USE OF SYSTEM CHARGES METHODOLOGY AND NORM MODELS FOR DISTRIBUTION SYSTEM INCLUDING DER

Dr. J. DEUSE*, Dr. S. GRENARD*, D. BENINTENDI, Prof. P.J. AGRELL**, Prof. P. BOGETOFT****
***Tractebel Engineering (Belgium), **FEEM (Italy),**
jacques.deuse@tractebel.com

ABSTRACT

As the design policy of current distribution networks was based on the principle that only demand is connected to the network (i.e. a unidirectional flow existing from high voltage to low voltage networks), potential technical problems could occur following DER connections. Similarly, regulatory frameworks currently in place were not designed with micro generation schemes in mind. Therefore, the existing rules could be a barrier in relation with the introduction of DER in the system and their profitability. To face these matters, the methodology developed in the EU-DEEP project starts from an electro-technical background. It focuses on two main concerns: the incidence of DER on distribution system costs and the use of system charges allocation between local generation and load. This paper discusses the set up of norm models enabling the tightly coupled interaction between technical and regulatory aspects. It is illustrated by presenting the incidence of different DER types on the development costs of distribution networks and on distribution system losses. The paper also discusses a method for "use of system charges" allocation presented earlier by the University of Manchester, but now adapted for being applicable to MV and LV systems.

INTRODUCTION

The design and the operation of the incumbent distribution network and the associated regulatory and market rules were decided on the basis of a unidirectional flow in the distribution network –since only demand was connected to the network. Therefore, the current integration of Dispersed Energy Resources (DER) poses a valid challenge to both utilities and regulators due to technical and regulatory issues. The potential technical problems are well documented and a careful examination of these questions shows that a large margin exists before DER introduction leads to technical difficulties. However, the introduction of DER in distribution networks touches two core issues related to the existing regulatory frameworks: the impact of DER connection on distribution network cost drivers from which rise the network design decisions and the corresponding investment costs; and the allocation of use of system charges allocation between local generation and load. *Per-se*, these concerns are both closely related to the technical context. Therefore, the methodology developed in the EU-DEEP project and presented in this paper starts from an electro-technical ground.

The introduction of DER in the system, their profitability and their efficient introduction in the electric market (often referred as "levelling the playing field") requires three main questions to be solved. They concern (1) the incidence of DER on system costs, (2) the "use of system" charges allocation between production and demand; and (3) the compatibility of new allocation schemes with EU treaties. In the regulation context, the set up of normative engineering regulation models (also called norm models) is of interest for regulatory bodies, particularly because this process permits illustration of the tightly coupled interaction between technical and regulatory aspects. This is discussed in the first part of the paper, while results obtained with an optimising tool on the incidence of DER on the development costs of the distribution system and the cost of losses are presented in the second part. Finally, the third part focuses on an existing use of system charges allocation methodology and extends its application range to the medium and low voltage parts of the distribution network.

NORM MODELS AND DER

Long-term planning of the distribution system is an essential part of the activities of a distribution network operator. Its main purpose is to determine the optimum network arrangements, and its corresponding investments to obtain maximum benefits. Normative models are a conscientious attempt to model such a complex planning problem without duplicating the industry planning system. They are a good compromise between benchmarking methods which usually do not consider inherent and inherited characteristics of utilities, and a really precise modelling of the network which is difficult to handle particularly when medium and low voltage parts of the distribution network are studied. Therefore, they are attractive from a regulatory point of view as they avoid the regulator to micromanage the utilities and they could help the regulator overcome the difficulties faced due to the lack of information. As examined in a survey carried out in EU-DEEP, norm models in general, are just special cases of engineering cost functions with varying level of information requirements leading to a high level representation of the considered network. They must, however, be able to include all distribution network cost drivers in order to enable us to find the right balance between these cost drivers and the investment required in the network. By doing so, the connection and reinforcement costs, as well as the benefits obtained with DER could be quantified from a system point of view.

IMPACT OF DER ON DISTRIBUTION SYSTEM DEVELOPMENT COSTS

Tool description

The objective of a study using the "Dimensionnement" model is to establish long-term network development criteria at the planning stage for the electrical transmission and distribution system of a given area [1]. Development criteria and technical options are leading to specific network architectures, to equipment types and sizes and to densities of substations. The complexity of an electrical distribution system arises from its following cost drivers:

- Several voltage levels are linked together through substations and are highly dependant on each other.
- The peak demand of consumers are not requested at the same time, influencing the equipment size to be chosen.
- Power and energy losses.
- Voltage drop along cables and lines.
- A given part of the demand must still be satisfied even if a failure of equipment occurs.

As a consequence of such a complexity, there are several opposite effects related to equipment choice that call for best compromise at the optimum. The “Dimensionnement” model does optimize the size of the equipment in a distribution electrical network in such a way that the total equipment cost and cost of losses is minimized. To do so, cost functions modelling the cost of different distribution network equipments as a function of their rating are used. The “Dimensionnement” model enables us to obtain an optimal equilibrium between the density of substations, the number of transformers per substation, the transformer nominal power, the cross-section of cables/lines, the length of cables/lines and the number of outgoing feeders per substations. Such an optimal equilibrium is reached under the condition that all the voltage levels are considered simultaneously (which was lacking in [2]).

Costs of distribution networks

The first step of the case study using the “Dimensionnement” tool is to derive the total cost - investment cost plus cost of losses- of the distribution system (without DER) as a function of the load density.

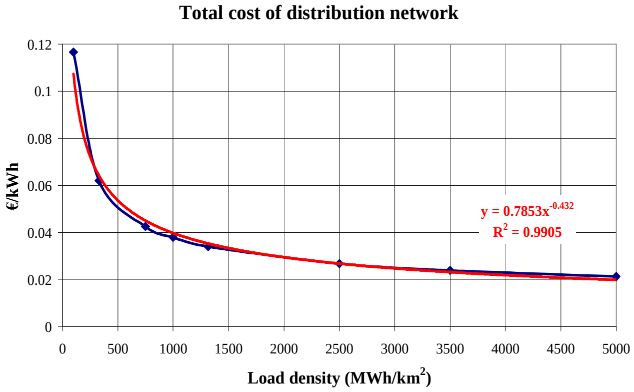

Figure 1 – Total cost of distribution network (and corresponding regression analysis) as a function of load density

Figure 1 depicts how the total cost -in €/kWh- including investment cost and cost of losses, decreases when the load density increases. The following formula is derived by regression analysis to describe this trend (similar results can be found in the literature):

$$TC = \frac{0.7863}{\sigma^{0.422}}$$

where TC is the total cost of distribution network (in €/kWh) and σ is the load density (MWh/km^2).

This illustrates the fact that rural networks are more expensive than urban networks for a given supplied energy. As a consequence, one could conclude that DER installations would be most beneficial in regions with low load density as it could considerably reduce the total cost. In the extreme case (on the extreme left hand side of the curve), it could even be beneficial not to build a network and to operate an islanded zone as it would considerably reduce the total cost.

Incidence of DER on investment costs and cost of losses

The second step of this case study is to connect two different types of DER (micro-CHP and Photovoltaics (PV)) to the LV part of the distribution network. It is assumed that the DER capacity installed is equal to 100% of the demand capacity. Hourly and seasonal demand and generation profiles are used to model the micro-generation as well as the demand connected to the network. The main features of the generation profiles are described in Figures 2 and 3. A sort of correlation between the micro-CHP output and the demand profile exists. However, the PV profile is totally uncorrelated with the demand, as its peak of production occurs at midday during the summer, time at which the demand in North-Europe is at its lowest point, while PV production is quasi nil during the winter.

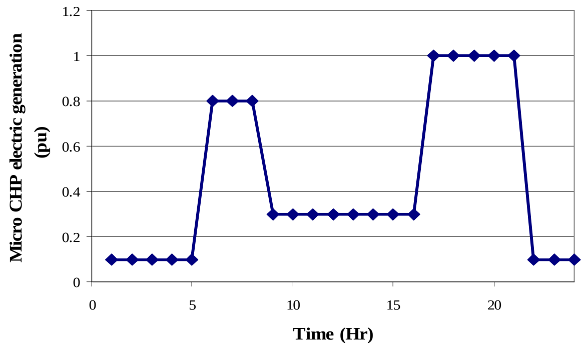

Figure 2 Micro-CHP profile during the winter period

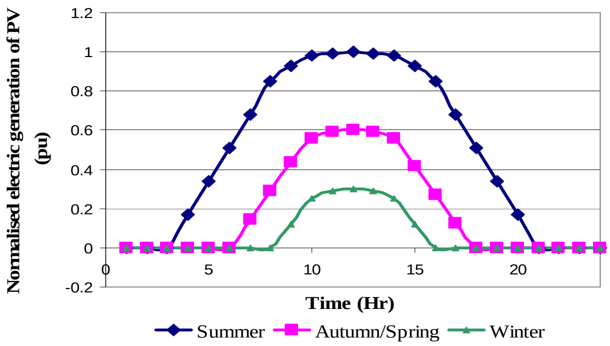

Figure 3 PV profile during different seasons

Applying these profiles to the “Dimensionnement” model leads to optimum distribution networks which corresponding investment costs are described in Figure 4 for the three following cases: the case with no DER; the case with micro-CHP and the case with PV. For all load densities, connecting DER decreases the investment cost. However, this reduction is quite insignificant, particularly in the case of PV connection. This tiny reduction in distribution investment cost when having production connected at low voltage is mainly due to the high fixed cost related to distribution networks (fixed cost of manufacturing equipment, fixed cost of digging to install cables, etc.). The main impact of DER is to decrease the flow of energy required from higher voltage levels, leading sometimes to reduction in the rating of the equipment (usually defined by security requirements, losses and voltage drop limitations): this reduces the variable cost of investment but hardly impacts on the fixed cost.

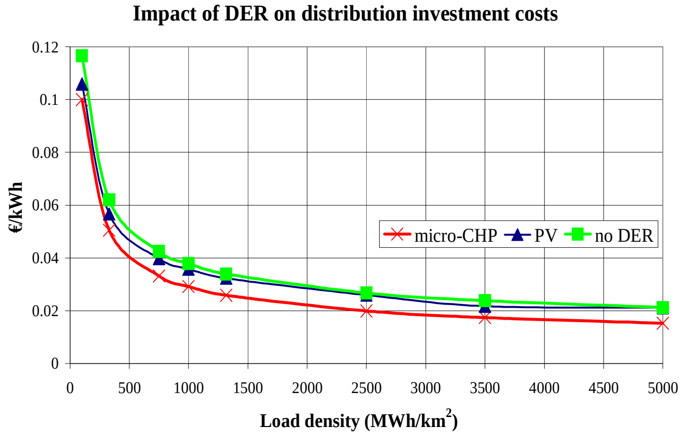

Figure 4 Distribution investment costs for the three cases

One can notice a difference between the investments required when micro-CHP and PV are connected: for a load density of 2500 MWh/km^2, the investment costs of distribution networks with micro-CHP correspond to 0.02 €/kWh, while it is 0.025 €/kWh when PV is connected. This difference is mainly due to the fact that the micro-CHP output is somehow correlated to the demand profile in North Europe while PV is not, as previously discussed. Therefore, micro-CHP schemes tend to relieve the network during times of high demand (periods driving the investments required) and consequently reduce its corresponding investment costs.

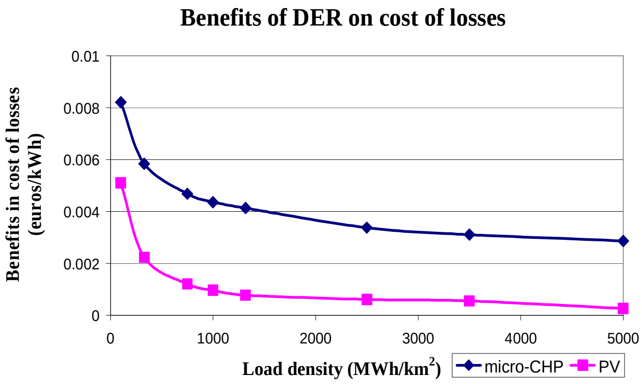

Figure 5 Benefits of DER on cost of losses

The impact of DER on distribution network losses is mainly due to two factors: the geographic location of DER compared to load centers and the time correlation between DER production and demand in the network. In this case study, only the latter is considered as the geographic distribution of DER and of the demand is similar. Figure 5 illustrates the benefits obtained on the cost of losses when connecting DER. As explained above, the benefits obtained are more important with micro-CHP than with PV. Furthermore, the benefits are more significant in rural areas which are parts of the network with high losses. In urban networks, the decrease in cost of losses due to the presence of DER is quasi insignificant.

ALLOCATION OF DISTRIBUTION INVESTMENTS

Existing methodology

Once the design rules of the distribution network with and without DER have been established and the corresponding costs of investment decisions are quantified and allowed by the regulator, an allocation methodology must be defined in order to distribute these investment costs to the different users of the network (both consumers and generators). A framework and methodology for allocating distribution network investment costs to customers and distributed generation was developed by the University of Manchester [3]. This cost reflective pricing methodology computes times of use and location specific Distribution Use of System (DUoS) exit and entry charges for demand and generation customers. It is based on a marginal cost pricing method where the capacity of individual network components (lines and transformers) is determined by considering two critical conditions which are clearly relevant for the design of each circuit in turn: Maximum load and secure generation output (for demand driven design)/ Minimum load and maximum generation (for generation driven design).

These situations are determined by running a load flow for each of these two conditions. If the critical flow in a component is going downwards, the demand connected at lower voltage levels is charged for the use of that component, while the generators are rewarded for decreasing this critical flow. On the other hand, if the critical flow is going upwards then generators connected at lower voltage levels are charged for the use of that component while the consumers are rewarded.

However, this framework seems to be appropriate for a UK type distribution network, where the 132 kV and the 33 kV voltage levels belong to the Distribution System Operator (DSO), which is usually not the case in continental Europe. Applying different load flows in order to study the critical flows at 132 & 33 kV is feasible, however, it seems to be more difficult to implement at medium and low voltage levels because of the complexity and large number of data required (feeders and transformers technical data, allocation of the load and generation along the circuits and so on). Moreover, the technique presented above deals only with feeders being either demand or generation driven. However, since load and generation are distributed along the MV and LV feeders, a single feeder-and particularly long tapered rural feeders- could be divided into sub parts being either demand or generation driven.

Since modelling LV and MV systems would require a huge amount of effort, only the use of appropriate meters and measurements placed in the distribution network can take into account all these different details at LV and MV in order to reflect the impact of the different users on network design and consequently to assess their distribution use of system charges. These real time meters would measure the real time consumption and generation for all the different network users, as well as the flows in the most appropriate parts of the distribution network. As illustrated below, the aim is to retrieve *ex post* the participation of individual load and generation to peak loading of upstream equipments.

Obviously, this is a very costly solution requiring a huge amount of data acquisitions and computations, therefore such approach should probably be simplified to a certain level for being acceptable, but installing new measurement systems might not be required only for the purpose of pricing as it could also support an efficient use and operation of the system at a time where high penetrations of DER in the distribution system are expected.

Example of extension to MV and LV systems

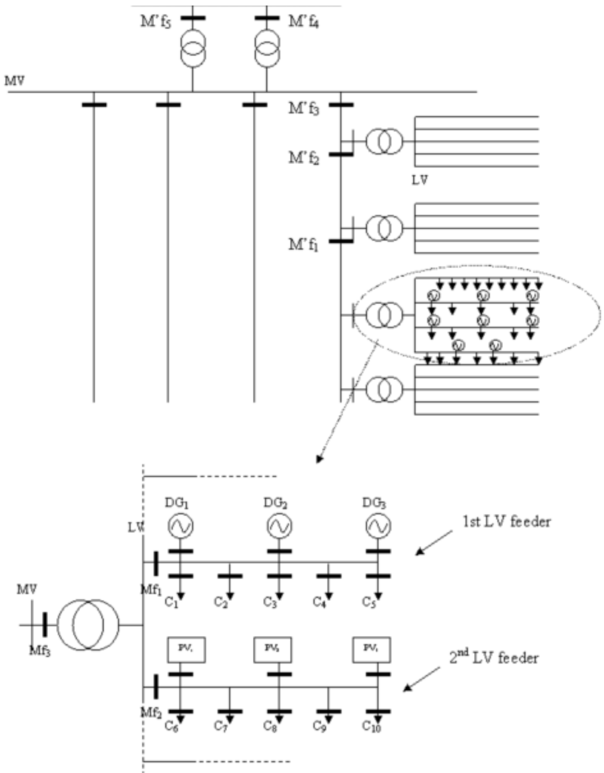

Figure 6 Single line diagram of the MV and LV systems

As previously explained, the application of the previous methodology to the MV and LV systems requires the investment in real time meters and measurements systems: they are represented by the black thick lines in Figure 6.

Firstly, as the purpose is to assess the contribution of each user on the critical flows in the system, it is inevitable to require each connected customer and generator to be equipped with a real time meter in order to measure their quarter hourly (or ten minutes or half hourly or hourly) consumption and generation respectively. The second requirement is to install meters at the right places in the system. The main concern is to be able to divide the system into demand driven and generation driven design. However, a single feeder could have several parts with several flow directions. Its design could therefore be driven by both demand and generation.

The first step in the methodology to allocate the 1st LV feeder cost is to analyse the annual measurements of real time meter Mf_1, in order to define the time of year when the maximum flow occurs (represented by the black column in Figure 7). The charges for the use of the 1st LV feeder are defined by the contribution of each of its connected customers and generators to that flow. Therefore, customers $C_{1,2,3,4}$ contribute to the critical flow and are charged for it, while $DG_{1,2,3}$ reduce the critical flow: they are rewarded.

The methodology for allocating the costs of the MV feeder is similar to the one presented above for the LV feeder. The only difference is reflected in the fact that the exercise of cost allocation will divide the feeder in several parts ($M'f_{1,2,3}$); each of them having a different critical flow.

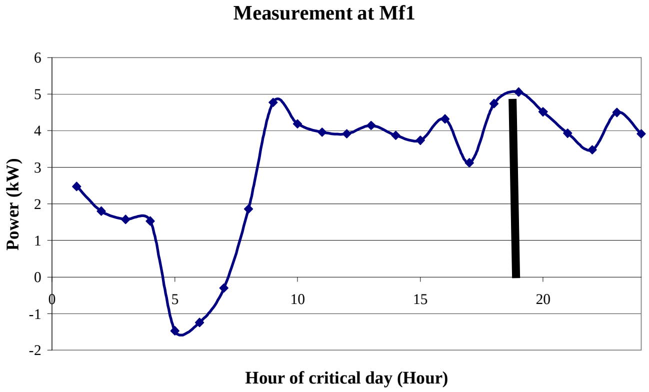

Figure 7 Power measured (Mf_1) flowing through feeder 1 during the critical day

CONCLUSIONS

This paper presents the methodology developed in the EU-DEEP project to study the impact of DER on network costs and their allocation to the different users. The usefulness of norm models for distribution system including DER was discussed and their attractiveness for regulatory purpose was described through an example quantifying the impact of DER on network costs. Besides, an existing use of system charges methodology was also extended to LV and MV systems by implementing real-time measurement systems.

Acknowledgments

This work is funded by the European Commission as part of EU-DEEP, a European Project supported by the Sixth Framework Programme for Research and Technological Development (grant SES6-CT-2003-503516).

REFERENCES

[1] Stubbe M., Doulliez P., 1982 “A theoretical model for the determination of the optimal design of a power transportation and distribution system with several voltage levels”. *Mathematical Programming Study*, vol.20, 72-95.
[2] Demailly, F., Even, A. et *al*., 2005 “Optimal design of the distribution infrastructure and the impact of distributed generation”, *CIRED Turin*
[3] Strbac, G. et *al*., 2005 “Methodology for pricing of distribution networks with DG”, *CIRED Turin*