Development of a retrofit program for distributed generation in Germany for the prevention of frequency stability problems in abnormal system conditions

- Summary Report -

Study by order of the Federal Ministry for Economic Affairs and Energy

Development of a retrofit program for distributed generation in Germany for the prevention of frequency stability problems in abnormal system conditions

Summary Report

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1 Executive Summary

In the last decade, electricity production from distributed generation (DG) has increased significantly in Germany due to the German Renewable Energy Sources Act (EEG) and the Heat and Power Generation Act (KWK-G). Having an installed capacity of 70 GW at low or medium voltage levels, distributed generators have gained increasing relevance for transmission network operations.

Under § 19 of the Energy Industry Act (EnWG), electricity supply network operators are obligated to specify technical requirements for electricity generation plants. These requirements specify the design and operation of distributed generators in order to guarantee the security of supply as well as grid integration.

Despite the successive revision of the grid codes for the integration of Renewable Energy Systems (RES), the development of DG and the grid codes is somewhat divergent. Out of this challenge arises the problem that the protection settings of the portfolio need subsequent adjustments.

Such adjustments are required for the automatic disconnection triggered by over- and under-frequency. At a system frequency of 49.5 or 50.2 Hz, distributed generation of up to 48 GW instantly disconnects from the network because of the conditions of historical grid codes. Only the required extended frequency range of 47.5 to 51.5 Hz in modern grid codes offers a sufficient framework to ensure system stability. In the case of large-scale failure, as in 2003 and 2006 when the system frequency increased to 50.2 Hz or decreased to 49.5, there is currently the risk of a system-wide blackout. Considering the significant size of the generation portfolio, the available primary reserve cannot compensate for the power that would be immediately disconnected. According to current studies regarding system stability [17, 21] the current behaviour of DG significantly endangers the stability of the interconnected European power system. Therefore, the European Network of Transmission System Operators for Electricity (ENTSO-E) attaches great importance to this issue.

Retrofitting for German photovoltaic (PV) power plants was initiated as a reaction to this risk. A regulation on network stability (SysStabV) was put in place in 2012, which governs the retrofitting of more than 300,000 PV power plants with more than 12 GW of installed capacity. Subsequently, the German Federal Ministry for Economic Affairs and Energy (BMWi) commissioned a study regarding the development of retrofitting strategies for other distributed generators (wind, biomass, CHP, hydro) in 2012. The present summary presents the essential results from the final report of this study [14]. The key recommendations are summarised as follows:

Power at risk

- The priority for retrofitting is to adjust the frequency protection settings (especially adjustment of lower frequency limit to 47.5 Hz).
- To optimise the concerned plant portfolio to be retrofitted, technology-specific criteria were developed (especially for plants >100 kW).

- Approximately 1 GW of the concerned installed distributed generation should not be retrofitted.
- Retrofitting is needed for approximately 21,000 existing plants with a combined installed capacity of 27 GW.
- A deadline of 12 to 18 months is considered appropriate.

Economic impact

- The costs for retrofitting the protection equipment and control technology are adequate for the plant operator.
- In most cases, the modification can be performed with regular maintenance.
- The estimated total cost range for the adjustment of the frequency settings is € 4 - 28 million.
- The coordination and monitoring conducted by a central authority has clear synergies compared to decentralised governance conducted by over 800 distribution system operators.

Technical derogation measures – reduced technical feasibility

- For distributed generators with reduced technical feasibility, reduced requirements for the frequency range are legitimate.
- The burden of proof of the reduced technical feasibility lies with the plant operator.
- The establishment of lists with specifications about the acceptable frequency range for the DG can help improve the acceptance and retrofitting process itself. These lists should be created with the help of the manufacturer.
- If it is necessary to exchange essential plant components in order to comply the obligations, DG should be exempted.

Process and implementation

- Coordination and monitoring should be conducted by a central authority, such as transmission system operators.
- We propose a direct process chain between all involved parties (distribution system operator → plant operator → service provider or manufacturer).
- Distribution system operators play a central role in the communication with the plant operator during the retrofitting process.
- System operators should ensure the quality of the retrofitting process with the help of adequate quality management.

2 Background

2.1 Development of distributed generation plants in the German power distribution grid

During the last decade, the supply of distributed generators (DG) increased significantly, in particular due to promotion via the Renewable Energies Act (EEG) and the Power-Heat-Coupling-Act (KWK-G). These distributed generators mainly feed into the low or medium voltage distribution network. In the end of 2012, approximately 76 % of the installed distributed generation capacity was connected to the distribution grid (<110 kV). With the increase of generation capacity shown in Figure 1, DG and the whole distribution network reached an increasing systemic importance, also in the context of operating the transmission system.

In accordance with § 19 EnWG in the German law operators of electricity supply networks are obliged to provide and publish technical requirements for power generation plants. Amongst others, these guidelines include specifications for cut-off criteria of the DG at under- and over-frequency. In the past, the grid connection guidelines demanded a disconnection of power plants close to the nominal frequency of 50.0 Hz[1]. Current grid studies by the association of European transmission system operators (ENSTO-E) [21] rate the historical cut-off frequencies as very critical, in particular the value of 49.5 Hz in the medium voltage level and 50.2 Hz in the low voltage level.

Figure 1 clearly indicates that the growth of installed DG capacity and the development of uncritical frequency settings did not proceed at an equal pace. This tension results in a plant population which potentially needs a subsequent adjustment of the frequency settings. A survey conducted on the system operators confirms the presence of possibly critical cut-off values at under- and over-frequency.

[1] Historical guidelines for distribution grids focused on safe mains separation of DG during maintenance work and on anti-islanding. This was ensured with a mains separation close to 50.0 Hz.

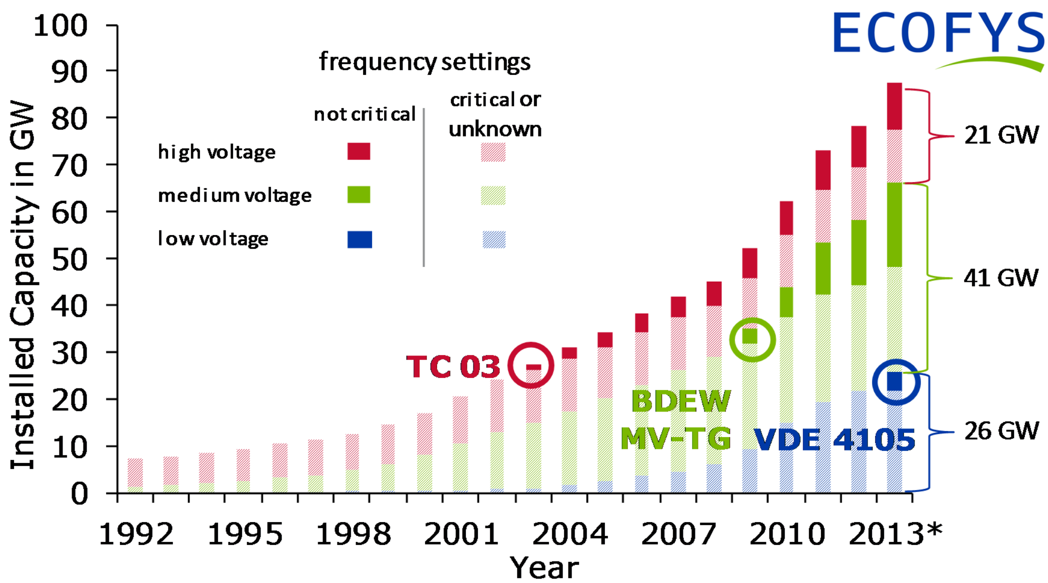

Figure 1: Comparison of the development of distributed generators and the introduction of technical connection conditions; decommissioning is not taken into account; TC 03: Transmission Code 2003 by the Association of German Network Operators (VDN); BDEW MV-TG: Technical Guideline for Generating Plants Connected to the Medium-Voltage Network by the German Association of Energy and Water Industries (BDEW); VDE 4105: Application Guide “VDE-AR-N 4105” for Generating Plants Connected to the Low-Voltage Network by the German Association for Electrical, Electronic and Information Technologies (VDE); 2013*: own forecast; Source: own chart based on [6, 8]

2.2 Risk situation

ENTSO-E took care of the facts, not least because of the results published in the study on grid stability [17], and commissioned a study on the system stability in case of frequency deviations [21]. Since the grid frequency of the European electricity power system is synchronous and the distributed generator population contains a variety of different plant types, an isolated evaluation of different energy sources and concerned countries would be insufficient.

Switching DG on and off uncontrolled at 50.2 Hz and at 49.5 Hz endangers the stability of the entire continental European power system due to the significant amount of installed capacity. The active power frequency control is not designed for the emerging power imbalances and switching operations and cannot ensure the grid frequency stability under these conditions. Currently, the probability of reaching these critical thresholds is very low during normal operation. However, as soon as a major failure in the integrated network meets a high feed-in of DG, an urgent endangerment of the system stability can potentially arise, especially at 49.5 Hz. In addition, the uncontrolled on- and off-switching of DG complicates the system operations considerably, in particular the implementation of stabilising measures after major failures. As a result of this, an urgent need arises to retrofit DG and ensure system security. A 1 GW-limit was set as an acceptable residual amount of concerned DG with critical frequency settings in Germany in coordination with the ministries and the transmission system operators (TSO). [14], [21]

Given these findings and the apparent non-compliance with the acceptable system limits, ENTSO-E urged the national transmission system operators to take care of the problem and is currently considering its own initiatives to retrofit DG. As a result of this request, an adjustment of the frequency protection values of PV plants in Italy and Germany was already performed. Currently, more than 300,000 PV plants are retrofitted in Germany alone. These measures are expected to be widely implemented by late 2014. At the same time, ENTSO-E has asked Member States to back up the results of the previous study [17] with their own detailed values. This process is on-going.

Furthermore the current development of legally binding European Network Codes offers measures to implement future retrofit programs. The network code "Requirements for Generators", which is currently in the comitology process, provides that, in appropriate cases and after a cost-benefit-analysis by the transmission system operators, compliance with the new requirements may be demanded from existing plants as well. To what extent this legal framework represents a suitable means for dealing with challenges of the kind described here remains to be seen.

3 Summary of study results

The development of recommendations for action for the retrofitting process is based on a technical, economic and legal evaluation. The results of this assessment include

- an assessment of the plant population that needs to be upgraded,
- suggested technical solutions to retrofit affected plants and
- a review of the legal framework and legal applications.

For our data basis, we used publicly available registers of power plants and conducted a branch survey. For this, we interviewed over 50 plant manufactures, service providers, protection device manufactures, plant operators, system operators and representatives of industry associations. This high number is necessary to ensure a sufficiently representative query, due to the very heterogeneous market and the type-specific plant constructions. The analysis focused on existing installations with cut-off frequencies in a range of 49.0 to 50.2 Hz that are based on the following technologies:

- wind power plants (wind) according to the Renewable Energies Act (EEG)
- solid biomass according to EEG
- EEG-gas (e.g. bio-, landfill-, sewage-, mine gas) and liquid biofuels
- Combined Heat and Power (CHP) according to the Combined Heat and Power Act (KWK-G; plants up to a maximum of 100 MW_{el})
- small hydroelectric power according to EEG

3.1 Estimation of the amount of affected power units and their overall behaviour

Despite the gradual introduction of fixed cut-off frequencies of 47.5 and 51.5 Hz, many decentralised power plants that reach critical grid frequencies close to 50.0 Hz will disconnect from the grid immediately (i.e. within 170 to 200 ms). For the assessment of the amount of affected power units that have critical frequency settings, we blended the information about historical cut-off values with the details of the publicly accessible asset master data collected by network operators.

In total, up to 27 GW installed capacity and up to approximately 60,000 units of the named plant types may potentially disconnect at grid frequencies of 49.0, 49.5 and 50.2 Hz. With a share of 95 %, the affected production capacity focuses almost completely on the 49.5 Hz cut-off frequency. In general, at all plant types a significant part of the power capacity and number of existing plants are affected.

At under-frequency the resulting **cumulated maximum affected capacity** amounts to 30 GW. The estimated affected capacity in the range of 49.0 to 51.0 Hz is presented in Figure 2.

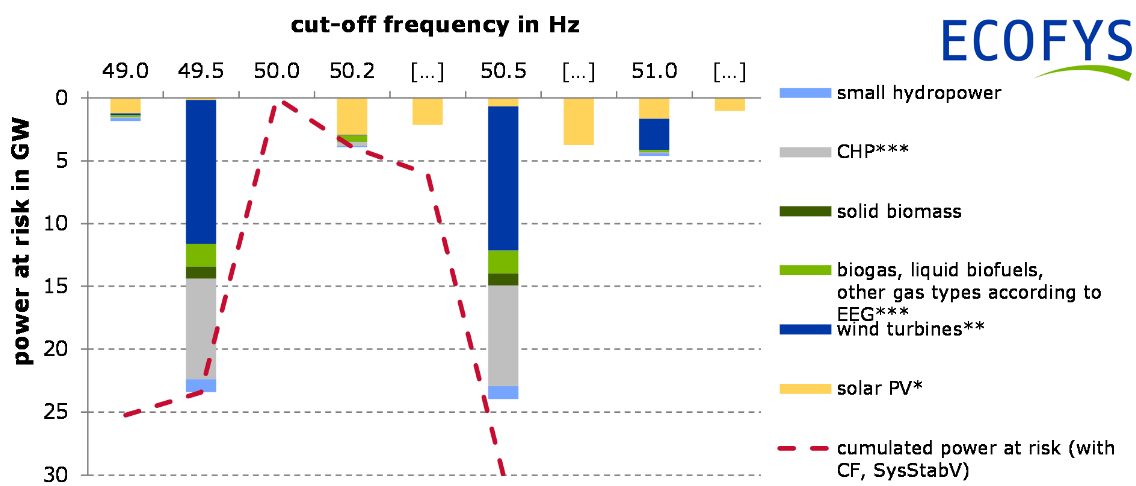

Figure 1: Estimation of the maximum expectable affected capacity considering coincidence factors (CF)[2] of individual energy sources and the PV- retrofitting program; *: Considering the FNN-transitional arrangement, **: Considering the SDLWindV-retrofitting, ***: Considering the specific lifetime of CHP plants; Source: own calculations based on [6, 7, 8] and data from Deutsche WindGuard and manufactures

[2] Coincidence factors represent an estimation of the maximum simultaneously in-feeding installed capacity. In particular, they depend on the following parameters: wind volume, solar radiation, maintenance and full-load hours.

In summary, the assessment of the overall behaviour represents a ***worst-case-scenario***. In this scenario, we assume a maximum expectable affected capacity. The likelihood of this case is very low but it involves extremely high economic costs. For an in-depth risk analysis, further investigation is needed. An additional probabilistic analysis requires a high range of empirical data for the whole European power system. An isolated analysis of the German network would be inadvisable.

3.2 Limiting the retrofit scope and plant population that needs to be retrofitted

Against the background of a high number of 60,000 affected power units and in some cases very individual plant specifications, a high need for time, a high degree of complexity and high costs are expected in case of a complete retrofitting on the technologically-available solution. However, an affected capacity of approximately 27 GW threatens the stability of the entire continental network due to its significant value. Given the complexity on the one hand and the potential risk on the other, we derive a simplification of the retrofitting process in the following paragraphs. This aims at a simple, fast and effort-minimizing retrofit.

Limiting the retrofit scope

The evaluation as a part of the industry query and the coordination with the transmission system operators showed that the following two solutions for DG retrofitting are suitable:

- *Variant 1, reconfiguration of fixed cut-off frequencies:* re-parametrization of the fixed thresholds at over- and under-frequency according to VDE-AR-N 4105, stochastical distribution at over-frequency between 50.2 and 51.5 Hz, reconnect-frequency matches cut-off frequency
- *Variant 2, retrofitting to active power reduction at over-frequency:* Implementation of frequency settings of VDE-AR-N 4105 with active power reduction characteristic at over-frequency (without hysteresis)

Variant 1 represents merely a manual change of statistical cut-off values at frequency deviations which are set in existing power unit protection equipment (re-parameterization). In most cases[3], such a change can be carried out without great effort. Variant 2 is more demanding for the individual plant's control technology and might be significantly more complex and costly in the case of adverse plant configuration (no software update possible). From a system perspective and considering the whole plant population, variant 1 approximately imitates the behaviour of the more complex variant 2, at least in terms of primary, intended power reduction at over-frequency.

[3] Compared to photovolatics, technical peculiarities (see [14]) of the studied plant types exist due to the partly very heterogenoeous design and have to be taken into account accordingly for the practical retrofitting.

Given decisive disadvantages[4] of variant 2, we recommend to postpone this option and put it into practice at a later point in time after an additional in-depth study has analysed the necessity for a selected part of the plant population.

Limiting the plant population that needs to be retrofitted

Under the objective of minimizing the retrofitting-effort, we used an iterative process to derive the plant population that needs to be retrofitted. Thereby, we minimized the total number of plants to be included, which is in an approximately linear relationship with the efforts. The initial value was set as the number of affected plants at which cut off frequencies could be re-parameterized at a reasonable level of effort[5] according to the manufactures' information. In a further step, the performance class[6] and the commissioning year[7] for the other energy sources were increased sequential, until the 1 GW limit had been reached. At each iterative step, the potential to lower the system risk has been set in relation with the associated expenses[8]. The resulting minimum limits are summarized in Table 1.

[4] The other disadvantages refer to a high number of expected case by case examinations, time-consuming retrofitting, low expected acceptance by the plant operator for the substantial additional costs in individual cases, etc. (cf. [14]).

[5] Provided the full expansion of the frequency range is possible without an exchange of components which are allocated to the powertrain or energy conversion unit including power electronics.

[6] The performance classes used base on the manufactures' information.

[7] The commissioning year was increased in increments of 1 year between the years 1990 and 2012.

[8] At the gradual increase, the minimum levels for each plant type were chosen to always cause the largest reduction of retrofitted plants with a minimal increase of the remaining power capacity.

Table 1: Estimation of the retrofitting scope including minimum limits, the remaining number of plants and number of plants to be retrofitted; Source: own calculation

plant type	**minimum limit**		**remaining generation capacity**	**to be retrofitted**	
	performance class in kW_{el}	commissioning year	in GW_{el}	in GW_{el}	number of plants
Wind	>450[9]	no limit	0.3	12.1	11,500
Solid biomass	>100	no limit	<0.1	1.1	100
Biogas and other EEG-types*	>100	2000	0.1	2.8	6,500
CHP	>5,000	no limit	0.0	9.1	400
	5,000 ≥ x > 100	2000	0.4	0.3	1,000
Small hydropower	>100	no limit	<0.2	1.2	1,500
Sum			**1.0**	**26.7**	**21,000**

Upper limits for the included power plants with regard to the commissioning date depending on the voltage level are determined by the introduction of current technical connection conditions.

[9] There is an accumulation of affected wind turbines with a capacity of 500 kW. In contrast to the other plant types, an inclusion of this performance class is necessary. Therefore, the minimum is specified in the form "> 450".

Resulting retrofit requirements

- On the basis of the analysis of the plant population and technology-specific features, we suggest using minimum limits for the retrofit-obligation for generation capacity and commissioning years according to Table 1. This reduces the number of plants that need to be retrofitted from about 60,000 to about 21,000. Compliance with the 1 GW limit for the remainder is a persisting major challenge.
- We also suggest limiting the first step to a re-parameterization of the existing plants' frequency protection (variant 1). The relevant measures can be implemented easily on a large part of the plant population. To improve the system's behaviour, the implementation of an active power reduction characteristic at over-frequency (variant 2) can be performed subsequently for a portion of plants that is still to be determined.
- Thorough monitoring is essential for the rapid implementation of retrofit measures and achieving the desired 1 GW target. In addition, only the monitoring can provide the necessary information to further assess of the remaining risk potential.

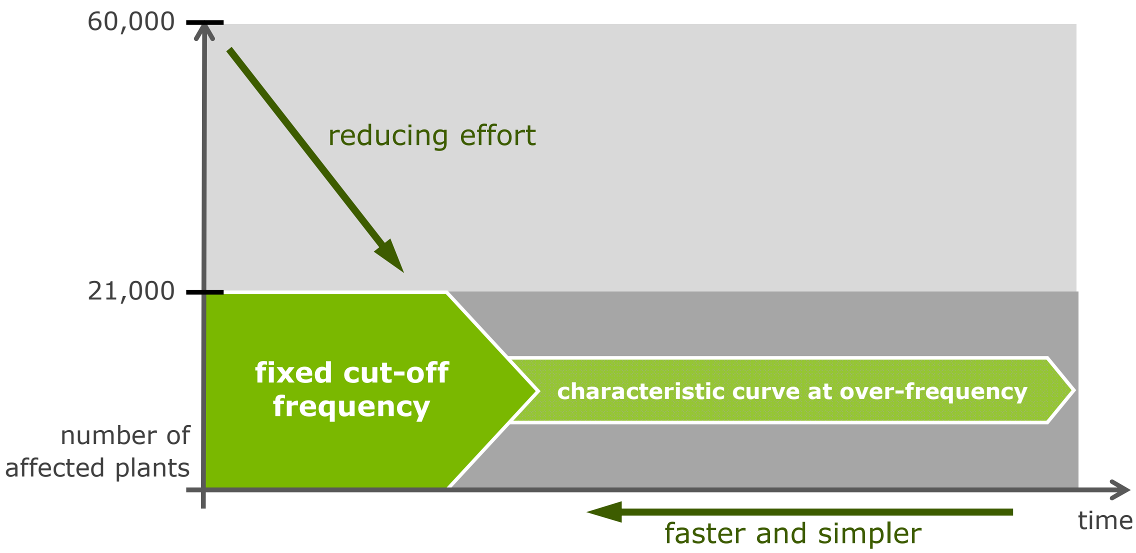

Figure 3: Retrofitting process: suggested simplification and acceleration (division into step 1 and step 2) as well as effort reduction (introduction of minimum limits to reduce the number of retrofitted plants)

3.3 Assessment of the control technology proposal

The fundamental goal of the retrofitting by means of the recommended variant 1 (retrofit of fixed cut-off frequency) is to operate the power units in a frequency band between 47.5 Hz and 51.5 Hz, which is wider than in affected existing power plants. This extended frequency range might cause increased strain on the electrical equipment under certain circumstances. Therefore, not only should the **frequency** be specified, but also the **duration** for which this operation must be ensured and the **active power output** that must be provided.

Frequency range requirements

The goal of the retrofitting measures is primarily to broaden the frequency range in which the plants keep their feed-in and, in this way, to increase the stability of the power system. In cooperation with the transmission system operators, we recommend the reconfiguration on the frequency settings of the current technical requirements. According to [23, 2, 4], a disconnection in the frequency range of 47.5 to 51.5 Hz is inadmissible. Finally, the following new parameters are to be requested:

- Fixed lower cut-off frequency: f_{low} = 47.5 Hz
- Fixed upper cut-off frequency: 50.2 Hz < f_{up} < 51.5 Hz (stochastically equally distributed, exception lower voltage: 50.2 Hz < f_{up} < 51.0 Hz due to the operation of emergency power supply, cf. [14])

In some cases, especially in case of very old plants and generation units in high performance classes, a review of the plant specifications can result in reduced requirements regarding the frequency settings.

Requirements for the operating time in the required frequency range

According to [4] and in cooperation with the transmission system operators, we recommend the specification of a duration of at least 10 minutes for the extended frequency range. These specifications comply with the current technical requirements for the equipment and can be kept by the vast majority of affected generation plants, according to the manufacturers' information.

Peculiarities regarding an active power reduction at under-frequency

Due to the described mechanisms, an operation at under-frequency (cut-off value: 47.5 Hz, duration: minimum 10 minutes) might be only possible with a reduction of active power generation at the same time. According to the manufacturers this affects only a small portion of the plants involved, particularly CHP plants in higher performance classes.

Fundamental limits of operation in an extended frequency range

The increased strain on the electrical equipment applies to almost every technology considered here. At some plants, the working range described above could infringe upon the specified limits of essential components. There are two obvious reasons for this:

- Stimulation of mechanical resonances, if the plant's natural frequencies (in their entirety) are close to the frequency range extended to the previous operating mode. This aspect is primarily relevant for turbine units and wind power plants.
- Overexcitation of the generator / saturation of the magnetic circuit at under-frequency and as a result, thermal stress on generator components. This aspect is especially important for turbine units and plants in high performance classes.

We recommend basing the assessment of the achievable frequency band exclusively on the plant specifications (manufacturer's datasheet). Affected plants should be excluded from further operation in critical frequency ranges by reducing the specific requirements.

Principles of reduced requirements

In the interest of a maximum increase of system security, it is preferable that plants which cannot fully meet the new requirements are upgraded. At least to the extent that acquiring a broader frequency range is achievable with reasonable effort. In principle, we see a required retrofitting of the protection- and control technology as acceptable. To determine the reduced requirements, the TSO give out the following principles:

- A power reduction at under-frequency is preferable to a restricted frequency band and a reduced duration.
- Neither reduction in frequency nor in duration can be prioritised.
- The reasonable plant specifications should be as close as possible to the general requirements (47.5 Hz, minimum operating time of 10 minutes).

Who can perform a re-parameterization?

First and foremost, the staff of the equipment manufacturer or a service provider comes into consideration. The staffers need to be qualified electricians according to DIN VDE 0105-100:2009-10. Also, a maintenance mechanic with an appropriate additional qualification (electrician) is qualified for the parameter change.

For the re-parameterization of the additional external protection equipment further staff might also need to get involved, especially since the personnel of the manufacturer or service provider do not usually have experience with these devices. In this case, the system operator should be included in the process when appropriate.

3.4 Economic impacts

On the basis of the conducted industry survey, it can generally be determined that the cost of the reconfiguration to fixed frequency values per plant are a few hundred euros for each plant [14], which is quiet low and in most cases, does not significantly affect the normal operational costs of the plant. Even if a replacement of the frequency relay is required in individual cases, in most cases costs are limited to a few hundred euros. The costs can be limited further if the re-parameterization is carried out during a regular maintenance, saving separate call-out charges. Given these limited costs, we see it appropriate to leave them with the plant operators and put a cost rollup aside. In some cases, the operators might face significantly higher costs if extensive hardware modifications are necessary or uncertainty regarding the technical feasibility of retrofitting exists. Such special cases must be considered by a central instance according to the hardship scheme (see chapter 4).

Considering the PV-retrofitting program experience, a cost rollup would probably include administrative costs in the same scale at the least. If a cost rollup was conducted, the administrative process and related, not technically justified costs would increase dramatically compared to the suggested re-parameterization without reimbursement.

In addition, there are also one-off administrative efforts of the distribution system operators to contact the plant operators and pass the essential data on to the central authority.

However, the variance in costs for the pure retrofitting that was specified in the surveys is very high. Therefore, the assessment of the retrofitting-costs for the reconfiguration is represented as a range. Figure 4 shows the costs depending on the chosen commissioning year as a minimum limit. In this example the performance classes are fixed and correspond to the values indicated in Table 1. The total costs of a pure parameter change are estimated between 4 and 28 million Euro[10]. Although the inclusion of plants commissioned earlier than 1990 is necessary to achieve the 1 GW mark, the total expenses increase only slightly with the reconfiguration of the old plants. Thus, the economic costs associated with retrofitting are relatively low, which is also the case for the total plant population[11].

[10] Compared to [14], the upper border of the cost estimate is higher, since the pure costs for the re-parameterization of wind turbines and CHP plants have been adjusted in coordination with the stakeholders.

[11] [14] provides a differentiated analysis of the retrofit requirements and the associated costs per plant type.

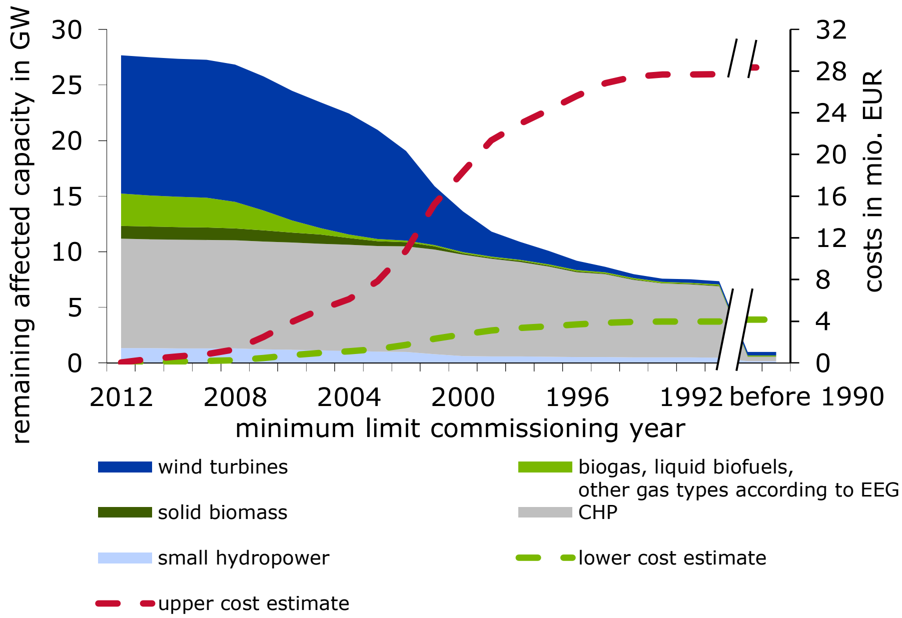

Figure 4: Estimated retrofitting-costs depending on the chosen commissioning year as a minimum limit, excluding call-out charges. Source: own diagram

The biggest efforts are incurred at the coordination centre. The handling of the retrofitting process, as well as the monitoring, examination and assessment of documents regarding limited technical feasibility of operating in an extended frequency range, will require considerable resources. To ensure the work of the coordination centre, the regulation must ensure that the expenses associated with these tasks are refundable.

The consumer would be marginal affected by the retrofit because the proposal abstains from a full rollup of the costs associated with the retrofit program. Even if a cost rollup of the one-off retrofitting costs is considered at a later stage, these are irrelevant to the electricity consumer given a small number of affected plants. Only the implementation of the second step (power reduction characteristic at over-frequency) might be possibly connected with noticeable costs.

3.5 Reviews on the legal framework for the retrofit program

The following summary is based on the study of the legal framework of the retrofit strategy for generation plants on medium- and low-voltage grids by Becker Büttner Held in [14]. The purpose of the investigation was to demonstrate the need for the implementation of the law and to make proposals for the implementation of the energy economic suggestions. It also reviewed how an extension of the SysStabV can be coordinated with the existing provisions of other laws and how violations of overriding laws can be eliminated. On the whole, different proposals for the legal implementation of the suggestions by the energy economics were developed as well as an examination of a number of different relevant legal issues for the preparation of the regulation text.

In the following section, individual legal problems are addressed and – where possible – solutions for a legal implementation of the retrofit program are suggested.

- The understanding of the concept "plant" in terms of EEG has been controversial in legal literature and case law for a long time. The German Federal Supreme Court (BGH) has now decided that two power generation units form one plant in terms of § 3 No. 1 EEG when they share the required structural or technical facilities for the operation. Clarity should be achieved about whether this "broad" interpretation of the EEG-plant term had been applied by the respective system operator when the master data register was created. Additionally, future changes of the EEG should be considered and therefore, references to the EEG should be static rather than dynamic. This should also be considered in the recommendable definition of "commissioning time" in the notified regulation. The same also applies to CHP-plants.
- We believe that it is justified for factual reasons (especially technical reasons as the complexity and individual design of the power plant) to modify the distribution of the obligations and costs in comparison to the current obligation and cost system in the SysStabV. In particular, the respective burden of the plant operators is relevant.
- Since legal ambiguity in terms of liability can also occur if the plant operators are obligated to perform the retrofit, an explicit clarification in the new legal framework should be taken into account.
- The new legal framework should contain hardship clauses, which exclude plant operators from the retrofit obligation. These clauses should be formulated broadly enough to cover unexpected cases, and should expressly mention certain facts such as violating public law. At the same time, the standards must be clear enough that no legal uncertainties of interpretation arise.
- The legal relationships between plant operators, system operators and transmission system operators must be designed in a way that sufficient incentives and, if necessary, required sanctions ensure that the parties actually carry out their duties and within the prescribed time limits.
- In the new Regulation the concept of the grid to which the regulation refers must be clear to operators. Additionally, it should include a legally certain provision that ensures the setting of the necessary system operators' cost in the network charges.

4 Recommendations for the practical design

Retrofit – affected plant population and retrofitting option

To reach the set 1 GW limit, we recommend the binding retrofitting of all plants above the **technology-specific minimum limits** according to Table 1, which take into account the upper limits for the commissioning year according to current technical requirement [14].

At the same time we recommend imposing only variant 1 (**re-parameterization of fixed frequency thresholds**) in the first step. Usually a change in the plant hardware for energy conversion is unnecessary in this step. Therefore, we see a time limit of 1 to 1 ½ years as appropriate for these measures.

For the behaviour of distributed generators at **under-frequency** in terms of system and plant safety as well as retrofitting costs, we see the values described in section 3.3 for **frequency, duration and active power (reduction) at under-frequency** as appropriate.

The implementation of a power reduction characteristic at over-frequency is expected to be only realisable for **a part of the affected plant population** if the plant operators bear the costs. We advise to defer this step in the beginning and, if necessary, implement it at a **later point of time,** using the experience from the previous retrofitting. There should be no adjustment of the fixed upper cut-off frequency parameter for plants that already have an active power reduction characteristic at over-frequency because of regular maintenance etc.

For plants where a power reduction characteristic at **over-frequency** cannot be readily implemented, we recommend a modelling of the characteristic curve through a power-based **stochastic uniform distribution** of the cut-off frequencies in a range from 50.2 to 51.5 Hz as a first step. For installations above 5 MW frequencies near 51.5 Hz should be dictated. A classification of the cut-off frequencies belonging to zip-code areas (cf. [14]) appears to be a pragmatic, easily enforceable and unambiguous way to assign and communicate the appropriate values to the operators.

Cost allocation

Given the suggested minimum limits and the limited costs associated with the retrofitting, we consider it **reasonable** that the **operator alone bear the expenses caused by the adjustment of protection and control technology**. Earnings and compensation failures related to the retrofitting are negligible. Due to the experience gathered by the PV-retrofitting program, a reimbursement for the retrofitting expenses would probably result in comparable administrative follow-up costs. Therefore, we do not consider such refunds to be reasonable. Thus a rolling of the costs connected with the retrofitting is unnecessary.

Also for the distribution system operators, the effort that is directly connected to the retrofitting is limited to measures that can usually be implemented as a part of regular maintenance, in particular the reviewing and adjustment of parameters of external protection devices. In addition, there are also one-off administrative efforts of the distribution system operators for contacting the plant operators and passing the essential data on to a central authority. Here, a cost rollup would result in additional costs and higher total costs of the retrofitting program. Particular tasks of coordination and monitoring could be faced by a central instance to meet the complexity and need for the quick implementation of the retrofitting program. Compared to a purely distributed controlling and processing by more than 800 distribution system operators, a central instance brings significant synergy effects.

The retrofitting of fixed cut-off frequencies implies that the proper operation of the plant in the broader frequency range brings **no inadmissible infringement** of the manufacturer's specifications on the mechanical, electrical or thermal **limits of key components**, which could be avoided only by **replacing** these components. In this sense, key components are considered to be components of the powertrain and energy conversion, including in particular engines, turbines, electromechanical generators, drive shafts, gears and power electronic converters. If a replacement of such components proves to be necessary for the operation in an extended frequency range, the retrofit-obligation should not be applied in this step. Components that are associated to protection and control technology are not considered to be key components in the sense describe above. Their replacement would not negate the retrofitting obligation.

Limited technical feasibility

At some plants, the operation range described in section 3.3 will infringe the specified limits of key components. Consequently, the proposed response values of frequency protection must not be set without replacing[12] these key components. We recommend transferring the obligation of proving **conflicts between the new parameters and the plant's hardware specifications** by presenting appropriate manufacturer's documents, data sheets or expert's opinion to the network operator. In this case, the plant operator should explain and submit technical documentation that show which settings (frequency range, duration, power), as close as possible to the requirements, can be implemented for its plant without replacement of key components. Usefully, the operator bears the costs of providing such documents. Thus, the operator's declaration must meet the criteria of admissibility of the origin of the evidence and the completeness of the given specifications.

Such technical limitations likely concern distributed generators based on solid biomass, large CHP plants in the MW-class and (older) hydroelectric power plants. Overall, we expect a maximum of 2,000 plants[13] that use these technologies and legitimately report such limitations.

In particular for wind turbines we recommend that the manufacturers create a list of types which can specify the realisable adjustment ranges for a large portion of the plants.

The power capacity represented by the plants with technical limitations is too large to consider a full release from the retrofitting-obligation. To let them contribute to an increased system stability within the range of reasonability (no replacement of key components) nevertheless, we recommend the

[12] Due to individual plant design, modifying the key components would come up to a replacement.

[13] This estimation should be seen as an assessment of the magnitude and may differ number of plants that is from the retrospectively determined in the monitoring.

definition of reduced requirements to which most plants can reasonably comply with by the transmission system operators. Only for power units that cannot even meet the reduced requirements, do we recommend continuing the operation with today's settings in the framework of a temporary exemption (e.g. for EEG- and KWKG-plants until the end of the funding, non-funded plants until the next revision).

Measures of the distribution system operators

Regardless of the plant operator's measures, the distribution system operators must ensure that the grid protection settings are constantly adapted to the new values. Otherwise, retrofitting the plants could be ineffective.

Process control and implementation

Given the heterogeneity of the plant population and the uneven geographical distribution, we explicitly recommend that the retrofitting process and the respective monitoring are coordinated by a central authority. Here, e.g. the transmission system operators come into consideration. Distributing the responsibility to the individual distribution system operators in whose systems the single distributed generators are installed, would inevitably lead to huge delays as well as uncertainties in communication and additional expenses. However, distribution system operators play a crucial role in the retrofitting process. They have the data of connected installations and can inform and establish contact with the coordination centre. The challenges from the PV-retrofitting program showed that a simplification of the relationships of the involved parties is necessary. In contrast to the complex triangular relationship in the SysStabV, we recommend a simple and straight process chain for the upcoming retrofit program. According to that, the system operators are in direct relation to the plant operator and the plant operator is in direct relation to the manufacture or service provider.

We recommend that the coordination centre also registers to what extent the distribution system operators adapt the external protection equipment to the new requirements.

5 Outlook and other recommendations

From our point of view, it is advisable that the distribution system operators implement a coordinated process for the controlled restart of distributed generators after a disconnection due to frequency deviation, preferably via the cascade according to § 13 Abs. 2 EnWG. To avoid the automatic reconnection of great power capacities of distributed generators within a few minutes after a frequency deviation, which potentially disrupts the balance of the system, it should be possible for the transmission system operators to send reduction commands to all plants and reconnect them again gradually. Such a command must be forwarded immediately by all affected distribution system operators. Therefore it is advisable to coordinate this process consistently and to integrate it into regular exercises.

An instrument was created with the regulation on agreements on disconnectable loads (Regulation on disconnectable load, AbLAV) [12] which can, in principle, contribute to the network stabilization in case of frequency deviation (under-frequency). However, in the current design the benefits from the regulation are limited, since the response time of 1 second required in the regulation is too long to develop the desired stabilizing effect in the case of a relevant fault situation. A further development of the regulation in accordance with the recommendation of FNN [25] (200 ms) seems reasonable.

In addition, switchable loads have a comparable potential for system stabilization in case of over-frequency (excess supply). They would be suitable to reproduce an active power reduction characteristic curve of the distributed generators. In certain circumstances, they could provide the intended systemic effect at significantly lower costs than a corresponding retrofitting of many small power plants. Against this background, this option should be considered appropriately during the preparation of the second step of the retrofit program.

From today's perspective, an increasingly divergent dynamic of the development of distributed generators and technical connection conditions has to be assumed in the future. On the one hand, the forecast of the transmission system operators [33, 34] predicts a sustainable high growth of distributed generators in the medium term, but on the other hand, a slower adjustment of the technical network codes can be expected due to the complex European harmonization on the basis of the ENTSO-E Network Code. Against this background, it must be questioned whether the proven instruments for reviewing and implementing regulation can continue to ensure system stabilization. The work of this study shows repeated challenges to the conformity of distributed generators. Therefore, it is difficult for the actors to ensure that under the current conditions, power plants are sustainably serving the grid and systemic plant specifications are still maintained after several years.

In fact the VDE-AR-N 4105 specifies an extended frequency range compared with the previous guidance but makes no specifications on minimum duration at under-frequency, admissible active power reduction at under-frequency and preferred reconnecting behaviour. We recommend a timely development of the technical regulations on this point.

Given the relevance and urgency of the 49.5 Hz issue, the associations and industry organizations should serve as mediators and support the retrofitting process.

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7 List of figures and tables

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