Assessment of a New Flexibility Instrument for Electric Vehicles to Increase Network Utilisation

Proposal of a network capacity allocation scheme for the low voltage system in Germany

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Abstract— **The growth of flexible and controllable demand units in the low voltage system, like home charging infrastructure for electric vehicles or heat pumps, is the key driver of the transition to a coupled system across all energy sectors. To address related challenges and opportunities by the distribution system operators, new flexibility instruments are needed. Based on a study contracted by E.ON this paper propose a new network capacity allocation scheme for the low voltage system in Germany. The proposed concept is based on a "flex window" which defines the maximum available network capacity for the flexible demand unit over time.**

Keywords-component; electric vehicles; flexible demand units; flexibility instrument; smart markets

I. INTRODUCTION AND MOTIVATION

The context of this paper are three main developments

- Intensified coupling of all energy sectors and massive growth of flexible consumers
- Further digitalization of the distribution system, especially through integration of advanced intelligent metering and control equipment
- Current discussion on the revision of the legal framework for controllable load devices in the low voltage system in Germany

The growth of flexible and controllable demand units in the low voltage system, like home charging infrastructure for electric vehicles or heat pumps, is the key driver of the transition to a coupled system across all energy sectors. Until 2030 the number of flexible (controllable) demand units in households is expected to grow from 0.3 million to around 1.5 million units in the network regions of E.ON in Germany. This is equal to around 10 GW of additional installed demand capacity and is expected to increase the of energy consumption of flexible demand units in households from 11% to 25%. Especially the high penetration of electric vehicles with high connection capacity and high concurrency levels as a result of market price signals result in challenges for distribution system operators. Recent studies [1] have shown an increase of network congestions due to new demand units and the need for significant network extension in the low-voltage system, if the load behaviour of flexible demand units is not coordinated with the available network capacity.

In parallel, further digitalization offers distribution system operators new opportunities to apply advanced metering (e. g. smart meters) and control equipment (e. g. wall connector or wallbox for electric vehicle).

However, to address these challenges and opportunities by the distribution system operators, enhanced and new flexibility instruments for distribution system operators are needed. In Germany there is already the possibility to stimulate network friendly operation by reducing grid charges for controllable demand units in the low voltage system, according to the current energy law (§ 14a EnWG). For this purpose, the distribution system operator can agree with the unit owner to control the demand unit. In this case the unit requires a separate metering equipment. At the moment this framework is mainly used for night storage heaters and existing heat pumps. The control function is currently applied by static timetables, that means the system operator provides time frames in which the demand unit is allowed to load. The distribution system operator distributes the time frames across the whole population to optimise the maximum load per feeder and network region. The flexibility potential offered by new consumers, such as electric vehicles or battery storage, or changed consumption behaviour of new heat pumps is only marginally exploited. Whereas almost all night storage heaters in Germany fall within this framework, almost no home charging infrastructure for electric vehicles is in this framework. To fully exploit the flexibility potential and ensure network friendly integration of electric vehicles a revision of this framework (§ 14a EnWG) is currently under discussion in Germany.

This paper is based on results from a study by Ecofys, a Navigant Company, performed for E.ON. In this paper we focus on key elements of the technical and economic framework conditions to integrate electric vehicles 'grid friendly' at households. However, the proposed flexibility instrument can be applied to any flexible demand units in the low voltage level. The target of the proposed instrument is to increase network utilization in the distribution network through the use of controllable consumers and to avoid inefficient grid expansion. We focus on the regulation in Germany and use quantitative data from German distribution systems (E.ON), but our conclusions provide general principles for generic distribution systems.

We structure the further description in five sections. First we introduce and explain key terms of the context. Afterwards we describe the targeted use cases in which new flexibility instruments could provide additional benefits. In the next sections we specify technical framework and the incentive scheme of our proposed instrument. The final section summarizes key conclusions and recommendations.

II. Terminology

The activities of the actors in our German and European electricity system can be divided into two central spheres based on [2]: The market and network sphere.

The trade of electricity and thus the coordination of power generation with electricity consumption is assigned to the market sphere, we also call it "green phase". Bilateral trade and the power exchange in the day-ahead and intraday market determine the power plant dispatch. There is no significant regulatory intervention in this area. Market players in this field, like electricity generators, electricity traders, market operators or electricity consumers, must be guaranteed non-discriminatory network access and operation.

In contrast to the market sphere, coordination functions related to security and safety of the system and network operation are clearly assigned to the power network sphere which we call red phase. In this area, there are extensive legal assignments of tasks and cost allocation to system and network operators. For example, to ensure system security in case of network congestions, system operators do have priority rights to control generation and demand in the red phase.

The transition between the green and the red phase is the yellow phase. In this phase, network restrictions influence the operation of the power market. Through ancillary services, like reserve control or redispatch, system operators coordinate requirements from the power market and power network sphere. Fig. 1 illustrates the three phases.

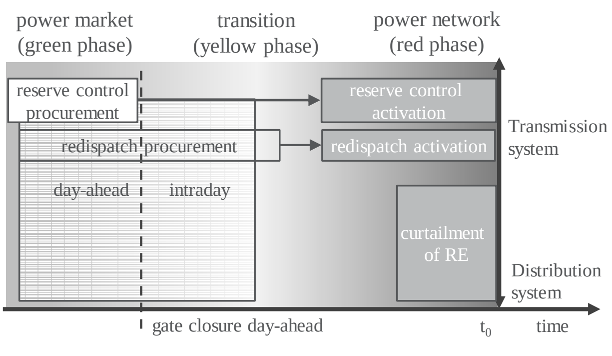

Figure 1. Illustration of different operation phases for market actors and network operators.

The proposed flexibility instrument aims to integrate demand units 'grid friendly'. However, there is no legal definition of this term. In this paper we align with the definition of the German association for electrical systems (VDE): A demand unit behaves grid friendly if it supports the functions of network operation of the responsible network operator. This includes for example activities to reduce network losses or safety-relevant peaks and to avoid network congestions. In contrast, a purely market-oriented behaviour, like to optimize the load behaviour on the spotmarket (global prices) can lead to critical network situations.

The ability of the system operator to control generation or demand units is fundamental for system security and flexibility instruments. However, the term control is usually used with different meanings. Therefore, we differentiate in this paper two principal types of control:

- Active control means switching operations or direct power control by the system operator or power plant operator. Switching is done in real time. Example: curtailment of renewable energy systems.
- Passive control means operations that are not carried out directly via the affected power or demand unit and usually involve further actors. This kind of operations are part of a planning process – usually via schedules – and not in real time. Examples are requests of power adjustment via the power plant operator as part of the redispatch or the allocation of network transfer capacity of interconnectors.

III. Use Cases

Our analysis and recent studies show [1, 3] the need for grid extensions in the low voltage level in regions with a high penetration of electric vehicles and heat pumps. The main drivers are the high concurrency levels (in contrast to conventional demand units) and a high maximum load in combination with a low annual energy demand of these units. For example, the full load hours of a typical night storage heater are around 600 h, whereas the home charging infrastructure for electric vehicles with a maximum load of 11 kW has around 200 full load hours.

However, only a few regions of the analysed network region of E.ON have currently medium to high concentration of controllable demand units. Especially the share of electric vehicles can be neglected. Until 2030, the share of regions with a high proportion of flexible demand units will increase significantly. The forecast for the network regions of E.ON for 2030 shows that in the majority of all regions, electric vehicles are the dominant technology among the installed controllable demand units (night storage heater, heat pumps or batteries). Nevertheless, some individual network feeders (with households of early adopters of electric vehicles) could already reach a relevant penetration of electric vehicles in the next years and may can require network extension.

In addition, we analysed the potential of flexible demand units in the low voltage level to avoid curtailment of renewable energy. This potential is strongly limited, as there appears no correlation of high renewable energy curtailment (usually rural areas) and high potential penetration of demand units (sub/urban areas) in the analysed network regions.

Based on the analysis we identified two main use cases for flexible demand:

- Preventive management of network congestions due to load peaks to avoid or manage network extensions in time
- Increase of the network utilization by distribution of the actual demand over time, having a positive effect on the network cost per kWh

To fully exploit the use cases, the proposed flexibility instrument is assigned to the yellow phase. In alignment to the current framework in Germany (§ 14a EnWG) the instrument is based on voluntary contracts between the demand unit owner and the responsible system operator.

IV. Technical Framework

The proposed concept of the network capacity allocation in the low voltage system (see Figure 2.) integrates requirements from the market and network sphere. The concept is described by the following key aspects:

- The owner of the flexible demand unit (home charging infrastructure for electric vehicles) and responsible network operators agree on a flex window. This flex window defines the maximum available network capacity for the flexible demand unit in time and amount.
- This flex window is a further development of currently used binary schedules for night storage heater and based on the concept of capacity allocation for cross-border interconnectors.
- The unit owner is responsible to keep the load of the flexible demand unit within the limits of the flex window. He could transfer this obligation to third parties, like aggregators or energy suppliers.

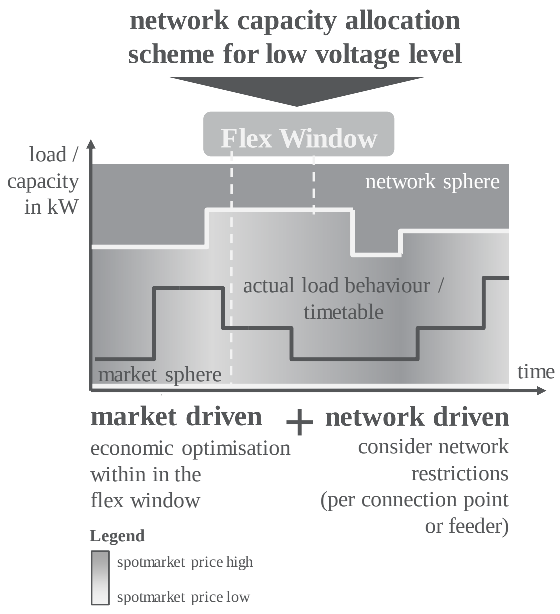

Figure 2. Illustration of the proposed network capacity allocation scheme and its flex window

The proposed flex window (or capacity allocation quota) replaces today's rigid control concept of flexible demand units by binary and static timeslots. In contrast to the current control system, which provides just on or off information, the flex window can also define a percentage of grid capacity as available.. The unit owner or energy supplier is able to optimise the operation of the demand unit within the flex window and define its cost optimal load profile.

In the beginning of the roll-out of the concept the flex window can be published by the responsible distribution system operator one month in advance and for a certain network region. After the concept is established the flex window can be defined in days ahead and and consider specific feeder information, such as the predicted load flow and forcasted generation of renewable energies. DSO could transmit the information of the flex window directly to the control equipment of the flexible demand unit, like wall connector or wallbox. However, the detailed planning processes in system operation for a flex window require further specifications by the industry.

Although the proposed instrument focuses on the yellow phase, a mechanism for very critical situations (red phase) is still necessary to ensure system security and safety. Therefore, in critical exceptional events the responsible distribution network operator should be able to have direct access on the controllable demand unit, for example via an emergency stop.

Using the proposed network capacity allocation scheme instead of curtailing electric vehicles while they are loading on ad hoc basis to avoid network congestions has several advantages, like:

- No negative impact on the balance of balancing responsible parties, like suppliers, or the system balance;
- Optimization of charging strategies are possible;
- Surveys by E.ON show that customers of electric vehicles clearly prefer foreseeable load restrictions instead of ad-hoc curtailment;
- Real-time measurements of the actual load flow in the low voltage system to detect network congestions are not needed and therefore the implementation do not require extensive investments in ICT and secondary equipment of network components;

Nevertheless, the obligation to create the flex window results in new requirements and processes in system operation. For example, the distribution system operator needs local load forecasts, grid security calculations for lower voltage levels or new data interfaces.

The development and implementation of new planning processes at the distribution system operators takes time. In order to be able to use the new processes or instruments at the time having higher penetrations for electric vehicles, it is necessary that distribution system operators decide fast which specific instruments they require for future network operation.

V. Incentive Scheme

As the proposed instrument is voluntary, a strong financial incentive scheme is necessary to address the additional costs for the unit owner which are related to the required control equipment.

In the existing German framework for controllable demand units the responsible system operator is allowed to reduce the network charges by roughly 50% For a typical night storage heater, the reduction results in around 500 EUR of cost savings per year. The exact number is depending on the load profile and network region, as the network charges and the reductions differs in each region. As electric vehicles do have a much lower annual energy consumption, the annual cost savings would be just below 200 EUR per year. At the moment, these cost savings seem to be not sufficient for owners of electric vehicles to apply the existing framework and invest in the required control equipment.

Therefore, we propose to implement an additional incentive to ensure the application for new demand units, like home charging infrastructure for electric vehicles. The additional incentive addresses the investment costs of the customer. In addition, we propose to implement a combination of malus and bonus system. At the moment, households in Germany do not pay a connection fee at the time of the installation for a total capacity of up to 30 kW. However, the actual load is in average just around 4 kW per household and is at maximum around 10 to 15 kW for most households. The current framework focuses just on regular network charges in ct / kWh for households. We propose that the limit of 30 kW will be reduced to 11 kW. Above 11 kW the customer has to pay once a connection fee in EUR / kW at the time of the installation of additional capacity at the household. One example: The current installed capacity of one household is around 10 kW and the customer want to install a home charging infrastructure of 20 kW. In this case the customer has to pay connection fee for the additional 19 kW. But if the customer participates in the flexibility scheme, the responsible system operator is allowed to reduce the network fee for the flexible demand unit. The described scheme is illustrated in Fig. 3.

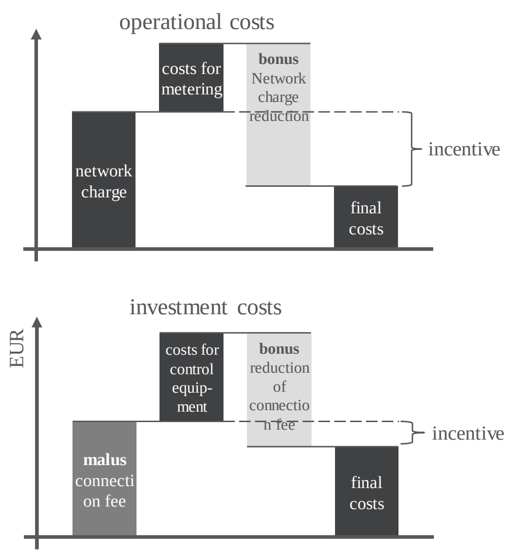

Figure 3. Simple illustration of the incentive scheme and resulted costs for operational costs and investment costs

VI. Key Conclusions and Recommendations

The proposed network capacity allocation scheme for the low voltage level enables the owner of home charging infrastructure for electric vehicles to apply a flexibility instrument on a voluntary basis. The focus of this paper is on home charging infrastructure, but the principles apply for any flexible demand unit, like heat pumps or battery storage.

- The unit owner and network operators agree on a flex window. This defines the maximum available network capacity for the flexible demand unit in time and amount.
- The proposed instrument is placed in the yellow phase and coordinates requirements from market actors and the responsible distribution system operator.
- The unit owner is responsible to operate within and comply with the given flex window. He can transfer this obligation to third parties.
- In order to ensure sufficient incentives for new flexible units, like home charging infrastructure, to participate in the flexibility mechanism, additional incentive schemes are necessary. We propose to implement a network fee based on the installed capacity at the household. If the customer participates in the flexibility scheme, the responsible system operator is allowed to reduce the network fee.
- Optimization of charging strategies by market actors or the unit owner are possible.
- Specification of the flex window and the required planning and forecast processes requires further research and industry discussion.
- Limited investment in new assets and ICT of the system operator required.

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