REACTIVE POWER CONCEPTS IN THE FUTURE DISTRIBUTION NETWORKS

Daniel UNGER[1]
d.unger@tu-bs.de

Nasser G. A. HEMDAN[1,2]
n.hemdan@tu-bs.de

Michael KURRAT[1]
m.kurrat@tu-bs.de

[1]Institute of High Voltage Technology
and Electric Power Systems
Technische Universität Braunschweig
Germany

[2]Electrical Engineering Department
Faculty of Engineering
Minia University
Egypt

ABSTRACT

The main objective of the current work is the evaluation of the implications of the decentralized generation reactive power control on the system operation. The investigations were conducted on a real life network in MV and LV levels. A LV network has been built behind each MV/LV transformer. In the MV network three wind mills are existed while in the LV side 70 PV generators are existed. Measured generation profiles of the wind and PV were used for three weeks representing three seasons, one week in January, one in April, and one in July. Generic load profiles of households and commercials are taken into consideration. The analysis was conducted using PowerFactory DIgSILENT software. The results show that controlling of the reactive power of the decentralized generation plays an important role in the future distribution networks.

INTRODUCTION

The amount of installed small scale decentralized generation (DG) has been growing in the last years. In many countries, government policies have favoured the installation of new small-scale DG. DG has brought up the possibility of making a more efficient use of fuel, even at the domestic level, as is the case with micro-CHP, or utilizing renewable energy sources available on-site, as in the case of solar power [1]. Uncorrected reactive power makes it too hard for stabilizing the network voltages. Moreover, it will be the cause of additional costs throughout the entire network since all the power systems components such as cables, transformers, and generators must be sized to carry the total current. Moreover, that will increase the cost of reactive power which is supplied from the transmission system [2]. For decades the reactive power control has been identified as one of the crucial operation functions of the distribution system. Efficient reactive power control reduces system losses, improves voltage profile, and hence enhances the delivered power quality and overall system reliability [3]. In the future distribution grids a large number of DG's will be exist; therefore the implications of reactive power flow through these resources into different voltage levels have to be analyzed.

CASE STUDY

The MV grid under study comprises a suburban area and two rural areas [4]. The MV network is operating at 20 kV. The energy is supplied to the network through a 40 MVA, 110/20 kV transformer located at the main station, three wind mills and 70 PV generators, respectively. The loads are connected at each MV substation through transformers of 20/0.4 kV with different ratings. Consequently the number of MV/LV transformers in the network is 36. The whole network including the LV grids was built in one network model, hence the interaction of the different voltage levels could be considered in the simulation.

GENERATION AND LOAD PROFILES

In the network under study wind generators are connected at the MV level where PV's are connected at LV level.

Wind Generation

In the MV network the three wind mills of 0.5, 0.6, and 2 MW are already interconnected into the grid. They are connected to the grid through 630, 800, 2500 kVA transformers, respectively. Three weeks representing three seasons of measured data of the output power for the three mills is used in this work. Figure 1 a) shows the normalized output power of the three wind mills.

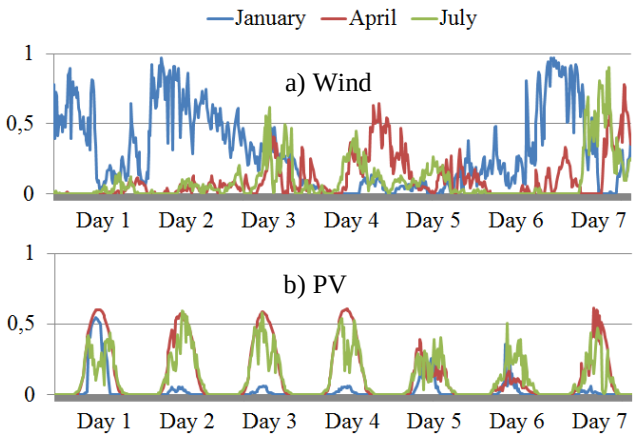

Figure 1: Normalized wind and PV active power of the week for the three seasons

PV Generation

The PV generation in Germany is mainly connected at the LV grids. The four German transmission system operators publish jointly the master data annually [5]. The last published data at the end of 2011 was used in the current investigation. The data was used to implement the PV in the network model at the same point of common coupling as in the real situation. Thus 70 single generators were distributed in the network model. The rated power varies from 1.98 to 87.12 kWp. The overall generation capacity regarding solar power is 809.02 kWp. The generation profile for the PV was derived from the output power of an existing PV inverter. Due to the regional area of the investigated network the generation profile of this sample inverter was assumed as a reference for all inverters in the network. In terms of the time period for the measurement, the same weeks were used as for the measurement for the three wind mills. Thus a consistent generation profile can be assumed for the investigation. The normalized output power for the PV inverters is depicted in Figure 1 b).

Load Profiles

The network model was built in such a way that one load represents one household. The whole network model comprises more than 2600 single households. To simulate the energy consumption of the households generic load profiles were used. The annual energy consumption for each household was assumed as 4500 kWh. An own simulation tool considers 20 domestic appliances such as washing machine, cooking plate and TV. The usage of each domestic appliance is subject to the configuration of the respective household, probability of usage and usage period. The load profiles were attached to the respective loads arbitrarily. For the verification the sum of all generic load profiles was compared to the corresponding standard load profile. The sum of the simulated load profiles resembles the respective standard load profile. This proves the usability of the generic load profiles. In terms of the power factor, 0.9 inductive was assumed for the households.

Reactive power characteristic

The German guideline for the technical connection conditions VDE-AR-N 4105 prescribes the conduct of power generating units in LV networks [6]. The injection of active power in LV networks raises the voltage at the point of common coupling. With the ongoing installation of small-scale DG, this issue will increase in significance in the future. In former papers the usability and viability of the injection of reactive power for improving the voltage quality could be proved [7]. Usually the grid operator can prescribe a characteristic dependent on the actual grid situation. According to the LV guideline units with a rated power between 3.68 and 13.8 kVA have to be able to inject power with a power factor from $0.95_{overexcited}$ to $0.95_{underexcited}$ ($0.9_{overexcited}$ to $0.9_{underexcited}$ for units with a rated power exceeding 13.8 kVA).

The requirements of the guideline for DG connected to MV grids resemble the directives for LV grids [8]. The grid operator can induce the conduct of DG in MV grids regarding the injection of reactive power. The units have to be able to operate with a power factor from $0.95_{overexcited}$ to $0.95_{underexcited}$.

In order to improve the voltage quality at the point of common coupling the LV guideline proposes a cos(φ)/P-characteristic (Figure 2, continuous line). This characteristic was applied in the current study for the generation units with a rated power exceeding 30 kW in order to increase the voltage quality at the respective connection point (first scenario).

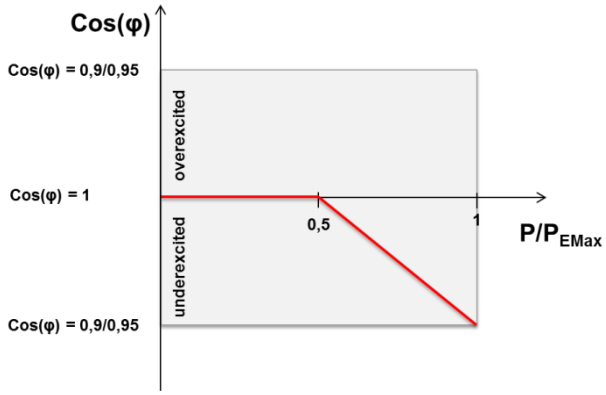

Figure 2: Characteristic for the power factor as a function of the ratio of current power (P) to rated power (P_{EMax})

Another possible characteristic for the voltage regulation with reactive power is depicted in Figure 3 (second scenario). The injection of reactive power and the power factor, respectively, is determined dependent on the ratio of the current voltage to the rated voltage. The second characteristic has the advantage that generation units inject reactive power only in case the voltage exceeds the defined limitation.

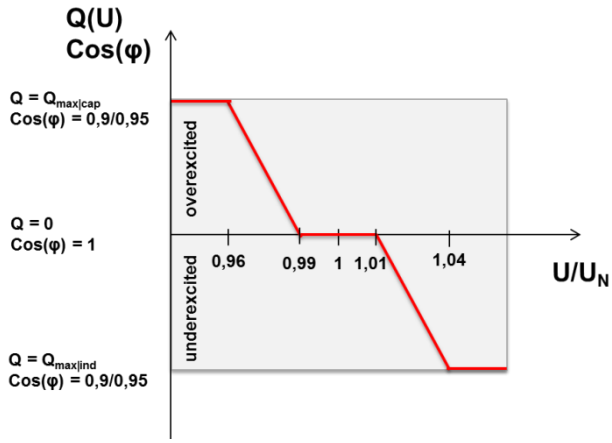

Figure 3: Characteristic for the reactive power injection and power factor, respectively, as a function of the ratio of current voltage (U) to rated voltage (U_N)

SIMULATION RESULTS

Through this work the analysis was conducted using PowerFactory DIgSILENT software. The different results are shown in this section.

Supplied active and reactive power

Figure 4 shows the main transformer supplied active and reactive power for three weeks for the base case, consequently without implemented characteristic for the DG. Figure 5 shows the results with the same network configuration but the implemented cos(φ)/P-characteristic. It can be seen that the main impact of reactive power is subject to the wind generation more than to the PV generation. It can be inferred that as the wind generators exceeds 50% of its rated power it starts to absorb reactive power from the system (e.g. January, Day 6 and Day 7). That was to be expected considering Figure 1. The normalized active power injection of the PV inverters rarely exceeds the magnitude 0.5.

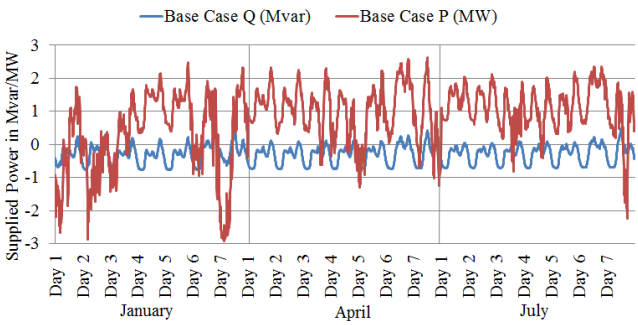

Figure 4: Main Transformer supplied active and reactive power for the base case

Especially during periods with a high wind generation the whole network absorbs reactive power in the first scenario, whereas in the base case it injects reactive power in that time. The difference is nearly 2 Mvar.

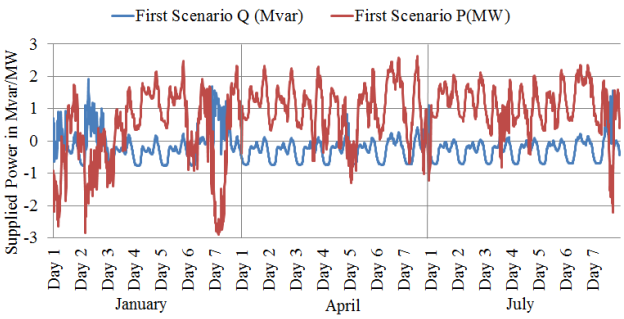

Figure 5: Main Transformer supplied active and reactive power for the first scenario

Voltage curve at MV and LV nodes

The basic assumption of the reactive power characteristic is the improvement of the voltage quality. Figure 6 contrast the load curve of one MV node at the base case with the first scenario. It can be seen that the voltage rise can be mitigated especially during high wind periods (nearly 1 %). This affects also the voltage rise at the LV node (Figure 7).

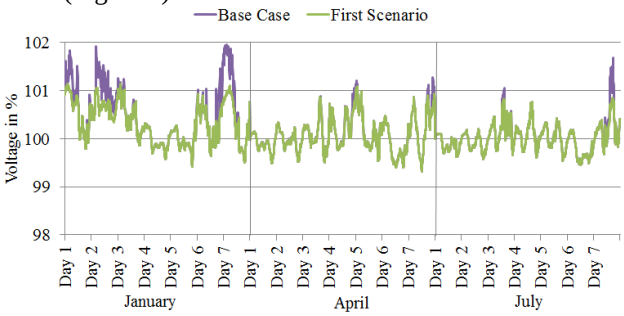

Figure 6: Voltage in % at the MV node where the 2 MW wind mill is connected

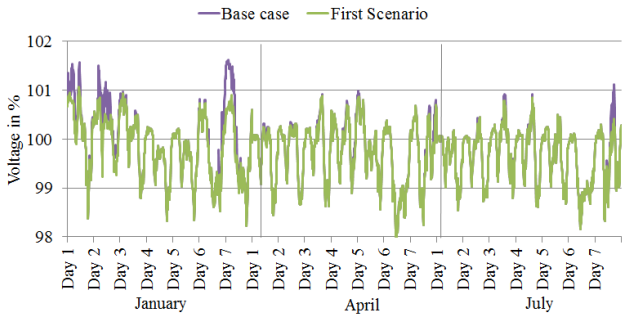

Figure 7: Voltage in % for a LV node at the same feeder where the 2 MW wind mill is connected

Second scenario

In the second part of the analysis two days with high wind generation in January have been selected to perform the application of the second scenario. Figure 8 and Figure 9 show the active and reactive power supplied from the 2 MW wind mill using the two control schemes.

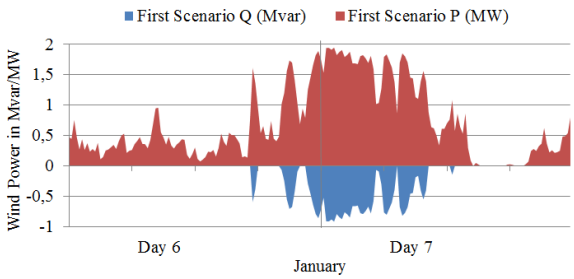

Figure 8: Active and reactive power supplied from the 2 MW wind mill in 2 days (first scenario)

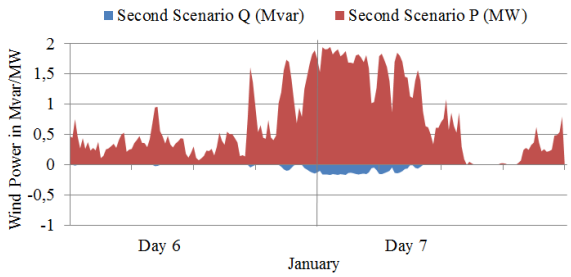

Figure 9: Active and reactive power supplied from the 2 MW wind mill in 2 days (second scenario)

It can be seen that in the second scenario a smaller amount of reactive power was absorbed. Consequently in the second scenario the voltage should be higher at the two former nodes (Figures 10 and 11). It can be inferred that the first scenario represents the best solution in terms of voltage quality but also leads to the highest amount of absorbed reactive power.

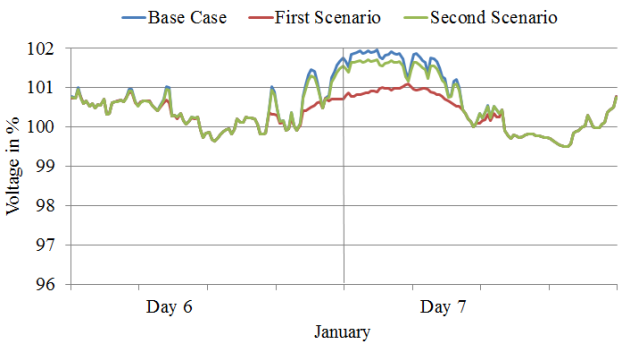

Figure 10: Voltage in % for the 2 MW wind mill node for different cases in two days

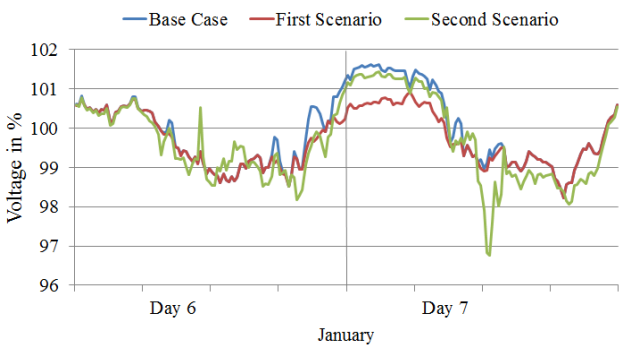

Figure 11: Voltage in % for the LV node for different cases in two days

CONCLUSIONS

In the current work different control schemes of decentralized generation reactive power have been implemented in order to assess the impact of reactive power flow (injection/absorption) on the operation of the future distribution networks. A real life distribution MV network with the corresponding LV networks has been used to carry out the investigations. Three weeks presenting different seasons have been implemented for the load and generation profiles. From the results the following conclusions can be drawn:

1. The reactive power control scheme of decentralized generation which implement the cos(φ)/P-characteristic represent the best solution form the voltage quality point of view. However more reactive power is to be absorbed from the system in this case.
2. The standard characteristic has to be adapted to the respective grid situation. Thus still an improvement in terms of voltage quality can be achieved. Especially PV in LV grids can be used to support the voltage in the case the voltage fall below a lower limit (e.g. 99 % in Figure 7 and Figure 11) by injecting reactive power.
3. The interaction between the different voltage levels of the power supply networks regarding the reactive power has to be more analysed in the future while more decentralized generations are intended to interconnect.
4. More standards for reactive power flow from decentralized generation are needed in the near future.
5. The results of the current work will be used in the future to inquire further issues, such as the different concerns of reactive power flow at different voltage levels and presenting different strategies for their control in the smart grid of the future.

REFERENCES

[1] F. Sulla, J. Björnstedt, and O. Samuelsson, "Distributed Generation with Voltage Control Capability in the Low Voltage Network," in *International Conference on Renewable Energies and Power Quality*, 2010, pp. 1-6.

[2] ECHELON, 2010 "Improving Volt / VAR Control Tighter Control Reduces Waste and Increasing Grid Capacity," Available: www.smartgridnews.com

[3] M. E. Elkhatib, R. E. Shatshat, and M. M. a. Salama, 2012 "Decentralized Reactive Power Control for Advanced Distribution Automation Systems," *IEEE Transactions on Smart Grid*, vol. 3, 1482-1490

[4] N. G. A. Hemdan and M. Kurrat, 2011 "Interconnection of Decentralized Renewable Resources into Distribution Grids: Implications and Planning Aspects," *Electric Power Systems Research*, vol. 81, 1410-1423

[5] EEG-KWK, 2012 Available: http://www.eeg-kwk.net

[6] VDE FNN, 2011, "Erzeugungsanlagen am Niederspannungsnetz, Technische Mindestanforderungen für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Niederspannungsnetz", VDE-AR-N 4105. Berlin

[7] G. Kerber, R. Witzmann, and H. Sappl 2009, "Voltage Limitation by Autonomous Reactive Power Control of Grid Connected Photovoltaic Inverters," presented at Compatibility and Power Electronics conference

[8] BDEW, 2008, "Technische Richtlinie Erzeugungsanlagen am Mittelspannungsnetz – Richtlinie für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Mittelspannungsnetz". Berlin.