Process approaches for the integration of controllable consumers and producers in the energy market, taking account of the distribution grid

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***Abstract*—Medium term, the availability of controllable decentralized feeders and loads within the low-voltage distribution grid provides grid operators with a major challenge but also a great opportunity. Either expansion of the local network area and thus the ability to transport and distribute every kW of power and each kWh of energy. Or the efficient use of the existing infrastructure by appropriate measures to reach a local balance between supply and consumption. In this work, two main process approaches developed within the project sMobiliTy are introduced. Aim is the use of available network capacity as flexibility to integrate controllable resources in the liberalized energy market, taking account of the distribution grid. It will be presented on the example of electric vehicles.**

***Index Terms*--flexibility management, distribution grid, smart grid, smart market**

I. Introduction

To motivate and illustrate the problem and approach, the following example is given. Considered will be a low voltage network section from a reference model for low and medium voltage distribution grids developed at the Fraunhofer Institute [1], especially a settlement structure with the following parameters: a substation with 630kVA apparent power, 135 buildings, 2 apartment units per building and 2 inhabitants per apartment. The transformer is operated at a maximum load of 70% of installed capacity and an active power factor of 0.95. This results in an operating limit of 418 kW for the load (*CmaxL*) and feedback (*CmaxS*) from and to the upstream network. In the low-voltage grid PV feeder according to the BMU pilot study 2011 [2] are modeled for the year 2018. Figure 1. shows the local load, feed-in from the installed PV and the resulting residual profile as balance of load and feed-in for a typical summer day in 2018 for the considered local service area as well as the maximum capacity for the transformer (Assuming that *CmaxL* equals *CmaxS)*.

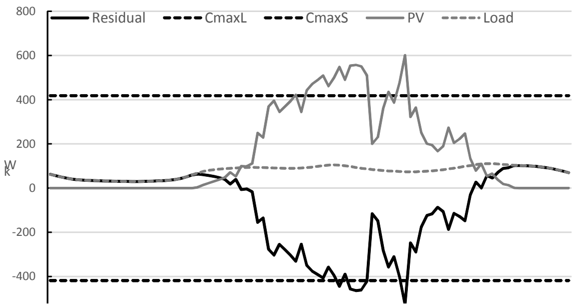

Figure 1. Representation of the resdiual profile on a summer day

Clearly the influence of the high PV feed-in can be seen. The residual balance reaches values that cannot be transferred through the substation. The network operator has to reduce feed-in systems in terms of security of supply.

II. The Flexibility Frame

At the same time the Figure 1. shows the huge potential for further loads and generators. Without taking into account restrictions from the upstream network the area above the residual load up to the load limit of the local substation is available for further consumers, the area below the residual load for further producers. These areas represent a *flexibility frame* determined by an upper limit or *load flexibility* (*FlexL*) as difference between *CmaxL* and the residual load and a lower limit or *feedback flexibility* (*FlexF*) as difference between *CmaxS* and the residual load. This frame depends on the behavior of producers and consumers, which are not directly influenced and thus determine the residual load.

The project sMobiliTy (http://www.smart-mobility-thüringen.de) is a public research and demonstration project founded by the German Federal Ministry of Economic Affairs and Energy (BMWi).

In addition to the residual load the flexibility frame also depends on the requirements from the upstream network. These are manifested in a change of the restrictions on the local substation. The Figure 2. shows the flexibility frame whereby the feedback over midday is restricted by the upstream network operator. This results in a higher shift of *FlexF* into the positive range. If available, new controllable consumer could prevent the shutdown of uncontrolled feed-in by shifting load into this time.

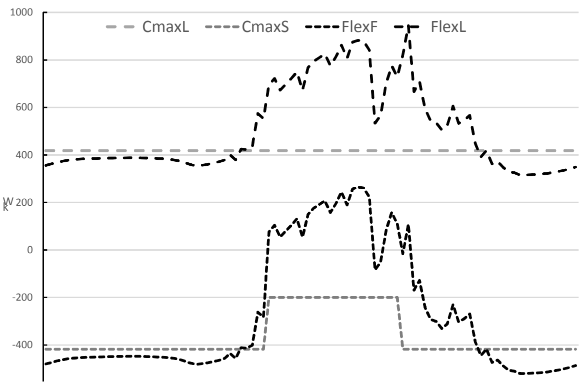

Figure 2. Flexibility Frame with restrictions from upstream network

The integration of new producers and consumers without coordination and harmonization can lead very quickly to the operating limits of the distribution grid. If new resources are controllable, the available flexibility frame of the distribution grid should be provided. Thus, the use of the network is made more efficient. With this aim the flexibility frame can be considered as a specification for the power balance of controllable producers and consumers in the considered network area. The following assumptions apply on the frame limits for the balance:

- *FlexL* > 0, an increased load is possible
- *FlexL* = 0, the balance must not contain any consumption, the feed-in must be at least greater than consumption
- *FlexL* < 0, there must be a feedback, thus in balance the feed-in must be higher than consumption by the required amount of FmaxL
- *FlexF* < 0, an increased feedback is possible
- *FlexF* = 0, the balance must not contain any feedback, the consumption must be at least greater than feed-in
- *FlexF* > 0, there must be a consumption, thus in balance the load must be higher than feed-in by the required amount of *FlexF*

III. Technical Assumptions

The theoretical assumptions for the approaches presented in this paper are explained in detail in [3]. In the project sMobiliTy electric vehicles (EV) are considered controllable consumers. The charging rules or charging restrictions are transmitted to the charging infrastructure or *Autostrombox* (ASB). Charging of electric vehicles is based on the standard ISO 61851 mode 3. The ASB calculates the resulting charging profile and defines the available charging power for the EV. To realize the metering, smart meters in conjunction with a communication unit (MUC) are installed on every ASB, installed feed-in resources (DER) within the considered local network area and on the substation. The communication between the meter operator system (MSM) and the MUC is done via GSM radio, between ASB and MUC via wM-Bus. The ASB provides customer specific data such as plug-in and plug-off. For the power supply every ASB is associated with an energy service provider (ESP). For non-discriminatory transmission of information to the ESPs the cloud approach is pursued in the project. To transmit the control signals, the long wave radio is employed. The addressing of the ASB is done in groups or individually. Depending on the priority the control signals are transferred via a data service (Service) or directly via long wave management (EFR).

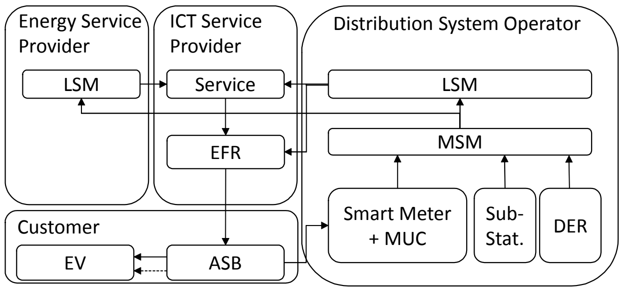

Figure 3. simplified representation of the technical structure

The determination of the control signals is carried out depending on the approach by the ESP or DSO in the load and supply management system (LSM). The definition of the flexibility frame for each substation is as described above using a forecast for the residual load and taking requirements of the upstream network level into account. Forecasting approaches to predict local feed-in from wind and PV as well as investigations regarding local consumer predictions are described in [4] and [5].

The technical structure thus supports the implementation of the processes for the security management from the perspective of the network operator as well as two alternative approaches to the integration of the network aspects in the energy market.

IV. Network Security Management by the DSO

If there is an immediate threat to network stability and security of supply, the responsible system operator must immediately intervene in the market. This is done based on legal regulations through automated controls. The process of the network security management in the project is shown in the Figure 4.

The DSO monitors the grid area based on the defined limits, upstream network constraints and current network information from the installed smart meters.

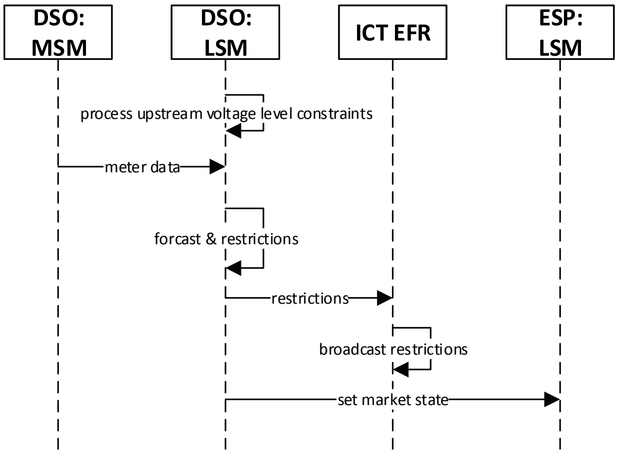

Figure 4. Network Security Management

In case of a violation the DSO controls the ASB through specific restrictions directly transmitted via EFR, thus shifting planned downtime or vary the charging restrictions. With respect to market phases of the BDEW concept [6], this is the market phase "RED". No ESP is entitled to control the available units in the affected area. With regard to secure supply and an economic implementation, this phase represents a high planning risk for all partners. Two further approaches are presented, which are intended to minimize or even avoid direct intervention by the network operator. In comparison to aproaches described in [7] or [8] this approaches do not intend to implement a local market with local prices. Target is the integration of local grid aspects into the existing energy market by providing restrictions from the DSO to the market partners.

V. DAY-AHEAD RESTRICTIONS BY THE DSO

To enable the integration of the network aspects in the market, the market partner information about the current grid status and a way of considering them. In the project the necessary day-ahead forecasts to determine the flexibility frame are based on the smart meter data and the present weather forecasts for the following day. The compliance with the flexibility frame is determined by identifying individual restrictions for every ASB taking into account the customer's specifications. Finally, the restrictions are communicated to the ASB via the ICT Service and to the market partners using the cloud. In terms of BDEW concept, it means the market phase "YELLOW" for the next day when restrictions are present. The EV-loads must not exceed the transmitted specifications. ESPs have the opportunity to take advantage of the scope of the restrictions for further optimization in terms of the energy procurement since a shortfall of the restrictions is possible. That might be useful, assuming that variable tariffs for controllable consumers in the distribution grid are possible in the future.

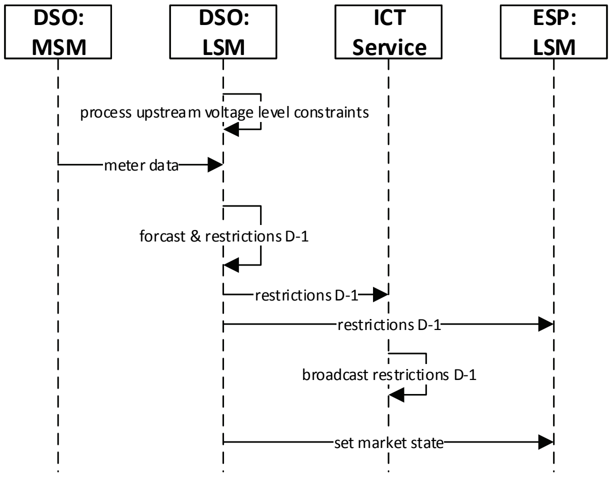

Figure 5. The process of Day-Ahead restrictions by the DSO

VI. FLEXIBILITY MANAGEMENT

In contrast to the approach of individual restrictions for every resource defined by the DSO, an individual flexibility frame for the considered local service area is provided to the participating ESPs. Thus control by the ESP who finally acts on the energy market is possible. There is also the possibility for the ESPs to adjust the provided flexibility by returning and applying for unused capacity. It is a two-step process of specification of flexibility and then optionally the allocation of flexibility that is executed and controlled by the DSO.

A. Specification of Flexibility

Basis for the flexibility specification is the calculation of individual flexibility frames per ESPs by the DSO. As described above, the flexibility frame of the network area constitutes the limits for the balance of controllable loads and controllable feed. The individual flexibility frame thus represents the limits of the balance of units controlled by the ESP. To calculate the individual load flexibility $FlexL_S$ and feedback flexibility $FlexF_S$ the proportions of controllable consumers I_{CLAP_S} and producers I_{CFAP_S} of the participating ESP are used to the total installed capacity of controllable units in the considered local service area. The following rules apply:

$$\text{If } FlexF < 0 \text{ then } FlexF_S = I_{CFAP\_S} \times FlexF \quad (1)$$

$$\text{If } FlexF = 0 \text{ then } FlexF_S = 0 \quad (2)$$

$$\text{If } FlexF > 0 \text{ then } FlexF_S = I_{CLAP\_S} \times FlexF \quad (3)$$

$$\text{If } FlexL > 0 \text{ then } FlexL_S = I_{CLAP\_S} \times FlexL \quad (4)$$

$$\text{If } FlexL = 0 \text{ then } FlexL_S = 0 \quad (5)$$

$$\text{If } FlexL < 0 \text{ then } FlexL_S = I_{CFAP\_S} \times FlexL \quad (6)$$

For the individual flexibility frame the same assumptions as described above apply (II The Flexibility Frame). It is important to consider what power of controllable production $CFAPS_{inst}$ and consumption $CLAPS_{inst}$ per ESP is installed.

If $FlexF < 0$ then $|FlexF_S| \leq CFAPS_{inst}$ (7)

If $FlexF > 0$ then $|FlexF_S| \leq CLAPS_{inst}$ (8)

If $FlexL < 0$ then $|FlexL_S| \leq CFAPS_{inst}$ (9)

If $FlexL > 0$ then $|FlexL_S| \leq CLAPS_{inst}$ (10)

If the installed capacity is exceeded by the individual frame, compliance is not possible. Thus, the non-controllable units have to be shut down or a warning has to be given to the upstream system operator on the impossibility of compliance with given constraints.

The Figure 6. shows the individual flexibility frame for two ESP with only controllable loads and the overall flexibility frame for the network area.

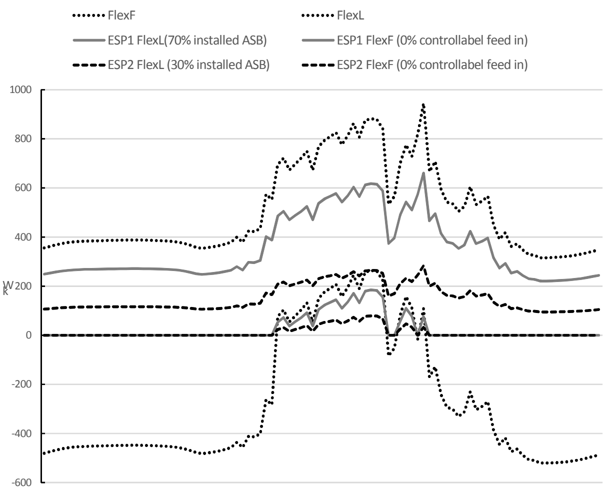

Figure 6. individual flexibility frame for two ESPs

In the project sMobiliTy only ASB will initially be available as a controllable load. Thus, the individual feedback flexibility (*FlexF*) for both ESP is zero or positive in the case of a forced consumption.

The individual flexibility frames are communicated day-ahead to the ESPs. This is done in due time, so that the market partners can include them in the procurement processes.

B. Allocation of Flexibility

After receiving the flexibility frame the ESPs execute their planning processes. This can lead to the determination of free capacity or required capacities for certain periods. In the next step, after a defined period, these free or required capacities will be reported to the network operator. After a matching of demanded and offered capacities the individual flexibilities will be adjusted by the DSO accordingly and the results are transmitted to the affected ESPs. This phase may be optionally offered by the network operator. The Figure 7. shows a graphical representation of the process with an optional allocation of flexibility.

The process of specification and allocation can be carried out day-ahead and intraday. It is important to ensure that when determining the individual flexibility intraday previously adapted day-ahead allocations are taken into account.

The flexibility frames are calculated every day for each local service area. Limitations for the ESP arise, if they cannot use the full installed capacity of controllable units over the entire time. In this case, with regard to the BDEW concept, market phase "YELLOW" is declared. This means for the project, that the aggregate load of the ASB per ESP must not exceed or go below the flexibility. No limitation means market phase "GREEN".

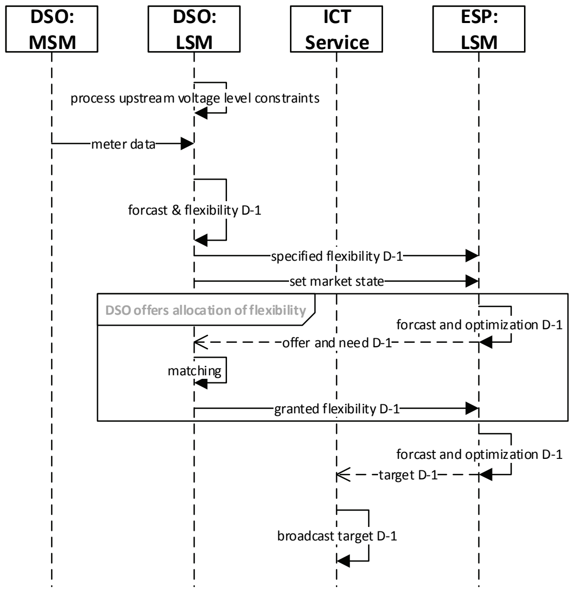

Figure 7. The process of the flexibility management

VII. Resume and Evaluation

Both approaches support the integration of grid issues in the market and are examined in the project. In addition, the network security and feed-in management must be performed by the network operator. In case of an intervention, the market phase "RED" is declared for the considered the network area and substation.

Advantage of the day-ahead restrictions is the consideration of possible individual conditions on the network connection point by the network operator. Disadvantage is the increased data overhead because the customer data must be available to the DSO and the ESPs if they want to use the degree of freedom left by the restrictions. With more data the complexity of processes of the network operation increases. When calculating the restrictions the DSO must also ensure non-discrimination for the ESPs at the individual network connection points. Another disadvantage of the day-ahead restrictions is the lack of a minimum target. If at certain times consumptions are enforced, they have to be implicitly considered while calculating the restrictions for all controllable loads in the local service area. Controllable producers are not considered in the project. Expanding the concept for feeders, it must be also a non-discriminatory approach to the definition of the separate feed in restrictions. Thus the complexity of the models to calculate the restrictions by the system operator continues to increase.

Advantage of the flexibility management is the simple approach for the network operator when specifying the flexibility and the possibility of subsequent adjustment by the market partners. Furthermore, the process could also be implemented intraday, thus increasing the effective use of the network infrastructure. By specifying and allocating the flexibility to the ESPs non-discrimination is implied although a legal assessment has not yet taken place. The consideration of customer needs can be assured directly by the ESPs and it is possible to optimize their portfolio in the local service area according to their own objective.

For both approaches, the control to comply with the communicated requirements and limits by the ESPs is executed by the DSO on the received meter data of the controllable units. For the first approach, these data are evaluated against the given restrictions. In case of the flexibility management the aggregated balance is evaluated against the individual flexibility frame. Open questions in this matter are:

- Sanctions for non-compliance, e.g. by withdrawing the reduced network charges for controllable consumers
- Sanctions for non-use and non-disclosure of spare capacity by the ESP

Market rules and common communication processes for the flexibility management are not yet defined. Further work is also necessary for finding sufficient matching algorithms for the allocation of flexibility. The day ahead definition of restrictions could partially be implemented today.

Challenging for both approaches is that voltage problems and frequency problems are considered only indirectly. They must be implicitly included in the individual restrictions or the flexibility frame of the considered local service area. In the project local areas were identified in which not the transformer but the cable represented the limiting resource. Thus the applied specifications need to be below the limits of the transformer. Individual analyzes in terms of thresholds and limits are necessary. A general definition may not be possible.

Within the project, both approaches will be tested for their suitability of daily use. For a realization after the project a further automation of the processes on the part of network operators and ESPs is essential.

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