DISTRIBUTION NETWORK DESIGN, MANAGEMENT AND REGULATION

Jacques DEUSE
Tractebel Engineering – Belgium
jacques.deuse@tractebel.com

Konrad PURCHALA
Tractebel Engineering – Belgium
konrad.purchala@tractebel.com

Gilles BOURGAIN
Gaz de France – France
gilles.bourgain@gazdefrance.com

ABSTRACT

In the present context of the Electric Supply Industry characterized by a market that is open down to the small customers connected to the low voltage network, the implementation of Distributed Energy Resources requires innovative solutions that could lead to efficient regulation schemes as well as new implementations of demand response and even defence plans for ensuring the robustness of the system facing serious disturbances.

This supposes that some of the propositions from the "SmarGrids" concept must be deployed. This is in fact one of the conclusions of the EU-DEEP EU integrated project about the integration of DER in the network and in the market.

INTRODUCTION

This paper aims at showing with the help of two examples regarding distribution network regulation and defence countermeasures in presence of Distributed Energy Resources (DER), why new Information and Computer Technologies (ICT) solutions are necessary for an efficient and secure operation of the electrical system. But it also recalls that distribution network design must be updated for a flexible acceptance of DER.

The approach of the EU-DEEP project will be first briefly summarized, the accent being put on conditions that are able to lead to profitable implementation of DER (first of all CHP of small size.) Then the role of ICT will be evoked as a means that can make explicit the role of DER considered as "network replacement". The already proposed Use of System charges [1] method that is *per se* "efficient", could lead in the long run to a reduction of system cost. This, however, asks for new solutions for maintaining the security performances of the system as distribution will not be unconditionally adequate anymore.

THE EU-DEEP PROJECT

EU-DEEP Project aims at integrating profitably decentralized generations in the network, in the system and in the market. Within this project, "distribution" means the medium and low voltage networks that are operated as radial circuits. System refers to the compound of generation and consumption as a whole. It considers the control of the balance between generation and consumption in terms of active power as well as in terms of reactive power. The market is supposed to be fully "open" and decentralized generation is supposed to be competing with "centralized" generation in a commercial way.

As a basic principle the study has been developed considering an integrated approach of technical questions, market aspects and their regulation. The process started form electro-technical considerations, because it is important to identify technical barriers that could impose severe constraints that could be difficult or extremely expensive to remove. Based on this knowledge a new context has been set up having these constraints in mind for defining the framework of the investigation. The process continued taking into account technical and economical access to the market. And finally, an updated regulation framework for the distribution system has been examined in depth.

It has been clearly established that a balanced approach is necessary based on updated network design criteria on the one hand and on active management of the system on the other hand.

The profitability of a project based on decentralized generation depends on different parameters: upfront investments, including connection costs; operation and maintenance costs; market architecture; T&D regulation; incentives; externalities (CO_2); etc. The objective of the project is to reach, as far as it is possible, in the mid-term, "autonomous" profitability without incentives.

Cost – benefit analyses implemented at different levels allow for defining fields where "resources" are able to be found. Cogeneration is mainly considered in the project because it corresponds to a significant market segment that is able to bring better overall efficiency. It should also be noted that this type of application is not far from being profitable, indeed sufficiently large plants are already profitable without incentives.

The analyses suppose nevertheless precise evaluations of the status of the different sources of value that can be brought by DG installed in medium or in low voltage networks. These sources of value are as follows: sales of energies, electricity, heating and cooling; the DER as a replacement capacity of the network; the participation to ancillary services market; the contribution of externalities (CO_2); incentives; etc.

As a final step, business models have been built considering situations that presently exist in certain European markets (the U.K., Germany, Greece, France and Spain). They are being optimized using information coming from one year full scale experiments that are presently ongoing. Further, the incidence on the profitability of the business models considering extrapolated market conditions and regulatory frameworks have also to be evaluated. In this last case "efficient" solutions already existing or developed within the project will be considered and applied.

ICT AND DESIGN CRITERIA

ICT will play a more and more important role in the future. The "SmartGrids" concept, even if it is not univocally defined yet, can be roughly presented as the progressive integration of the transmission & distribution networks with a communication infrastructure allowing for the implementation of technical as well as commercial support to the electrical system operation.

The question is in fact more complex that it seems to be at first sight. Indeed all types of interactions that can take place within the electrical system must be accounted for. It supposes that clear definitions have been proposed for characterising the different elements playing a part in the concept. This is especially true if a comprehensive integration is expected. This has to include, for example, the possibility to supply clients that are connected to a same network with different levels of security of supply. This also should include load participation to system control in normal situation as well as when the system is in emergency conditions. Last but not least, defence countermeasures able to limit the risk of system blackout should also be considered.

It is also fundamental to define what "Distribution" effectively means. The implementation of the electrical supply seems uniform in Europe: generation, transmission and distribution, with supply that is liberalised down to the final customer. Transmission and distribution, as *de facto* monopolies, are regulated on a country base. The location of the limit separating the transmission and distribution networks is one of the significant differences that characterises electrical power system throughout of Europe. This is not necessarily correctly accounted for when discussing about active management.

Active management in distribution supposes that network infrastructure has been updated when necessary. From preceding, already presented results [2], it is possible to straightforwardly define the basic requirements for a "flexible" distribution network. Such flexibility supposes a full symmetrical approach when considering local generation and consumption. The definition of the basic design principle lies in the depth of the solution. In the traditional approach the design starts from the load density. In the "flexible" approach load and generation densities are considered simultaneously and are playing symmetrical roles.

For the sake of simplicity, let's assume that 100% symmetry is the target (this means that at least one feeder of the substation is carrying load only and another feeder is carrying generation only.) The allowed voltage range has to be equally shared by generation and consumption. Bigger cross-sections cables could then be required, at least in rural area, as the allowed voltage drop is reduced, 50% being devoted to load and 50% to generation.

The consequences of such distribution network design are:

- The HV–MV distribution substation is able to operate at nominal power to or from the distribution network.
- A full "asymmetry" between feeders is acceptable without problems of voltage control.
- The HV–MV substation operates at nominal medium voltage in all circumstances, which is slightly lower than in the present situation.
- Distribution transformers must be set at their nominal transformer ratio at least for MV feeders which can change their operating point from consumption to generation and *vice-versa*.
- In low load density region, where distribution networks can be near to voltage drop limits, larger cross-section cables could be required.
- This can impact the costs of existing networks but for new installation or in case of replacement of old ones this should not lead to significant cost increase because installation costs dominate.
- In existing systems, the updated operating point could possibly lead to increased losses as the mean voltage in the system could be slightly reduced.

THE DER "VALUE" FOR THE NETWORK

Ranking the different values that can be brought by DER permits to understand that the part of the cost of the system that corresponds to avoided network investment, is a potential source of revenue for the DER operator. This supposes at least that DER has been sized and is operated adequately. This additional source of revenue is necessary for making small DER profitable, like for example µCHP.

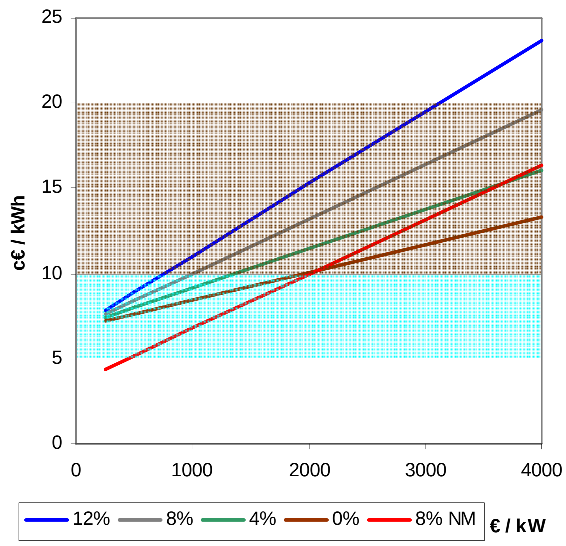

Figure 1 – Generating cost of a µCHP in function of the additional costs for electrical generation

Figure 1 compares the cost of electricity generated by a 1 kW$_e$ µCHP in function of the additional cost required for the machine compared to a boiler delivering the same heating service. The different curves correspond to different interest rates, from 0 to 12 % that have been used for performing the present worth analysis. A € 100 yearly maintenance is also considered. One case (8% NM)

corresponds to a rate of 8 % but without maintenance cost. The cost of gas for a domestic client corresponds to a Belgian situation in June 2006.
The light blue zone corresponds to the range of cost for electricity from the system. The grey zone shows the total cost of transmission and distribution. This indicates that for the most probable additional cost for such unit (estimated to be about € 2000) the role of DER considered as network replacement plays a fundamental role. Indeed if it is adequately determined, and if it leads to generator remuneration, local generation could become competitive.
Reference [1] presents previous results from EU-DEEP project that describes a "use of system" charges scheme able to make explicit the advantage that could be brought by DER generating during peak conditions (and not generating too much during off-peak situations).

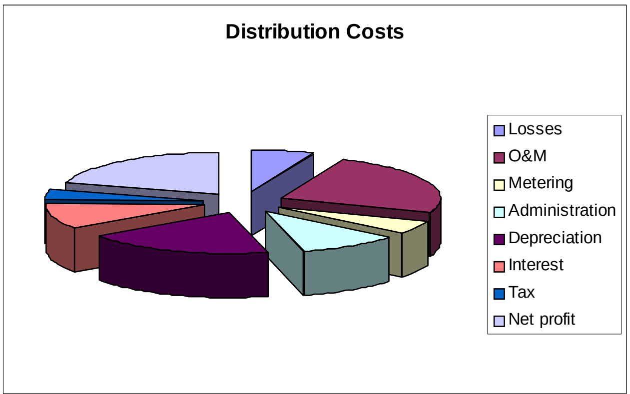

Figure 2 – Example of distribution costs

Figure 2 shows an example of decomposition of distribution costs. It indicates that decision has to be made about the part of them that could be considered for being integrated in the scheme.

CONSEQUENCES OF THE NEW REGULATION

Due to the presence of DER and for the reasons indicated just before, the regulation regime for the distribution network must be adapted. For its efficiency, it must consider separately generation and load. Similarly, incentives and use of system charges must be clearly separated (please note that it is just the opposite of what is proposed by net tariffs, for example).
A marginal approach is proposed based on a large set of "real time" measurements (interval metering) and on a downstream data treatment.
The marginal approach is well know for leading to efficient solutions, but it is worthwhile to note that equality of treatment of the customers, for example customers installed along a same feeder, does not allow to discriminate them too much (for example the one located at feeder extremity compared to the one connected directly behind distribution transformer.) A good balance between these principles must be defined.
Beyond, tariffs should be based on kW & kWh terms and even losses could be paid considering a marginal approach due to their significant impact during peak periods.
In the long run this tariff formula should lead to lower system costs following the "pressure" on generation and on consumption resulting from the Use of System charges scheme.
"Real Time" metering that is required for implementing this new regulation is all but sufficient. The capacity of DER to replace the network, to a certain extend, has limits that should be defined. The distribution system could no longer be adequate in the absence of DER.
This means that demand response is required for preserving the security of supply in certain circumstances. As an example, the reconnection of a medium voltage feeder cannot be anymore possible without demand response, considering also that in that case, the cold load pick up phenomenon is further increasing the initial loading.
The same situation could also take place during the restoration phase in post blackout conditions.
It means that "smart metering" must be completed by additional means that permit to reduce the demand during both situations that have been evoked just before.
This could evidently be made more flexible allowing for example demand response for commercial activities (in connection with the supplier of electricity) but also for a better security of supply when the system is stressed or in emergency conditions (in relation with Transmission System Operator as the responsible of system security) like the scheme proposed within the LipaEdge program in NY.
It means that a comprehensive "client – system" interface is to be recommended. This will permit the progressive implementation of such additional services. It becomes then worthwhile to examine the possibility to extend such system to automatic load shedding in case of risks of frequency or voltage collapse in the interconnected system.

ADAPTATION OF LOAD SHEDDING SCHEMES

Under frequency and under voltage load shedding are emergency countermeasures that are used to limit the consequences of deep incidents. They are most often implemented at distribution substation level and are usually based on medium voltage feeder tripping.
The presence of DER in distribution degrades the performances of load shedding schemes. Indeed the tripping of feeders in that case disconnects load and generation simultaneously. The loss of additional generation during generation shortage must be avoided. Such situation becomes more and more critical when the proportion of DER in the system increases.
In fact load shedding, traditionally based on local measurements, can be implemented locally, in the low voltage installation of domestic customers. The solutions for under frequency and under voltage situations are different and lead different questions. But one significant advantage exists for under voltage load shedding. It can become particularly effective and simple when it is implemented at the lowest possible location in the system.

Under frequency load shedding

Frequency can quite easily be measured wherever in the system. Except some local oscillations, the frequency is the same everywhere in the system and gives information about the actual balance between generation and load.
The more common application is based on a simple frequency criterion and on graded frequency thresholds.
Local implementation does not pose any problem except this gradation of thresholds. Indeed management of load shedding capacities become quite complex if the number of tripping place is large.

Under voltage load shedding

UVLS is not currently as widely implemented as UFLS. One of the main reasons of this rare implementation might be because of the higher probability of having voltage excursions outside pre-defined operational margins not leading to any risk of malfunction of the system, while frequency excursions outside pre-defined security margins are the result of critical event. Therefore, UVLS could lead to mis-tripping (i.e. trip a line while keeping it in operation would be secured). Moreover, UFLS are easier to implement as the system frequency gives a good picture of the imbalance between active power demand and active power production. On the other hand UVLS are more difficult to implement because measured voltages are not correlated to the system balance of reactive power which is highly influenced by the loading of the system. However, UVLS could be useful and could have avoided some blackouts in the past (but load-shedding schemes should be designed so as to distinguish between faults, transient voltage dips, and low voltage conditions leading to voltage collapse.)
Investigation made within EU-DEEP in connection with the detrimental incidence of DER on load shedding performances led to the test of local implementation of under voltage load shedding. It showed that the LV local voltage behavior is one of the best indicators of the system state. Using a unique voltage threshold is effective. The location of the relay will finally "decide" where to trip the load [3].

Implementation

It is worthwhile to implement this load shedding schemes using a comprehensive "client – system" interface integrating other kind of demand response.
EU-DEEP studies through one year aggregation tests the implementation of commercial demand response. The cost of this type of implementation in the field is one of the questions of these investigations.
In the future, the best option should be a comprehensive bi-directional interface integrating commercial as well as emergency control capacities:

- Commercial demand response;
- Emergency demand response ;
- And security demand response (UVLS and UFLS).

Such implementation should permit to supply electricity with different reliabilities of supply for a same site. This will also permit to operate the system more securely. Indeed in case of difficulties, it could be possible reduce the stress in the system by disconnecting some local loads while voltage is remaining on for all of the clients. This new possibility could lead to more economical operation of the system as the operational reserves could be reduced while keeping the global security of the system intact outside of demand response.

CONCLUSIONS

This paper shows with the help of 2 examples that in the present context of the Electrical Supply Industry large implementation of interval metering is required if the value of DER for the system has to be integrated in the regulation; but also that automatic meter reading is totally insufficient. A comprehensive "client – system" interface is necessary permitting to implement demand response for the system in emergency conditions. Further, based on the second example, the paper shows that new, local implementation of UF & UV load shedding are able to bring reliability advantages.
All these applications ask for "SmartGrids" concept and active management. But the benefits of active management can only be obtained with an upgraded network design. This shows once more that solving questions related to electrical system calls for holistic methodology, in this case mixing technical, market and regulatory aspects.

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