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Market design for the procurement of reactive power: the current state in Germany

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Abstract

The market-based procurement of system services for network operators is gaining momentum in the current debate about the future market design in the energy sector. Since current sources of reactive power are primarily fossil-fuel power plants which will not be available in a carbon neutral energy system, reactive power will be sources from distributed assets in the electricity networks. The German regulator has proposed new rules for reactive power procurement, which are based on three pillars: The technical connection agreements, fully integrated network components owned by the network operators and market-based procurement. While this approach is primarily aiming at the reactive power demand on the transmission grid level, assets from the medium voltage grid can participate in this process as well. We evaluate this approach from an economic perspective and conclude that while such a three-pillar system can secure an effective provision of reactive power, the efficiency heavily depends on the regulatory system and that it provides the correct incentives for the network operator.

Keyword: reactive power, electricity, network, market design

JEL-classification: D47, L51, L94,

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1. Introduction

Reactive power is one of the network services that are currently primarily supplied by central fossil power plants. To reach the EU climate targets the available capacity of those power plants will decrease in the near future. Hence, other sources for reactive power are needed to keep the electricity networks up and running. EU regulation (electricity directive 2019/944) prescribes a market-based, transparent and non-discriminatory procurement of non-frequency-based system services. Thereby, the EU strives to unlock the existing potential to provide system services like reactive power from distributed sources (generators, storage and loads) and to set investment incentives to secure a sufficient level of capacity for system services in the future. However, the electricity directive only requires a market-based procurement, if this approach results in an efficient outcome. For Germany, the evaluation by the project “SDL Zukunft” on behalf of the German Federal Ministry of Economics identified a potential for efficiency increases via market-based procurement in the case of reactive power (Schlecht et al, 2020). Hence, the Ministry tasked the project to draft a potential design for the market-based procurement of reactive power in Germany (Blumberg et al., 2021). This design resulted in a three-pillar system for reactive power procurement, one of which is market-based. The concept was then refined in a draft design by the German regulator (BNetzA 2023).

With this paper, we want to introduce the current proposal of the German regulator for the market-based procurement of reactive power in Germany and discuss the key features of this concept from an economic perspective. To do so, this paper is structured as follows: In chapter 2 we introduce key features of reactive power that define the relevant requirements for the market design. In chapter 3 we briefly introduce the international state of the debate for the market-based procurement of reactive power. Chapter 4 provides the key elements of the current approach proposed by the German regulator to implement market-based procurement of reactive power and a brief evaluation of the concept against the two primary economic criteria: effectiveness and efficiency. Chapter 5 concludes that the proposed approach seems fit to effectively secure sufficient reactive power capacity on the high- and ultra-high voltage level, but that further developments are required to exploit the reactive power potential from the lower voltage networks as well to increase overall efficiency.

2. Particularities of reactive power and current changes in procurement in Germany

Reactive power is less known to most people than active power and not easy for non-physicists or -engineers to understand. Although it plays a crucial role in the electricity system, it has attracted little attention in the past. This has changed due to the decentralization and decarbonization of electricity supply, which both increase the need for reactive power on all voltage levels and reduce the number of the previous main suppliers, namely large fossil-fuel power plants (c.f. dena, 2014; Amprion 2023).

Compared to active power, reactive power does not do any work (hence “reactive”) and it is not consumed, but "oscillates" back and forth in the grid between producer and consumer. Apparent power, to which cables, lines etc. are dimensioned, is the (geometric) sum of active and reactive power (see figure 1 for illustration). Therefore, active and reactive power have a joint effect on the utilisation of a resource and are interdependent. Put simply, the more reactive power is transmitted the less active power can be. Furthermore, apparent power determines the power loss, which means that an increase in reactive power, c. p., increases power loss (c.f. dena 2014).

On the other hand, however, the system cannot go without reactive power because it helps to regulate voltage both in normal operation and during sudden voltage drops. In the first case one speaks of steady state or stationary voltage control and in the second case of dynamic reactive current support, which is comparable to active balancing power. Also comparable to positive and negative balancing power, one further differentiates between voltage increasing (capacitive) and voltage decreasing (inductive) reactive power. Since overhead lines, for instance, have a voltage decreasing effect, voltage increasing (capacitive) reactive power is needed to ensure that voltage does not drop too much due to transmission.

In contrast to active power, reactive power cannot be transported over long distances. Its transportability depends on different aspects, such as the network condition and network load, the means of transport (cable or overhead line) and the voltage level. At the extra high voltage level, it can be transported roughly 100 km (c.f. INA, OTH & FENES, 2016). Therefore, reactive power needs to be supplied locally.

Network operators principally have two ways to procure reactive power: first, they can supply reactive power themselves by means of installed reactive power compensation systems, also referred to as fully integrated network components (FINC); second, they can secure it from third parties, i.e. other network operators (from upstream or downstream grids), generators, consumers, HVDC-systems or storage facilities, that can either provide reactive power directly by adjusting the power factor (see figure 1) or also by means of installed reactive power compensation systems. The capability to provide reactive power is usually expressed by the power factor cos(ϕ), which corresponds to the ratio of active to apparent power. The lower the power factor, the higher the capability to provide reactive power.

Figure 1 illustrates the relation between active, reactive and apparent power: The higher the power factor cos(ϕ), the higher the reactive power ability.

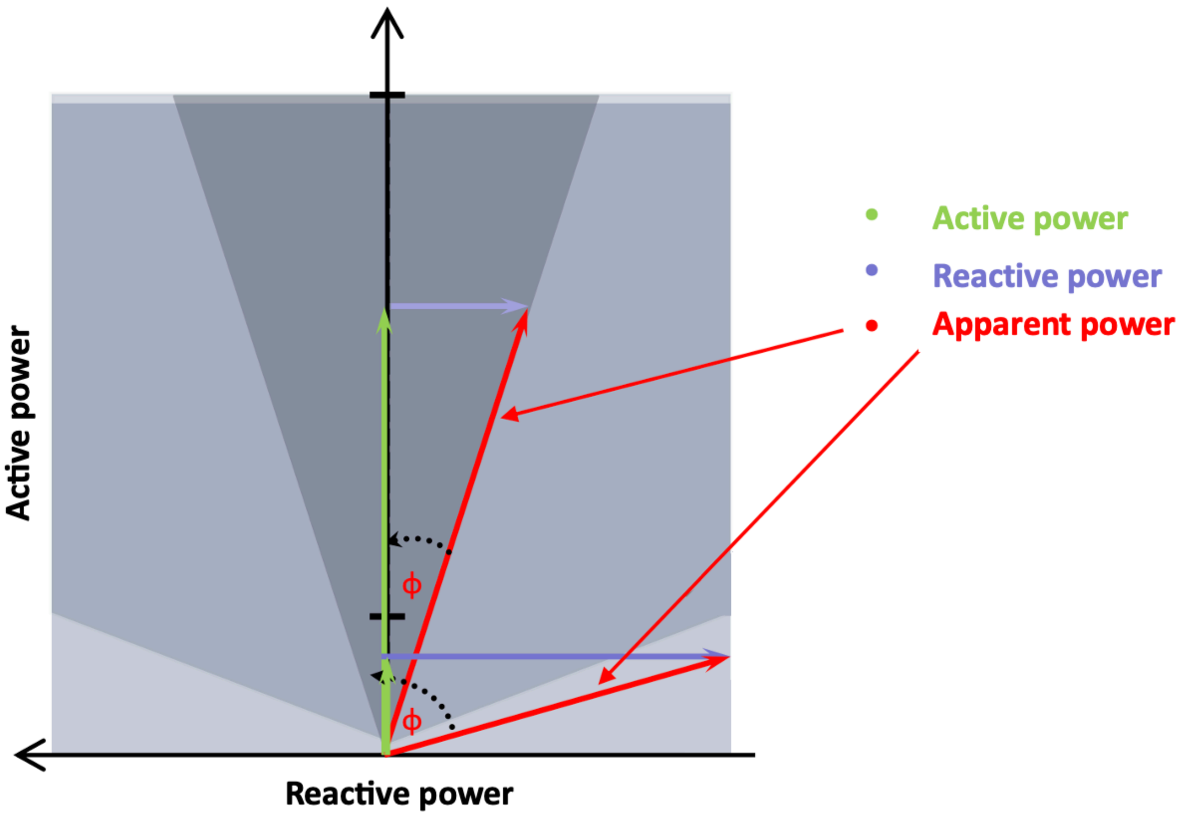

Figure 1: Illustration of the relation between reactive, active and apparent power (translated from (Palenberg, 2016)).

In Germany, reactive power procurement has been regulated as follows to date: All generators (conventional and renewable) on all voltage levels are obliged to have a certain reactive power capability as specified in the individual technical connection conditions (TCC) of the respective network operator, which requires a corresponding respective reactive power capacity. The technical connection conditions are based on the (general) technical connection requirements (TCR) set out by law (§ 19 EnWG). The specific requirements are uniform nationwide, but differ with the voltage level and the size of the generator. The TCC can be understood as a unilateral option right of the network operators (Blumberg et al., 2021). In addition, network operators use bilateral agreements for the procurement of additional reactive power provision with individual power plants (BNetzA, 2018).

Currently, reactive power capacity within the limits of the TCC is not compensated financially (BNetzA, 2018; Blumberg et al., 2021). Whether or not the provision of reactive power is financially compensated is context specific and depends on the network level: In some cases all reactive energy is remunerated at the TSO leveland reactive energy beyond the TCC obligations at the DSO level (based on bilateral agreements) (e.g. Brückl, 2019), while in other cases (partly) remuneration of reactive energy on the TSO level excludes the enforceable range of the TCC (dena, 2017; BNetzA, 2018, Blumberg et al., 2021).[2] Among distribution system operators directly compensated reactive power procurement is very rare today. Only three out of the more than 850 DSOs claim costs for the contractual procurement of reactive power according to the German regulatory agency (BNetzA, 2018). Estimates for the remuneration of reactive energy range between 0,08 and 2,27 €/MVarh (BNetzA, 2018).

Loads are permitted to use reactive power in a certain PQ-area ("P" abbreviates active power), in which they may choose freely. Due to this freedom, they are not remunerated for reactive power, but reactive power utilisation beyond the specified area is penalized. Consumers on the low voltage level may by law be obliged to install a reactive power compensation system (§ 16 NAV).

Due to the EU directive (2019/944) this current set-up is about to change, because it obliges the market-based procurement of steady state voltage control and fast reactive current injection, next to other non-frequency ancillary services. An exception to this is only possible if the regulatory agency has granted a derogation due to economic inefficiency. In Germany, this obligation of the directive was implemented into German law with § 12h of the energy act (EnWG). The regulatory agency has granted a derogation for, among other services, fast reactive current injection, yet it has started a consultation process on the procurement of steady state voltage control (BNetzA, 2023).

3. International experience and key challenges for the market design

In most European and also in other countries (e.g. US, Australia), generators that are connected to the transmission grid and/or of a certain size are obliged to have a certain reactive power capacity, not least but to be able to compensate for their own effect on voltage in the grid (c.f. ENTSO-E, 2022, Anaya & Pollitt, 2020). The picture is mixed when it comes to the

[2] The TSO 50Hertz, for instance, offers a fixed remuneration for the supply of reactive power. See https://www.50hertz.com/de/Vertragspartner/Systemdienstleistungen/Spannungshaltung

compensation of reactive power provision: In some countries (like Italy, Spain or Sweden) it is not financially compensated by the TSO, in others it is (e.g. France, UK, Switzerland, Norway) and in still others it is partly paid (e.g. Germany, Denmark, Netherlands) (c.f. ENTSO-E, 2017; 2022). When directly compensated, the settlement rules also vary between countries from regulated prices to pay as bid actions (c.f. ENTSO-E, 2022).

	DE	F	NL	B	CH	I	ES	SE	DK
Procurement scheme	Mandatory Service	N/A	Hybrid	Hybrid	Mandatory Service	Mandatory Service	Mandatory Service	Mandatory Service	Mandatory Service
Service Paid*	Partly	Yes	Partly	Yes	Yes	No	No	No	Partly
Settlement Rule	Free	Regulated Price	PAB	Hybrid	Regulated Price	N/A	N/A	N/A	Free

*Table 1: Overview on procurement schemes, remuneration and settlement rules in selected European countries (based on ENTSO-E, 2022; and *ENTSO-E, 2017), N/A=data not available*

Only some countries have established additional reactive power procurement options, e.g. bilateral agreements or auctions (e.g. UK, Australia). Hence, the experience with market-based procurement of reactive power is very limited or "practically non-existent globally" (Anaya & Pollitt, 2020, p. 11): Belgium that had introduced a market for reactive power in 2006 reformed it recently due to issues of market power and since 2021 has a hybrid system of obligatory provision (for network users attached to the transmission grid only) and tenders for non-mandatory units (technology-neutral and open to units connect to transmission/distribution and closed-distribution grids) (Anaya & Pollitt, 2020; Elia, 2018, ENTSO-E, 2022). The Netherlands and Great Britain also have hybrid systems of tenders in addition to obligatory supply (ENTSO-E, 2017 & 2022; Anaya & Pollitt, 2020). In Great Britain, the hybrid system consists of the Obligatory Reactive Power Service (ORPS) by power plants exceeding 50 MW, remunerated by a formula-based standard payment, and a voluntary provision via tenders (Enhanced Reactive Power Service). The latter is, however, not bearing fruit: since 2009, no contract has come about through the tenders and since 2011, not even bids have been submitted (cf. National Grid 2018, AFRY 2022). The reasons given for this are the competition with the mandatory, remunerated ORPS provision and the capping of procurement costs for this service (Anaya & Pollitt 2020). The Netherlands organize yearly tenders for supply contracts of stationary reactive power (TenneT 2019); the remuneration scheme is pay-as-bid (ENTSO-E 2022).

In sum, due to the particularities of reactive power two central challenges arise for the set-up of a market-based procurement. First, the interdependency with active power supply needs to be considered, i.e. effects on the active power markets should be reduced to a minimum in order to avoid causing economic inefficiencies. This relates in particular to the timing of the markets: Either the reactive power market is activated sequentially after the closure of the active power market, or simultaneously with the active power market. While a reactive power market close to real time allows for co-optimization, it also may create situations of market power (Anaya & Pollitt, 2020). This is the second challenge, which needs to be taken into account, i.e. the geographical restrictions of reactive power supply and resulting possibility of market power of suppliers. Besides the timing of the markets this relates to the different voltage sensitivities of the suppliers for a specific reactive power demand: Since reactive power can only be delivered within a limited regional area (~ 100 km) the potential of market power is high given that only a few suppliers have a high impact on a reactive power demand at a specific point in the network. Since market power has been identified as a significant challenge for market-based procurement of reactive power, different counter measures to limit market power have already been discussed in the literature. Anaya & Pollitt (2020), for example, suggest to not use tenders as the unique means of procurement, as a lesson learned e.g. from the case of Belgium. Hence, most international concepts combine market-based procurement with explicit or implicit price caps, e.g. via the requirement that the market-based procurement results in lower costs than the costs resulting from investments into fully integrated network components (FINC). Related to this are the suggestions to use a reverse clock auction that starts with the costs of the alternative (i.e. the network operator's own resources) and thus implement a price cap (Anaya & Pollitt, 2021) or that the network operator(s) participate in the auction with own compensation systems (Tronica et al., 2021). Alternatively, market power can be limited by a longer timeframe between the closure of the reactive power market and delivery, e.g. month to years, which creates investment incentives and thereby lowers the risk of market power in the long run.

To increase transparency about the true costs of reactive power provision, Anaya & Pollitt (2020) suggest to use pay as cleared instead of pay as bid pricing.

Furthermore, the integration or abolishment of the current setting needs to be dealt with. In Germany, this relates in particular to the handling of reactive power supply in TCC arrangements.

4. Current state in Germany

4.1 Outline of the draft concept

The German energy act (§ 12h), transposing the EU directive 2019/944 into German law, not only obliges network operators to procure non-frequency related ancillary services in a market-based way (unless exceptions are granted), but also regulates that the regulatory agency defines the specifications and technical requirements for market-based procurement of the respective service. In Spring 2023, the German regulatory agency has published a first draft of a concept for these specifications and requirements for the voltage service (reactive power) (BNetzA, 2023a), which we outline in the following.

First of all, the concept draft restricts market-based procurement of reactive power on the demand side to TSOs and to those DSOs that operate high voltage grids. On the supply side the concept only addresses reactive power sources that are connected to the extra high or high voltage grid. The focus lies on the provision of reactive power with systemic benefit, for which sources connected to lower voltage levels are argued not to be suitable (BNetzA, 2023b). A reactive power source is defined as an installation for feeding in or withdrawing reactive power and reactive energy and is hence not restricted to generators.

The object of such a procurement is the reactive power capability to be provided and/ or the available reactive energy that exceeds the requirements of the respective technical connection condition of the connecting network operator. In the corresponding explanatory document, the agency states that it explicitly deviates from the TSOs' proposal to include the capacity within the TCC for market-based procurement on the extra high voltage level (BNetzA, 2023b). The prerequisite for a market-based procurement procedure is that it may only be initiated if it appears to be the most efficient option for covering the reactive power demand according to the operator's own assessment, in particular compared to full integrated network components (FINC).

As a consequence, a three-pillar system for reactive power provision would result for the network operators on the EHV and HV level consisting of (1) TCC, (2) own operating resources (FINC) and (3) market-based procurement, which is largely in line with the recommendations of the project SDL Zukunft, conducted on behalf of the Federal Ministry for Economic Affairs and Climate Action (Blumberg et al., 2021). On the lower voltage levels, the existing two-pillar system of TCC and the network operators' own resources would be maintained.

To deal with the geographical restrictions, the draft concept provides that the grid operators can define procurement zones within their grid area, for which they then announce a specific reactive power requirement. The announcement must at least be published on the network operator's website. Suppliers may aggregate several reactive power sources in their offer within one procurement zone.

With regard to the details of the market design, certain leeway is given to the network operators. They may choose, for example, between four different standard products, for which they may further differentiate between capacitive and inductive reactive power. They may further decide themselves between a secured or non-secured provision of a product.

The remuneration for any of the four standard products depends on the availability requirements of the network operator: either only the reactive energy is remunerated (for non-secured provision) or additionally also the reserved reactive power capability is remunerated (for secured provision). In either case the settlement is pay as bid. The network operators may define a price cap for both the power and the energy price.

For the timing of the different steps of the procurement process, e.g. lead time, duration of delivery, etc., only upper limits are defined, implying that the draft concept allows for both (very) short term to long term procurement processes. The longest process can take up to 5,5 years between announcement and delivery, which itself can last up to 5 years.

With regard to the bid selection, the draft concept provides that all permissible offers (e.g. below the price cap, fulfilling the technical requirements) are listed in ascending order of the offered price(s). The network operator selects the lowest bids until demand is covered, without taken any further sensitivities into account. The bidders are informed about the result of the tender. Upon request the results of procurement and the selection process need to be transmitted to the regulatory agency.

4.2 Discussion

Whether or not the approach proposed results in an efficient procurement of reactive power depends to a large extend on the regulatory framework and the incentives for the network operators resulting from this framework. Since the network operator basically has the ability to choose between three different options to procure reactive power, the regulatory framework needs to secure an undistorted (aka efficient) consideration between the three options. This is especially true for the given case where one procurement option might not result in any costs for the network operators (if no regulated tariff within the TCC is applied), while the other two options result in costs the network operator must bear (and yet are mostly likely treated differently depending on the OPEX/CAPEX intensities). Otherwise, the efficiency and effectiveness of the reactive power provision via the three pillars will be reduced and consequently, costs will increase for the end consumers. In the following, we will assume that the regulatory framework is designed to secure efficient decisions by the network operator between the three options (which needs further investigation but is outside the scope of this paper). Our evaluation focuses on the current approach in Germany and we evaluate this approach against two criteria: effectiveness and efficiency.

We define effectiveness as the degree to which the concept makes use of the existing reactive power potential of all network assets across all network levels and secures sufficient reactive power capacity to operate the electricity networks. Since only assets from the HV and UHV-network level are part of the concept, the effectiveness is limited to this network levels. Assets from the low-voltage grid cannot provide reactive power via the concept, which reduces the effectiveness of the approach. Furthermore, network operators on lower levels cannot procure reactive power for their own need in a market-based way. The combination of the TCC with a market-based approach or the investment into a FINC secures that there will be sufficient reactive power available to the network operator. Hence, for the UHV and HV-level the approach will probably be very effective in providing sufficient reactive power capacity.

Given that we can assume that the approach secures sufficient reactive power capacity on the UHV and HV-grid level, the question then is whether this is efficient as well. Here, we discuss two dimensions of efficiency: First, the short-term operational efficiency (also known as static efficiency), which refers to the short-term incentives to match reactive power demand with the most favourable option available. Second, long-term (dynamic) efficiency, which requires that the incentives for investment in reactive power capacity match with the long-term demand and address this demand at the lowest costs.

Since the TCC ignores the relevant costs of each network user and requires a certain level of reactive power independent from the individual costs, this stage of reactive power procurement does not set any efficient operational or dynamic incentives. Additionally, it remains unclear if and how provisions inside the TCC are remunerated. Such a regulated remuneration was discussed in previous studies (e.g. Blumberg et al., 2021) for generators and storage on the UHV & HV levels for the provision of reactive power within the requirements of the TCC to secure correct incentives for the network operators to choose between procurement via the TCC or market base procurement. Without such a regulated remuneration within the TCC the network operators might have the incentive to make use of reactive power via the TCC at an inefficient high level.

Still, if we assume that there are no distorting incentives resulting from the regulatory framework, then the concept could secure short term efficiency via the market-based procurement.

Since the concept allows that the network operators can choose between different lead times, short-term efficiency can be increased by shorter lead times before delivery, which allows for co-optimization and reduces uncertainty for the market parties. However, short-term efficiency can be limited by the design of the procurement zones, which won't take into account the different sensitivities of the network assets on the reactive power demand: It might be possible that in a specific case an asset from a neighbouring procurement zone would be the more cost-efficient solution to fulfil the network operators demand in a neighbouring procurement zone, but will not be considered due to its allocation to a different procurement zone.

However, two factors may limit the short-term efficiency of the market-based procurement: First, the limitation to the network users on the HV- and UHV-Network level excludes potentially lower costs options for reactive power provision from the lower voltage networks. Hence, the concept is criticized for leading to over-capacities on the HV- and UHV-network levels in particular due to uniform requirements, and the exclusion of cost-efficient voltage control e.g. through other technologies than reactive power by generators from sources on the LV/MV levels (INA, OTH & FENES, 2021; Brückl, 2016). Second, due to the limited market size the risk of market power and is exploitation is high. While market power will be an issue in the model proposed by the German regulator, the concept provides different approaches to limit market power.

First, the network operators are only allowed to make use of market-based procurement if the investment costs in a FINC are higher than the expected market outcome. Hence, the FINC costs serve as an implicit price cap on the market prices. Furthermore, the network operators are allowed to set an explicit price cap on the specific product they require. While such a price cap does not limit market power per se, it limits the extent to which the market power can be exploited. As long as the market outcome is below the FINC costs, there is an efficiency gain from market-based procurement even with market power compared to a situation without market-based procurement where the investment in FINC is the only available option.[3]

Second, long term tenders send investment signals, which reduce the risk of market power, since potentially inefficient high prices will attract new investments, which will limit market power in the long run.

Third, the concepts foresees that the network operators publish the results of the tenders, in particular the cumulative reactive power of the accepted offers and the average accepted price.

Besides these implications for short-term efficiency the proposed approach gives network operators the option to procure reactive power up to five years in advance. If network operators make use of this long-term procurement, then we can expect that long term efficiency will increase. To balance especially the risk resulting from the uncertainty about future reactive power demand, network operators are likely to use a combination of short-term and long-term procurement, which will impact the short- and long-term efficiency considerably.

5. Conclusion

In this paper we have picked up the current debate about market-based procurement of reactive power in Europe. From the international experience with market-based procurement of reactive power it can be derived that a combination of market-based and regulated procurement can secure a sufficient level of reactive power capacity and increase efficiency. However, with reactive power procurement via a market the challenge arises how to limit market power. Here, different solutions are discussed in the literature, from explicit or implicit price caps to longer time frames between procurement and delivery. In this paper we take the insights from the international debate and apply those arguments to the current proposal for market-based procurement of reactive power in Germany. The proposed approach by the German regulator combines three procurement methods: First, generators are required to provide reactive power to a certain degree via the individual technical connection conditions (TCC) of the respective network operator TCC. Here, the question still needs to be addressed whether the provision of reactive power within the scope of the TCC needs to be renumerated or not. Second, network operators need to evaluate the costs of own reactive power sources in the network, so called fully integrated network components (FINC), and whether those

[3] As it is, the concept does not foresee a process if the market prices are higher than expected, which might make the investment into a FINC the more efficient solution.

assets can provide reactive power at lower costs than market-based procurement. If it is expected that market-based procurement will result in lower costs than would result from an investment into FINC, then the network operators are required to procure the required reactive power via a market-based approach, which is the third procurement mechanism in the proposed concept in Germany. Our evaluation shows that while such a three-pillar system can secure an effective provision of reactive power, the efficiency heavily depends on the regulatory system and that it provides the correct incentives for the network operator. Here, three aspects should be in the focus on the future debate:

⇒ First, regulation needs to secure that the network operator only makes use of the TCC to an efficient extent. Here, it should be discussed whether reactive power provided based on the TCC shall be compensated to make sure that the network operator does not have the incentive to require inefficient high levels of reactive power in the TCC, while other options (FINC or market-bases sources) would be cheaper.

⇒ Second, for those cases where a market-based offer would be more efficient than a provision via the TCC the market-based source should be procured. This requires that the networks operators are allowed to make use of market-based procurement even within the scope of the TCC.

⇒ Third, for market-based procurement, the question is which network levels are allowed to make use of market-based offers and how low-voltage network operators and assets from the low voltage grid can participate in this process, to secure efficiency given the situation that sources from the low-voltage grid might provide reactive power at the lower costs than the alternatives on the higher network levels.

While the current debate in Germany builds on the international experiences with market-based procurement of reactive power which leads to the three pillar system, at least the three issues raised above should be addressed to secure an efficient procurement of reactive power from distributed sources in Germany.

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