Bremen Energy Working Papers

Paperseries No. 28

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January 2019

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Suggested citing:
Furusawa, K., Brunekreeft, G., and Hattori, T. (2019). Constrained Connection for Distributed Generation by DSOs in European Countries, *Bremen Energy Working Papers* No. 28, Jacobs University Bremen.

Constrained Connection for Distributed Generation by DSOs in European Countries

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January 2019

Abstract

A high penetration of renewable energy sources (RES) connected to the distribution network due to Feed-in-Tariff (FIT) brought many challenges for DSOs. With the responsibility to connect, DSOs may be required to make investment in the network. In order to connect distributed generation (DG) while deferring the investment, European DSOs use "constrained connection" by which DG is connected conditional on the curtailment. Different approaches for constrained connection in Europe exist and case studies of the different approaches in Germany, France, and UK show that the relative acceptability of DG and ease of curtailment by DSOs are different, depending on the energy policy background and technology available in each country.

1 Introduction

A large amount of distributed generation (DG) including intermittent generation (like photovoltaic and wind farms) have been installed into distribution network as a result of Feed-in-Tariff (FIT) schemes or Renewable Obligation (RO) in many countries, including Germany and Japan. A rapid increase in installed DG with subsidies has posed challenges for Distribution System Operators (DSOs) in their management of the network (Brandstätt et al., 2011, BNetzA, 2018). Namely, it has been increasingly difficult for a typical DSO to manage network congestion caused by variability of output from DG without sufficient capacity of the network[1]. Since most renewable subsidy schemes require DSOs to connect renewables to the network, DSOs eventually have to increase investment to accept all the requests of the generation connection. The increase of investment would lead to a higher network tariff. This has to be borne by network users including DG.

This situation motivates the concept of "active" DSOs regarding network management, including investment planning, connection, and operation. An example of active network operation is the control of DG output in real-time in order to maintain the power flow within the network constrains by utilizing technology of sensor and forecast (ENA, 2015). By controlling the output of DG effectively, an active DSO can accept the connection requests while deferring additional investment. In order to realize such network benefits, an active DSO can implement a so-called "constrained connection[2]" of DG as an option. The constrained connection is defined as a generation connection to the network with the possibility of curtailment of the output; the owners of DG accept the curtailment if the network constraint is binding. It is also called "flexible connection" or "smart connection" at DSO level[3] in Europe. The DSO informs the DG owners about the connection cost and a rough forecast of curtailment volume of constrained connection as well as the connection cost of unconstrained connection. This enables DG owners to evaluate the profitability of the new investment of DG without facing the uncertainty regarding the curtailment during their operation. This constrained connection agreement could avoid additional investment cost for the DSO and reduce connection fee for the owner of DG as well as network tariff for the customers. European DSOs and regulators are developing this idea of "constrained connection," as it is believed to be a "win-win" solution for both DSOs and DG owners.

Although several approaches for constrained connection are proposed or actually implemented in Europe, feasibility or effectiveness of different approaches has not been much discussed in the literature, and it is not clear whether those approaches can be implemented in other countries. The purpose of this research is twofold. First, to investigate the pros and cons of "constrained connection" of the DG through case studies of the concepts actually implemented in Germany, France, and UK. Second, to clarify the applicability of the different approaches to other countries including Japan, which have not yet installed constrained connection. The Japanese government and electric power companies have started to investigate the pros and cons of such a connection methodology recently for the transmission network, but not for the distribution networks. Learning from the ideas and experiences of some European countries would be particularly useful not only for other European

[1] When installed capacity of DG was relatively small in ratio, conventional generation could compensate the deviation of output from DG. However, it recently becomes inefficient for the conventional generations to continue to cover and compensate the deviation of DG.

[2] Conventional generation connection is referred to as "non-constrained connection" in this paper.

[3] At TSO level, this constrained connection is called "Connect and manage" in UK or "Non-firm access" in Ireland.

countries but also for Japan, as they need to deal with the problem of integrating DG into electricity market and power system while minimizing the cost of network expansion.

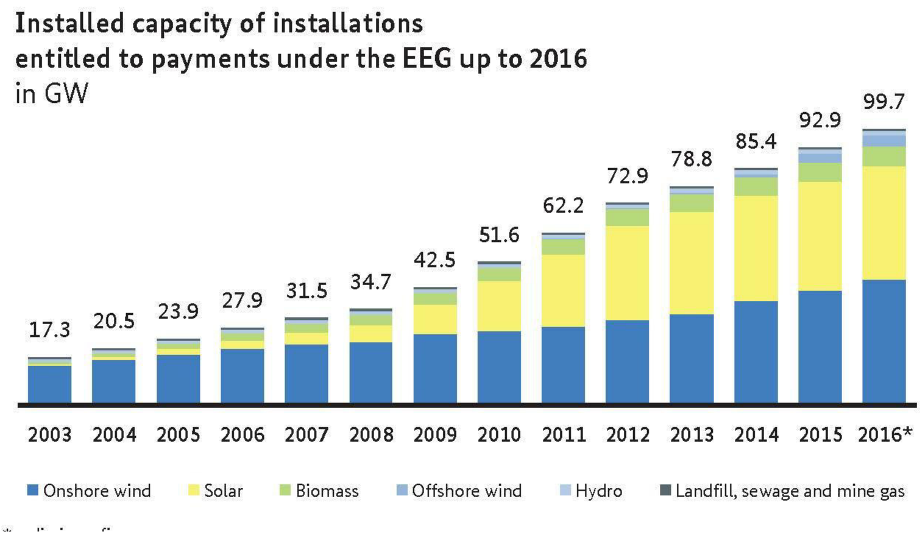
The report is organized as follows: the next section explains the change in the way of thinking for active DSOs and outlines the issues in connection of DG with curtailment possibility. Section 3 discusses some practical examples of constrained connection at the distribution network level in Germany, France and UK. Section 4 evaluates different approaches of constrained connection in the three countries with respect to implementation and effectiveness. Section 5 concludes our discussion and points to a future direction.

2 Background and issues in connecting DG at DSO level

In this section, we provide an overview of the recent development of DG in the major European countries; Germany, France, and UK. Then, we describe the need for change from passive DSOs to active DSOs and the background for constrained connection.

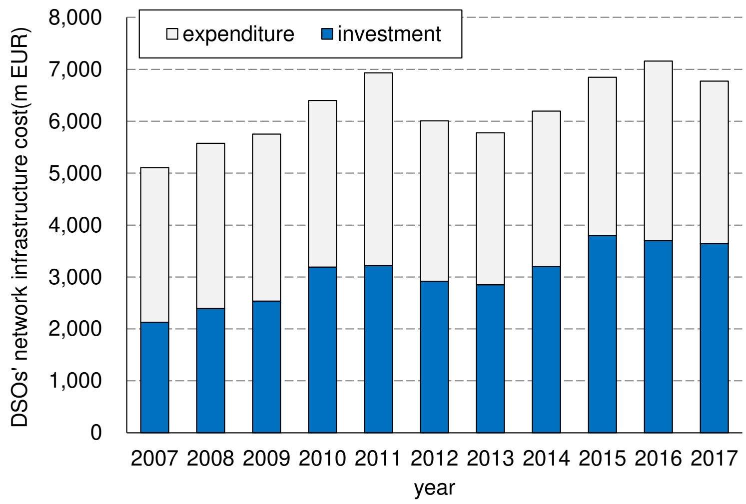
2.1 Recent development of distributed generation in Europe

In Germany, the Feed-in-Tariff was deemed to have a large impact on introducing RES generators (Figure 1). 90 % of the capacity of installed RES is connected to distribution networks (BMWi, 2014). The DSO has to accept these connection requests in order to comply with Renewable Energy Source Act (Erneuerbare-Energien-Gesetz, EEG) and Energy Industry Act (Energiewirtschaftsgesetz, EnWG). This trend causes an increase in distribution network investment cost (Figure 2). BNetzA expects this increase to continue. According to Monitoring report 2017 (BNetzA, 2018), the total cost of planned and ongoing distribution network expansion will be 10 billion euro in the next ten years. This total forecasted cost increases continuously. In the past, total forecasted cost for the next ten years was 9.3 billion euro in 2015, while it was 6.6 billion euro in 2014 and 6.0 billion euro in 2013. Distribution network usage tariff has increased recently as a result of increase in investment shown in Figure 2. The forecast of investment amount implies further increases of distribution usage network tariff.



Source: BNetzA (2018)

Figure 1: Development of installed RES capacity in Germany

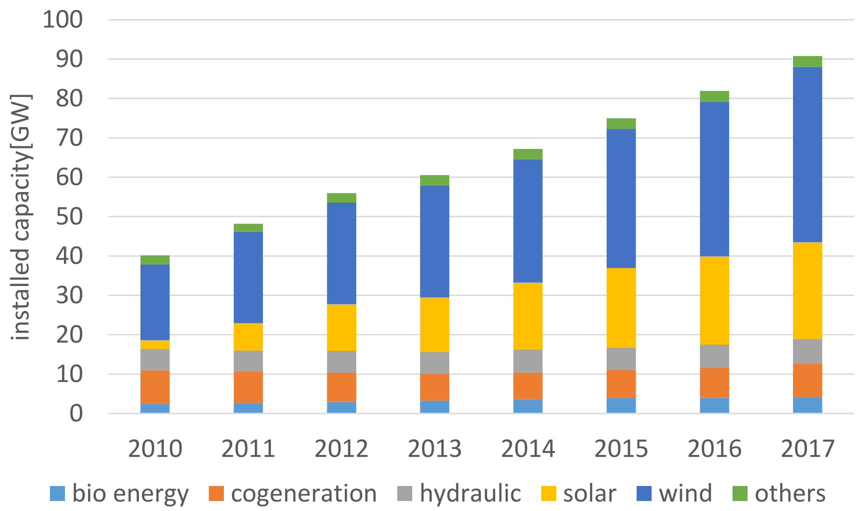


* the data at 2017 is a planned value

Source: BNetzA (2018)

Figure 2: Infrastructure cost of DSOs

In France, after introducing a priority policy for RES, French DSOs have received a lot of connection requests from DG and have connected DG to distribution networks (Figure 3). Such an increase in DG leads to high investment cost and long delays for connection because it may be necessary to upgrade networks to enable connections. This increase of investment has an impact on maintenance cost of reinforced networks[4]. The French DSOs and regulator are concerned about the increase of network usage tariff in the future.

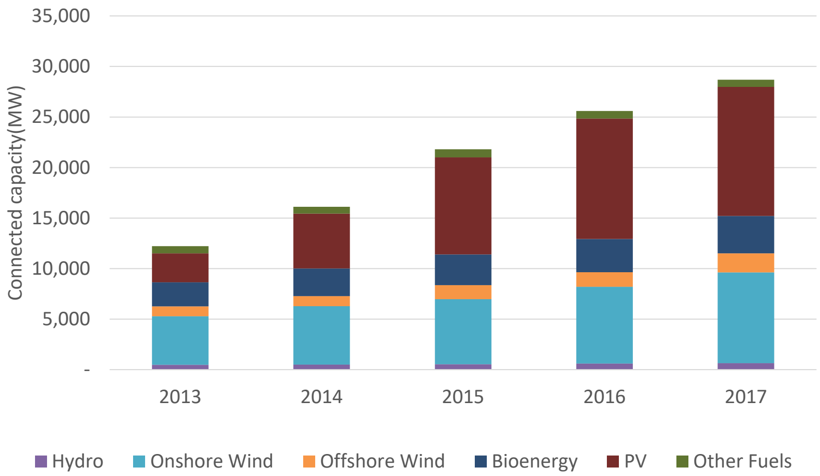


Source: Enedis (2018)

[4] The share of overall connection cost was about 1 percent of total DSOs' investment cost around 2000, but it became about 10 percent from 2010 till 2017.

Figure 3: Installed capacity of RES in French DSOs

In UK, introducing an RES promoting policy led to a large number of connection requests of DG. In some DSOs' regions[5], it is difficult to connect without upgrading the network. At DSO level, the share of PV and onshore wind increases (Figure 4). The increase of cost for upgrading network is reflected to the network usage tariff, once it is approved by the regulator. It is necessary for the owner of DG to wait for upgrading the network.



Source: DUKE (2018)

Figure 4: Installed generation capacity in UKs' distribution network

In these three countries, the increase of network usage tariffs and the delays for connecting to the distribution networks have become serious issues, and increasing shares of renewable generation in combination with renewable generation subsidy schemes tend to lead to network tariff increases and delays in network connection.

2.2 Changes from passive DSOs to active DSOs

The introduction of a large amount of DG in distribution network may change the location of the resources and direction of the power flow. Before large-scale introduction of DG, the major driver of network investment was the increase of final demand. Therefore, the only thing DSO had to do was to evaluate the power flow in the worst case of large increase in demand. In such circumstances, the conventional DSO was "passive" in its management as follows:

- In their investment planning, DSOs considered the worst case of a given load forecast in a way that minimal or no active operation was required by deterministic simulation (CIGRE WG C6-19 2014).

[5] In UK, distribution network operators are called DNOs (Distribution Network Operators). In this report, however, the term DSO is used likewise.

- For the generation connection, DSOs accepted all generation connection requests. As a result, DSOs had to increase the network investment, resulting in significant cost.

- In the power flow management, DSOs assume the power flow from higher level, which is generated centrally, following the final demand (ENA, 2015). DG had only a little effect on the decrease in downstream power flows.

- DSOs recovered the cost mainly from the static volumetric tariff (AF-Mercados et al., 2015).

However, integration of increasing DG shares becomes increasingly challenging with the passive approach. In other words, it calls for an evolution from passive distribution networks to "active" distribution networks. Recent years have witnessed technological progress in monitoring systems and smart devices (i.e. advanced metering infrastructure, dynamic rating system, a remote voltage regulation device, and so on). These technologies enable the transformation from passive DSOs to active DSOs. Active DSOs change their management process as follows:

- In the investment planning, DSOs refer to the probabilistic approach based on the active utilization of DG in order to defer the investment (CIGRE WGC6-19 2014).

- Regarding generation connection, DSOs offer options with the possibility of curtailment (Cerqueira et al., 2014 and EDSO et al., 2018). These options are also used to defer the investment.

- For the power flow management, DSOs may utilize the flexibility of DG for congestion management actively (ANM, 2015). DSO can gather real time power information by the power flow management application and can control a combination of distributed energy sources (i.e. DG, controllable load and energy storage) (Cerqueira et al., 2014 and CIGRE WGC6-19, 2014). Such a consideration is helpful for effective utilization of the existing networks.

- DSOs may recover the cost from not only static volumetric tariff but also capacity tariff, fixed tariff and dynamic volumetric tariff (Pollitt, 2016). This change is required to prevent the death spiral[6] for network companies caused by the penetration of DG (Brandstätt et al., 2015, Frank et al., 2014 and Pollitt, 2016).

Table 1 summarizes the differences between the passive and the active DSO.

Table1: Approach of passive and active DSO

	Passive DSO	Active DSO
Investment	deterministic approach based on the heaviest power flow case	Probabilistic approach including the utilization of DG
Connection	Accepting requests even if it requires upgrading the network equipment	Option with possibility of the curtailment of DG's output
Power system operation	Mainly the direction of power flow from higher voltage level to lower voltage level	Monitoring the power flow on real-time and control the power flow by utilizing of DG

[6] Historically, DSOs collect all revenues through volumetric tariff. The declining sales caused by introducing DG may lead to an increase of the network usage tariff. The increase of the network usage tariff can trigger further penetration of DG which may lead to a further decline of revenues. This vicious circle is called death spiral.

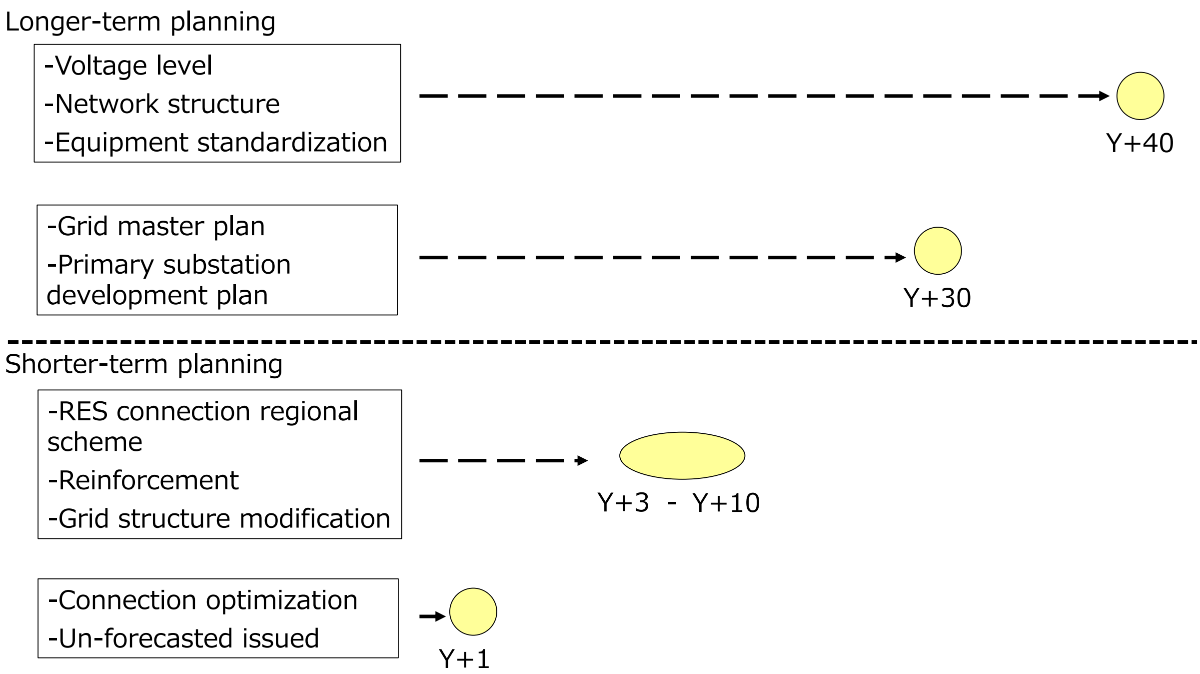
Network usage tariff	Static volumetric tariff	Mixed various tariff: capacity, fixed, or dynamic volumetric tariff

In the world of active DSOs, the above-mentioned different activities of management become highly interrelated. For example, if the network usage tariff structure is well designed for peak shaving, DSOs can defer the investment without facing the death spiral[7]. Other types of well-designed network usage tariffs can bring the flexibility for balancing control and congestion management from DG in an efficient manner. When DSOs can control power flow actively, they may change the investment planning. Initiating one active process would encourage the other process to become active.

It is worth noting here that active operation and the utilization of flexibility of DG by one DSO may have some impact on the network operation of other DSOs and/or the TSO by imposing constraints on their networks. For instance, the contribution to frequency control by flexibility of DG might violate voltage limits on transmission or distribution of different voltage levels.

2.3 Background for connecting DG with curtailment possibilities

The investment planning by DSOs has a multi-layer structure, from longer-term to shorter-term, as shown in Figure 5. For instance, DSOs consider appropriate voltage levels of 40 years from the time of planning. Regarding the DG connection, DSOs consider reinforcement or connection optimization of 10 years ahead of the time of planning. This shorter-term investment planning needs to be consistent with the existing longer-term investment planning.



Source: Authors' own illustration

[7] Some network companies started prosumer tariff. For example, DG owners in one distribution network have to pay additional network usage tariff as a proportion of installed capacity. Prosumers receive the benefit by utilizing distribution network.

Figure 5: Hypotheses of investment planning at each period in DSO

For the first step of investment planning with DG, some DSOs suggest "constrained connection" as one option for short-term investment planning, rather than a very long-term planning. When DG facilities are connected to the network by constrained connection, the output of DG will be curtailed before the network upgrade. Thus, the constrained connection can at least defer the additional investment for some months or a few years. For the owners of DG, the constrained connection may have the benefit of lower connection tariff and shorter waiting time for the connection. The other network users also benefit from the lower network usage tariff. In the near future, this would stimulate more DG to accept the same connection policy. Therefore, the constrained connection can be considered as a "win-win" solution for both DSOs and DG owners.

Since this constrained connection implies a kind of unit commitment without market transaction, it limits the upside potential for DG's revenue. Thus, it is difficult to force DG owners to accept constrained connection and it needs to be optional. Specifically, for each of the applications for connection, DG owners need to be able to select the constrained connection or the conventional non-constrained connection as an extreme case. In other words, the acceptance of DG owners is important in order to introduce this connection policy. When some DG facilities are connected with constrained connection, especially at the same location, the acceptable curtailment methodology for DG owners is also important (Laguna et al., 2013). The selection of the constrained connection may be an optimal solution for a particular DG owner but may not be optimal for other stakeholders. It may be necessary for DSOs and DG owners to be able to evaluate the cost-benefit of each constrained connection.

3 Case study of constrained connection of DG by DSOs in the major European countries

In this section, we describe the institutional framework of the constrained connection of DG by DSOs in practice in Germany, France (and Belgium), and the UK.

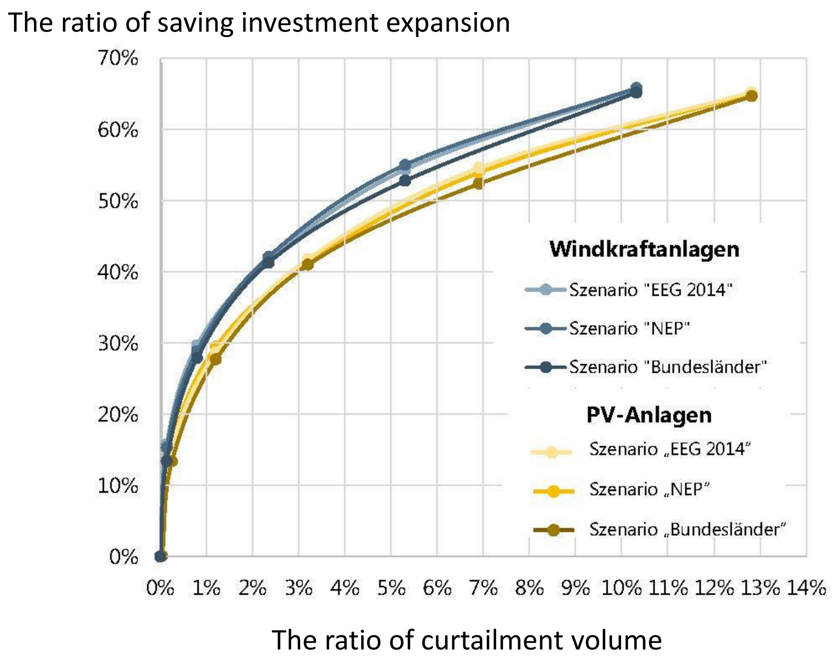
3.1 Three-percent curtailment rule in Germany

In Germany, the government has long supported the penetration of DG through several means. The Feed-in Tariff (FIT), introduced in 2000, has guaranteed the fixed income of DG for 20 years. It is worth noting here that the owners of generation in Germany do not have to pay network usage tariff and pay connection cost based on a shallow approach[8]. In the future, Germany will continue to install DG including RES so that RES energy is expected to account for 50% of total demand by 2030, 65% by 2040, and 80% by 2050.

However, in order to connect such amounts of RES, the cost of the required network investment at the DSO levels is expected to increase by 27.5 billion to 47.5 billion EUR by 2030 (DENA, 2012). In general, the curtailment RES output can bring cost reductions of network investment. Thus, in order to minimize the grid development cost while maintaining the income protection of DG, German government introduced the "3% curtailment rule", proposed by BMWi (2014). The 3% curtailment rule implies that DSOs can make the investment planning conditional on a 3% curtailment of the DG output per year. This rule was established in 2016 and implemented in 2017.

BMWi determined the level of acceptable curtailment based on future scenarios of the RES capacity. As illustrated in Figure 6, BMWi considered three scenarios ("EEG 2014", "NEP" and "Bundesländer"). The scenario "EEG 2014" assumes an installed RES capacity of 128 GW (Wind farm (WF) of 60 GW, Photovoltaic (PV) of 59 GW and 9 GW other) by 2032. The "EEG 2014" scenario reflects the political goals of German government in 2014. The scenario "NEP" assumes a total installed RES capacity of 139 GW (WF of 65 GW, PV of 65 GW and 9 GW other) in 2032. It is one of three network development plans by the four TSOs, published in 2013. The scenario "Bundesländer", which reflects the accumulated goal and forecast of individual federal states, assumes an installed RES capacity of 206 GW (WF of 111 GW, PV of 85 GW and 10 GW other). According to BMWi, the 3% curtailment would save about 40% of the network expansion (Figure 6). BMWi also recognized that this 3% curtailment would reduce investment cost by at least 15%.

[8] In this report, shallow approach means the owners pay the construction cost of the new line to connect to the existing network, while the network operators have to pay for the upgrade cost of the existing network if it is necessary. A deep approach means that the owners pay both costs. Semi-shallow approach means the hybrid of shallow and deep approach.

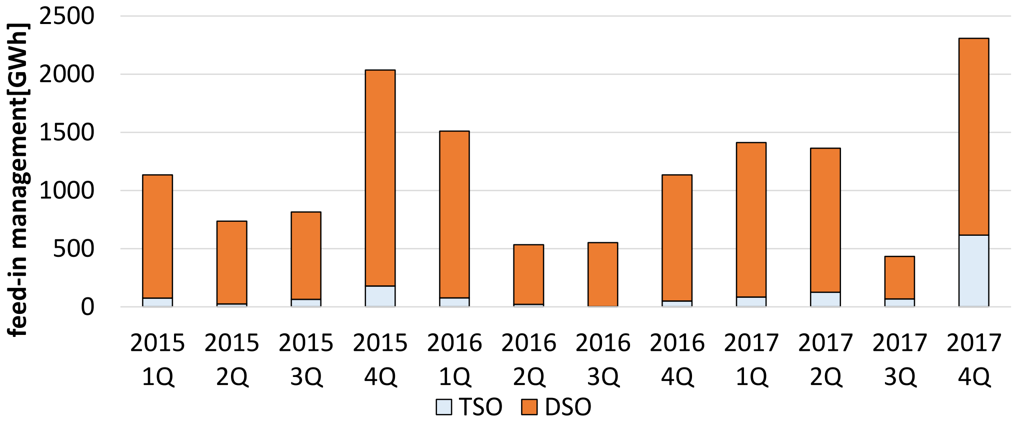


Source: BMWi (2014)

Figure 6: The saving network expansion by the curtailment of RES energy

This 3% curtailment rule, however, is optional; so the DSOs can choose whether they consider the 3% curtailment in their network planning or not (the latter case corresponds to the conventional investment planning). An effective ratio of curtailment volume for each DSO is different from effective curtailment volume based on German-wide scenario as shown in Figure 6. This is the reason why the German regulator considers that this curtailment rule does not always bring the reduction of the network investment cost. Currently, the impact of this rule on each individual DSO’s investment cost is under investigation.

Even if DSOs opt for the 3% curtailment rule, they are not able to specify the amount of curtailment for each individual DG at the time of the generation connection. Regardless of their choice of the 3% curtailment rule, after connecting DG, DSO could curtail the output of DG (also known as “feed-in management”) when it is necessary during their power system operation in the same way as before. This would not be a concern for DG as it gets full compensation of the curtailed output anyway. The recent development of the volume of the feed-in management of TSO and DSO is shown in Figure 7. When DSOs utilize “feed-in management”, DSOs implement a conventional method of curtailment by taking into consideration the following four points; the impact on the power flow, the compensation cost, communication methodology and the impact on heat supply.



Source: BNetzA, 2016-2018.

Figure 7: The volume of the feed-in management of TSO and DSO

DSOs typically decide to implement feed-in management at D-1 (a day before delivery). After determination of the D-1 schedule, DSOs can implement additional feed-in management at H-1. DSOs may decide on the final feed-in management at one minute before delivery. Compensation cost of feed-in management will be paid to the owner of DG if their output is curtailed. Therefore, the income of DG will not be reduced by feed-in management. In order to utilize the 3 % curtailment rule under FIT, it is necessary to ensure the certainty of revenue by providing the full compensation for the curtailment volume. In case of Germany, it is also difficult to motivate DG to accept curtailment in the absence of any network charge that DG must pay.

If the current FIT rule was ended and a full compensation is no longer provided, then, the owner of DG may not accept the feed-in management and German DSOs may need an approach with smarter curtailment methods. If a new approach of the curtailment methodology that does not require full compensation is introduced, German DSOs have to consider the rule of the curtailment order among new connection of DG, and among the new connection of DG and existing DG. Now some German DSOs are considering more flexible operation by utilizing the resources of DG[9]. They started to consider the smarter relationship between market and power system operations.

3.2 Smart connection in France and Belgium

In France, connection cost had been high, and connection request was handled individually, so that it was particularly difficult for a single DG owner to bear the cost. In order to reduce the connection cost, a new scheme called "S3REnR (regional renewable energy network connection schemes)" was implemented. Under the S3REnR, DSOs can suggest individual payment or coordinate the multiple requests to share the connection cost. DG owners will not select individual payment. DG owner could wait for additional DG plants to join in order to reduce the cost per plant. Despite this scheme, the long queue and the high investment cost of the generation connection remained as a big issue among French stakeholders. With this scheme, efficient DG owners may lose the opportunity to enter the market. Moreover, there is a risk that some new DG owners become "free-riders" if they are able to

[9] For example, ENERA project in Northern West Germany or Smart pool have started recently (ENERA, Smart pool).

connect to the network after the reinforcement under S3REnR. If French DSOs need to solve the problem by making investment at an accelerated rate, the regulator as well as DSOs themselves would be concerned about the high maintenance cost with greater length of added cables. As a result of these concerns, one French DSO and regulator discussed other countermeasures and selected the constrained connection, called “smart connection”, as a possible solution. By smart connection, the French DSO expects a decrease in the investment cost and in the delays of network connection. Though the network investment cost for the DG connection could also be decreased by employing 3% curtailment rule, as is done in Germany, it is not regarded an option to accelerate DG connection.

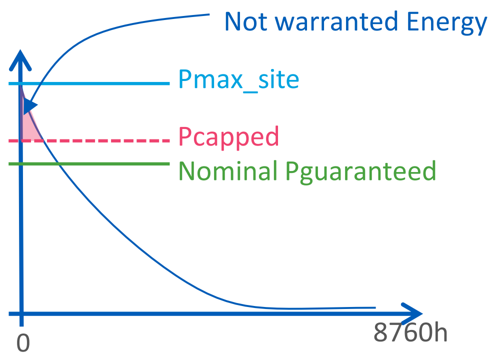
French DSO is planning to introduce smart connection as an optional approach. When the DSO receives a connection request from DG, it offers two types of connections (conventional connection and smart connection). When DG owners select smart connection, they have to accept the possibility of curtailment of the output of DG. By this smart connection, however, the owners pay less connection cost and it shortens the delay by some months as compared to that of conventional connection. At the moment, smart connection is in an experimental stage for a period of two years only in a specified area since 2017. The French DSO tries to demonstrate the advantages of smart connection, which would lead to a change of decree to utilize smart connection throughout the country. It is expected to realize a net gain of 65 million EUR for the connection of 720 MW of additional production to the existing feeders at a national-level (Enedis, 2017).

Under smart connection, the DSO cannot control the output of DG directly. Regarding the actual curtailment of DG connected by “smart connection”, the DSO forecasts power flows in D-1. If there is a possibility of congestion in the network, the DSO requests a curtailment of the output to the producers by asking to set the limit of the output from DG. The DSO recalculates the power flows intraday every 30-minutes and it can request again to the producers after the recalculation. If there is no response from the owner of DG to the request of curtailment, the DSO can operate the switching in distribution network and disconnect the DG in order to avoid the worst case.

There are two types of curtailment methodologies for French DSO.

- warranted capacity: the guarantee of the minimum instant load
- warranted energy: the guarantee of the minimum injected energy

Under the warranted capacity, the cap is set on the maximum level of output as indicated by “Pcapped” in the duration curve of generation output as shown in Figure 8. The amount of energy above the Pcapped is not warranted. Under the warranted energy, the maximum curtailment of energy for the DG owner is set at the network connection. The DSO can curtail the energy from DG output by the limit as specified in this warranted energy contract. Warranted capacity is less risky for DSO as compared to warranted energy, because DSO can easily assume the worst case of the power flow with their conventional congestion management. On the other hand, it is easier for the DG owner to evaluate the minimum profit in warranted energy as compared to that of warranted capacity.

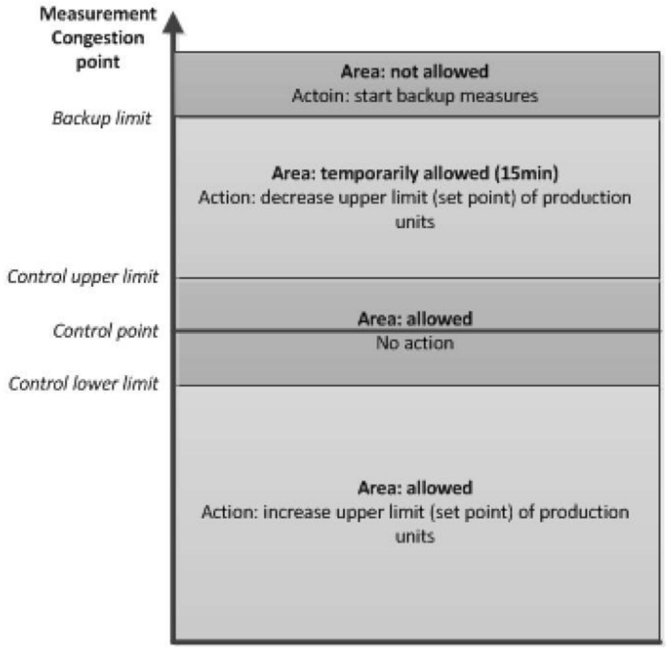


Source: Authors' own illustration

Figure 8: The concept of warranted capacity in smart connection

The DSO in Belgium are also testing "smart connection" because of a large amount of DG supported by the priority policy (Vandoorn et al., 2017). The methodology is similar to the "warranted capacity" of smart connection in France. Figure 9 shows the different control procedures depending on the degree of deviation of the power flow. If the power flow exceeds the "control upper limit", the active power of wind turbine with "smart connection" are decreased in order to keep the power flow within the control limit. With this smart connection, the DSO can control the output directly, which is different from the French smart connection. Belgium's smart connection is now in experimental stage. In this period, the output from wind farm is curtailed by pro-rata because the smart connection of all wind farms started at the same time.

After the experimental stage, the acceptability of priority of curtailment by DG's owners needs to be improved before smart connection is introduced in practice when multiple smart connections are requested at the same connection point. Because both in Belgium and France, the income of DG owners depends on the priority of curtailment and there is no compensation for curtailment, this is a crucial issue for DG owners. Yet, smart connection in France is in an experimental stage, and as a further step, French DSO may directly control the output of DG through secure power system operation when multiple DG facilities based on smart connection are connected at the same location.



Source: Vandoorn et al. (2017)

Figure 9: Different control procedures of smart connection for the Belgium DSO

3.3 Flexible connection in UK

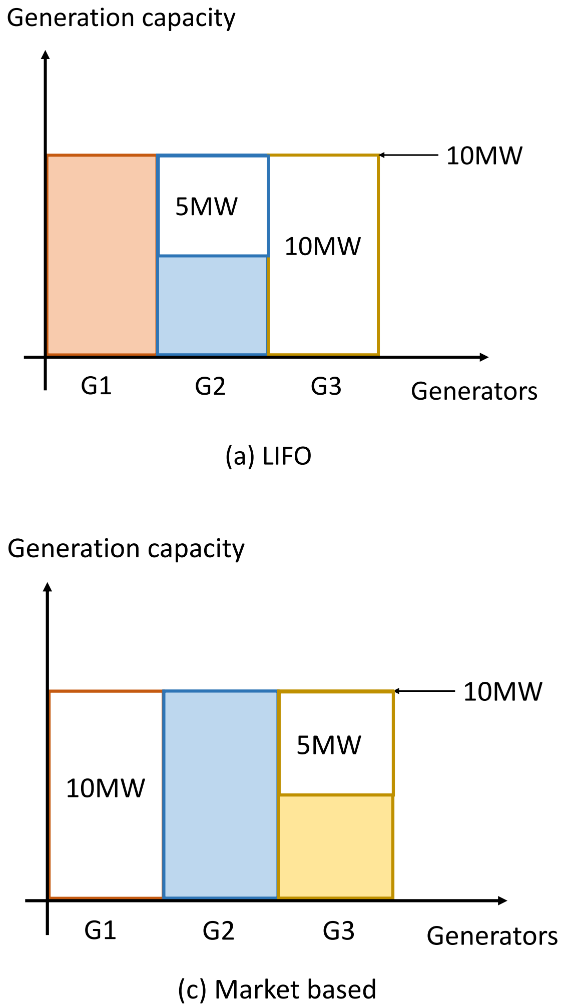
In the UK, the main policy to promote DG was RO (Renewable Obligation) until recently. The owners of DG have to pay the connection cost that exceeds a certain amount[10] (it is called semi-shallow) and network usage tariff. DSOs in the UK prefer smarter power system operation enabled by monitoring network constraints and controlling the output of DG. Such smarter power system operation is called "Active Network Management", the idea of which is to provide a cheaper and faster distribution connection to the electricity distribution network. Initially, DSOs in the UK had tested "timed/profiled connection". Timed/profiled connection means that prior to the connection, the DSO informs about the possibility of scheduled curtailment during the designated period with reference to the load profile. During the power system operation, the DSO could curtail the output of DG by a fixed volume during the informed period.

"Flexible connection" as an optional procedure, introduced after the experiment of timed/profiled connection, allows curtailment without specifying the time period of doing so. It enables DSOs to implement more flexible operation by flexible connection. The smart devices[11] need to be rolled out in order to monitor the network constraints and curtail the output of DG.

There are two types of flexible connections in practice. One is LIFO (Last-In-First-Out), the other is pro-rata (Figure 10). The owner of DG cannot choose between LIFO and pro-rata. It is the DSO to select the curtailment methodology in each control area. In some earlier studies (E.g. Anaya and Pollitt 2012 and Laguna et al. 2013), pros and cons of LIFO and pro-rata have been discussed. LIFO is a consistent approach with the conventional "first-come, first serve" principle. The last generator would never be

[10] For example, the DG owner has to pay the connection cost when the overall connection cost exceeds 200 pounds/kW in the service area of UKPN (UKPN, 2017).
[11] Smarter devices are dynamic line rating, voltage control relays and quadrature booster and so on (Cerqueira et al., 2014).

inclined to connect due to the high level of curtailment possibility. As shown in Figure 10, if G3 is the last to come, its output will be curtailed first. However, if G1, who comes first, is an old generator with low efficiency, while G3 is a newer one with high efficiency, LIFO is not an optimal curtailment methodology. Pro-rata, on the other hand, is considered a neutral approach and the DSO is able to fully utilize its network capacity. As more DG is connected, however, the capacity available for each of the DGs already connected will be smaller. The market-based capacity allocation is considered efficient (Anaya and Pollitt, 2012). In Figure 10, the bidding price of G1 is 40 EUR/MWh, G2 is 62 EUR/MWh, and G3 is 60 EUR/MWh. G1 is curtailed first and G3 is second. G2 can utilize all requested capacity. However, it requires a new market system to be installed. The cost of this new market-based capacity allocation would be high, and, moreover, the system will be useless after network investment or reinforcement. It is important to analyze the cost-effectiveness of this approach.



Source: Anaya and Pollitt (2012)

Figure 10: Examples of curtailment at network connection

A concept of a warranted capacity of smart connection in France is similar to flexible connection. DSOs in the UK have already installed the equipment for monitoring the network constraints and controlling the output of DG directly. Therefore, it is natural choice to continue direct control for the curtailment.

4 An initial evaluation of introducing constrained connection in the three countries and issues for future evaluation

In this section, we evaluate different approaches of constrained connection in the three countries with respect to its practicability of introduction. Then we discuss the issues for evaluating the appropriateness of the constrained connection.

4.1 Initial evaluation of different approaches of constrained connection

4.1.1 Criteria for our initial evaluation

In order for constrained connection to be beneficial for society, it needs to be widely used and its smooth introduction is important [12]. We evaluate different types of constrained connections implemented in Germany, France and UK with respect to the practicability of introduction. For this purpose, we chose two criterions: 1) acceptability of DG and 2) ease of curtailment by DSO.

1) Acceptability of DG

The acceptability of DG is evaluated by the possibility of a decrease of the DG's income. Typically, the DG owner can select the constrained connection with a small decrease of output or non-constrained connection with no decrease of outputs. The DG owner would select smart connection in France or flexible connection in UK if the benefit of connection outweighs the loss of revenue through the curtailment. On the other hand, there is no change in the income level of connected DG as a result of the 3% curtailment rule in Germany since DG owners receive the compensation according to EEG also in case of curtailment; thus DG owners can easily accept the curtailment. For smart connection in France, acceptability is more of an issue, because there is no full compensation for the curtailment. The level of acceptability of smart connection depends on the curtailment method. It would be more acceptable if the curtailment is implemented based on warranted energy than warranted capacity, since a minimum income would be guaranteed. Flexible connection with curtailment based on LIFO or pro-rata in UK may be the least acceptable among the three approaches, though it would have the same level of acceptability as smart connection based on warranted capacity.

2) Ease of curtailment by DSO

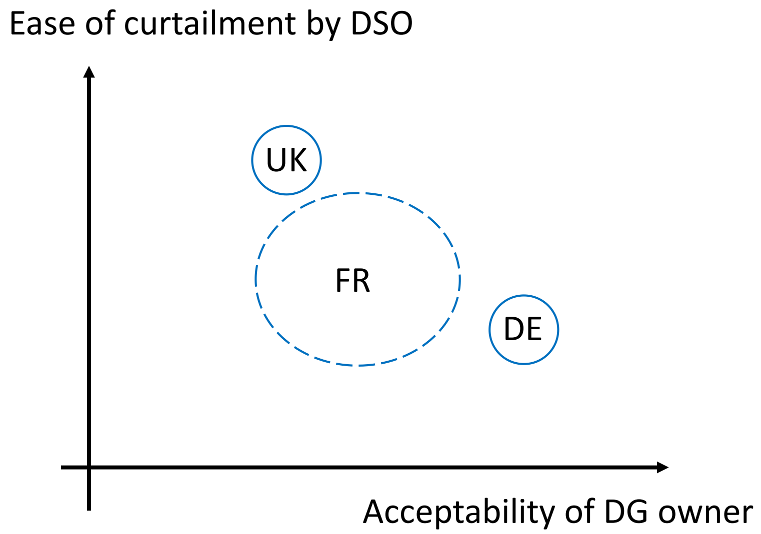
The ease of curtailment by DSO first depends on the share of DG that DSOs can control directly for congestion management. The curtailment may not be implemented successfully without the capability of direct control, as there is a case that DG owners may not respond to the curtailment signal from DSO. Currently, direct and dynamic control of DG is only possible in the UK, and in this sense, the curtailment of flexible connection is easiest among the three countries. As shown in section 3.2, the DSO cannot control DG directly with the smart connection in France. Also, DSOs cannot control the output of DG dynamically with 3% curtailment rule in Germany. The ease of curtailment by DSOs further depends on the room of the curtailment energy on the part of DG. The DG with constrained connection accepts the curtailment after connection within the range of volume specified in the contract of constrained connection. There are several ways of implementing the curtailment for DSOs. As shown in section 3.2, for smart connection with curtailment based on "warranted energy", the DG owner may not accept additional curtailment if the curtailment volume exceeds the limit of pre-

[12] Eventually, the analysis of social benefit is important. However, at this moment, such analysis is difficult to conduct as constrained connection is at an early stage of implementation. We also recognize that some kind of transitional phase would improve the prospects of implementation, but this applies similarly to all countries.

specified warranted energy. This would make it more difficult for the DSO's operation of the curtailment. It would be easier for DSOs if they could implement the curtailment by the constrained capacity with "warranted capacity", which allows DSOs to curtail the output of DG whenever it needs to do so[13]. For DSOs, the 3% curtailment rule is as difficult as the smart connection with curtailment based on warranted energy with respect to the restriction of curtailment energy [14].

4.1.2 Comparison of the introduction of three approaches

To summarize, we can illustrate the relative merits of introducing the three different approaches of constrained connection as shown in Figure 11. The German 3% curtailment rule is more acceptable for DG owner, but it would be more difficult for DSOs to implement the curtailment. On the other hand, flexible connection in UK would be the least acceptable option for DG owners but the curtailment of output would be the easiest among the three approaches. Smart connection in France would be the case in between Germany and UK with respect to acceptability of DG and ease of curtailment.



Source: Authors' own illustration

Figure 11: Relative merits of introducing constrained connections in three countries

Although the main common driver of the constrained connection is a reduction of the investment cost, each country has its own background and other drivers. For Germany, flexible connection in UK imposes the decrease of the income of DG owner. For UK, a 3% curtailment rule in Germany imposes additional compensation cost on DSO. Thus, there would be no single best approach of constrained connection to be introduced. It is important for DSO and regulator to understand that the energy policy background in promoting DG and the technology available for controlling DG in the country are important for the initial choice of approach for the constrained connection.

[13] We compare here the ease of curtailment by DSOs under the same curtailment technique (i.e. static or dynamic).

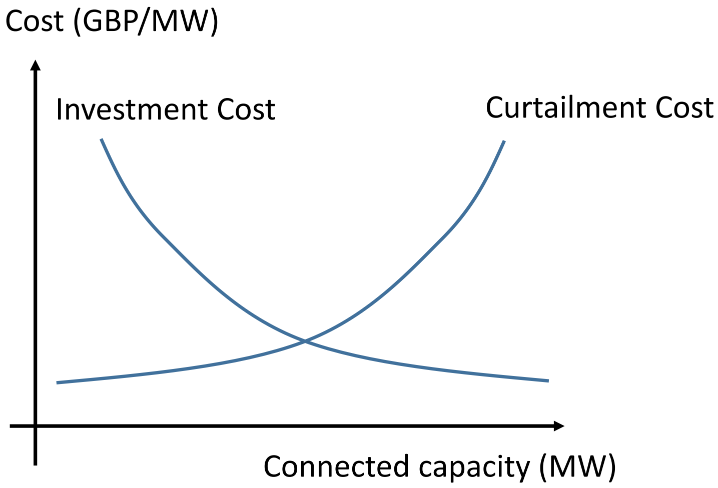
[14] In the future, so-called "dynamic curtailment" would be more effective than "static curtailment" (Schröder, 2015). The static curtailment is that the timing of curtailment is restricted to the period of large output, while the dynamic curtailment allows curtailment whenever DSO needs to curtail without pre-specified limit. Analysis of the impact of employing dynamic curtailment is a future research topic.

4.2 Issues for evaluating effectiveness of constrained connection

It is too early to determine the best approach for the constrained connection since the current approaches in three countries might evolve in the future, driven by changes in energy policy as well as technology. Yet, we can identify several issues to be considered for future evaluation of effectiveness of the constrained connection.

4.2.1 Relationship between investment and curtailment cost

European DSOs do not consider constrained connection as a permanent countermeasure; rather, it is a temporary solution. The effectiveness of constrained connection as an option depends on the investment cost to be saved relative to curtailment cost. An illustrative example of trade-off between the investment and curtailment cost is shown in Figure 12. It is assumed that there are multiple requests of DG connection in one place, all of which are wind turbines, and that DSO can select the network investment or constrained connection for the connection requests. An investment cost may depend on the reinforcement capacity and installed location. Suppose that only a constant capacity transformer is invested (i.e. 100 MW transformer). When the investment cost is constant, the investment cost per connected MW would be smaller as more capacity is connected as indicated by "investment cost" in Figure 12. Now let us assume that DG owners accept the constrained connection with hosting capacity of 2 MW. Let us also assume that the connected capacity is 10 MW and the output of DG is 8 MW at 5pm and 2 MW at 6pm, while the output in other periods is zero. Then, the curtailment volume is 6 MWh (=8-2) only at 5pm. When the connected capacity becomes 20 MW, and the output is assumed to double, the curtailment volume is 16 MWh (=16-2+4-2) at 5pm and 6pm. The curtailment volume increases with connected DG capacity without network investment ("curtailment cost"), and as a result, the curtailment cost would become large. There is a trade-off between the investment cost of network expansion and the cost of curtailment (and thus of constrained connection). For low levels of DG connection, investment costs are high and curtailment costs low and, hence, curtailment is better, while the reverse is true for high levels of DG. If DG continues to grow, there will be a moment where curtailment no longer pays off and investment in network expansion is better. These analyses are important for understanding which alternative is better. However, the investment cost for connection cannot always be distinguished clearly into different purposes because color-coding of electricity is difficult, and the investment has the benefit of reliability improvement as well as economic development. Especially the benefit of reliability improvement is a system-wide benefit and may not be evaluated by location.



Source: Authors' own illustration based on Laguna et al. (2013)

Figure 12: Trade-off between investment and curtailment

In Germany with 3% curtailment rule, the DSO has the information of investment cost and can forecast the curtailment cost at specified connection point. The DSO can make a profile as shown in Figure 12. However, a DG owner cannot make such an assessment, and it is difficult for them to evaluate whether constrained connection is better or not. Because of compensation, DSOs in Germany at present do not need to share the information with the DG. If the compensation is terminated in the future, the owners of DG have to be informed about the curtailment volume in order to analyze the cost-benefit of the curtailment. In France with an experiment of smart connection, the DSO has the information of investment cost and curtailment volume at a specified connection point and shares this information with the DG owner. Therefore, the owner of DG can decide between constrained and non-constrained connection with the given information. When the smart connection moves to a practical stage and multiple requests of the connection are made, the curtailment methodology may be important for the owner of DG. For example, by warranted energy of smart connection, the DG owner can realize the limit of the curtailment. In these countries including UK, the curtailment cost profile such as shown in Figure 12 may change in later years. Since the curtailment methodology has an impact on the income of the DG owners, it is important for DSOs to implement the investment planning without long delay in order to prevent this difference of the curtailment methodology issue. It is difficult, however, to determine the threshold at which the cost of investment is less than the cost of curtailment

4.2.2 Issues in allocation of the curtailment

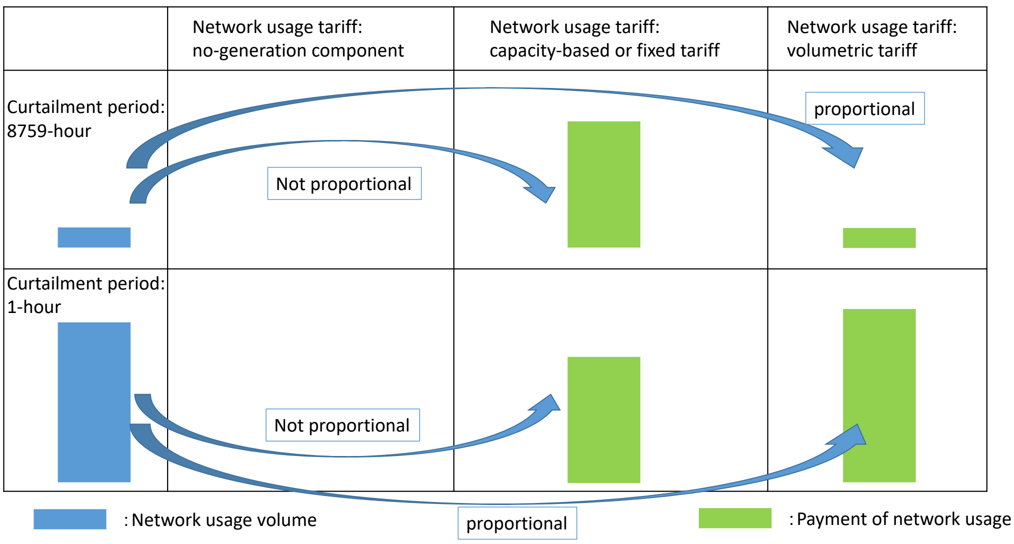
When some DG facilities with constrained connection are connected to the same network point, the allocation of curtailment capacity is a controversial issue. In Germany under the current 3% curtailment rule, the curtailment order among the multiple types of DG is based on the judgment of each DSO, which is technically best from the DSO's perspective[15]. The trend towards market integration of DG may eliminate the rule of the compensation for curtailment. If this happens, allocation of curtailment volume is critical for DG owners. Likewise, this issue becomes more important in France when the smart connection is implemented in practice.

[15] There seems to be no unified German-wide curtailment order among some types of DG because the curtailment sources depend on the control area of DSO.

Some DSOs in the UK that already implemented flexible connection, consider that constrained connection is a temporary countermeasure and the upgrade of network will be implemented without long delay. If the long delay of the investment planning happens in the control area of a DSO with LIFO, DSO would reallocate the capacity for the connection to all owners of DG, and a DG with first priority of capacity utilization at one point in time, might lose that priority after several years. In this way, the long delay of the investment planning has an impact on the owners of DG. Market-based methodology as explained in section 3.3 is one of the best countermeasures to resolve this issue, and the DSOs are now discussing this methodology. However, market-based methodology would require the DG owners to pay the network investment cost. Perhaps in countries without generation component of network usage tariff, it would be difficult to accept this methodology.

4.2.3 Relationship between curtailment period and network usage tariff structure

At the moment, adopting the constrained connection has not affected the network usage tariff and the discussion has focused on the level of connection cost. In the future, however, it needs to be considered how the network usage tariff is charged under the constrained connection. As we mentioned in Section 2, conventional DSO mainly employ volumetric tariff to charge network usage tariff. However active DSOs may introduce capacity or fixed tariff. This change may bring new issues as shown in Figure 13. If there is no generation-component of network usage tariff and a DG is curtailed 8759 hours and another DG is curtailed 1 hour, there is no difference as to the payment of the network usage between these DG owners. If the owner of DG pays the only volumetric-based network usage tariff and the situation of the curtailment is the above-mentioned, the difference of curtailment volume reflects the payment of network usage. However, if network usage tariff for DG is only capacity-based or fixed tariff, the benefit of DG owner with 8759-hour curtailment is 1/8759 compared with the benefit of DG owner with 1-hour curtailment, and the payment for network usage is the same as DG owner with 1-hour curtailment. This difference needs to be taken into account if the DSO is to introduce capacity or fixed tariffs while adopting constrained connection.



Source: Authors' own illustration

Figure 13: Relationship between payment of network usage and network usage volume

5 Conclusions

We discussed the challenge for active DSO to design and implement effective "constrained connection". With case studies of the different approaches in Germany, France, and UK, we evaluate each of the approaches for the constrained connection based on the relative acceptability of DG and ease of curtailment by DSO. We also discussed issues to be considered for future modification of constrained connection in these countries, as well as for application for other countries.

With the constrained connection as defined as a generation connection to the network with the possibility of curtailment of the output, the owners of DG accept the curtailment if the network constraint is binding. The constrained connection can defer the additional investment for some months or a few years. For the owner of DG, the constrained connection may bring the benefit of lower connection tariff, and shorter waiting time for the connection. The other network users also benefit from the lower network usage tariff. This constrained connection has the possibility of "win-win" solution for both DSOs and DG owners. However, this constrained connection is a temporary countermeasure in order to defer the investment. Some European countries have suggested and implemented constrained connections with different approaches;

- The 3% curtailment rule in Germany implies that DSOs can make the investment planning conditional on a 3% curtailment of the DG output per year. The volume and timing of curtailment is uncertain to the owner of DG. However, the full compensation makes this 3% curtailment rule in Germany acceptable for DG.
- The smart connection in France is one of optional connections in experimental stage. When DG owners select smart connection, they have to accept the possibility of curtailment of the output. DSO cannot control the output of DG directly. Curtailment can be done under the cap of curtailment capacity, or with the limit of curtailment energy.
- The flexible connection is that DSO sets the cap of maximum output level before the connection if network constraint happens. During the power system operation, DSO could curtail the output of DG by the fixed capacity directly. There are two types of curtailment; LIFO, which is consistent with the "first-come first-serve" principle and pro-rata, which is proportional to the number of DGs.

The 3% curtailment rule in Germany has the highest acceptability of DG thanks to the full compensation of curtailed volume, while flexible connection in UK coupled with direct and dynamic control gives DSO the easiest curtailment method. The energy policy background in promoting DG and the technology available for controlling DG in the country are important for the initial choice of approach for the constrained connection.

In order to realize and improve the cost effectiveness of constrained connection in the future, it is necessary to have detailed assessment of relationship between curtailment cost and network investment cost, methods of allocation of curtailment volume and impacts of network tariff structure. This would be a difficult task, but experiences of the early adopters would give valuable information and help other countries to learn about the potential benefit of constrained connection.

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