ADVANTAGES AND DRAWBACKS OF DISTRIBUTED GENERATORS REACTIVE POWER REGULATION IN THE LOW VOLTAGE NETWORK

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ABSTRACT

With more and more distributed generators (DG) in the utility networks, problems arise which were not predicted when the networks were designed. Reactive power generation of the DG units affects the voltage profile and power losses in the network. In order to be able to assess the situation, a combined MV and LV network simulation model was built, based on a real-case situation. Load-flow simulations with different reactive power management scenarios by the DG units were performed and are presented in the paper. Resulting voltage profiles and active power losses were compared for each scenario. A sensitivity analysis of the network based on voltage variations due to the active or reactive power variations of the DG units was also made.

INTRODUCTION

Distributed generators (DG) are becoming a very important factor in planning and operation of distribution network. Around the world, more and more of them are being connected to the medium-voltage (MV) and low-voltage (LV) networks. In Europe this is even catalyzed with an anomaly in electricity market called "*incentives for renewable energy*" which encourage the owners of (mostly) photovoltaic power plants to install as many as they can afford (not need!) because that poses a good business case for them. And when the money comes in question, there is never enough… But LV networks in particular are normally not designed for the connection of overwhelming numbers of those distributed sources.

LV networks are in vast majority of cases designed only to provide the power for the consumers in the network. That means that the maximum voltage drops in all points of coupling (PC) of the customers are calculated and predicted in advance. Normally the highest voltage amplitude in the LV network is at the MV/LV transformer and the lowest voltage amplitude is usually at the most distant customer's PC.

With the DG units present in the network, all this changes in one way or another. It may be in some cases that the voltage profile of a network is a mirror image of that, without the DG's present (voltage rises towards the end of the line) [1].

DG units contribute to the voltage rise in the LV network by feeding the active power to the network. But even though, the value of the resistive part of the impedance of a LV network may be a multiple (usually between 3 and 10) of the value of the reactive part of the impedance, reactive power management of the DGs can still play a role in the network voltage profile as well as in the network losses in the MV and LV network [1, 2].

To ensure as-easy-as-possible connection of micro generators (up to 16 A per phase) to the LV network, European standard EN 50438 [3] was agreed upon. In this standard the reactive power management is allowed with the generators PF varying from 0.95 leading (overexcited) to 0.95 (also noted as -0.95 in this paper) lagging (underexcited). For the generators whose nominal current exceeds 16 A per phase, no common EN standard exists. But several European countries have their own national rules [4, 5 and 6] for the connection of DG units into their network. These can differ from the rules for the connection defined in [3].

But there are noticeable differences in these national rules regarding the reactive power management concepts. Some rules define the demand for the reactive power production as a function of the active power production, some in positive way ($Q_{DG} > 0$) and some in negative way ($Q_{DG} < 0$). Some even use combined formulae of voltage level at the DG's PC and the active power of the DG units to define the demand for the reactive power [6].

This paper compares some of the reactive power management concepts in the real network case based on the active power losses and voltage profile in the network.

SIMULATION NETWORK AND CASES

To be able to analyze different scenarios of reactive power management, a MV / LV network simulation case was built. Simulations were performed using the PSS®E simulation program for the power flow analysis.

Simulation Network

Fig. 1 shows the network used for simulation. 'Src' is the equivalent voltage source with infinite short circuit power. It represents the HV network with the HV to MV transformer. The voltage at the source on MV1 busbars is fixed at the 100 % (1 p.u.) of nominal MV voltage (in our case 20 kV). Four equal MV/LV transformer stations (TR1, TR2, TR3 and TR4) with equal active and reactive power loadings are fed in series along the MV line. Each section of the MV line is 5 km in length, totalling 15 km. The transformers data is specified in Table 1. Electrical parameters of the MV overhead lines (OHL) are gathered in Table 2.

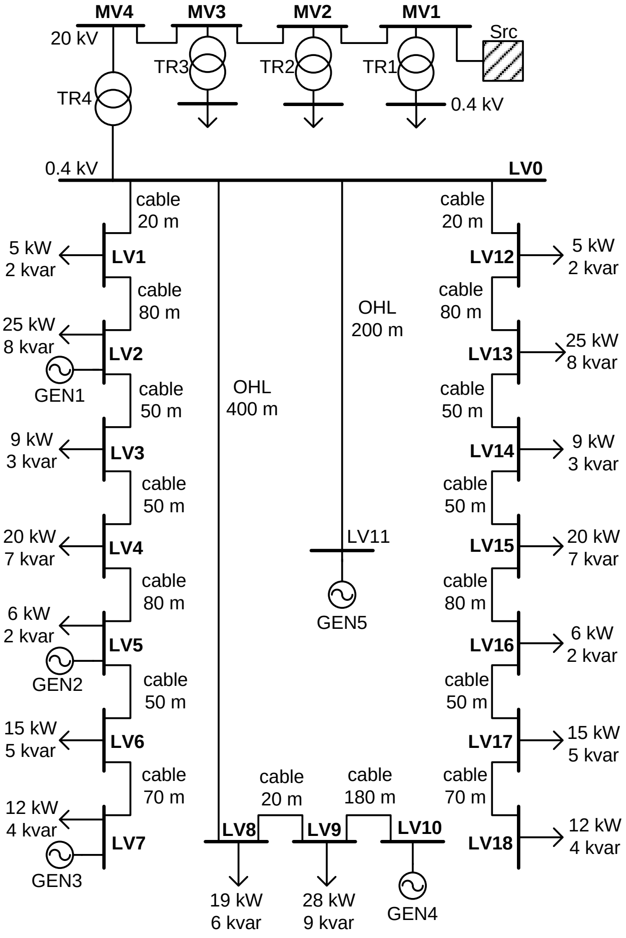

Fig. 1: Simulation network

The MV/LV substation TR4 is modelled in detail. Four parallel feeders with different load-to-generator ratios supply LV customers (loads) from bus LV0. Line 1 (LV1 to LV7) and Line 4 (LV12 to LV18) are similar lines, both with exactly the same dispersed loads connected using the cable lines. The only difference is that Line 1 has three DG units (GEN1, GEN2 and GEN3) dispersed along the line and Line 4 has none. All LV OHL and cable data is shown in Table 2. All the load data is shown in Fig. 1.

Table 1: Transformer Data

Transformer	S_n	u_{SC}	U_{PRIM} / U_{SEC}	$U_{SEC set}$
TR1, TR2, TR3, TR4	400 kVA	4 %	20 / 0.4 (kV)	1.05 pu

Line 2 (LV8 to LV10) is a mixed line of OHL and cable connections, with consumption concentrated towards the end of the line and with a DG unit (GEN4) located at the very end of the line. Line 3 (LV11) is a pure OHL with one DG (GEN5) connected at the end of the line. There is no load on Line 3.

Table 2: Line Data

Line	Voltage level	r'	x'
MV OHL	20 kV	0.41 ohm/km	0.35 ohm/km
LV OHL	0.4 kV	0.90 ohm/km	0.303 ohm/km
LV cable	0.4 kV	0.93 ohm/km	0.083 ohm/km

The generator data used in the simulation scenarios is gathered in Table 3.

Table 3: Generator Data

Generator	Gen. active power P_{DG} (kW)	Generator reactive power Q_{DG} (kvar)				
		CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
GEN1	32	-16	-10	0	16	10
GEN2	32	-16	-10	0	11	10
GEN3	32	-16	-10	0	-11	10
GEN4	47	-23	-15	0	-15	15
GEN5	38	-19	-13	0	0	13

Simulation Scenarios (Cases)

Six scenarios (cases) of the network in Fig. 1 were simulated.

CASE 1: All loads and no generators are connected to the network.

CASE 2: All loads and all generators are connected to the network. All generators operate at their maximum active power and with a constant power factor PF=-0.90. Minus sign means, that the generator is consuming reactive power.

CASE 3: All loads and all generators are connected to the network. All generators operate at their maximum active power and with a constant power factor PF=-0.95.

CASE 4: All loads and all generators are connected to the network. All generators operate at their maximum active power and with a constant power factor PF=1.0.

CASE 5: All loads and all generators are connected to the network. All generators operate at their maximum active power and with a variable power factor PF, ranging from -0.95 to +0.95, depending on voltage level at their PC. Plus sign means, that the generator is generating reactive power. The higher the voltage, the more reactive power the generator consumes. Similarly, generator produces more reactive power with lower voltage at its terminals. In this case generators try to keep the voltage profile of the network as constant as possible without raising the power losses in the network.

CASE 6: All loads and all generators are connected to the network. All generators operate at their maximum active power and with a constant power factor PF=+0.95.

SIMULATION RESULTS

Simulation results are presented from several different viewpoints. In the following analysis all the MV/LV transformers are assumed as a part of the MV network.

Active Power Losses in the Network

Prime task of the network is to deliver active and reactive power to the consumers with as little losses as possible. In Fig. 2 active power losses are depicted for all the six simulated scenarios (cases).

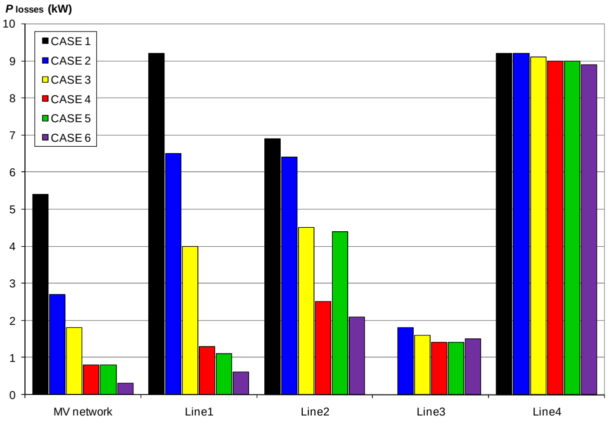

Fig. 2: Active power losses in the network

Fig. 2 clearly shows that for all cases Line 4 (the line without the DGs) has absolutely highest values of losses. Losses are smaller on other lines and more importantly have a clear tendency of being smaller when more reactive power is produced by the DGs.

Comparison of active power losses also shows one interesting difference between losses in the LV and MV networks. Active power losses in the LV network are on average by an approximate factor of 2 higher than losses in the MV network (MV feeder / LV feeder).

Voltage Variations in the Network

Fig. 3 shows cumulative active power losses for the LV Line 1 and voltage variations along the line for Line 1 for different cases. Fig. 4 shows cumulative active power losses for the LV Line 2 and voltage variations along the line for Line 2 in different analyzed cases.

Fig. 3 and 4 clearly show that by adding the reactive power production to the DG's production of the active power, active power losses in the LV network become smaller. The side effects are higher voltage levels in the network. When DGs inject too much of reactive power, voltage levels rise towards their limits (the ordinate axis "y" position of the red block on charts) and voltage variations in the LV network become wider (the length of the red block in the "y" axis on the charts on Fig. 3 and 4).The best solution for the reactive power management seems to be "somewhere in-between".

Fig. 5 shows cumulative active power losses for the MV network and voltage variations along the MV lines for all cases.

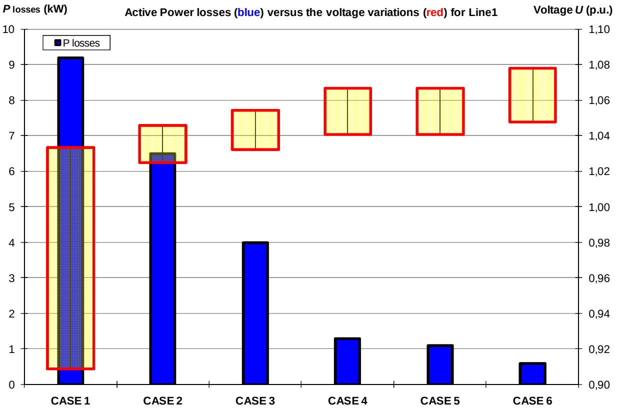

Fig. 3: Cumulative active power losses and voltage variations along the LV Line 1

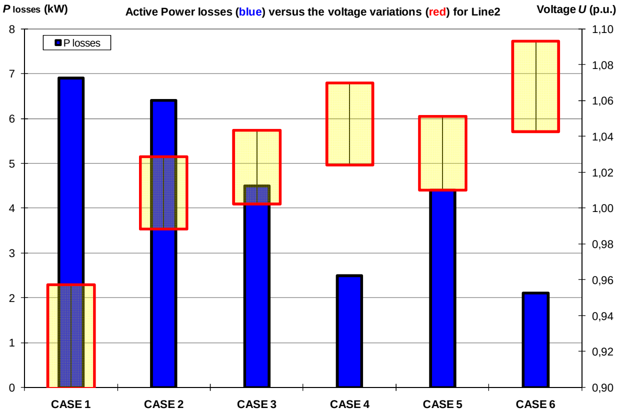

Fig. 4: Cumulative active power losses and voltage variations along the LV Line 2

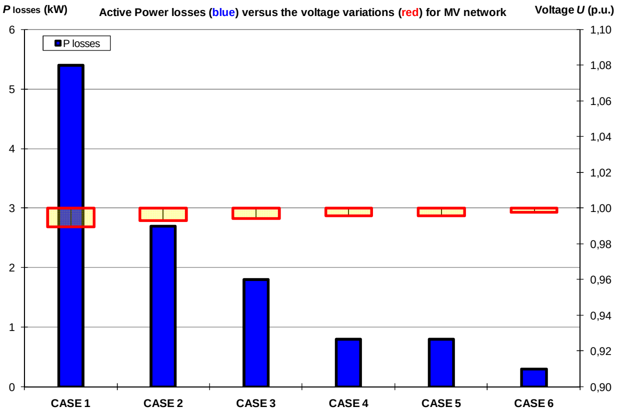

Fig. 5: Cumulative active power losses and voltage variations along the MV lines

Fig. 5 again clearly shows that by adding the reactive power production to the DG's production of the active power, active power losses in the MV network become smaller. The difference to the LV network is in the fact that by adding even more reactive power to the DG's production, the voltage levels in the network gravitate towards the set value on the MV busbars and thus the voltage variations become negligible.

Sensitivity Analysis of the Network

In this section we analyse sensitivity factors of voltage changes with regard to active or reactive power changes for the simulation network in Fig. 1.

Fig. 6 shows sensitivity analysis of all four LV lines for different cases.

For each case and gradually in steps along each line of the network, we changed active power consumption at the points where network users are connected to the network. We monitored what change of voltage level would a change of one kW of active power contribute to in a given point in the network. Then we did the same with reactive power for that same given point in the network. The result of those two changes in active and reactive power is one spot (dot) on the chart in Fig. 6.

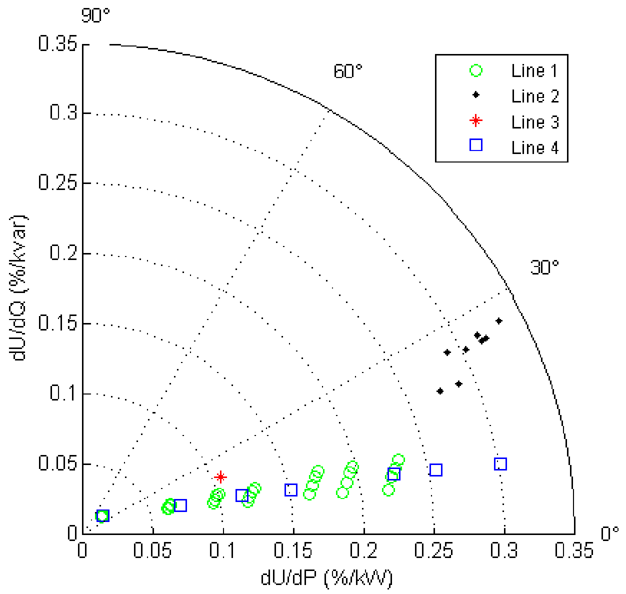

Fig. 6: Sensitivity analysis of all four LV lines for different cases

From Fig.6 we can clearly see the predominant impact of active power on the voltage level in the LV network. Dots representing Line 2 and Line 3 have a higher "pitch" than those of Line 1 and Line 4. The reason for that is the use of different line types. Lines 2 and 3 have quite a big portion of OHL lines whereas Lines 1 and 4 are both cable lines. Different R / X ratios of lines thus determine the phase angle in degrees (°) of results in Fig. 6.

CONCLUSION

The results of simulations made for this paper lead to a conclusion that it may be wise to allow DG units in the distribution network to inject some reactive power into the LV network along with the active power they produce. This causes the active power losses in the network to drop substantially. But because of the predominantly resistive (R) character of the LV networks, the impact on the additional voltage rise is relatively small.

This change in DGs operation in the distribution network causes smaller network losses. On the other hand there might be a problem on the total number of DG units which may be connected into the network because of the additional voltage rise reactive power injection causes.

There is a tendency in some European countries, especially in those who already suffer from major DG penetration, that DGs should consume even more reactive power when operating at their full active power. That gives them the ability to connect even more DG units into the network.

Our analysis shows that this can lead to increased active power losses in the network, which must be covered by the distribution system operator (DSO). That fact should be taken into account by the DSO prior to allowing connection of the DG units with such reactive power characteristics to the network.

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