INCREASING THE PHOTOVOLTAIC-SYSTEM HOSTING CAPACITY OF LOW VOLTAGE DISTRIBUTION NETWORKS

Thomas DEGNER
Fraunhofer IWES – Germany
thomas.degner@iwes.fraunhofer.de

Gunter ARNOLD
Fraunhofer IWES – Germany
gunter.arnold@iwes.fraunhofer.de

Thorsten REIMANN
Fraunhofer IWES – Germany
thorsten.reimann@iwes.fraunhofer.de

Bernd ENGEL
SMA Solar Technology AG – Germany
bernd.engel@sma.de

Michael BREEDE
SMA Solar Technology AG – Germany
michael.breede@sma.de

Philipp STRAUSS
Fraunhofer IWES and DERlab e.V.
philipp.strauss@der-lab.net

ABSTRACT

This paper shows how the voltage raise caused by distributed power generation in the low voltage network depends on the network characteristic parameters. The maximum permissible feed-in power without exceeding the allowed voltage change is calculated for different configurations and related to the network parameters. It is furthermore calculated how much the permissible feed-in power can be increased if reactive power is used to limit voltage raise. Finally the potential of controllable medium-voltage to low voltage transformers to increase the distributed generation hosting capacity of low voltage networks is shown.

INTRODUCTION

There is a strong increase of photovoltaic (PV) systems which are installed in Germany. The majority of the PV-systems are connected to the low voltage distribution network. The PV-systems must be operated without degrading the quality of supply. In low voltage grids compared to higher voltage levels we have relatively small short circuit impedance at the connection point, and a relatively large resistive fraction of the network impedance. Therefore staying within the allowed voltage band is one of the major issues. Often the upper voltage limit is reached even if the thermal capacity of the distribution lines would allow the connection of many more systems.

In the following we first analyse the effect of the network parameters on the voltage rise and then calculate the maximum apparent connection power assuming a maximum allowable voltage change in the network of +/-3% [2]. The potential of reactive power to reduce voltage raise and therefore to increase the PV-system hosting capacity is shown. Finally we quantify the potential of switchable medium voltage (MV) / low voltage (LV) transformers to increase the connectable power.

EFFECT OF NETWORK PARAMETERS ON VOLTAGE RISE

The voltage rise caused by PV-systems strongly depends on the network characteristic parameters, in particular to mention are the short circuit power and the network impedance angle at the connected point of the PV system, as well as the impedance of the LV/MV-transformer. A higher short circuit power S_{kV} at the PV system's connection point allows a higher active power in-feed. Besides the network short circuit power it is important to consider the network impedance angle ψ_{kV}, especially if the voltage control by reactive power is considered. The relative voltage rise Δu_{aV} at the connection point *V* can be calculated by:

$$\Delta u_{aV} = \frac{S_{A\max} \cdot \cos\left(\Psi_{kV} + \varphi\right)}{S_{kV}}$$

With S_{Amax} the apparent power at the connection point and φ the phase angle between current and voltage of the PV system.

<u>Typical Network data at the network connection point</u>

Figure 1 shows network short circuit power and network impedance angle at the low voltage bus bar of the MV/LV substation for different transformer types and MV network data. It can be seen that the LV-network short circuit power mainly depends on the properties of the MV/LV transformer, namely the rated power of the transformer and the short circuit voltage u_k. The network impedance angle varies between 63° and 80°.

Figure 2 shows how network the short circuit power and the network impedance angle change according to the distance from the substation. This diagram was also made for other transformer types (not shown here). For short distances the network short circuit power and the impedance angle are mainly depending on the transformer properties, while for longer distances the properties of the cable type are dominating.

MAXIMUM PERMISSIBLE CONNECTION POWER OF PV SYSTEMS

How much apparent PV power can be connected to the LV network and how does this depend on the network data? In order to answer these questions we have first investigated how much PV power can be fed into the LV network of the system, until the criteria of a voltage change that is caused by all generating plants in the LV network reaches 3%. This criterion is proposed in the latest draft of the German FNN requirements for generators connected to LV networks [2]. The network data and analysed cases are shown in Figure 3: Case A refers to a single feeder, single PV system configuration, Case B to a single feeder configuration, with 5 PV systems equally connected along the feeder, and Case C to a radial network with 4 feeders, each hosting 5 PV systems. For all cases different feeder lengths have been studied, in each case the rated power of the PV systems is assumed to be equal for all PV systems. The apparent power of the PV systems is increased stepwise until the voltage change compared to the zero load case exceeds the 3% limit. A standard power system simulation tool is used for the calculation of the voltage rise.

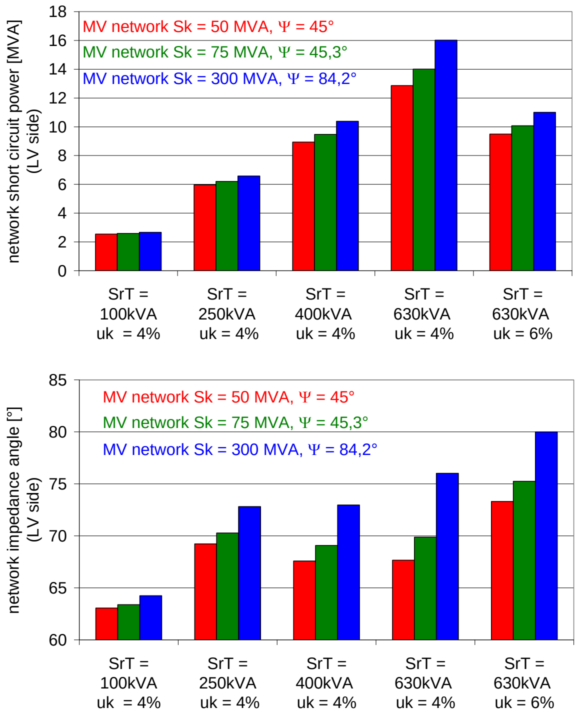

Figure 1. Network short circuit power (top) and network impedance angle (bottom) at the low voltage bus bar of the MV/LV transformer for different transformer types

As a result Figure 4 shows the maximum permissible connection power as percentage of the short circuit power at the end of the feeder and as function of the network impedance angle. Case A shows, that in this kind of presentation different transformers or network cables have nearly no effect. The maximum permissible connection power is very well given by the network parameters of the network connection point (S_k, ψ_k).

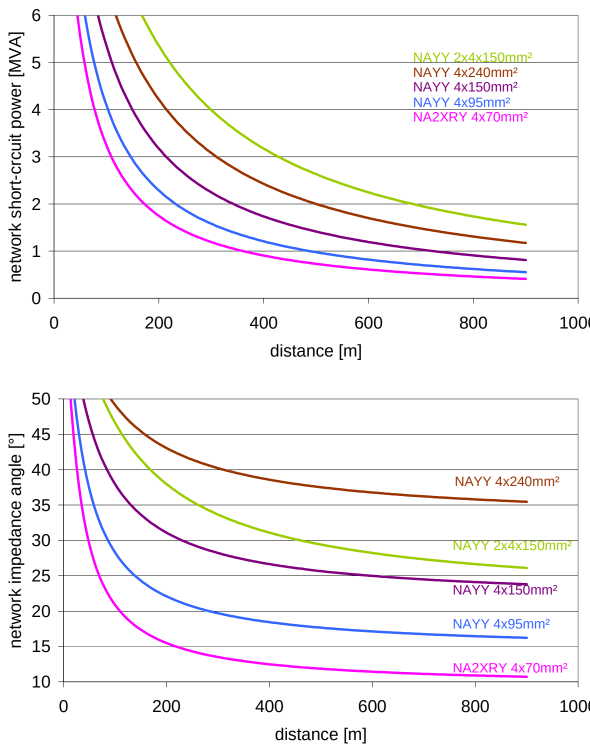

Figure 2. Network short circuit power (top) and network impedance angle (bottom) as a function of the distance to the low voltage bus bar at the transformer for different types of cables. Values for a substation with a MV/LV transformer of S_{rT} = 630 kVA and u_k = 4% with connection to a MS network with S_k = 75 MVA and ψ_k = 45,3°.

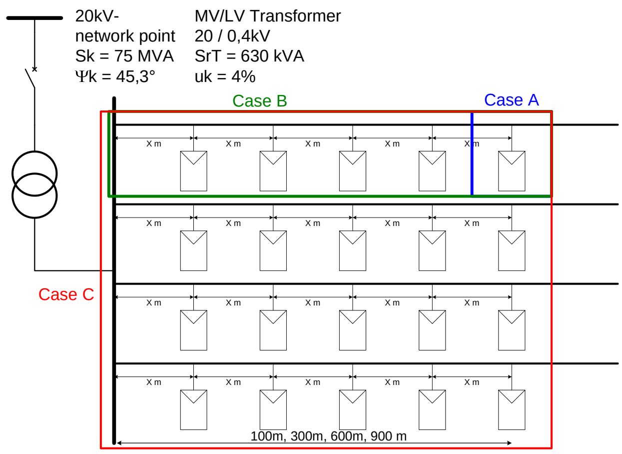

Figure 3. Network topology and analysed cases.

This also applies to the single feeder case (Case B), if the network parameters S_k and ψ_k at the end of the feeder are taken as reference values. In the multi feeder case (Case C) the difference between different cables and transformers are getting bigger, however the curves look still similar. In the multi feeder case the voltage rise in each feeder adds at the bus bar of the transformer and decreases the allowed voltage range in each single feeder. However the total permissible PV power is bigger compared to the single feeder case.

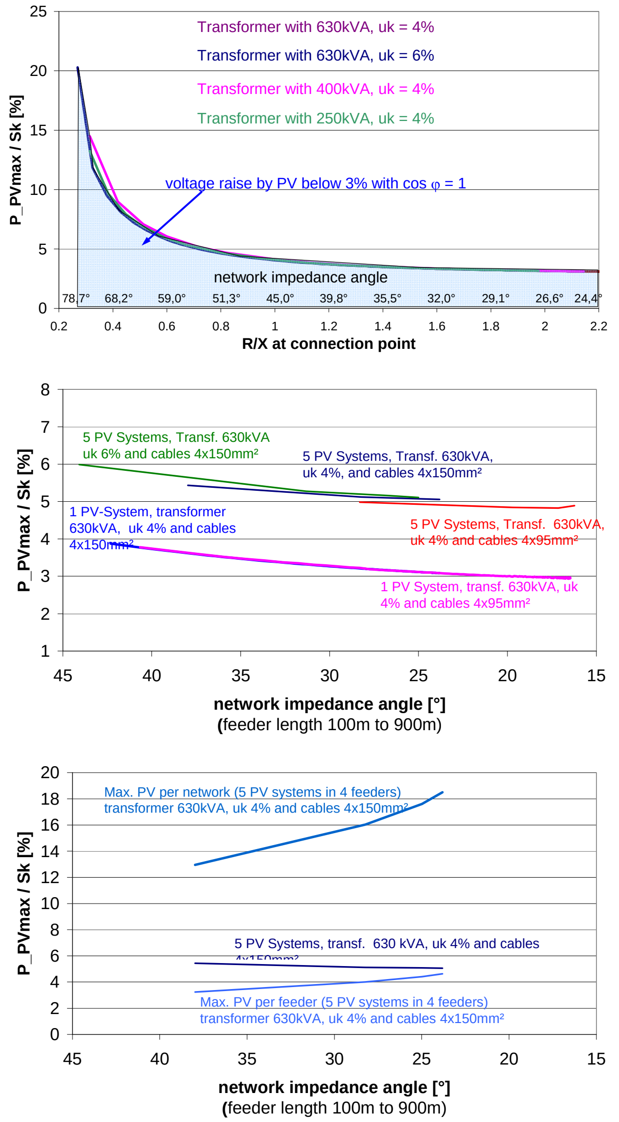

Figure 4. Maximum permissible connection power for the analysed cases A, B, and C (from top to bottom).

POTENTIAL OF REACTIVE POWER TO SUPPRESS VOLTAGE RAISE

If PV systems are used which can provide reactive power to the network the voltage in the network can be regulated. According to [2] PV system with a rated power greater than 13.8 kVA will be required to provide a power factor of up to cos φ = 0.9. Figure 5 shows the effect of reactive power provision by a single PV system (Case A) for different values of power factor cos φ. Each curve is a result from reaching either the upper voltage limit at the network connection point, left part of curve, or by a voltage decrease at the transformer which is larger than 3%. The effectiveness of voltage control by reactive power clearly depends on the network parameters S_k, ψ_k. Similar relations can be found for Case B (Figure 6, single feeder, multi PV system case). Figure 7 shows the relative increase of the permissible connection power for a power factor cos φ = 0.9 compared with cos φ = 1.In the analysed cases the increase due to reactive power provision is between a factor 1.5 and more than 2.5. It should however be noted, that in the latter case the thermal limits of transformer and cables may be exceeded.

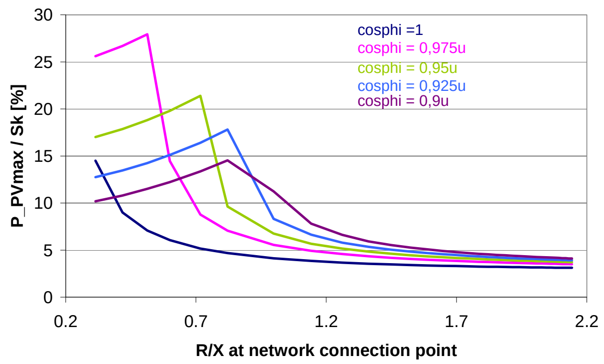

Figure 5. Maximum permissible PV power for different power factors of the PV system for Case A (single PV system, single feeder)

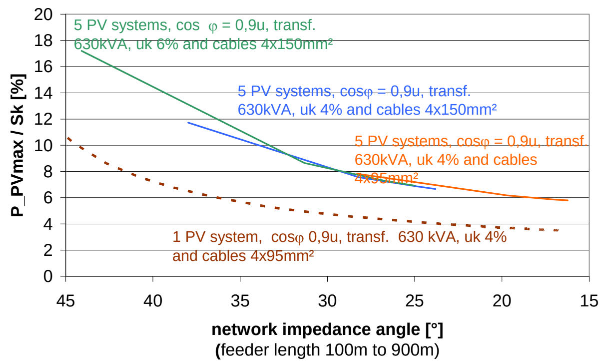

Figure 6. Maximum permissible PV power for PV systems with power factor 0.9 Case A, and Case B (single feeder, multiple PV systems.

IMPROVED USE OF THE AVAILABLE VOLTAGE RANGE BY SWITCHABLE MV/LV TRANSFORMERS

According to EN50160 [3] the permissible voltage range for customers connected to low voltage distribution grids is 400V +/- 10%. Currently the voltage in low voltage distribution networks is controlled at the transformer of the HV/MV substation. Following the assumptions in [4] the MV voltage at the HV/MV substation is set to 104% for the high load case and the voltage at the MV side of the MV/LV transformer may be as high as 106%. In this scenario only 4% voltage raise is allowed until the upper voltage limit is reached.

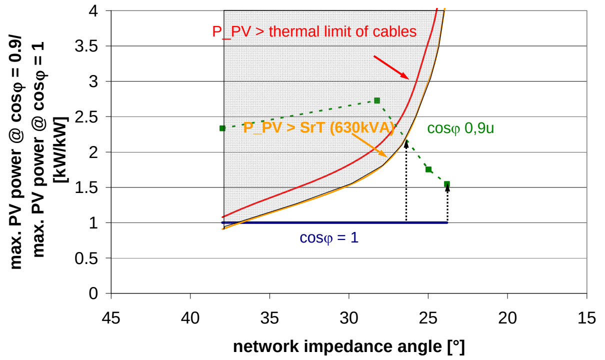

Figure 7. Relative increase of the permissible connection power for a power factor cos φ = 0.9 and Case C (multiple PV systems, multiple-feeders)

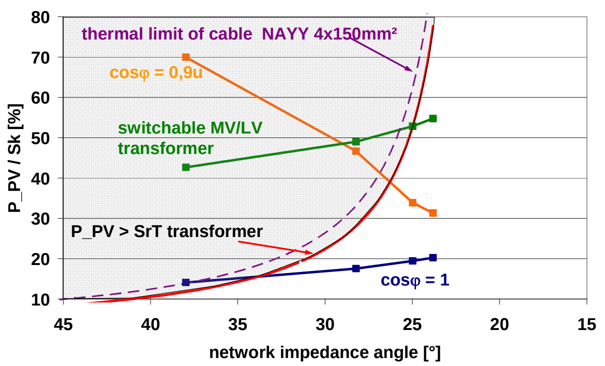

Figure 8. Maximum permissible connection power for extended voltage range with reactive power or controllable MV/LV transformer (Case C: multiple strings, multiple PV systems). Indicated points refer to feeder length 100m, 300m, 600, 900m, cable NAYY 4x150mm², transformer 630kVA, u_k=4%).

By using power factor control at the PV systems not only the upper voltage at the end of the feeder can be lowered, moreover the voltage at the LV-busbar substation is lower compared to the no-load case because of the reactive power flow from the superior network. While in the calculation of the previous section a maximum voltage change of 3% was allowed, in Figure 8 an increased voltage range was assumed: The upper limit for the feeder is 109% and the lower limit 96%, which still gives sufficient reserves for highly loaded LV feeders operated in parallel to feeders with predominantly generation. This extended range leads to a significant increase of the maximum permissible connection power (see Fig. 8).
Switchable MV/LV transformers provide an alternative way to control the voltage in LV networks. We have assumed a transformer with steps 2x +/- 2.5%. With this new asset the allowed voltage raise in the LV network (including the transformer) can be increased from 3% to 8%. The maximum permissible PV power is therefore increased by the factor 8/3=2.7. For the calculations we have assumed the same scenario which was used for the reactive power voltage control: MV voltage 106%, maximum LV voltage 109%, minimum. LV voltage 96%.
With both approaches the permissible PV connection power can be increased significantly up to and beyond a level where the thermal limits of the transformer or the cables are reached. The controllable transformer is in particular useful for long feeders, where reactive power control is less effective.

CONCLUSIONS

In our contribution we show general diagrams concerning the maximum permissible connection power from distributed generators into low voltage radial distribution networks. Network short circuit power and network impedance angle at the end of the feeder turn out to be appropriate parameters for the diagrams.
By using reactive power voltage control the maximum permissible PV power may be increased by a factor 1.5 up to more than 2. For higher penetration levels however other limits, like thermal limits of transformers and cables become applicable. While voltage control by reactive power is quite limited in long feeders a controllable MV/LV transformer allows to connect 2.7 more PV power to the network compared to the normal case. This would however require allowing a voltage change caused by PV power of more than 3%.

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