dispatched. This proceeding allows refused flexibility providers to sell their flexibility short-term at the continuous intraday market.

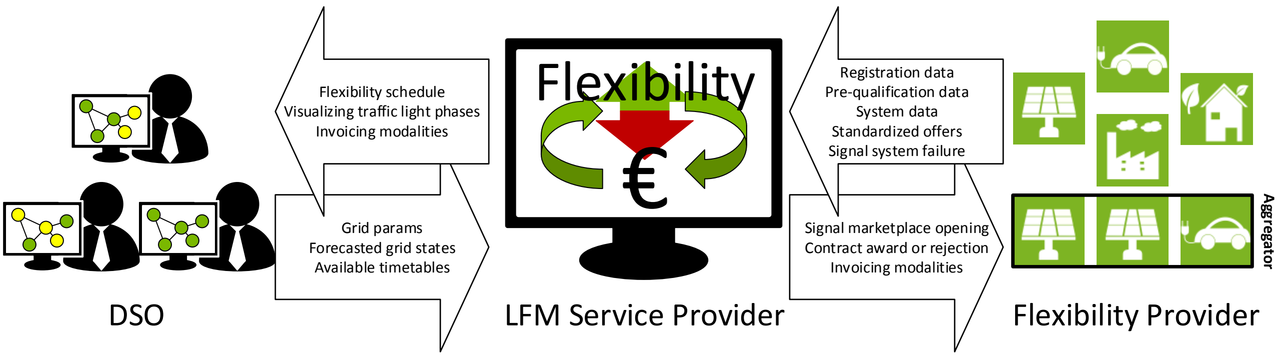

Figure 1: Interface overview of mandatory market actors

Signals for marketplace openings directly reach out to local flexibility providers that could influence a predicted congestion due to their grid connection point. Notifications of firm commitments or rejections of bids received and invoicing modalities have to be transmitted like the proceeds achieved by selling flexibility at the LFM. A further part of the sensitive data communication is the data interface between LFM service provider and the DSO. Flexibility schedules as the output of the optimization module and a visualizing of traffic light phases are made available for the participating DSO. Meanwhile, the LFM service provider needs forecasted grid states which predict voltage boundary violations or overloads for defined 15 minute timeframes. Another input parameter are the accurate grid parameters to describe the relevant node relations and other grid

TRAFFIC LIGHT CONCEPT

Green Phase

In addition to the determined course of time, all LFM procedures are classified in three traffic light phases based on the BDEW TLC [5]. Most of the presented processes take place in the green and yellow phase, whereas the red phase is a fallback level that will be discussed briefly. At first the concrete contents of the green phase will be presented in this subsection.

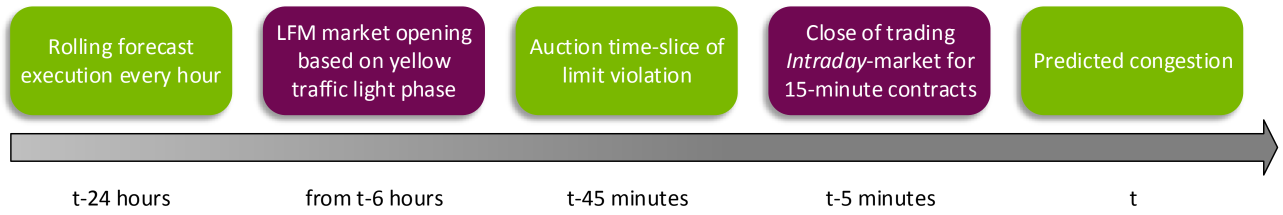

Figure 2: LFM course of time

In the green phase flexibility providers can operate freely at all accessible power markets. The specific LFM marketplace is closed and the flexibility provider can be neglected, except for providing schedules as an GSF input parameter. The TLM verifies by means of power flow calculations whether a predicted grid state results in a congestion or not. If a possible future voltage boundary violation or a cable overload is detected the TLM examines possibilities of the DSO. As a first step, assets for voltage control are considered, followed by reactive power control and concluded by active power measures.

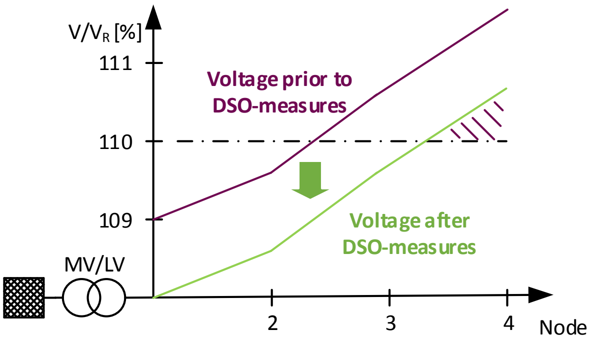

Figure 3: Influence of own DSO-measures

Figure 3 demonstrates the influence of a variable transformer on the LV level voltage curve. After exploiting all available DSO-measures the TLM decides whether there still exists a predicted congestion and the LFM marketplace has to be opened or the options for action in the green phase are enough to solve the occurring problem. Because of the unavoidable error deviation of forecasting in general, the TLM trigger to signal a necessary marketplace opening should not be initiated on the basis of just one long-term predicted grid state. The presented concept provides to gather single results based on outputted grid states by the GSF for separate time steps and evaluate them afterwards.

The evaluation of voltages is performed by the weighting function below (Eq. (1)).

$$V_{i,t} = \sum_{k=1}^{n} a_{t-k} \cdot V_{i,t-k} \qquad (1)$$

The functional value $V_{i,t}$ describes the predicted voltage of node i at event start time t. The variable $V_{i,t-k}$ is the predicted voltage of node i for the time step k hours before event start. Due to improving weather forecasts and more available schedules predicted nodal voltages should be weighted more strongly with decreasing forecast horizon. The weighting factor a_{t-k} increases for every time step, but the following equation must be satisfied (2).

$$\sum_{k=1}^{n} a_{t-k} = 1 \qquad (2)$$

However, the mathematical correlations to characterize the increase have to be validated with measured values and further research. In case of a linear correlation the specific weighting function might look like equation 3.

$$V_{i,t} = \sum_{k=1}^{n} \frac{2 \cdot (n+1-k) \cdot V_{i,t-k}}{n(n+1)} \qquad (3)$$

Only if the outcome of at least 18 weighted forecasted grid states determine a probable congestion, non-solvable by all available DSO-measures, the TLM triggers the change to the yellow traffic light phase. Modified grid states based on a short-term forecast, which include all impacts of DSO-measures, will be dispatched to the LFM service provider as an input factor for the optimization.

Yellow Phase

As soon as the change trigger is initiated the online trading platform opens the relevant marketplaces and signals reach out to affected flexibility providers. Offers can be submitted via individual user access for critical 15-minute time slices within the sensitive grid territory. Instead of indicating specific power values the online trading platform visualizes just the existence of a predicted congestion. Flexibility providers should be incited to offer their maximal power change potential to enhance possible optimized flexibility schedules calculated by the LFM optimization module. Cost functions will be considered in the optimization algorithm besides other parameters like the grid connection point because of the physical sensitivity. Variable costs must be declared by the creation of offers at the online interface. Fixed cost components are optional and serve the purpose of compensate flexibility providers for additional effort. This lump sum provides additional incentives to participate at the LFM.

The possible lack of liquidity and large gaps in this regard between separate grid territories is often mentioned. That effect will be much stronger if hurdles for participation are extensive and expensive. The presented design supports even private flexibility providers with small power change capacities to participate at the LFM.

The more flexibility offers can be recorded during the time frame of the opened marketplace, the more combinations to solve predicted limit violations can be considered in the optimization process. Moreover, it is expected that the competition accelerates and flexibility providers undercut each other's prices. As a consequence, costs of the DSO to purchase flexibility should decrease due to an increased use of storage systems, e-mobility and combined heat and power applications.

The market closing comes up 45 minutes before start time of the critical event. At this point, all submitted bidding data are passed to the optimization module as an input parameter along with necessary grid data and the newest predicted grid state based on the short-term forecast. The matching algorithm will satisfy the cost-reducing objective under all these constraints and the optimization module will output a system schedule. Another objective can be taken into account to minimize the curtailment of renewable energy systems. This option is selectable by the DSO depending on his individual preferences. Notifications of contract awards or rejections complete the trading cycle at the LFM for one single time slice. If the optimization module does not converge, because of too low participation or other causes, the red traffic light phase will be enabled and the Smart Grid System will operate to solve the congestion in real-time.

CONCLUSION AND OUTLOOK

The independence of all involved modules in the presented Local Flexibility Market design allows the replacement of individual components and is open to the interaction with various Smart Grid Systems. Low obstacles should enhance the participation of small flexibility providers to increase the liquidity and the remuneration model offers further incentives. These aspects could provide a widely prosumer acceptance for developing Local Flexibility Market solutions. Forecasts with a maximum 24 hours' horizon and flexible marketplace openings ensure the avoidance of long-term contracts. This framework simplifies especially the participation of e-mobility charging stations, because they are only available in certain periods. Partially rigid schedules provide clarification for promised flexibility providers. Meanwhile, the appropriate lead-time after auction ensures marketing at other power markets for rejected offers.

Furthermore, the stated procedures taking place in the Local Flexibility Market cycle, from the green phase through a specific explained change trigger to the yellow traffic light phase, illustrated a concrete Local Flexibility Market design. Market actors and mandatory data exchange were determined throughout this paper. The possibility for Distribution System Operators to complement the optimization process with the objective of minimize curtailment of renewable energy systems should be highlighted. Invoicing modalities as well as standardized contractual arrangements after the market auction and verification of flexibility service provisions are organizational challenges to overcome for the establishment of the designed Local Flexibility Market. Beyond that, amendments of the current energy industry regulations seem absolutely necessary, for example the creditability in the Incentive Regulation Ordinance for Distribution System Operators by acquiring flexibilities for their congestion management.

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