IMPROVING DISTRIBUTION NETWORK REGULATION FOR THE ENHANCEMENT OF SUSTAINABLE ELECTRICITY SUPPLY

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Abstract

The amount of decentralised electricity generation (DG) connected to distribution networks increases across EU member states. This increasing penetration of DG units poses potential costs and benefits for the owners of the distribution network (DSOs). These DSOs are regulated since the business of electricity distribution is considered to be a natural monopoly. This paper identifies the impact of increasing DG penetration on the DSO business under varying parameters (network characteristics, DG technologies, network management type) and argues that current distribution network regulation needs to be improved in order for the DSOs to continue to facilitate the integration of DG in the network.

Introduction

In European member states, the public goal of a sustainable electricity system is strived for through a number of technology-specific member state support schemes for renewable-based electricity generation (RES-E) and co-generation of electricity and heat (CHP). This drives the growth of distributed generation (DG) – generators connected to the distribution network – to significant levels. Most EU member states implemented specific regulation to allocate (part of) grid integration costs caused by distributed generators to operators of distribution networks, i.e. distribution system operators (DSOs) in EU legislation. These costs may be substantial and, if allocated fully to the DG operator, cause an economic barrier to connect to the network. To guarantee non-discriminatory network access, charges for DG connections to be paid to the DSO should preferably be based on shallow costs. In contrast to deep cost charging, meaning that DG operators have to bear the costs to reinforce the network, shallow costs are only the direct costs of the connection. Also from the point of view of market access shallow cost charging is to be recommended because DG operators have to compete with large power plant operators.

The consequence of not allocating all of the grid integration costs to the DG operator is that DSOs should be able to recover the remaining costs from the use of system charges imposed to all connections (consumers and DG operators). Many EU member states apply shallow or shallowish connection charging for DG (Skytte and Ropenus, 2006), but DG related network costs are not taken into account explicitly in network tariff calculations. As a result increasing DG deployment may have a negative impact on the DSO revenues and DSOs may raise objections to further DG deployment. However, according to European regulation DG should be considered by DSOs when planning the development of the distribution network (Article 14/7 of the EU Electricity Directive).

In the DG-GRID project, a project co-financed by the European Commission[1] and carried out by nine European universities and research institutes[2], the impact of a high DG deployment on the electricity distribution system costs and the impact on the financial position of the DSO were analyzed. Furthermore, several ways for improving network regulation in order to compensate DSOs for the increasing DG penetration were identified and tested. This paper discusses the results of these analyses and the options for improving distribution network regulation.

Costs and benefits of DG integration

Insight into costs and benefits of increasing levels of DG in distribution networks is obtained through a load flow model analysis (Cao et al. 2006). Increasing DG into distribution networks was analysed for two types of networks: rural networks and urban networks. Besides the amount of DG connected to the network, two other parameters were varied: (1) the "DG-type" - electricity generation from intermittent sources (wind, solar) or non-intermittent sources (CHP) - and (2) the "DG density" - DG concentrated in specific parts of the network because of local available renewable sources or heat demand in the case of CHP.

Normally, because of the constantly growing electricity demand, DSOs have to increase the capacity of the grid connection to the transmission network by adding or replacing a transformer. With DG on the distribution network the net demand to be supplied from transmission network to distribution networks will not grow or even decrease. A DSO can postpone the capacity increase of the connection to the transmission network or may even be able to reduce investments required in case of equipment replacement. Elsewhere in the network a DSO may need to reinforce the network to allow DG to connect. At low DG penetration levels reinforcement costs are close to zero, but they will increase progressively with higher DG penetration. Reinforcement costs will also increase due to a high DG density. In many situations the investment deferral for connecting to higher voltage network levels will not fully offset the reinforcement costs leaving the DSO with extra capital expenditures as the results of the increase of DG deployment.

Large DG deployment may also have an impact on the operational costs. With electricity supplied from DG, distribution losses will reduce resulting in lower operational costs. However, if the DG deployment increases the distribution losses will increase again, because the larger load flows over the network, in particular in situations of high DG density.

In today's practice DSOs reinforce the distribution network so that DG that is connected to the network can be operated reliable and safely at all times. This conventional approach is referred to as "passive network management" or "fit and forget" philosophy. Reinforcement costs can be

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[2] Energy research Centre of the Netherlands (ECN), The Netherlands; Öko-Institut e.V., Institute for Applied Ecology, Germany; Institute for future energy systems (IZES), Germany; RISOE, Denmark; University of Manchester/Imperial College, United Kingdom; Instituto de Investigación Tecnológica (IIT), University Pontificia Comillas, Spain; Inter-University Research Centre (IFZ), Austria;VTT, Finland; Observatoire Méditerranéen de l'Energie (OME), France.

reduced with "active network management". Instead of increasing the network capacity the power quality and network reliability is warranted by active control of distribution assets and with active support of the generators connected to the network. The required investment for information and communication technologies (ICT) is relatively small compared to the avoided or lower reinforcement costs. At high DG penetrations the power flow from the generators will however exceed local demand and local generated electricity has to be transported to other regions. If this electricity surplus increases network reinforcement cannot longer be avoided. When active network management is applied operational costs (i.e. distribution losses, curtailment compensation to DG operators[3], extra labour costs for the DSO) are also affected and may increase. Distribution losses can become significant at high DG penetration levels because the network is operated with a relative high load factor.

Impact on the DSO's revenue

The result of the analysis on the system costs was used as an input for a study on the impact of DG deployment on the DSO's revenue. In this study the incremental impact of DG penetration in the distribution network was analysed using a spreadsheet model representing the financial position of the DSO (De Joode et al. 2007). Because the business of operating an electricity distribution network is considered a natural monopoly, network regulation is implemented. Different types of regulatory regimes exist. For this analysis one specific type of incentive regulation was used: revenue cap regulation. This basically states that the DSO is only allowed a maximum total allowed revenue (TAR) for its services in one year, with the TAR in one year being equal to the TAR in the previous period corrected for (i) a requirement on improved efficiency performance, (ii) change in overall price level (inflation), and (iii) optional compensation schemes for developments in demand. Mathematically, this results in the following formula:

$$TAR_t = TAR_{t-1}\left(1 + CPI - X\right) \pm AF \qquad \textbf{Equation 1}$$

TAR_t is the total allowed revenue in year t and is equal to total allowed expenditures, which is the sum of capital expenditures and operational expenditures. Capital expenditures are a function of the regulated asset base (RAB) and the weighted average cost of capital (WACC). The CPI (consumer price index) compensates for yearly rate of inflation. The X factor represents the required yearly improvement in efficiency performance.

Finally, an adjustment factor (AF), may be included to compensate for adverse movements in factors determining ex ante the revenue cap, for example growth in demand. The DSO model describes the financial accounts of one DSO over a longer period of time. It basically consists of a number of cost and revenue items that together determine the financial result of the DSO for a given number of consecutive years. These costs are: depreciation and financing costs of investment of network assets, operational and maintenance costs, energy procurement costs for

[3] In an active network management mode DSOs integrate DG operations into their network management. This can involve a ramping up or down of electricity generation by the DG operator. It is likely that this will be accompanied with a contractual arrangement in which the DSO and DG operator agree upon a compensation fee for the DG operator for the foregone revenues of electricity sales.

compensating distribution losses, payments to DG operators to compensate for curtailments (only in case of active network management) and corporate tax.

In order to analyze the impact of a gradual penetration of DG in the distribution network assumptions were made on the realization of DG connections over a 12-year period. The total amount of DG capacity is assumed to penetrate the distribution network in a period of 10 years linearly over time. Investments needed to facilitate DG penetration are assumed to precede DG connection one year ahead. Operational costs and benefits of DG penetration for the DSO are assumed to be incurred/realized at same pace as DG capacity is connected.

The model lists expenditures and costs and calculates the net present value of the annual net profit over 12 years. In order to get insight into the meaning of these figures and to answer the question of how much the DSO relatively gains or loses when DG enters the network, the incremental profit is related to the profit that a DSO can earn under 'business as usual' operations. Since a DSO is a regulated entity, this boils down to a regulated profit margin for every Euro invested in the network. Therefore we introduce the term 'regulated profit' ($\overline{\pi}$). This is defined as:

$$\overline{\pi} = RAB \cdot WACC \qquad \textbf{Equation 2}$$

RAB is the regulated asset base and WACC the weighted average cost of capital.

In total 32 different distribution network cases were analyzed on their impact on the DSO revenue by varying 5 different parameters:

1) DG level (low: 50 MW, medium: 100 MW and high: 200 MW on a distribution network with a total system load of 1155 GWh per year);
2) concentration of DG on the network (low, high);
3) DG type (intermittent/non-intermittent);
4) network type (rural/urban), and;
5) management type (passive/active).

Furthermore, the impact of DG deployment on DSO revenues was analyzed including and excluding the potential value of deferred investment due to DG. The estimates of the potential value of deferred investments were made in a separate analysis (Cao et al. 2006). This analysis did however not distinguish rural or urban networks nor active or passive management, nor intermittency.

The results of the analysis in Table 1 show that, if the potential value of deferred investments is not taken into account, DSOs operating under a passive network management regime generally do not profit from the presence of DG in their distribution network. Although low DG penetration levels do benefit the DSO somewhat, higher penetration levels result in a negative overall impact. The concentration of DG within the network is a particular influential factor: the more concentrated the presence of DG in the distribution network, the more negative the impact. The driver for the generally positive results for low penetration levels and the generally negative results for high penetration levels are distribution losses.

Case	Parameter					Impact on DSO revenue	
	Level DG (MW)	Net-work type	Concen tration DG	Type of DG	Managem ent type	Excluding potential deferred investment	Including potential deferred investment
1	100	Rural	High	Intermittent	Passive	7.8%	29.6%
2	100	Rural	High	Intermittent	Active	9.2%	31.0%
3	100	Rural	High	Non-intermittent	Passive	-7.0%	14.8%
4	100	Rural	High	Non-intermittent	Active	-6.7%	15.1%
5	50	Rural	Low	Intermittent	Passive	2.1%	12.9%
6	50	Rural	Low	Intermittent	Active	2.1%	12.9%
7	50	Rural	Low	Non-intermittent	Passive	5.2%	15.9%
8	50	Rural	Low	Non-intermittent	Active	5.2%	15.9%
9	200	Rural	High	Intermittent	Passive	-16.2%	1.0%
10	200	Rural	High	Intermittent	Active	-21.6%	-4.4%
11	200	Rural	High	Non-intermittent	Passive	-44.7%	-27.5%
12	200	Rural	High	Non-intermittent	Active	-57.3%	-40.0%
13	100	Rural	Low	Intermittent	Passive	-4.3%	17.6%
14	100	Rural	Low	Intermittent	Active	-4.5%	17.4%
15	100	Rural	Low	Non-intermittent	Passive	0.3%	22.2%
16	100	Rural	Low	Non-intermittent	Active	0.3%	22.2%
17	100	Urban	High	Intermittent	Passive	-1.2%	20.6%
18	100	Urban	High	Intermittent	Active	4.6%	26.4%
19	100	Urban	High	Non-intermittent	Passive	-10.5%	11.3%
20	100	Urban	High	Non-intermittent	Active	-3.8%	18.0%
21	50	Urban	Low	Intermittent	Passive	-8.4%	2.3%
22	50	Urban	Low	Intermittent	Active	-1.6%	9.1%
23	50	Urban	Low	Non-intermittent	Passive	2.6%	13.4%
24	50	Urban	Low	Non-intermittent	Active	0.4%	11.2%
25	200	Urban	High	Intermittent	Passive	-26.4%	-9.2%
26	200	Urban	High	Intermittent	Active	-32.9%	-15.7%
27	200	Urban	High	Non-intermittent	Passive	-41.1%	-23.9%
28	200	Urban	High	Non-intermittent	Active	-51.9%	-34.6%
29	100	Urban	Low	Intermittent	Passive	-10.6%	11.3%
30	100	Urban	Low	Intermittent	Active	-2.3%	19.6%
31	100	Urban	Low	Non-intermittent	Passive	1.2%	23.2%
32	100	Urban	Low	Non-intermittent	Active	0.1%	22.1%

Table 1 Impact of DG deployment on the DSO's revenue relative to 'business as usual'

DSOs operating under an active network management philosophy are generally confronted with comparable results as the passive network management case. Penetration of DG in the network is favorable for the DSO for low penetration levels, but becomes unfavorable the higher the penetration rate, and the more concentrated the DG in the network. However, it should be noted that the negative results are relatively small for the majority of the cases analyzed: the net impact of DG penetration is mostly within the range of 8% of the 'business as usual' profit DSOs make.

The added value of DG with respect to the investment deferral for connections to the higher voltage network levels can be substantial. However, the realization of this positive value for the

DSOs is dependent on a larger number of non-DG related factors and is beyond the scope of this investigation (e.g. load growth dynamics and the status of interconnection equipment). However, considering the maximum replacement values of DG, it can be expected that the overall impact of DG penetration on the DSO business, can be neutral or positive in the majority of cases. Observing the differential impact on the DSO under passive and active network management we conclude that there is an implicit incentive for the DSO to adopt an active network management approach in a number of cases, in particular the case where DG penetration is low or mediocre.

Improving regulation

The negative impact of DG integration on the DSO's revenue may hamper the deployment of DG resulting in a 'conflict' with the national and European policy objectives for CHP and RES-E. To solve this problem the extra costs of DG integration should be socialized among all customers connected to the network, i.e. electricity consumers and generators. The network costs for connecting and integrating DG is then treated in the same way as network costs related to electricity consumption. This reflects the role of the distribution network: providing access to the electricity market for consumers and (distributed) generators under similar conditions. The extra network costs induced by DG connections can be allocated to consumers and DG operators through the use of system charges. These tariffs (connection charges and use of system charges) are calculated from the TAR by taking into account the number of connections, size of connections, amounts of kWh and kW_{peak}, etc.

With the revenue cap formula (Equation 1) as a starting point, five different ways to compensate for DG penetration have been identified (De Joode et al. 2007). The spreadsheet model was applied to test the effectiveness of four improvement options (see below). The fifth option is to consider DG as a cost driver in the DSO benchmarking. The model is however not suited for analysing this option. Table 2 shows the DSO's revenue in case of DG penetration relative to 'business as usual' for the four regulatory improvement options in comparison to a reference case excluding the potential deferred investment value. The four options shown in Table 2 are:

1. An *allowance in the regulated asset base* (RAB) for the DSO for DG related investments. This option compensates for the negative impact of DG penetration on capital investment but not on operational expenditures. A pass-through of DG related investments less than 100% is used so that an economic incentive remains to limit these investments. A 30% pass-through is used for a low, 70% for a medium and 90% for a high DG penetration rate. This type of compensation measure can be described in a formula as follows:[4][5]

$$TAR_t = TAR_{t-1}(1 - X) + y\%\ I_t^{DG} \qquad \textbf{Equation 3}$$

where
y = Share of eligible DG related investments in distribution network assets

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[4] Since the DSO model uses and presents nominal prices the revenue cap scheme included in the model does not contain a correction for inflation.

[5] The assumption is made that demand growth is zero, therefore the adjustment factor AF (see equation 1) is equal to zero.

I_t^{DG} = Total eligible DG related investments in distribution network assets in year *t*

Case	Parameter					Reference	Improvement options			
	Level DG (MW)	Net-work type	Concentration DG	Type of DG	Management type	Impact on DSO revenue	Allowance in RAB	Quality indicator	Direct revenue driver	RAB and direct revenue driver
1	100	Rural	High	Int.	Pas.	7.8%	10.6%	12.7%	9.9%	17.2%
2	100	Rural	High	Int.	Act.	9.2%	10.6%	14.1%	11.3%	16.3%
3	100	Rural	High	Int.	Act.	-7.0%	1.0%	11.5%	9.3%	9.1%
4	100	Rural	High	Int.	Act.	-6.7%	-1.8%	11.7%	9.5%	7.3%
5	100	Rural	High	Int.	Act.	2.1%	2.1%	4.6%	3.2%	4.5%
6	100	Rural	High	Int.	Act.	2.1%	2.1%	4.6%	3.2%	4.5%
7	100	Rural	High	Int.	Act.	5.2%	5.2%	10.1%	6.2%	9.8%
8	100	Rural	High	Int.	Act.	5.2%	5.2%	10.1%	6.2%	9.8%
9	100	Rural	High	Int.	Act.	-16.2%	2.8%	4.7%	5.4%	8.9%
10	100	Rural	High	Int.	Act.	-21.6%	-6.6%	-0.2%	1.6%	1.7%
11	200	Rural	High	Non-int.	Pas.	-44.7%	-18.3%	-1.8%	3.0%	-3.8%
12	200	Rural	High	Non-int.	Act.	-57.3%	-36.4%	-13.6%	-8.2%	-19.0%
13	100	Rural	Low	Int.	Pas.	-4.3%	-2.4%	1.9%	-1.3%	4.1%
14	100	Rural	Low	Int.	Act.	-4.5%	-3.2%	1.7%	-1.5%	3.1%
15	100	Rural	Low	Non-int.	Pas.	0.3%	3.7%	16.7%	14.5%	12.0%
16	100	Rural	Low	Non-int.	Act.	0.3%	2.5%	16.6%	14.5%	11.2%
17	100	Urban	High	Int.	Pas.	-1.2%	3.8%	4.1%	1.3%	11.7%
18	100	Urban	High	Int.	Act.	4.6%	5.6%	9.5%	6.7%	10.8%
19	100	Urban	High	Non-int.	Pas.	-10.5%	2.7%	9.0%	6.8%	9.8%
20	100	Urban	High	Non-int.	Act.	-3.8%	-1.0%	13.7%	11.5%	8.2%
21	50	Urban	Low	Int.	Pas.	-8.4%	-2.3%	-5.0%	-6.9%	3.9%
22	50	Urban	Low	Int.	Act.	-1.6%	0.6%	1.3%	-0.1%	4.3%
23	50	Urban	Low	Non-int.	Pas.	2.6%	2.6%	5.3%	1.5%	7.3%
24	50	Urban	Low	Non-int.	Act.	0.4%	2.3%	5.3%	1.5%	8.2%
25	200	Urban	High	Int.	Pas.	-26.4%	7.2%	-4.7%	-2.5%	9.7%
26	200	Urban	High	Int.	Act.	-32.9%	4.2%	-10.9%	-9.0%	6.2%
27	200	Urban	High	Non-int.	Pas.	-41.1%	3.4%	1.6%	5.5%	8.6%
28	200	Urban	High	Non-int.	Act.	-51.9%	-2.8%	-8.4%	-2.8%	1.6%
29	100	Urban	Low	Int.	Pas.	-10.6%	-4.4%	-4.0%	-7.6%	4.8%
30	100	Urban	Low	Int.	Act.	-2.3%	-1.7%	3.3%	0.5%	3.8%
31	100	Urban	Low	Non-int.	Pas.	1.2%	1.2%	17.6%	15.4%	10.6%
32	100	Urban	Low	Non-int.	Act.	0.1%	1.2%	16.5%	14.3%	10.2%

Table 2 The DSO's revenue relative to 'business as usual' in the reference case (without potential deferred investment value) and four regulatory improvement options

2. Including *an additional quality indicator* through which DSOs are compensated for higher DG presence in their distribution network:

$$TAR_t = TAR_{t-1}\left(1 - X + K_{Ind}\right) \quad \textbf{Equation 4}$$

The chosen value for the K_{Ind} is 0.75% for a DG penetration level of 11% and 1.5% for 23%, 5% for 46% and 10% for 91% respectively.

3. Allowing one or more *DG based direct revenue driver(s)* in the revenue cap formula:

$$TAR_t = TAR_{t-1}(1-X) + F_1 \cdot kW^{DG} + F_2 \cdot MWh^{DG}$$ **Equation 5**

The allowance is based on the DG capacity (F_1=2.5 €/kW for a low, F_1=2 €/kW for a medium and F_1=1 €/kW for high a DG penetration) and the electricity supply of DG (F_2=0 €/MWh for a low, F_2=2.5 €/MWh for a medium and F_2=3.5 €/MWh for a high DG penetration).

4. A *combination of a special RAB allowance and direct revenue driver*. While the direct revenue driver in this scheme is still based on energy, the capacity based direct revenue driver is replaced by a special RAB allowance for DG related investments:

$$TAR_t = TAR_{t-1}(1-X) + y\% \cdot I_t^{DG} + F \cdot MWh^{DG}$$ **Equation 6**

The rate for total eligible DG related investments (I_t^{DG}) is 50% and the direct revenue driver (F) has the value of 2 €/MWh.

As the results of the analysis of improvement options shown in Table 2 indicate there is no 'one size fits all' solution for neutralizing the negative impact of DG penetration on DSO's revenue. Since the negative impact of either operational expenditures (distribution losses) or capital expenditures (network upgrades) in some specific cases (for mostly cases with high penetration rates and concentrated DG units) is very dominant, a specific regulatory arrangement with compensatory elements based on either 'DG energy produced' or 'DG capacity connected' can not fully compensate the DSO without unnecessarily 'subsidize' other DSOs. The regulatory arrangement most successful is the combination of a special allowance and a direct revenue driver. When applying this option DSOs will be able to recover their costs. It should be noted that a mediocre 'overcompensation' of DSOs for the negative impact they experience from DG penetration of the network might work effectively as an incentive to fully facilitate DG connection within their distribution network

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