MV-NETWORK-CONNECTION OF DISPERSED GENERATION: NETWORK REINFORCEMENTS VS. OPTIMISED OPERATION

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SUMMARY

Dispersed generation (DG) from units generating a few megawatts is an ongoing trend in many countries. In Germany mostly wind energy converters (WEC) and co-generation units (CHP) are installed. Many of the DG are connected to the medium voltage distribution network. This may adversely affect the operation of these networks as well as the quality of supply. Occurring problems can be solved either by investments (new lines etc.) or by optimising the operation of networks and DG together. Today the second way is more desirable because it helps increasing the utilisation of existing assets.

INTRODUCTION

Dispersed generation (DG) is an ongoing trend in many countries, in Germany mostly wind energy converters (WEC) and co-generation units (CHP) are installed. The total capacity of small CHP reaches 1300 MW in 1998 and will continue growing, the total WEC-capacity exceeds 2400 MW in 1998. Many of those units are connected to the medium voltage distribution network which affects network operation and the quality of supply. The traditional way of planning DG-network connections mostly refers to simple rules, covering the "standard"-case. In case these rules indicate that the network capacity is exceeded or the quality of supply is affected by new connections, investments in new lines etc. have to be done.

The alternative way is the optimisation of the operation of networks and DG together, aiming at an increasing utilisation. Both ways have their pros and cons. RWE Energie decided to focus at first on methods for optimising existing networks and, thus, increase the utilisation of their assets. During the ongoing co-operation with Aachen University of Technology a planning- and optimisation tool was developed in order to handle the new planning task.

ORGANIZATIONAL FRAME IN GERMANY

In case many DG are installed in a certain area the new connection lines grow up to DG-networks which are separately operated from the supply grids. This makes planning easier as the quality of supply is not affected at all and the traditional planning methods can be used.

In case the total DG-power in a certain area is not large enough to justify separate networks they have to be connected to the supply grid. In rural areas with low load-density this often causes problems especially in terms of voltage quality (steady state, less important are fast fluctuations) as they are typically supplied with MV-networks with long branches. Reinforcements are then necessary and increase the network-costs. Therefore, it is desirable to reduce extensions as much as possible.

Another item has do be added here: The main limiting factor in connection of DG is the steady state voltage and the current carrying capacity of the equipment. Principally DG lead to opposite load-flow-direction than load does when connected to the same network, which also helps reducing network losses, if DG does not exceed load significantly. But: Steady state voltage is not improved in case the DG is not dispatchable (which is the normal case for CHP and WEC), because it may feed into the grid also in low-load-situations and thus increase the difference between minimum and maximum voltage at every node in the branch they are connected to (voltage bands). This leads to the situation, that DG compete with load-customers for transmission-capacity in terms of steady state voltage. In case methods are developed which allow increasing connection of DG by optimising the operation in a way that voltage bands are decreased, these methods can also be used for increasing the connection of additional customers and, thus, decrease grid costs.

DG-CONNECTION IN MV-NETWORKS

Constraints

DG-connections to MV-networks have to be in line with a number of technical and quality-related constraints. The respective guideline in Germany [1] comprises technical performance of DG (e.g. protection system), operational constraints (e.g. synchronising) and how to select the connection point. Planning the connection point requires consideration of network capacity (current carrying capacity, steady state voltage), voltage quality (flicker, dips, harmonics) and other requirements (short circuit current, AF remote control). Nevertheless, the experience shows that due to the development of new types of DG with better dynamic performance (especially WEC) only the network capacity is the limiting factor in most cases, in rural networks usually steady state voltage.

In MV-networks the requirements on steady state voltage are mostly set by the LV-customers supplied via this grid, because the MV/LV-transformers usually don't have a voltage controller, the tap-changers have to remain in the same position all year long. There is normally no detailed information about the voltage drops between the MV/LV-station and all LV-customers. In this study it is estimated to a maximum of 5% at peak load. The MV/LV-transformer itself usually does not exceed 2.5% voltage drop. Following the LV-customers requirements of $230V^{+6\%}_{-10\%}$ [2] this means, that on every MV-node a variance of roughly 8.5% (1) between minimum and maximum supply voltage U_v must not be exceeded. (2) gives the example of a node where the MV/LV-transformer is stepped into the 20/0.4-position.

$$U_v \begin{cases} < U_n + 6\% \\ > U_n - 10\% + 5\% + 2{,}5\% \end{cases} \quad (1)$$

$$U_v \begin{cases} < 20kV + 6\% \quad = 21{,}2kV \\ > 20kV - 2{,}5\% = 19{,}5kV \end{cases} \quad (2)$$

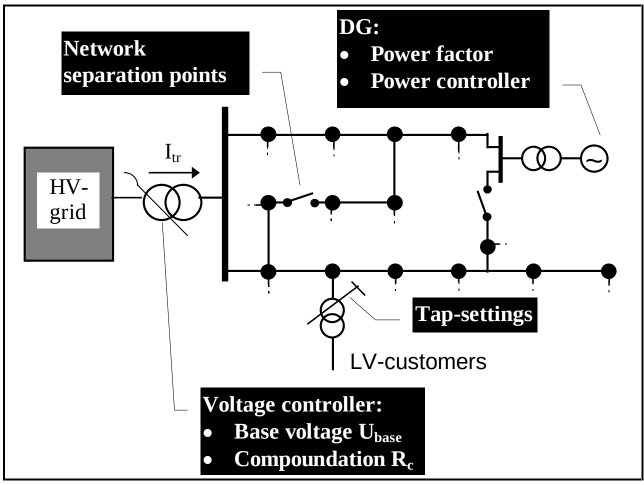
The best way to estimate the utilisation of these admissible ranges on every node is the performing of load-flow calculations for peak load without DG-injection and low load with full DG-injection. It should not be neglected that the voltage controller at the HV/MV-transformer acts discretely with an adequacy of a few percent. In order to avoid load-flow calculations the guideline [1] suggests to assume, that 2% voltage increase is admissible in every node of the network and gives an equation to (roughly) estimate the influence of DG.

Even though the respective norms [2] don't give any clear definition it has to be assumed that the supply voltage must never be totally out of range under abnormal conditions (maintenance, restoration). In this investigation the exemplary assumption was made to avoid voltage levels U'_v above 230V+6% and below 230V-15% under abnormal situations (e.g. in (n-1)-situations) (3). It has to be remarked here that depending on the network this condition can be a lot more restrictive than keeping the voltage range under normal conditions.

$$U'_v \begin{cases} < U_n + 6\% \\ > U_n - 15\% + 5\% + 2{,}5\% \end{cases} \quad (3)$$

The current carrying capacity of the equipment is the second major constraint for DG-connections. First the load factor has to be analysed, it depends on the DG-scheduling and is 100% in case a 24-h-full production period may occur (which is true for WEC also in non coastal regions of Germany). Furthermore, (n-1)-situations may occur where DG have to be disconnected in order to avoid overloading. This can be done manually on the spot, by remote control or automatically by voltage control.

Operational Degrees of Freedom



Degrees of freedom for the optimisation of MV-network-operation

The performance of the MV-network and the directly connected LV-networks can be improved with a number of degrees of freedom as depicted above [3]. They have mostly influence on the steady state voltage but some of them may also be used for reducing line currents in critical situations.

Usually MV-networks in Germany are built in different types of meshed structures with short branches supplying 1-3 nodes without structural redundancy on the MV-side. They are operated as open branches which gives the network separation points an important role for balancing voltage bands and reducing losses in normal configuration. Of course temporary reconfigurations for maintenance or after failures may occur at any time, in those situations the separation points are moved in order to again achieve the optimal performance. In case DG are connected to the network the optimal separation points may change.

The setpoint of the HV/MV-voltage controller U_{base} together with the settings of the MV/LV-tap changers has significant influence on the steady state voltage because it determines the position (not the extension!) of the voltage bands on the LV-side resulting from the variations of the load-flow. In contrary to this the compoundation R_c and the power factor cosφ determine the extension of the voltage bands: Compoundation helps decreasing the voltage variations on the long ends of branches but increases variations at the beginning. In case DG-power exceeds the minimum load the compoundation should be able to detect the direction of the load-flow, otherwise the reaction to a strong load-flow from the MV- to the HV-side would be an undesirable voltage-increase. The power factor on the DG can be used for reducing voltage increase, its impact on network losses – especially in cable networks – and line currents is usually of minor importance, if it is not lower than 0.9_{cap} [4].

The power controller of DG can be used for handling abnormal conditions like line-failures or maintenance actions: In case the DG is temporarily switched into the long end of a branch it will cause a large voltage increase which can be detected by a local controller and be used as a signal to reduce the power output and thus voltage. This type of controller is installed in a number of WEC in Germany and has proven its capability to avoid manual disconnection.

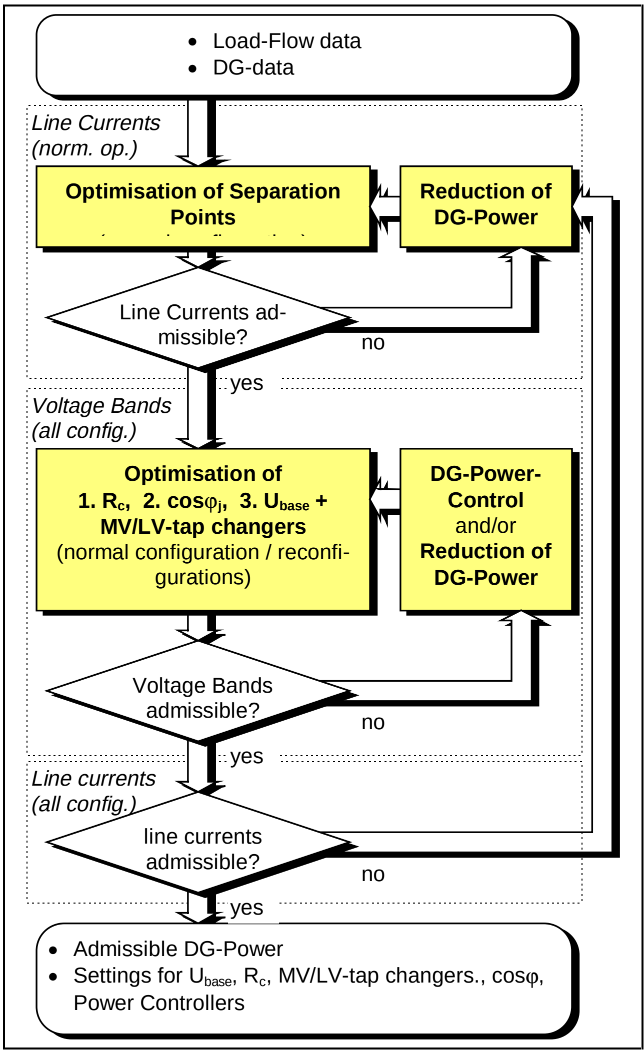
NEW PLANNING METHOD

The new planning method aims at optimising the degrees of freedom in network operation under consideration of all constraints mentioned above. The idea is to predetermine the structure of the network including the existing and planned load and DG connections and to evaluate whether or not the structure is able to fulfil the requirements all year long. In case no admissible solution is found the planner may reduce DG-power or introduce network extensions. Those extensions depend highly on the local conditions, so the decision here was not to integrate them in the optimisation tool. The degrees of freedom all refer to existing equipment, so investment costs are not integrated in the optimisation.

The method suggested here is divided into three steps, each of them supported by the tool developed for this purpose. This tool automatically performs load-flow calculations for all relevant states. These states are first of all the load-states: peak load without DG-power injection, low load with full DG-power injection and intermediate states. Intermediate states have to be used when compoundation is activated. Furthermore, either only normal configuration is calculated or the full (n-1)-analysis for all load-states can be performed alternatively. In addition the tools provides optimisation-functions for each single degree of freedom mentioned above, again under consideration of all states as desired.

In the first step only line currents in normal operation are analysed. For this purpose the network separation points are optimised. They are not touched by the remaining steps and, thus, can be finally determined in this first step. In case the line currents are inadmissible the DG-power (or additional load respectively) can not be connected as desired.

In the second step the steady state voltage is analysed. First compoundation R_c and power factor cosφ are optimised, because they have major influence on the extension of the voltage bands. Objective function in this step is to minimise the largest voltage band in the network. The optimisation can be interrupted, when all bands are small enough to fulfill the requirements (e.g. to be smaller than 8.5% as explained above). It is recommended to consider only normal configuration here, the consideration of all (n-1)-situations is possible but may lead to extreme settings of R_c and cosφ. The subsequent optimisation of base voltage U_{base} and the settings of the MV/LV-tap changers shifts the voltage bands in the position according to equations (2) and (3). The objective function in this step is to minimise network losses. In case no admissible solution is found the DG can be equipped with automatic power controllers or its power has to be reduced. During the optimisation it is taken into account that the voltage controller does not act discretely.



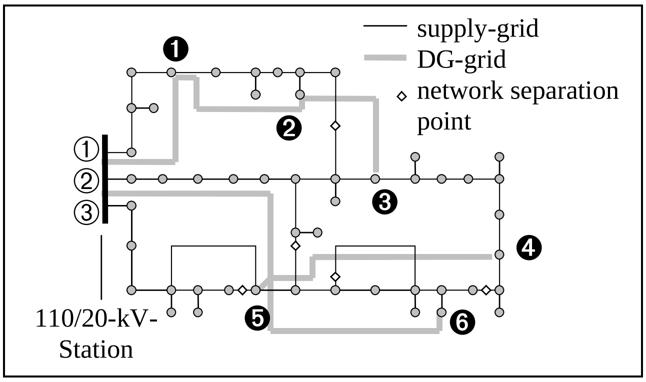
Method for the optimisation of MV-network-operation [5]

In the third step the (n-1)-analysis is performed with regard to line currents. R_c, cosφ, U_{base} and tap-settings don´t have significant influence in this step but automatic power controller has. Nevertheless, the analysis of several networks has shown, that in case of DG-connection the automatic power controller has to be used in many cases. This voltage-dependent power output limitation usually acts in (n-1)-

cases, when DG are temporarily switched to long ends of branches or as a second case several DG, which are usually connected to different branches are switched together. In this second case line currents are especially critical but as voltage will practically always be also too high the power controller reduces the output to an amount which is usually also tolerable with regard to line currents.

EXAMPLE

The aim of introducing the new planning method is to connect DG or additional customers to the already existing supply grid in situations where otherwise network extension would be necessary. The example of the network below depicts the planning task of connecting 18.5 MW DG in 6 locations. The traditional way is to erect a separate DG-network as the drawing shows (grey lines).



Sample network (peak load 5,2 MVA) with 3 branches with a length of up to 25 km and 6 DG-installations under construction

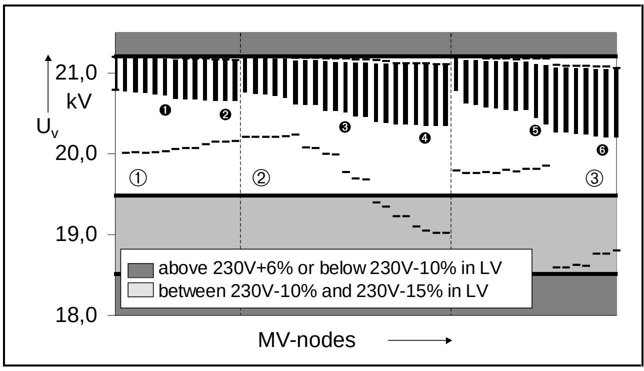
In this rural area considerable long cables have to be installed, summing up to a total investment of 3.5 Mio. DM (see table). The direct connection to the supply network can be erected for only 560 000 DM. The question is whether it is possible to connect 18.5 MW to the existing grid without further extension only by adjusting the existing degrees of freedom.

The analysis of the initial situation without DG is depicted above. The MV-nodes of the three branches ① to ③ are arranged according to their position in the branch, starting at the HV/MV-station. For every node the minimum and maximum expected voltage U_v during the year are indicated by the vertical extension of the bars. Furthermore, the small strokes above and below the bars indicate the extreme values U'_v which may occur, in case the worst (n-1)-situation has to be handled during peak load (lower value) or minimum load respectively (upper value).

The restriction in this network arises from the requirement to handle (n-1)-situations at the end of branch ③, where the voltage may go down to values of 18.6 kV, which is a result of the length of the branches and the low meshed structure typical for rural areas. For this reason the base voltage is set to 21 kV, a lower value would shift the U'_v-values into the inadmissible range below 230V-15% on the LV-side. With regard to steady state voltage no significant DG-connection is possible here, because any significant power injection on one of the nodes ❶ to ❻ would increase the voltage bands above the upper limit.

Financial calculation of the two alternatives

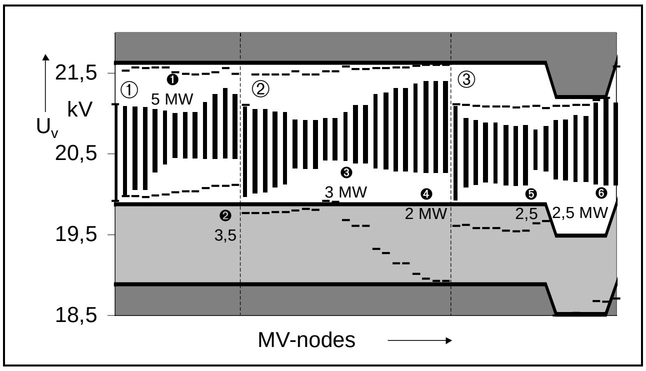
Connection in separate DG-network		
length of connection		
	HV/MV – ❶	4500 m
	❶ – ❷	6100 m
	❷ – ❸	1800 m
	HV/MV – ❺	4800 m
	❺ – ❹	6600 m
	❺ – ❻	9000 m
Σ length		32800 m
average costs for cable installation		100 DM/m
reinforcement in HV/MV-station		200000 DM
Σ costs		3.5 Mio. DM
costs per kW (18.5 MW)		190 DM/kW
Connection in supply-network		
Σ costs		560000 DM
costs per kW (18.5 MW)		30 DM/kW



Voltage bands in initial state

The optimisation of R_c, cosφ, U_{base} and tap-changers and the additional equipment of all DG with power controllers allows handling even the connection of 18.5 MW DG-power to this network in normal operation and in (n-1)-situations. The compoundation strongly decreases the extension of the voltage bands in (n-1)-situations but the extension of the voltage bands in normal operation increases above the upper limit. Therefore the base voltage has to be reduced to 20.6 kV and most of the tap-changers have to be switched to the position (20 kV + 2%)/0.4 kV.

The power controllers of the DG reduce the admissible voltage on the nodes ❶ to ❹ to 21.6 kV and on the nodes ❺ and ❻ to 21.2 kV without DG-disconnection in case of unfavourable (n-1)-situations. Without these devices extreme values of 23 kV would be reached. In normal operation DG-power must not be reduced. The line currents just don't exceed their maximum admissible value in normal operation. In the worst (n-1)-situation they go up to 140% on some lines, which is eventually tolerated for a few hours in case of cables with a high thermal capacity.



Voltage bands with DG after optimisation:
U_{base} = 20,6 kV, R_c = 1 Ω

CONCLUSION

Dispersed generation units are often connected to the medium voltage distribution network. At the same time many network operators intend to increase the utilisation of their assets and avoid further investments. Therefore, the installation of new lines or networks for the DG-connection should be avoided if possible. The alternative way is to increase the capacity of the supply network by optimising the network separation points, the settings of the voltage controller at the HV/MV-station, the MV/LV-tap-changers, the DG-power factors and by introducing automatic power controllers on the DG, which reduce the power output in case the voltage exceeds a certain value. These degrees of freedom have little influence on the maximum line currents but - more important in rural areas - on the steady state voltage, which is often the most violated constraint.

During the ongoing co-operation between RWE Energie and Aachen, University of Technology a planning tool was developed to assist the planner. The procedure suggested here consists of three steps: first optimising the network separation points only with regard to line currents, afterwards optimising the settings of the HV/MV-voltage-controller and the MV/LV-tap-changers together with the power factor of the DG, and finally the (n-1)-analysis with regard to line currents. It is important to notice that the optimisation must consider all load-states in one step, which may lead to extreme voltage-values on any of the nodes. These are low load in combination with maximum DG-injection, peak load without DG-injection and some intermediate states in case compoundation is activated. The tool supports this procedure in a way that the total analysis can be performed in a few minutes.

The case study shows that the inherent reserve in supply networks is bigger than expected, the installation of a separate DG-network can be avoided if the capacity of DG is not higher than the admissible line currents allow. It is usually not necessary to have an (n-1)-secure network from the DGs' point of view. In many cases the installation of automatic power controllers which are available today guarantee automatic disconnection or power reduction in (n-1)-situations to avoid inadmissible voltage increase and line overloading. The same procedure will also help avoiding or delaying network extensions in case new customers have to be connected.

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