Final report

"Future procurement of reactive power and other measures to ensure grid security"

on behalf of the
Federal Ministry for Economic Affairs and Energy

09/09/2016

Chapter 6

SUMMARY

The final chapter repeats the main content and recommendations regarding the four ancillary services reactive power, inertia, short-circuit power and grid restoration.

6.1 REACTIVE POWER

SUMMARY OF RESULTS AND ANALYSES

The analyses of four real and differently structured medium-voltage (MV) grids show that the behaviour of Q in a distribution grid is strongly determined by the topological circumstances of the grid including the connection points of the generating plants, but can also be significantly influenced by a suitable choice of voltage stability concept. If the integration of generating plants mainly takes place via the laying of additional cables, the behaviour of Q clearly shifts to the more overexcited state in the long term. If voltage stability is mainly ensured via the use of reactive power, the capacitive behaviour is weakened, but the overall range of the behaviour of Q is extended. The use of voltage regulating distribution transformers can generally keep the behaviour of Q within a relatively narrow band. But this does not permit the general conclusion that voltage regulating distribution transformers would be most advantageous in terms of the behaviour of Q, because the absolute range of the reactive power values and the requirements of the upstream system operator ultimately determine the assessment.

Other very significant factors are the assumptions about the behaviour of Q of the consumers and the voltage range to be adhered to, or reactive power reserves to be maintained for deviations from the (n–0) case.

The growing fall in the amount of available reactive power, as conventional power stations are displaced from the grid, is largely being offset by compensation systems constructed by the TSOs. For example, by 2018, the inductive compensation capacity is to be expanded from just under 17 GVAr (before 2012) to just under 20 GVAr and the capacitive capacity from just over 3 GVAr to just under 10 GVAr. Also, the envisaged HVDC converters will provide, roughly, 23 GVAr of inductive and capacitive reactive power.

The grid expansion will shift the overall behaviour of Q of the German electricity network to the more overexcited state. Correspondingly, despite a higher contribution from sources of Q in the extra-high-voltage (EHV) grid in future, there will be a rise in the need for additional inductive compensation capacity, from 13.3 GVAr today to 15.1 GVAr by 2034. If one were to change in normal operating mode from a permissible voltage of 420 kV to a maximum of only 415 kV, the total additional German need for inductive compensation capacity would rise to around 35 GVAr.

The high-voltage (HV) grid is also increasingly serving as an additional source. Whilst the supply of reactive power can already be regarded as exhausted due to the change in the voltage level of the HV grid, potential still exists to make use of the reactive power potential of generating plants. For example, there are already an increasing number of attempts and projects based on stronger coordination of the exchange of reactive power between TSOs and DSOs. However, the model calculations of the present study show that, of the RES installations in the HV grid (including the installations connected to the HV/MV transformer), at most, and depending on the wind year, only approximately 30% of the reactive power of generating plants can be used at present. In view of grid restrictions (adherence to electricity and voltage limits in the HV grid), a correspondingly smaller figure should be assumed for actual practice, and particularly as a secure figure for planning. In order to make better use of this potential, strategies need to be drawn up for coordinated provision of reactive power between the grid operators, and corresponding technical and organisational access processes defined. Also, there is a need for procedures to forecast the availability of reactive power and assess its reliability. However, the model calculations for 2024 and 2034 show a fall in the potential available for the EHV grid to below 20% (2024) and ultimately (2034) to only just over 10%. So it can already be seen at this stage that it would be more useful to make reactive power available in installations with the highest reliability at suitable sites, rather than providing a high amount in all generating plants.

Stronger, i.e. more flexible, coordination of the exchange of Q between TSOs and DSOs would permit better use to be made of the existing synergies, even if such synergies are not available everywhere in large quantities. In this context, it should also be noted that cost savings can arise simply by having the compensation take place at the optimal grid level, rather than rigidly in line with the actual fields of responsibility.

In addition to the use of reactive power to stabilise the voltage, there are more and more tools to tackle voltage problems in a cost-efficient manner in the distribution system, e.g. smart voltage control algorithms or adjustable local grid transformers. In future, it will also be possible to curtail generating plants and to give storage facilities incentives to serve the system. Whilst these instruments and grid expansion entail costs for the system operator, the use of reactive power to stabilise the voltage is a privileged special tool available free of charge, and is thus the only tool which is not exposed to competition amongst the voltage stability technologies.

The argument that generating plants must use the (free-of-charge) reactive power to balance the rise in voltage caused by them leads to unequal treatment of generation, storage and purchasing installations, with the latter even generally being said to have a voltage-lowering effect. Also, the voltage variation depends largely on the grid topology and the connection point of the generating plant.

In the course of the energy transition, the minimum requirements imposed on generating plants in terms of reactive power provision have been repeatedly increased. When today's grid codes are updated, the provision of reactive power, which was previously less than 90 GVAr, will rise to just under 165 GVAr or 200 GVAr by 2050 if the minimum requirements were to be extended to a power factor of 0.90. This would entail a rise in costs from what was previously less than €170m/a to an estimated €640m/a in 2050.

RECOMMENDATIONS FOR ACTION

In view of all of these aspects, we arrive at the view that it would be technically better and economically more beneficial to end up with fewer, reliable, highly available sources of Q with adapted control dynamics and appropriate dimensions at the right locations.

Here, market-based procurement of reactive power could provide the corresponding stimulus to orient the provision of reactive power in line with needs and at minimal costs, to the extent that there are incentives for a careful use of reactive power in terms of providing it, but also in terms of deploying it and of the related losses and restrictions to the transmission capacity. Also, a suitable procurement and remuneration/billing system could leverage possible potential synergies between individual system operators and between system operators and users.

It is certainly necessary to bear in mind that there may be a lot of costs in terms of billing and administration when designing market-based Q procurement. Market-based processes make sense only where they increase efficiency in terms of the economic costs. Here, consideration must also be given to indirect effects.

We believe that this reactive power procurement system should:

- leave it up to the system operator as to whether it wishes to obtain reactive power using its own operating resources, via bilateral contracts, or via suitable marketplaces,
- be seamless from the EHV to the low-voltage (LV) level, involving generating, storage and purchasing installations,
- retain the possibility to formulate requirements regarding the provision of Q in grid codes, whereby in future this should use transparent benchmarks to demonstrate the need or economic viability,
- in principle also include the code-based procurement of Q in the remuneration system, and do so in such a way that on the one hand the incentive to avoid unnecessary capacity to provide Q is maintained, and on the other the need can be evaluated in a transparent manner and the theoretical proof of the efficiency of generalised Q requirements can be evaluated in practice.

A proposal for an underlying structure of the procurement system which establishes the greatest possible transparency and a very high incentive to restrict the provision and the use of reactive power to an economically sensible level without endangering grid security can be found in section 2.5.9.

However, in view of all of the technical, operational and economic, legal, regulatory, legislative and political aspects, the conversion of the system is enormously complex. For this reason, it is proposed that a process be initiated whereby

- initially the requirements and goals of the provision of reactive power are defined,
- the criteria for the assessment of the procurement models are coordinated,
- the various procurement models and methods are then described, whereby
    - these are discussed in terms of their advantages and disadvantages,
    - the countervailing barriers and problems[22] are presented along with solutions, and
    - the need for adaptation and development is shown.

[22] The problems arising include, for example, the possible fall in profits for the system operators and the increased costs borne by the customers of the companies operating extensive systems.

We believe that the following associations and authorities should be involved in this process:

- BDEW
- BEE
- BMWi
- BNetzA
- BWE
- FNN
- VDMA
- VGB
- VIK
- VKU
- ZVEI

Further to this, it is necessary to coordinate the methods by which and the parameters for which the need for reactive power is to be ascertained. On the one hand, this is necessary so that cost savings will not be to the detriment of security of supply. On the other hand, the results show how significant the selection of the voltage range, for example, is for determining the need for Q.

Answering the main questions posed at the beginning

Finally, the main questions posed in section 1.2. can be answered as follows:

- The potential of the existing technologies is still not being used cost-efficiently, because
    - there is a lack of coordination processes and monetary incentives for a mutual exchange of reactive power across voltage levels and between system operators,
    - the provision of reactive power by generating plants is unnecessarily high in some grid regions and too low in some others,
    - the reactive power installed in generating plants and power stations is largely dependent on active power or the market, and is therefore not always fully available or available when needed,
    - there is a lack of incentives for the sparing use of reactive power, because the use of reactive power to stabilise the voltage is privileged compared with all other voltage stability concepts and because generating, storage and purchasing installations are treated differently in terms of grid access requirements.
- Greater cost efficiency could be attained via more transparent and market-based procurement, because

- in the long term, and assuming that the procurement and remuneration system is designed correctly, it will only be necessary to stipulate nation-wide minimum technical requirements which impose minimal costs in overall economic terms,
- reactive power will then be installed at the locations, availability, level and control dynamics which are needed,
- greater use can also be made of possible potential on the consumer side,
- some of the reactive power compensation can be carried out at a different voltage level or by a different system operator if this is cheaper.

- An important incentive to reduce the necessary minimum generation by conventional power stations can be provided via a suitable procurement and remuneration system. To this end, the system must be seamlessly designed from the EVH to the LV level and cover all grid participants equally. If the code-based provision of reactive power in particular has to be paid for by the system operator, the cost differential compared with alternative sources of reactive power will be reflected in real terms and will be smaller. This will make alternatives to conventional power stations more attractive.

6.2 INERTIA

The previous studies have all shown that, up to 2025, and in some cases up to 2035, there is sufficient dynamic frequency stability, largely due to the conventional power stations outside Germany. In this respect, however, it is necessary to discuss the extent to which the provision of inertia should be divided up between the regions. This question does not merely arise for reasons of solidarity, but also affects the maintenance of supply following the formation of a partial grid in the continental European interconnected system.

In order to carry out the model calculations to **investigate the dynamic frequency stability** and to derive the necessary measures:

- a scenario framework should be coordinated at national and ENTSO-E level (development of installed capacity, exchanged capacity, simultaneity and correlation factors of RES, ...),
- the most precise information about the dynamic system behaviour should be available (development of the effect of consumers balancing themselves, consumer-side inertia, delays in protective facilities, ...) in order to be able to work from robust and current values,
- in addition to the case of a disruption which is of relevance for the calculations, the conditions/scenarios should be clearly defined in which situations which are not of relevance to the calculations are not to result in a grid collapse; here, it would be necessary to examine what partial grid formations are feasible with what exchanged capacities.

In parallel to this, the potential to improve the dynamism of the **overarching protective facilities** needs to be leveraged and the technical rules adapted accordingly and harmonised across the voltage levels and across Europe. This means that:

- alternative methods of identifying stand-alone grids must be studied and implemented where necessary,
- in the field of overfrequency output reduction the real behaviour must be evaluated and in principle the existing potential for a faster rate of overfrequency output reduction must be used, and if necessary technology-specific rules must be included in the grid codes,
- a faster rate of response must be required for underfrequency load shedding (max. 150 ms).

In order to prevent misunderstandings and to achieve a clear delineation between inertia and primary balancing capacity, the activation profile of primary balancing capacity should be made more precise. This aspect will be dealt with when the current draft RfG [62] is implemented.

This advance coordination and work is necessary in order to avoid unnecessary procurement measures.

There are numerous ways to **provide inertia.** When the suitability and costs are studied, it is necessary to ensure that the focus is not excessively or exclusively placed on generating plants. For example, market-based procurement offers an additional way to refinance the deployment of storage facilities. And base-load consumers can also be expected to have a significant and, in some cases, very low-cost potential, because their purchasing installations are rarely off-grid and generally offer corresponding capacity reserves to provide inertia.

In view of this wide range of possibilities, it is not possible simply to say at the present time what technology or measure can offer the cheapest form of procurement for the economy. This is because a crucial aspect in determining the optimal procurement process will be the ability to provide reliable inertia. Going by the current level of knowledge, any need for inertiawhich is identified in future should be met via an auction, unless it can be proven that it is simpler to cover part of or the entire need for inertia reserve via grid codes. Here, the system operator should also be granted the possibility to participate using his own measures or equipment. Also, the possibility of payment for intrinsic inertia should not be excluded *a priori*, because otherwise there could be higher real system costs as technologies are forced out because the services they provide are not recognised.

Finally, it should be pointed out that the afore-mentioned studies should also include the questions of whether and the extent to which it makes economic and technical sense:

- to ascribe to the consumer or certain categories of consumer a certain degree of frequency-related actual power behaviour, i.e. an **increase in the effect of self-regulation by the consumer**,
- to attach greater requirements to the product of "primary balancing capacity" in terms of its response rate,
- or to introduce an additional product, "primary balancing capacity plus",

so that these measures can avoid or reduce the need for inertia.

We propose that a task force also be set up for this, consisting of representatives of the same business associations as in the task force on the future procurement of reactive power; the task force would take up these recommendations, and initiate a process to shape and support a future market-based procurement system for ancillary services to maintain the dynamic frequency stability, and to set out the design and principles of a documentation procedure for code-based procurement.

6.3 Short-circuit power

All of the existing studies show that, over the next 10 to 20 years, there will be no acute nation-wide need to restrict or increase the short-circuit power. On the one hand, the nuclear phase-out and the reduction in the number of the large thermal power stations will remove the more problematic generators in terms of transient stability; on the other, the grid expansion ensures (over-)compensation for the related loss of short-circuit power. However, action may be required in individual instances. Also, there are a range of possibilities, some of which are either planned for the long term or still have to be developed.

In the interest of the greatest possible transparency and cost-efficiency regarding the ensuring of orderly grid protection and transient stability, the following recommendations should be implemented.

In Germany in the short term

Alongside the Network Development Plan, regular detailed analyses should be undertaken separately for short-circuit power and polar wheel angle stability.

These detailed analyses should look separately at the various voltage levels and analyse the contributions to short-circuit power across the grid voltage levels. Also, the actual power-plant-specific characteristics should be used as a basis, in order to attain more precise findings.

Furthermore, the effects of changing levels of local and regional short-circuit power on the coordination of the protection should be fundamentally analysed and, building on this, transparent and technically justified criteria should be derived to show the point at which specific need for action arises. These criteria answer questions like:

- What minimum level of short-circuit power must always exist?
- To what amount should the short-circuit power be limited?
- Why must volatile short-circuit power be equalised?

Here, all the technologies and measures which are basically possible should be identified, and it should be shown what technical and organisational advantages and disadvantages can be expected for the specific network nodes, the German transmission system and the European interconnected system. The technologies must be assessed in terms of their economic costs in terms of the extent to which nation-wide requirements for participants in the system should be imposed in the grid codes or individual measures should be taken. Here, it is necessary to include the question of the extent to which a measure can actually fully or only temporarily solve a problem, meaning that other measures are needed.

Further to this, there is a basic need to initiate studies, to analyse the technical and economic potential for greater sensitivity, dynamism and possibly also adaptability of protective concepts. This will round off the basis for decision-making as to the extent to which an increase in the flows of short-circuit power is actually needed.

We therefore see no need to adapt the grid codes with regard to the provision of short-circuit power until these questions have been clarified.

Also, it is suggested that the short-circuit power should not be counted as part of the voltage stability category of ancillary services, but should rather be subdivided into two separate categories of ancillary services, one of which addresses transient polar wheel angle stability, and one of which addresses secure and faster detection of short circuits. This seems useful because the problems and remedies differ greatly and should be kept separate from each other.

Short term in Europe (ENTSO-E)

The current calculation basis, which disregards the contributions from inverters in the calculation of the minimum short-circuit power, should be reconsidered. After all, it is logical that a need which has been identified using this methodology cannot be covered by inverter-based generating plants.

Also, there should be coordination at ENTSO-E level as to whether a minimum amount of short-circuit power needs to be attained for specific (yet to be defined) grid regions (e.g. in the case of the formation of sub-grids, grid restoration).

Long term

Whereas at present short-circuit power of at least five times the apparent power of the station must be available in order to comply with the critical error clarification time of 150 ms, the question certainly does arise as to whether this design still makes sense for the future electricity supply system if power generation mainly consists of inverter-based feed-in. Here, the effort involved in the provision of generally higher short-circuit power must be weighed up against the effort required for individualised stability-improving measures and adapted protective concepts. Corresponding studies into this should be commissioned.

6.4 Grid restoration

Sufficient power stations with black start capability will be available until 2034. However, for the time after that, thought must be given to at least replacing gas-fired and coal-fired power stations with black start capability. A further problem – which will occur before this – results from the removal of conventional power stations from the grid. If the supply were to collapse, there would then be far fewer (conventional) power stations meeting their own needs in stand-alone mode, which then make a major contribution to grid restoration thanks to their stand-alone capability. This means that there is a need for alternative or additional solutions to safeguard grid restoration both in terms of stand-alone operational capability and black start capability, so that the grid can be restored following a breakdown of supply.

Large-scale storage facilities in particular could close this gap and also provide a major element of grid restoration. Further potential supplies exist in the form of µGrids, consumers with their own generating plants, and operators of renewable energy installations. And even the transmission system operator could use new types of grid equipment with an integrated storage function to at least assist grid restoration. In addition to this stakeholder diversity, one could also envisage distributed concepts, e.g. as supplementary or safeguarding elements of a central concept. Since the technical preconditions in particular are not yet known in detail, and since they differ for the various stakeholders and concepts, it is impossible at present to undertake a robust cost assessment. This problem is exacerbated by the fact that the future developments in the field of grid automation, storage installations, etc. are hard to estimate because they are driven in some cases by more than just economic factors. Also, it must be noted that synergies exist with the provision of ancillary services for normal operations, and attempts are being made to use these as well as possible. The fact that the potential aspects of solutions are hard to grasp, and that possible synergies are complex, not only in the field of grid stability, but also in connection with the generation equalisation which will be needed in future, suggest that the most appropriate (combined) solutions can be arrived at via market-based procurement.

Prior to this, if there is to be low-cost grid restoration, there must be precise awareness of the need for stand-alone capability to cover in-house needs, grid stand-alone capability, and black start capability. This requires corresponding methods to identify these needs. In this context, it is also necessary to clarify the extent to which grid stand-alone capability can be counted as a (partial) substitute for installations with black start capability and vice versa, and for how long the capacity would have to be available.

All of these reasons show that there is a need to reflect not only on black start capability, but in future also on grid stand-alone capability, because this requires certain grid control characteristics, but not in all installations. This does not however necessarily mean that there is a need for stand-alone capability for in-house needs.

Even though the development of a strategy for grid restoration without thermal power stations does not yet appear urgent, the basic concept should be developed in the near future, because use can be made of synergies with the procurement of other ancillary services. Experience shows that some policy decisions affecting the electricity supply cannot be altered, or only with great difficulty. Perhaps suppliers or solutions will emerge which not only ensure round-the-clock problem-free grid restoration, but can also offer other ancillary services.

6.5 Summary in Brief

In this summary in brief, it should be noted that it is not intended to substitute the summary, just to highlight the main points. The reader is recommended to at least familiarise himself with the foregoing more detailed summary in order to gain a better understanding of the recommendations.

GENERAL BASIC RECOMMENDATIONS

Identifying the need

The methodology and input data (scenarios, design criteria, ...) for the identification of the need should be coordinated and published at national or international level.

In future, the studies of grid security and the identification of the need should be undertaken and evaluated regularly, e.g. at the same time as the Network Development Plan.

Procurement

Procurement of the ancillary services reactive power, inertia and grid restoration should in future basically be market-based.

Partial procurement via grid codes should in future take place only if the economic efficiency of this has been demonstrated. In particular, consideration should be given to differences in terms of geography and grid topology. In this regard, all the alternatives, with their advantages and disadvantages and their technical and economic characteristics, should be presented

General Recommendation of Implementation

There should be an orderly process to shape the appropriate future market-based procurement system and the design and principles of the documentation procedure to assess the cost-efficiency of general requirements, imposed irrespective of geography and grid topology, in grid codes.

Here, the following associations or representatives both of transmission system, extensive system, and municipal system operators, of generation, storage and consumption facility operators, and regulatory and ministerial authorities should be included:

- BDEW
- BEE
- BMWi
- BNetzA
- BWE
- FNN
- VDMA
- VGB
- VIK
- VKU
- ZVEI

SPECIFIC RECOMMENDATIONS ON REACTIVE POWER

The identification of the need should take place uniformly at least at national level.

The procurement system should be more competition-based and market-based. There should not be a requirement to auction it: because of the strong local reference of reactive power, it should also be possible on a bilateral basis. Also, it must be possible for system operators to undertake their own measures.

The remuneration system must provide incentives for system operators to restrict not only the use of reactive power, but in view of the significantly higher cost element, also the provision of reactive power, to the level which is technically necessary and costs the economy the least. To this extent, attention should be paid to the differentiation, but at least to an objective reflection of the costs of providing the capacity and of the use of the energy. The code-based procurement should also be included in this remuneration system. The remuneration system should be logical and technology-neutral, and should cover all grid levels, whilst still permitting differences for specific voltage levels. The participation and remuneration should take place without distinction between installations of consumers, grids, generating plants and storage operators.

There is already a need for additional reactive power in the transmission system today. For this reason, the procurement concept needs to be drawn up in the near future.

In view of all of the technical, operational and economic, legal, regulatory, legislative and political aspects, the conversion of the system is enormously complex. For this reason, it is proposed that a process be initiated whereby

- initially the requirements and goals of the provision of reactive power are defined,
- the criteria for the assessment of the procurement models are coordinated,
- the various procurement models/methods are then described, and
    - these are discussed in terms of their advantages and disadvantages,
    - the countervailing barriers and problems are presented with along with solutions, and
    - the need for adaptation and development is highlighted, and

and ultimately the target system and perhaps an intermediate system are defined.

SPECIFIC RECOMMENDATIONS ON INERTIAThere is sufficient dynamic frequency stability up to 2025, and in some cases up to 2035.

First of all, use must be made of the potential from adapting the protective concepts, the rules should be harmonised accordingly, and a clear distinction should be drawn between inertia and primary balancing capacity.

In parallel to this, the identification and breakdown of the need at ENTSO-E level should be coordinated (scenario framework for input data, formation of partial grid, ...).

This is followed (in the medium term) by the drafting of a procurement concept.

There are numerous ways to provide inertia; one key aspect will be the ability to provide secure inertia. Going by the current level of knowledge, any need for inertial response which is identified in future should be met via auctions, in which the system operators can participate with their own installations, and unless it can be proven that it is simpler to cover part of or the entire need for inertia via grid codes.

Remuneration for the provision of intrinsic inertia should be considered, and the relevance of opportunity costs should be borne in mind.

Further to this, consideration should also be given to:

- an increase in consumer-side inertia for certain consumers by prescribing a stipulated effective power response regarding frequency,
- higher dynamism for primary balancing capacity,
- or an additional product, “primary balancing capacity plus”

in order to reduce the need for inertia.

Specific Recommendations on Short-circuit Power

Up to 2034, there is no need for nation-wide action to limit or increase short-circuit power, or at most in specific instances.

In future, a distinction should be made between short-circuit detection and polar wheel angle stability.

The calculation base (contribution from inverter-based generation and from other voltage levels) needs to be developed further and coordinated at ENTSO-E level, and it is necessary to clarify whether a minimum level of short-circuit power needs to be provided for certain (yet to be defined) grid regions.

Regular detailed analyses should be undertaken separately for short-circuit power and polar wheel angle stability. Here, the effects on coordination of protection must be studied, and transparent and technically justified criteria for the identification of a need for action derived. All solutions should be shown, along with their advantages and disadvantages.

A fundamental study should be made of the potential for higher sensitivity, dynamism and adaptability of protective concepts, and use should be made of this potential.

Specific Recommendations on Grid Restoration

No problems relating to a lack of possibilities to restore the grid can be expected in the short and medium term.

The basic concept needs to be developed in the near future in order to make use of synergies with other ancillary services. Here, a procedure needs to be developed to ascertain the need for stand-alone capability to cover in-house needs, grid stand-alone capability, and black start capability, including the possibility of mutual compensation between these ancillary services.

There are a variety of possible solutions to provide stand-alone capability to cover in-house needs, grid stand-alone capability, and black start capability. The high complexity due to synergies for normal operations argue in favour of market-based procurement.