TECHNICAL ANALYSES OF NETWORK STRUCTURES REGARDING DECENTRALIZED FEED-IN

Maria Aigner
TU Graz / IFEA – Austria
maria.aigner@tugraz.at

Ernst Schmautzer
TU Graz / IFEA – Austria
schmautzer@tugraz.at

Domenik Buchauer
TU Graz / IFEA – Austria
d.buchauer@tugraz.at

Gernot Bitzan
EKG-StromNetz (StN-G) – Austria
gernot.bitzan@energieklagenfurt.at

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ABSTRACT

This paper focusses on low voltage networks and issues which come along with load flow characteristics through decentralized feed-in.
Based on three different load flow and energy consumption scenarios of an exemplarily low voltage network under consideration of the current situation and predicted energy generation and demand for 2020 and 2030 simulations and measurements should prove, if the existing networks are already sufficiently dimensioned to fulfil the future tasks.
Resulting experiences of the measurements, considering the behaviour of the de-/centralized generation (supply of reactive power) and de-/centralized consumption, validates the results obtained by simulations.
The paper presents simulations and measurements in a rural network periphery in Austria and shows the influence of reactive power supply into the low voltage network.

INTRODUCTION

Within the funded project “ECONGRID – Smart grids and economic effects: an economic assessment of smart grid solutions“ technical analyses and an overall national assessment of the wide-area implementation of smart grids in Austria shall be carried out [1]. In the present project issues, which come along with an inversion of the load flow in the distribution network caused by decentralized generation (DG), load flow and PQ aspects are addressed.
Simulation results of load flow calculations and measurements considering centralized and decentralized energy demand and feed-in of typical rural network structures in Austria will be presented.
The measurement should prove that the simulation model is sufficient to extrapolate various load flow scenarios using calculation methods.
Up to now in Austria the criteria based on the national grid code for decentralized generation and connection to the distribution network were predominantly based on the installed power. A generator is accepted in the network, if it is possible to inject permanently its maximum active power under compliance with the electrical operating conditions [2], [3]. In case of a fault decentralized generation usually plays a passive role because of low short circuit power and do not influence the fault clearing in the network.
In future the increasing penetration of DG on the distribution network requires in addition active supporting functionality of the DG.
This circumstance is already considered in the German the national grid code VDE-AR-N 4105 [5] requiring an active role in the static voltage stability through a selective reactive power supply.
Especially pv-inverters provide the possibility for a coordinated control of the system voltage and reactive power flow to achieve optimal distribution network operation and to maintain the tolerated limits for voltages [3], [4].
In order to provide practical experiences, how different decentralized generation units (PV with inverters, wind turbines and small sized hydro power plants) can influence the feed-in power respectively the PQ, simulations and measurements are compared in the following.
The field tests include measurements under consideration of a periphery network in a rural distribution area with a medium sized generation unit. The influence of reactive power injection in praxis (cos φ variable in the range from 0.85 to 1.00, overexcited) on the voltage at the point of common coupling (decentralized feed-in), at the substation transformer (busbar) and the end of the periphery network is shown.

INVESTIGATED SCENARIOS

The following simulations are based on scenarios which include the energy generation and demand for the year 2012, 2020 as well as 2030 and will show, if the existing network structures are already sufficiently dimensioned or if additional constructional measures are necessary.
The scenarios are defined considering an urban distribution area (high load density, short distribution lines …), a sub-urban distribution area (medium load density and a combination of long and short distribution lines) and a rural distribution area (low load density, long and weak-scaled distribution lines …) as following:

a) current policy scenario: includes legal requirements regarding renewable sources

b) renewable scenario: ambitious use of renewables
c) flex demand scenario: high potential of demand side management measures and use of a high amount of renewables

SIMULATIONS

Usually simulations are used for dimensioning of medium and low voltage networks. To demonstrate the impact of an increased decentralized generation on low voltage network structures for the years 2012, 2020 and 2030 a representative distribution network has been divided into the three mentioned scenarios.
The following simulations should prove, if representative typical networks are already sufficiently dimensioned (work load and PQ) to fulfil the future tasks till 2020 and 2030. Type and material of cables and overhead lines as well as transformer types, sizes and settings are implemented in the simulations as currently in the field.
The scenarios are analysed under consideration of a varying amount of an increased energy production from renewable sources and energy demand (scenarios: current policy, renewable, flex demand) for Austria. The assumed energy demand and decentralized generation - differing in the three scenarios - is determined by a top-down approach to the analyzed network region. That means that the assumed national overall energy generation through decentralized generation units in the Austrian distribution network is equally distributed to a feed-in power for each building in the scenarios.
The increased energy consumption considers an intensified appearance of electro mobility, a rise of the energy demand caused by a growth of population and technological progress for the year 2020 as well as 2030.

Load cases

To exemplify the limits of the low voltage network and the installed components the following load cases till 2020 and 2030 respectively have been performed:

1. Initial electrical load and generation situation
2. Electrical load = max. generation = max.
3. Electrical load = max. generation = zero
4. Electrical load = zero generation = max.

In the following only the case of the highest feed-in power of decentralized generation from renewables besides an advanced demand side management (scenario: flex demand) is described for each load case.
A simultaneity factor has not been considered in the simulations because this worst - case has to be respected in dimensioning distribution networks especially for extended decentralized generation.

Results - urban distribution area
The simulation results in regard to usually planned urban distribution areas show that the used substation transformer (size and settings) is overloaded (planning value: less than 50 % transformer load) for the load case 1 (initial situation), load case 2 (load = max., gen. = max) and load case 3 (load = max., gen. = zero) till 2020. In the scenario till 2030 the cables and overhead lines are also overloaded for the load cases 1 to 3. In respect to the analyzed situations the voltage stay within the required limits [4]. Due to the top-down approach an individual statement for each point of common coupling at the customer side (building) regarding compliance of voltage limits cannot be given [3].

Results - sub-urban distribution area
The simulation results in regard to usually planned sub-urban distribution areas demonstrate that the network does not need any adoption to integrate increased decentralized generation till 2020. This network region has a high potential for photovoltaics due to extended roof areas on - for example - agricultural buildings. For the observation period till 2030 the transformer is overloaded (planning value: less than 50 % transformer load) in the load case 3 (load = max., gen = zero) and load case 4 (load = zero, gen. = max.); in load case 4 the cables and overhead lines are overloaded, too. The voltage stays within the required limits [4].

Results - rural distribution area
The simulation results in regard to usually planned rural distribution area shows that the used substation transformer (planning value: less than 50 % transformer load) is overloaded for the load case 1 (initial situation) as well for the load case 3 (load = max., gen. = zero) till 2020. The result for the initial situation (load case 1) is caused by the currently used small sized substation transformer, non-consideration of the simultaneity factor and by a high network load in relation to the decentralized generation. Therefore the results for the initial situation (load case 1) and load case 3 till 2020 are identical. Till 2020 the results for load case 2 (load = max., gen. = max.) show that the ratio between decentralized generation and energy consumption is balanced. Load case 4 (load = zero, gen. = max.) demonstrates that in sparsely populated distribution areas the low consumption as well as the high amount of decentralized generation are the crucial factors. Till 2030 load cases 1, 3 and 4 show an overload of the transformer. Only in case of a balanced situation between generation and demand (load case 2) the transformer is working in the normal operation mode. In all load cases no overload of the cables and overhead lines can be seen and the voltage limits are maintained well [4].

Influence of decentralized feed-in on the voltage changes in the network periphery

The measurements show that feed-in with less than 50 % of the installed transformer power do not influence the voltage limits. Therefore in the simulation the feed-in power has been increased to 100 % of the installed transformer power at ②, Figure 1.

Results - rural distribution area, voltage limits

To demonstrate the violation of the voltage limits the described scenario: flex demand has been analysed under consideration of an additional injection of 125 kW at the point of common coupling in the periphery network (see ②, Figure 1 for the years 2020 and 2030.

2020 - Scenario c): Flex demand			
Load case	**Max. conductor workload**	**Voltage limits**	**Transformer workload**
2. Electrical load =max. , generation = max.	79,93%	complied	60,59%
3. Electrical load =max. , generation = zero	23,84%	complied	65,24%
4. Electrical load = zero , generation = max.	90,70%	complied	119,65%

2030 - Scenario c): Flex demand			
Load case	**Max. conductor workload**	**Voltage limits**	**Transformer workload**
2. Electrical load =max. , generation = max.	98,84%	complied	124,06%
3. Electrical load =max. , generation = zero	33,51%	complied	80,77%
4. Electrical load = zero , generation = max.	119,81%	non complied	200,17%

Table 1: Simulation results under consideration of an additional injection of 125 kW at ② for the years 2020 and 2030

As shown in Table 1 for load case 2 (load = max., gen. = max.) to load case 4 (load = zero, gen. = max.) the conductors and the transformer are overloaded till 2020. The voltage limits under consideration of [4] are observed. Due to increasing generation, demand and additional supply of 125 kW at ② the transformer is overloaded for load case 2 to load case 4 till 2030. Furthermore there are violations of the voltage limits regarding load case 4 in 2030 [4].

ANALYSED NETWORK PERIPHERY – RURAL DISTRIBUTION AREA

In Figure 1 the characteristics of the analysed network periphery as well as technical parameters of the actually components are depicted. Number ① to ③ demonstrates the measurement points including the distances between each other in the network periphery.

External factors like a reduced or increased demand in the network which can cause changes in voltage level have been considered during the field tests.

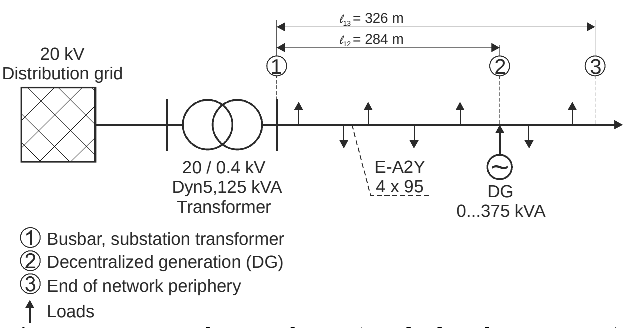

Figure 1: Network periphery (rural distribution area) with geometric distances

NETWORK SIMULATION MODEL

Several European grid codes require an active participation of network connected generators onto the reactive power management (cos φ control). The power factor cos φ is defined as the ratio between active and the apparent power. An overexcited power factor means that the generation unit takes capacitive reactive power and supplies inductive power. An underexcited power factor means that active power is fed to the network and inductive reactive power is taken from the network.

In several cases the voltage change, which is given through decentralized generation is too high and voltage limits required in national grid codes (exemplarily, [3]) cannot be maintained. In these cases it is necessary that the installed DG is operated in the underexcited operation mode.

In Figure 2 the effects of supplying an active power factor cos φ = 1.00 and varying power factors cos φ = 0.95/0.90/0.85 (overexcited) and cos φ = 0.95/0.9 0/0.85 (underexcited) on the voltage change are depicted for the three mentioned representative measurement points for an infeed of P = 45 kW. The power factor cos φ = 0.30 (overexcited) and cos φ = 0.30 (underexcited) shall demonstrate the effects of a high amount of supply of reactive power into the low voltage network. The voltage at the busbar of the substation transformer (see position ①, Figure 2) is used as reference voltage. At the point of common coupling of the decentralized generation ②, Figure 2, it can be seen that due to an overexcited injection of active power the voltage increases. The voltage at the point of common coupling is decreased, using an injection of underexcited active power. The same facts occur for the end at the periphery network ③. The influence of a reactive power feed-in is not so significant than the supply of active power into the low voltage network.

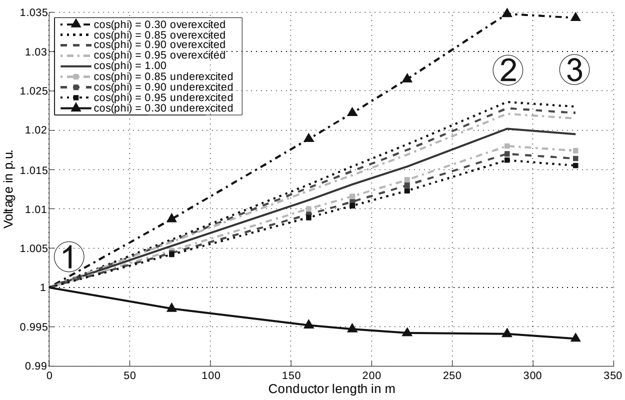

Figure 2: Simulation results, active power P = 45 kW, variable power factor cos φ (over- and underexcited)

FIELD TEST – MEASUREMENTS

Voltage behaviour in the network periphery

Due to the capacity of the decentralized generation unit the active power P has been varied between 30 kW and 80 kW, considering an overexcited power factor, injected at the point of common coupling; results are shown for an feed-in of active power of P = 45 kW because the resulting voltage drop caused by an overexcited power factor can be demonstrated in all feed-in scenarios.

Table 2 shows the influence of an overexcited power factor on the measured voltages at several points in the network periphery. The values are depicted in relation to cos φ =1.00. The reference voltage is assumed at a value of 230 V (1.00 pu). The measured voltage increases at the point of common coupling under consideration of an overexcited power factor. The voltage at the end of the periphery network shows similar values to the voltage values at the point of common coupling. This result is caused by the voltage drop along the conductor over the short distance between point ② and ③ and the low consumption at the end of the network periphery.

		①	②	③
P in kW	cos φ	U in p.u.	U in p.u.	U in p.u.
45	1.00	0,987	1,006	1,006

		①	②	③
P in kW	cos φ, overexcited	ΔU in p.u., in relation to cos φ= 1	ΔU in p.u., in relation to cos φ= 1	ΔU in p.u., in relation to cos φ= 1
45	0.95	0,008	0,010	0,008
45	0.90	0,012	0,013	0,012
45	0.85	0,017	0,021	0,020

Table 2: Measurement results - voltage behaviour at several locations in the network periphery, active feed-in power P = 45 kW, cos φ = overexcited, variable[1]

Table 3 shows the influence of an overexcited power factor on the voltage level simulated at several points in the network periphery. The reference voltage is also assumed at a value of 230 V (1.00 pu). The simulated voltage increases at the point of common coupling under consideration of an overexcited power factor.

		①	②	③
P in kW	cos φ	U in p.u.	U in p.u.	U in p.u.
45	1.00	0,987	1,007	1,007

		①	②	③
P in kW	cos φ, overexcited	ΔU in p.u., in relation to cos φ= 1	ΔU in p.u., in relation to cos φ= 1	ΔU in p.u., in relation to cos φ= 1
45	0.95	0,005	0,007	0,007
45	0.90	0,007	0,010	0,010
45	0.85	0,009	0,013	0,013

Table 3: Simulation results - voltage behaviour at several locations in the network periphery, active feed-in power P = 45 kW, cos φ = overexcited, variable

1 The used generator was only able to feed-in active power with an overexcited power factor.

The voltage behaviour under consideration of an overexcited power factor shows a corresponding trend in measurements and simulations. The deviations are caused by a fluctuating load during the measurements and further external influences like network realisation.

CONCLUSION

The simulations of representative distribution areas (urban, sub-urban and rural distribution) under consideration of different load cases till 2020 and 2030 (considering legal requirements regarding renewables, extensive use of renewables, use of demand side management including high amount of renewables) show the limits of network components (conductors, substation transformers …) in respect of demand and decentralized generation.

It can be observed that the active power is the substantial factor for the voltage change at the point of common coupling as well as at different locations in the analysed periphery network. The reactive power can influence the voltage change only in a restricted way but increases the current load of network components.

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