COST-EFFICIENT INTEGRATION OF DISTRIBUTED GENERATION INTO MEDIUM VOLTAGE NETWORKS BY OPTIMIZED NETWORK PLANNING

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ABSTRACT

In this contribution, a method for evaluating and minimizing network related costs for distributed generation in an objective manner is presented.
The network optimization tools used provides functionality to realize long-term cost-efficient integration of distributed generation. Besides, short-term measures for connecting distributed generation to an existing network with minimum financial effort can be determined as well.
To evaluate costs related to distributed generation, minimal costs for networks with integrated distributed generation are calculated and compared in two steps. In the first step, cost-efficient networks for a given supply area with distributed generation are determined in a green-field approach, neglecting existing assets. In the second step, costs for stranded investments–e.g. existing overhead lines or cables that are not used in cost-efficient networks that have been calculated beforehand–are considered during optimization as well.
In this contribution, an exemplary rural supply area is considered for presenting the functionality of the method. Stranded costs due to the integration of distributed generation into medium voltage networks are discussed.

BACKGROUND

Traditional grids are based on large central power stations connected to extra high voltage and high voltage networks, which in turn supply power to medium and low voltage local distribution systems. The idea of SmartGrids includes the use of distributed generation connected to distribution networks according to the increasing use of renewable energy sources. In contrast to the traditional unidirectional power flows, this may cause bi-directional power flows in the system. This leads to new challenges for planning and operation of electricity distribution networks.

Due to European and German national energy laws on renewable energy, the total installed capacity of distributed generation (DG) has increased rapidly in the last years in Germany. Till the end of 2010 the total capacity of onshore wind energy is expected to be about 24.5 GW [1]. A large share of DG is connected to medium voltage (MV) distribution systems. Due to this, wind energy generation already exceeds the load in some rural regions of Germany. Thus distribution networks must be adapted adequately.

In recent years, computer-based optimization tools for calculating cost-efficient network structures with respect to technical boundary conditions have been developed. In this contribution, it is demonstrated how those methods may be used for improving network planning and quantifying costs that are required for integrating DG into medium voltage networks. Especially stranded costs related to integration of DG are evaluated. Such costs are caused by assets that are no longer required after restructuring the network due to DG.

COMPUTER-BASED LONG-TERM PLANNING OF MV NETWORKS

Long-term planning of MV distribution networks is usually based on a green field approach, with a planning horizon of a long period of several decades. Thus existing assets and their age structure can be widely neglected in the planning process.

By varying boundary conditions of network planning in a systematic manner, the impact of planning constraints on network structure and costs can be quantified. Based on this, impartial conclusions about the influence of DG on distribution network costs can be drawn.

Network planning is carried out with respect to geographic constraints such as substation positions and useable routes. Besides, technical constraints must be fulfilled. Feed-in and load of network customers, maximum equipment load in normal and faulty operation, admissible voltage limits and the short-circuit currents are to be considered. With DG, the voltage rising effect has an important impact on the optimal networks. Besides the European standard EN 50160 on voltage quality there are additional national standards for the integration of DG, such as “guidelines for the connection of distributed generation in distribution systems” in Germany. In this guideline, the difference of voltages with and without feed-in of DG at the point of connection is limited to 2% [2]. Particularly in long MV feeders, this cannot be assured and thus a reduction of the feeder length is necessary. This leads to an increase of total line length and the number of switchgears. In order to guarantee an adequate reliability, the (n–1)-criterion should be applied. A restoration of supply should be possible via switching or emergency supply in case of any failure.

The objective of network planning is to minimize the sum of capital investment and annual operating costs of equipment as well as annual costs of power losses. Capital investment costs are traversed into annual costs with the annuity method to enable a comparison of costs of alternative projects.

In this contribution, a computer based tool for planning distribution systems with DG is used [3]. It is based on an efficient two-stage heuristic method which is capable of considering all relevant geographical and technical constraints. In a first step, an initial solution is generated with an algorithm originally developed for the vehicle routing problem. Afterwards, the initial solution is improved iteratively with a method based on large neighbourhood search algorithms. A schema of this method is shown in figure 1.

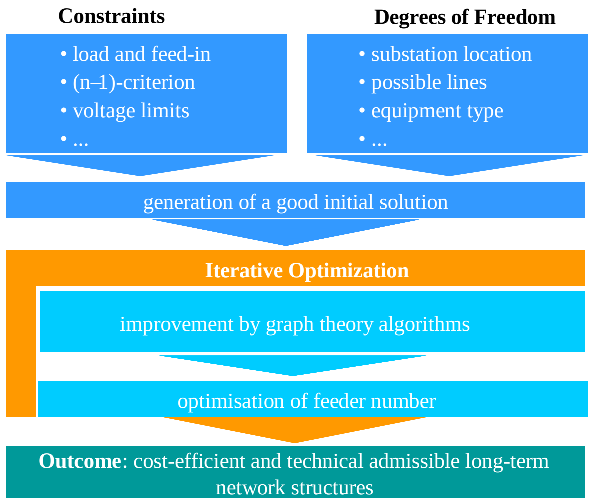


Figure 1Computer-based network planning

QUANTIFYING COSTS RELATED TO DISTRIBUTED GENERATION

The methodology for quantifying costs for DG is based on optimal network planning. The associated evaluation approach can be divided into two steps.

In the first step, optimal networks are planned based on a green field approach for different DG scenarios to evaluate cost influences. The resulting optimal networks are compared to identify additional costs caused by DG in the long-run.
In the second step, additional costs caused by integration of DG into an existing network structure are evaluated. For this evaluation, cost-minimal networks are developed for the same DG scenarios as in the first step. In contrast to the first step, existing assets are now considered during network optimization as well. For this, investment costs for existing assets are neglected so that existing assets are preferably used during optimization.

For all optimal networks, stranded investments are calculated by annuity costs of existing assets that are not used in the target networks with DG. Those stranded investments have to be considered as part of the costs for a complete evaluation of the cost-influences of DG.

Finally, the method allows a complete evaluation of all relevant expenditures due to DG.

EXEMPLARY RESULTS

In the following, exemplary results for the rural supply area are presented.

Figure 2 shows the optimal cost-efficient network structure for the supply area without DG. This network is assumed to be the existing network structure in this area for the following evaluations.

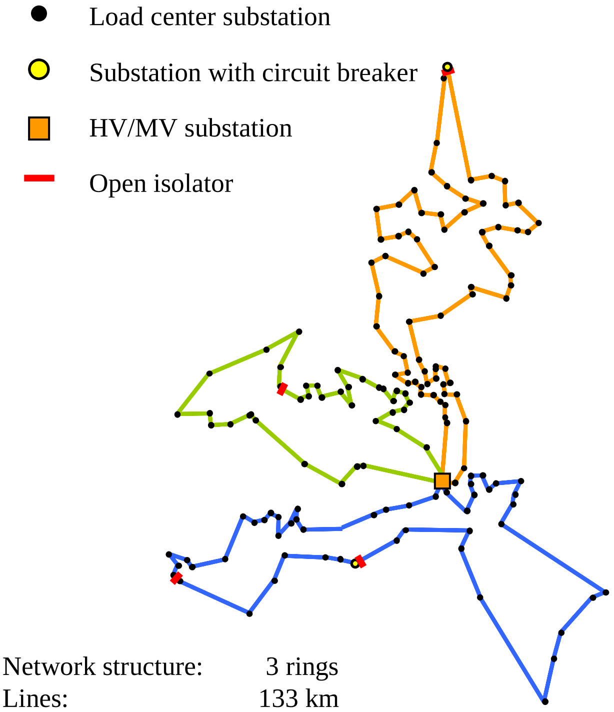
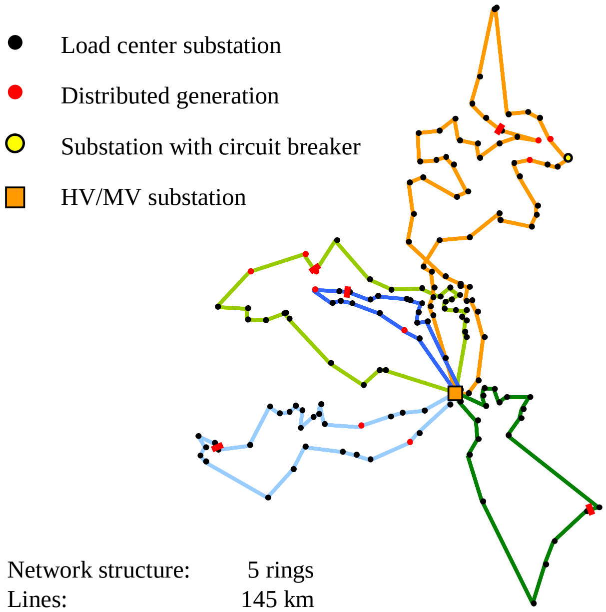


Figure 2Supply area and existing network

The area is supplied via a ring-operated network with a total line length of 133 km. Three normally opened rings are required for supplying the load of all network costumers without violating technical constraints.

The optimal long-term network structure based on a green-field planning approach and 18 MW installed DG is shown in figure 3. According to green-field planning, existing assets have not been considered during network planning.

Two more rings are required to integrate DG and to fulfil all technical constraints. The optimal network structure consists of 145 km lines of which 114 km are already used in the existing network. 19 km of the existing lines remain unused and thus are stranded investments.

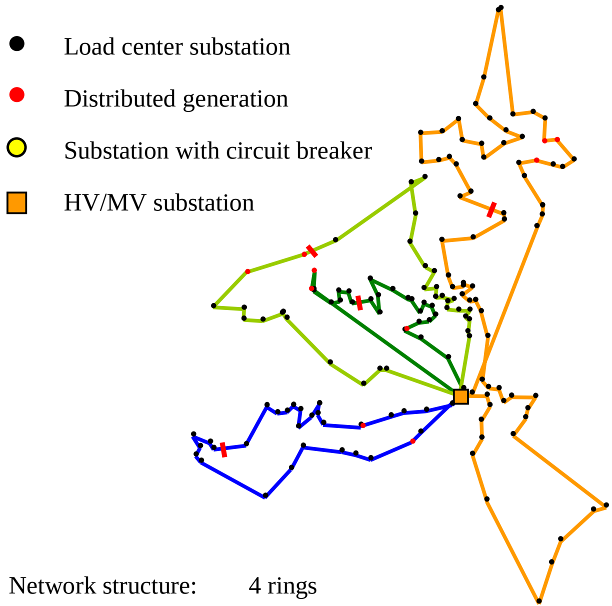


Network structure:	5 rings
Lines:	145 km
Used existing lines:	114 km
Additional lines:	31 km
Unused existing lines:	19 km

Figure 3Cost-minimal network with 18 MW distributed generation (green-field approach)

Obviously, the cost-minimal network for the supply area with 18 MW installed DG differs significantly from the existing network structure.

Furthermore, an optimal network calculated with respect to existing assets and 18 MW DG differs from both alternatives discussed beforehand. Figure 4 shows the corresponding target network. In comparison to the optimal network from figure 3, the number of rings is reduced from 5 to 4, but the total line length increases to 149 km which are 4 km more than in the green-field approach. 125 km of lines are used in the existing network as well so that only 8 km of existing lines remain unused. Thus, stranded costs of the network from figure 4 are reduced compared to green field planning.



Network structure:	4 rings
Lines:	149 km
Used existing lines:	125 km
Additional lines:	24 km
Unused existing lines:	8 km

Figure 4Cost-minimal network with 18 MW distributed generation (considering existing assets)

Figure 5 shows the annuity network costs for the existing network and for cost-minimal networks for two DG scenarios. Network costs consist of investment and maintenance costs as well as costs of losses respectively.

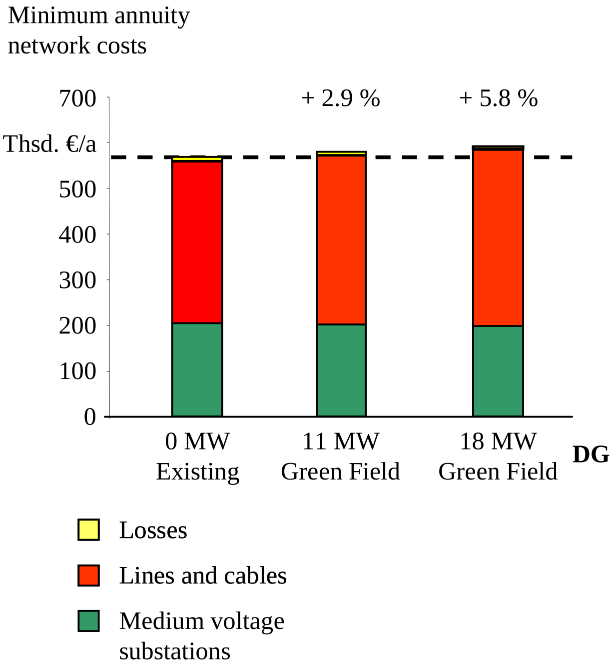


Figure 5Minimum network costs for two scenarios with different amounts of DG (green-field approach without stranded costs)

Besides the scenario with 18 MW DG, an additional scenario with 11 MW installed DG capacity is considered to evaluate cost influences of DG.

Figure 5 illustrates that the integration of DG in the long-run causes network related costs to increase depending on the amount of DG installed. Additionally in figure 6, network related costs for the optimal networks with respect to costs for stranded investments are compared.

Annuity costs of the existing network structure without DG are less than network costs in other scenarios. Thus DG leads to additional costs even in case of optimal long-term planning.

Integration of DG into existing networks leads to additional costs of up to 12 % compared to the existing network. The green field approach cannot be applied in this case, since stranded investments cause a large fraction of the additional costs related to DG.

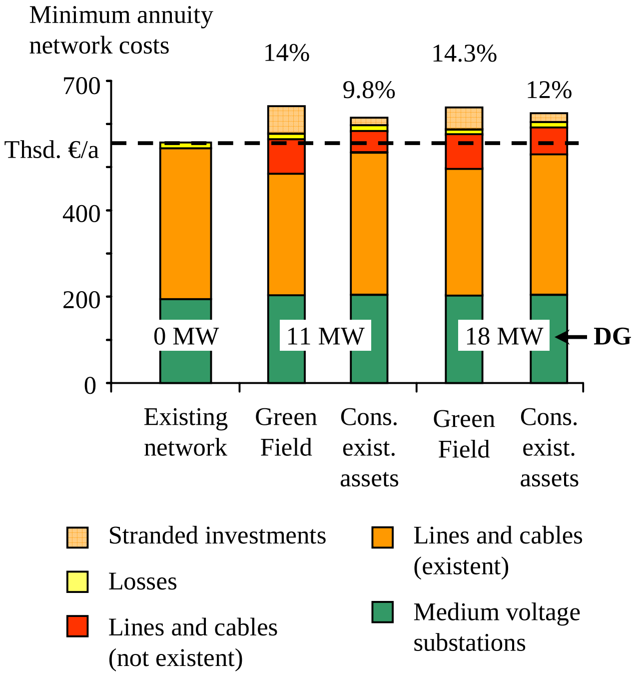


Figure 6Minimum network costs for scenarios with different amount of DG (including stranded costs)

Obviously, the consideration of existing assets during network planning avoids stranded investments. This reduces the additional costs for DG. Nevertheless, DG still leads to 10% to 12% of additional expenditures in this exemplary supply area.

SUMMARY

The idea of SmartGrids includes the use of distributed generation connected to distribution networks according to increasing use of renewable energy sources. This leads to new challenges of planning and operation of distribution networks.

This article presents a methodology based on computer-based network planning for quantifying expenditures caused by DG.

Besides a pure comparison of networks planned with and without DG, the existing network structure can be considered during network planning. This enables evaluation and minimization of stranded costs resulting from existing assets becoming unnecessary in optimal networks after integration of DG.

The functionality of the method is shown on the basis of a rural supply area. The results prove that the integration of distributed generation leads to significant additional expenditures and that the consideration of existing assets during network planning reduces the negative cost influence. However, those costs strongly depend on individual characteristics of the supply area and thus need to be quantified for every particular case.

REFERENCES

[1] Deutsche-Energie-Agentur, 2005, "Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020"

[2] VDEW, 1998, "Eigenerzeugungsanlagen am Mittelspannungsnetz, Richtlinie für Anschluss und Parallelbetrieb von Eigenerzeugungsanlagen am Mittelspannungsnetz"

[3] X. Tao, 2006, "Optimal Planning of Distribution Systems with Distributed Generation", *Proceedings of the CRIS Workshop 2006*
CRIS Workshop - Influence of Distributed and Renewable Generation on Power System Security, 185–189