# NEW NETWORK DESIGN STANDARDS FOR THE GRID CONNECTION OF LARGE CONCENTRATIONS OF DISTRIBUTED GENERATION

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## *ABSTRACT*

*Connecting large concentrations of Distributed Generation to the distribution networks usually requires high investments in network extension. This contribution describes how Enexis used its Risk Based Asset Management approach to develop new network design standards for the grid connection of large concentrations of DG in a cost-effective way.*

## INTRODUCTION

In many West-European countries an increasing interest in Distributed Generation (DG) can be observed. In the Netherlands especially small combined heat and power (CHP) installations and wind turbines are installed. Geographical concentrations of such units require large investments to increase the capacity of the distribution network. Especially rural areas are often critical, since the distances to the main substations are relatively long and in most cases the amount of electricity that is generated is much larger than the local demand, so that the capacity of the existing grid is rather limited. Other problems are that short-circuit power limits can be exceeded, since distributed generators (DGs) usually contribute significantly to the short-circuit power and that voltage limits are exceeded.
Dutch law and legislation prescribes that DG projects less than 10 MVA can be charged only for the cost of the grid connection and not for the additional costs caused by deeper grid reinforcements. The latter ones have to be paid by be distribution system operator (DSO). Therefore, Enexis - one of the largest DSO's in the Netherlands - developed new design standards for networks with large amounts of DG.
The paper starts with describing the applied RBAM methodology [1]. Based on this methodology, the next sections of the paper describe how the risk analysis and strategy development have been performed. After comparing the effectiveness of the various strategies, new network design standards have been selected. The paper finishes with an example and concluding remarks.

## RISK-BASED ASSET MANAGEMENT (RBAM)

The methodology that is applied is based on the Risk Based Asset Management (RBAM) approach developed by Enexis [1]. This approach was certified against the well-known international PAS-55 and ISO 9001: 2000 standard in 2006.

In the RBAM-process, as depicted in figure 1, the Asset Manager's task is to identify and analyse risks that threaten the business-values of the Asset Owner. In the next step, the Asset Manager formulates different strategies in order to reduce these risks. Strategies with the highest expected yield, in terms of risk reduction per Euro spent, are selected to be implemented. After implementation, the effectiveness and efficiency of the chosen strategies are evaluated.


**Figure 1: Various steps in the RBAM-process**

For the risk analysis, a so-called 'risk matrix' is used. With the help of this matrix, the impact of a certain risk on the company values of Enexis can be determined. The company values of Enexis are: Quality of supply, Safety, Legal, Economy, Customer satisfaction and Sustainability.
The risk-matrix contains 6 risk levels: Negligible, Low, Medium, High, Very High and Unacceptable. Each risk level is determined by the product of the frequency of its occurrence and its effect.

## RISK ANALYSES

### General

The number of CHP-units that is installed in greenhouses increased substantially during the past years. As a consequence, Enexis is confronted with a huge increase in the number of requests for connecting DGs to the medium voltage (MV) distribution networks.
Partly, the grid connections can be realised in the existing MV networks, but sometimes completely new networks have to be developed, including new HV/MV substations. The rate and scale of the requests for new DG connections imply significant risks for Enexis. Also, the high penetration levels of existing DG in the MV networks increase the risks.

### Definition of risks

This section describes the main risks that are caused by the fast and surprising increase of DG.

**Vast network extensions**
Most DGs in the supply area of Enexis are CHP-units in greenhouses. The greenhouses are mostly concentrated in

rural areas, where the network capacity is limited. Since the units tend to have a capacity of several MW's each, geographical concentrations of such units require huge investments in the distribution networks. Especially rural areas are critical, since the distances to the main substations are relatively long and in most cases the amount of electricity that is generated is much larger than the local electricity demand which can result in cable overloading and/ or violation the requirements for the grid voltage.
On the contrary, the Dutch legislation prescribes that for most DG projects only the cost of the grid connection can be charged ("shallow" connection tariff [2]). Additional costs that are caused by reinforcements of the distribution networks (the so-called deep connection costs) have to be paid by be DSOs. Contrary to consumers, DGs don't have to pay a transmission tariff. So, the DSOs have to do large investments to increase the capacity of the grid while at the same time the revenues are not enough to compensate these investments. This implies a very high risk level for the company value 'Economy' (see Table 1).

Due to all network extensions that have to be done, it often takes a long time before a DG can be connected to the network. Sometimes a complete new network has to be developed. The combination of the time involved with the delivery of electrical components, the time to acquire all official permits as well as the time for construction results in a long time before a DG can have its connection. In general this time is much longer than the time the CHP-owner needs for realising his installation. Therefore, customers have to wait for their grid connection, which implies a high risk level for the company value 'Customer satisfaction' (see Table 1).

### Exceeding short-circuit capacity

Usually, DG units contribute significantly to the short-circuit power in the network. As a result the short-circuit limits of several components in the MV-network are exceeded. When a short-circuit occurs, this poses additional risks for the company values 'Quality of Supply', 'Safety' and 'Economy' (See Table 1).

| Risk | Company value | Effect | Frequency | Risk level |
|---|---|---|---|---|
| Network extensions | Economy | Serious (1-10M€) | Yearly (1-10 p.a.) | Very High |
| | Customer satisfaction | Considerable (10-100 LC) | Yearly (1-10 p.a.) | High |
| Short-circuit capacity | Quality of supply | Serious (2M-20M CML) | Regularly (0.1-1 p.a.) | High |
| | Safety | Disastrous (Multiple fatalities) | Possible (0.001-0.01 p.a.) | Medium |
| | Economy | Considerable (0.1-1M€) | Regularly (0.1-1 p.a.) | Medium |

**Table 1. Summary of risk levels (LC: Large Customer; CML: Customer Minutes Lost; p.a.: per annum)**

## STRATEGY DEVELOPMENT

Once the risk levels are identified, various solutions for mitigation of the risks can be investigated. This section gives a summary of the most important ones. They can be grouped in two categories: measures to increase income and measures to reduce costs.

### Measures to increase income

According to Dutch legislation, DGs do not pay for network reinforcements and they do not pay a transmission tariff. One way to increase the income is lobbying for changes in the legislation, in such a way that (parts of) the cost for network reinforcement can be charged to the DG.
Another option is to make use of a specific article in the Dutch Electricity law, which gives DSOs the opportunity to ask the Dutch regulator for permission to increase the tariffs to cover the costs of investments that are 'exceptional and substantial'. As the required investments for DG are exceptional as well as substantial, Enexis is convinced that it is justified to apply this article of the Electricity law towards network extension for DG.

### Measures to reduce costs

A number of measures to reduce costs have been investigated. This subsection describes only the measures that have a positive influence on the company values.

#### Reducing redundancy in DG-networks

Conventional MV networks usually have a high redundancy, either inherently during normal operation or after performing switching actions. In order to reduce costs it can be an option to develop special DG networks without or with reduced redundancy. This can be justified by the fact that in general for producers an interruption is less problematic than for consumers due to the lower added value of generated energy compared to consumed energy.
Figure 2a shows the topology of a conventional MV-network, consisting of the distribution part (MV-D), the transmission part (MV-T) and the HV/MV transformer. The distribution part (MV-D), in figure 2a, has a ring structure, but is operated radially. In case of a failure, the fault is cleared automatically by protection devices, but the isolation of the faulted section and the restoration of the supply should be done manually; it is redundant after one or more switching events. Each disturbance in this part of the system will cause an interruption. The transmission part (MV-T) is inherently N-1 secure. When a fault occurs in one of the cables, it is automatically disconnected by protection devices, while the remaining cables are able to continue the supply. Each HV/MV substation has one spare transformer that can be used when the neighbouring transformer fails or is out of operation for inspection and/or maintenance. For each of the three parts, it was investigated whether or not they should be made redundant.

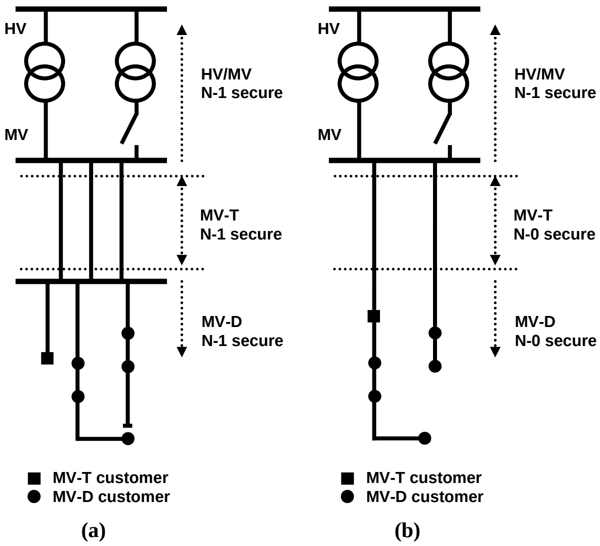


**Figure 2. Topologies of MV-networks; conventional network (a); network only for DG (b)**

Reducing redundancy will reduce investments on one hand, but will result in higher exploitation costs on the other hand. For the company value 'Sustainability' less redundancy means that less material is needed, but also that higher losses may be expected. In order to be able to make a comparison, a fictive but representative MV network has been developed. For this network several alternatives with different levels of redundancy have been investigated and for each of them required investments, exploitation costs and the overall impact on the various company values have been determined. From this thorough analysis it became clear that the best solution for DG networks is the topology as shown in figure 2b. In this topology no transmission parts and no MV/MV substations are applied. DG customers are directly connected to long distribution feeders from the main HV/MV substation.

Of course, several company values are affected by this new topology, namely:

- *Economy*: The new topology results in considerable lower investment costs and an increase in the cost of network losses. The net effect is positive, however.
- *Sustainability*: The costs for sustainability will increase due to the higher network losses. This is partly compensated because less material is needed.
- *Quality of Supply*: The availability and reliability of the network decrease slightly, but remain still at an acceptable level.
- *Legal*: There is no legal obligation to design or operate MV networks with redundancy and therefore this company value is not affected.
- *Customer satisfaction*: When on beforehand a clear explanation is given to the customers involved, the negative effect will be limited.

## Applying higher voltage levels in DG networks

When network extensions are necessary, or complete new networks are developed, mostly the voltage level of existing networks is chosen (for Enexis 10kV). Introducing another voltage level has serious consequences for design standards and reduces the flexibility of network operation as well.

However, for DG networks higher voltage levels are a good option, especially in the case of complete new networks. Application of a higher voltage level implies that fewer cables are required and simultaneously network losses are reduced. Further, there will be less problems with voltage profiles and violations of short-circuit power limits.

Several voltage levels have been investigated. Application of 20kV appeared to be the most attractive option. The impacts on the company values are as follows:

- *Economy*: Investment and operational costs reduce significantly.
- *Sustainability*: Use of less material as well as lower losses have a positive influence on sustainability.
- *Customer satisfaction*: Possibly the customer needs an additional 20kV/10kV transformer. When this is made clear on beforehand, no serious negative effects are expected.

## Measures to reduce short-circuit power

The two most important measures to avoid provisionally existing short-circuit power problems are: applying Is-limiters and using the spare transformer in the HV/MV substations.

In order to reduce the short-circuit power contribution of a specific DG, a so-called Is-limiter can be used. This device is based on a fuse and its main advantage is that it reduces the contribution to the short-circuit power significantly. Is-limiters have some disadvantages, however, like high replacement costs of the fuses and the possibility of unnecessary (unselective) trips

Using Is-limiters, necessary investments in the network can postponed, and therefore this measure is still investigated. The impacts on the company values are:

- *Economy*: About 8% of the total investments that are required for the DG networks can be avoided when Is-limiters are used.
- *Safety*: Application of the Is-limiters improves safety.
- *Legal*: According to Dutch legislation DSOs are allowed to require measures to reduce the short-circuit contribution and therefore, this company value is not affected.
- *Customer satisfaction*. The Is-limiter should be placed on the site of the customers, who also should pay for it. Besides that, the number of supply interruptions will increase. Therefore, the negative influence on the company value customer satisfaction is serious.

Another option is to use the spare transformer in the HV/MV substations and to distribute the DG customers over both transformers via the duplicate MV busbar schemes in the main substations. Major problems occur however when the spare transformer is needed in case of a failure or during maintenance. Probably a part of the DGs has then to be disconnected. The impacts on the company values are:

- *Economy*: Using the spare transformer postpones additional investments.
- *Safety*: It significantly improves the safety in cases where the present short-circuit limits are violated.
- *Customer satisfaction*: It might be necessary to disconnect DG customers in some cases. This certainly have negative consequences for this company value.

**Summary**

Several solutions have been described in the previous sub-sections. Finally, it has been determined how much each solution saves on the total annual costs. The results are shown in Table 2. All values are given as percentages of the total risk level. The total risk level is determined by expressing the risk levels for all company values in euros. The first row in the table shows how much each business value contributes to the total current risk level (as a percentage of the total risk level, which is set as 100%). In the other rows, for each of the solutions, it is shown how much it reduces or increases the risk levels of all company values and the total risk level. A negative value means a reduction in the risk level and thus lower investments.
From the table it can be seen that the measures to increase income are by far the most effective, followed by applying higher voltage levels and reduction of the redundancy.

| | Safety | Quality of supply | Legal | Economy | Customer satisfaction | Sustainability | Total |
|---|---|---|---|---|---|---|---|
| Current risk level | 1 | 1 | 0 | 86 | 1 | 11 | 100 |
| ***Solutions*** | | | | | | | |
| Increasing income | 0 | 0 | 0 | -76 | 0 | 0 | -76 |
| Less redundancy | 0 | 0 | 0 | -10 | 0 | 4 | -6 |
| Higher voltages | 0 | 0 | 0 | -11 | 0 | -5 | -16 |
| Is-limiters | 0 | 0 | 0 | -8 | 7 | 0 | -1 |
| Spare transformers | 0 | -1 | 0 | 0 | 0 | 0 | -1 |

**Table 2. Summary of risk reductions (all values in % of the total current risk level)**

## IMPLEMENTATION: NEW NETWORK DESIGN STANDARDS (EXAMPLE)

In the previous section, the most effective strategies were presented. Based on these strategies new network design guidelines for networks with large concentrations of DG have been selected and implemented. The following example illustrates the essentials.
In several rural areas in the neighbourhood of the city of Helmond, in the south-eastern part of the Netherlands, many greenhouses with CHP-plants are built. The minimum and maximum amounts of installed power that will be realised, together with the distance to the nearest 150kV substation in Helmond are shown in figure 3. As complete new networks have to be developed and the distances are long, the new network design standards are applied in this region for the first time. Thus the network, which is under construction at this moment, is a 20kV network, with a layout shown in figure 2b, i.e. without redundancy. Applying the new network design standards saves more than 50% compared to a conventional 10kV topology.


**Figure 3. Areas with CHP-plants in the neighbourhood of Helmond (picture courtesy of Google Maps)**

## CONCLUSION

The RBAM approach appeared to be a valuable methodology to develop new design guidelines for DG networks, resulting into considerable expenditure savings without compromising company values. It was decided to introduce new (higher) medium voltage levels for typical DG areas, a lower degree of redundancy in networks for DG areas and new solutions to reduce provisionally the short-circuit power. The paper illustrated the main results of the RBAM approach by means of a real case of a rural region in the south-eastern part of the Netherlands.

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