IMPACT OF LARGE SHARE OF RENEWABLE GENERATION ON INVESTMENT COSTS AT THE EXAMPLE OF AÜW DISTRIBUTION NETWORK

Birgit MEYER
Siemens AG, Germany
birgit.meyer@siemens.com

Dr. Holger MUELLER
Siemens AG, Germany
hmmueller@siemens.com

Robert KOEBERLE
AÜW GmbH, Germany
robert.koeberle@auew.de

Dr. Michael FIEDELDEY
AÜW GmbH, Germany
michael.fiedeldey@auew.de

Prof. Dr. Clemens Hoffman
IWES Kassel, Germany
clemens.hoffmann@iwes.fraunhofer.de

Joachim Bamberger
Siemens AG, Germany
joachim.bamberger@siemens.com

ABSTRACT

In this paper the integration of an excessive share of distributed generation into a T&D system in the southern part of Germany has been examined. Various solutions like conventional network extension, energy storage, load management and controllable smart grid components are compared in terms of number of assets and investment costs.

INTRODUCTION

Increasing numbers of distributed renewable energy sources - mainly wind and photovoltaic generation – integrated into distribution networks result in several challenges for network planning and operation. Excessive share of distributed generation can result in the temporary equipment overloading of cables and transformers, and in an extensive rise in voltage especially in rural networks with large remotely connected renewable installations. The operating voltage of 110% nominal voltage can be violated at low voltage level (LV) and the transformers are temporary overloaded, which yields possible disturbance of customer's appliances due to overvoltages and equipment aging.

In this paper the development of renewable energy integration into a southern Bavarian grid until year 2022 is analyzed. The target of the transmission and distribution system operator Allgäuer Überlandwerk GmbH (AÜW) is to cover 70% of the yearly energy demand in 2022 with 50% photovoltaic (PV) and 50% wind generation. This value is the realistic and feasible potential of renewable generation defined according to the available rooftop space and areas where wind and PV parks can be installed in the AÜW area. Since generation highly exceeds even the peak load of 230 MW in times of high solar irradiation in LV systems, the directions of power flow are reversed and the large power transfer from LV generation via the medium voltage (MV) network into the high voltage (HV) transmission systems results in congestions and limit violations. Network extension projects and high investment costs are therefore envisaged for AÜW. To investigate the consequences into the distribution network of AÜW and to estimate the investment necessary in the future, typical types of low voltage and medium voltage networks from the AÜW system are selected in order to distinguish between the different network characteristics. Several solutions like conventional network extension, storage implementation and smart grid components are implemented and the required equipment is determined in number and investment cost.

SCENARIOS AND NETWORK DATA

Allgäuer Überlandwerk GmbH provides electrical power to about 42000 consumers. The yearly peak load is currently 230 MW. In order to fulfil the 70-50-50 goal described in the introduction 430 MW PV and 200 MW wind generation have to be installed in the grid.
Those figures already show that the generation exceeds the peak load by more than three times in the case of ideal weather conditions. In the case of low load conditions, e.g. on a weekend at the end of April the reverse power flow is even higher. Thus, the power system has to be designed in order to transfer the power to the HV grid or to store it.
The general approach of the study is described in Figure 1.

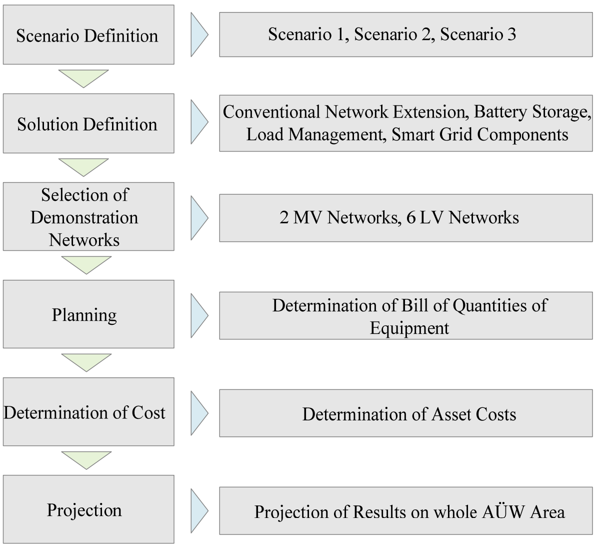


Figure 1: Project workflow

First, three basic scenarios are defined:
Scenario 1 focuses on integrating distributed PV panels on rooftops in the LV grid. Wind generation is integrated into the MV grid. This scenario addresses the current situation in German distribution systems, esp. in the South of Germany.
Scenario 2 identifies areas near highways and railways where larger PV installations are directly connected to the next available MV connection point. Wind generation is again integrated into the MV grid. This scenario addresses a current development in German distribution systems.
Scenario 3 integrates the PV and wind parks directly into the HV grid by connecting them to new and existing substations. This scenario addresses the current development of integrating large PV parks, but suggests a strategic integration directly into the HV grid.

Second, several types of solutions are defined. Those solutions are shown in Figure 2. All three scenarios evaluate the required equipment in case of conventional network extension. Scenario 1 furthermore evaluates the integration of battery storage, load management and smart gird components like regulated distribution transformers, PV inverter control and extended control of substation transformers. Storage integration is also evaluated for Scenario 2.

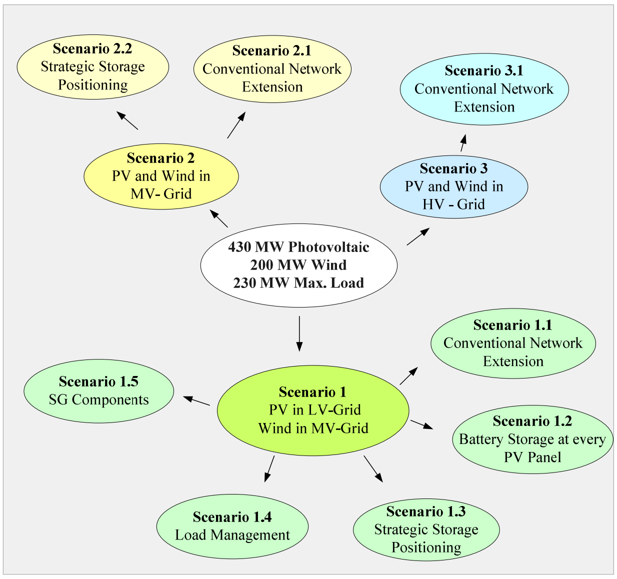


Figure 2: Scenarios to be analyzed

The planning is executed for two representative 20 kV medium voltage networks. The main data of these open ring networks is given in Table 1. Furthermore, six representative 0.4 kV low voltage networks are chosen in order to analyze the influence of a large share of PV infeed on rooftops. The respective data is shown in Table 2.
It can be seen that the number of existing equipment per network type compared to the PV potential is highly variable.

Table 1: Data of two MV networks to be analyzed

MV network	**Immenstadt**	**Wildpoldsried**
Cable	67 km	25 km
Overhead Lines	58 km	42 km
Substation No.	2	1
Ring Main Units	145	86
Potential Wind	17.5 MVA	20.0 MVA
Potential PV	37.6 MVA	23.5 MVA
Peak Load	29.5 MW	5.6 MW
Minimum Load	3.0 MW	0.6 MW

Table 2: Data of six LV networks to be analyzed

Network Type	**City**	**Suburb**		**Countryside**		
Cable [km]	5.5	5.5	4.0	3.4	3.7	1.1
Overhead Lines [km]	0.0	1.5	0.0	0.6	0.6	0.4
Ring Main Units	3	2	1	1	3	1
Households	351	334	40	71	40	24
Potential PV [MVA]	1.3	1.6	1.0	1.0	1.0	1.0

Finally, information on the equipment required for the respective MV and LV is provided. Those results are then projected to the whole AÜW area and total investment costs are evaluated.

SCENARIO 1 - NETWORK 2022

In Figure 3 node voltages for the six low voltage networks when integrating a high share of renewables without supplying network extension in 2022 are depicted. The results are sorted by magnitude and do not provide any information about the location of the node.

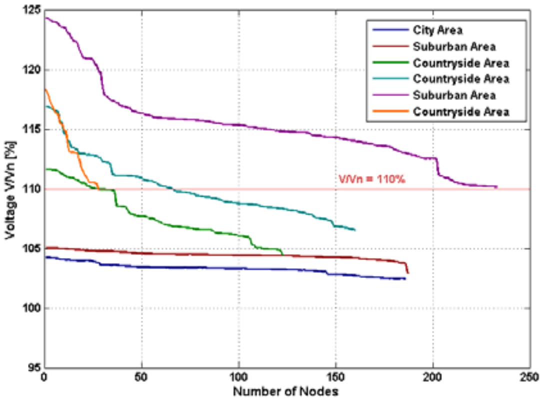


Figure 3: Voltages LV - 2022 without network extension

The main challenge for equipment is the rise in voltage. In the MV grid the values are close to the tolerable voltage of 110%V_n. In LV grids they even rise up to 124% V_n. This is due to the fact, that maximum generation is facing minimum load, see Table 1.
The generated electrical power can not be absorbed by the

grid itself and has to be transported via the MV into the HV grid. Thus, line overloading is only a minor issue generally affecting lines close to transformer substations or ring main units. Furthermore, the power transfer results in overloading of distribution system transformers.
Moreover, the voltage increase in the LV networks is up to 24% V_n. In contrast, the tolerable voltage increase in LV and MV grids defined in BDEW guidelines is 2% V_n [1],[2]. The suggested solutions for all three scenarios are respecting voltage increases up to 3% V_n instead of 2% V_n, transformer overloading up to 150%I_r for oil-immersed "PV-transformers" [3] and line overloading by taking into account the respective reduction factors.

SCENARIO 1 - STUDY OUTCOME

The study outcome in terms of bill of quantities of **Scenario 1.1** is shown in Table 3.

Table 3: Scenario 1.1 - Required bill of quantities

LV Type	**Cable Extension**	**Transformer Extension**
City Area	0 km	-
Suburban Area	2.7 km	4 x 630 kVA, 1 x 500 kVA, 2 x 400 kVA
Countryside Area	2.8 km	5 x 630 kVA, 3 x 400 kVA
MV Type	**Cable Extension**	**Substations**
Wildpoldsried	34.3 km (18.7 km for Wind Integration)	Transformer replacement by 31,5/40MVA
Immenstadt	15.5 km (10.3 km for Wind Integration)	New 20/25 MVA substation

Projecting those results to the whole AÜW area, 341 km LV cables, 390 km MV cables and 1378 ring main units as well as 14 substation transformers with 21 high voltage connection points have to be installed.

Scenario 1.2 and 1.3 analyze the results of storage implementation in the LV grid. In case of cutting e.g. 30% of the maximum electrical PV power [kW] at every PV panel and providing the respective storage capacity [kWh], the rise in voltage is less severe for the following: One or two storage devices cutting 30% of the total feeder PV infeed [kW] have to be strategically placed at the respective ring main unit feeder. This is due to the fact that the storage capacity can be designed so as to meet the critical "hot spots".
In order to respect the defined constraints distributed storage of 10.4 MW and 41.6 MWh size is required for the total LV grids connected to the 200 ring main units (RMU) in the two MV networks. Furthermore, conventional extension of the grid due to line and transformer overloading in MV is still required. In Figure 4, different location of storage devices are shown exemplarily for the countryside network, Wildpoldsried. Strategic storage positioning is implemented by a Siemens developed VBA tool in combination with the network simulation software PSS®SINCAL. Summing up, battery storage can improve local problems but as a single solution is currently not cost-effective.

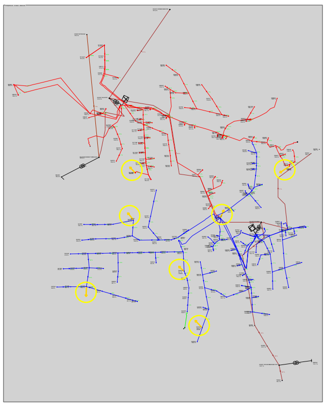


Figure 4: Storage positioning in LV grid "Wildpoldsried"

The results of **Scenario 1.4** show that load management is not effective due to the high infeed versus a relatively low load. The required network extension is in the same range as in Scenario 1.1.

Scenario 1.5 analyses two solutions:
First, the reference value of the main infeed transformer control is temporary changed to 95%-97% V_n. All node voltages, except from 20% in one extreme suburban area, see Figure 3, are within the limits. Even if this solution seems very effective it bears several risks:

- Tap changing takes up to 20 seconds. In case of change in weather the voltages in the grid can drop below 90% V_r.
- Substation transformers are not designed to change their taps several times an hour.
- The change in reference value requires detailed knowledge of the current state of the grid in order not to violate the voltage range limitations.

Second, regulated distribution transformers (rDT) and reactive power control of PV inverters according to [2] are analyzed. Current rDT provide a control range of up to +/- 4.3% V_n. If 5 out of 6 RMUs are replaced by substations with rDT and local inverter control is applied at several points in the suburban LV network displayed in Figure 4, no more conventional extension is required at LV level. Due to the inverter control the PV generation behaves like an underexcited generator in terms of reactive power supply. Thus, node voltages are reduced. Nevertheless, the MV network extension is still required.
The following items characterize this solution:

- Tap changing of rDTs is fast due to a thyristor-based regulation unit.
- PV inverter control can not be implemented as the only solution, since massive reactive power transport increases line losses.

- Solutions on the LV level require communication in order to monitor and control the different network states.

In Table 4 a classification of the effect of the different solutions per LV network type is suggested. It serves as a rough orientation depending on the respective network equipment and generation density.

Table 4: Comparison of solutions for LV networks

Network Type	City	Suburb	Countryside
Classical Planning	--	0	++
Battery Storage(*)	+	+	0
Load Management	++	0	--
Smart Grid Components	+	++	+

(*) Suggestions dependent on battery storage type and size

SCENARIO 2 - STUDY OUTCOME

The results of **Scenario 2.1** are shown in Table 5.

Table 5: Scenario 2.1 - Required bill of quantities

MV Type	Cable Extension	Substation Transformer Extension
Wildpoldsried	37.1 km	Replacement by 31,5/40MVA
Immenstadt	32.4 km	-

By projecting those results to the whole AÜW area, 549 km MV cable and as well as 7 substation transformers with 21 high voltage connection points have to be provided.

Scenario 2.2 examines the possibility of replacing conventional MV network extension via storage facilities. The size of the storage devices is 57 MW and 340 MWh for the two medium voltage grids. Thus, either seasonal storage devices like "power-to-gas" are required, or conventional network extension like line enforcement. The installation of new substations is currently more effective.

SCENARIO 3 - STUDY OUTCOME

The results of **Scenario 3.1** are shown in Table 6.

Table 6: Scenario 3.1 - Required bill of quantities

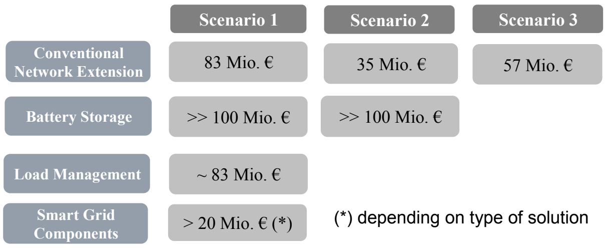
MV Type	Cable Extension	New Substations
Wildpoldsried	9.6 km MV 9.7 km HV	Guenzach 31,5/40MVA
Immenstadt	24.3 km MV 0.2 km HV	Teufelsee 20/25 MVA Seifen 25/31,5 MVA

By projecting those results to the whole AÜW area, 264 km MV cables and 45 km HV cables as well as 21 substation transformers with 42 high voltage connection points have to be provided.

Due to the rural area the HV grid of AÜW is over-dimensioned as for the power to be transported, so no more network extension in the HV grid itself is required.

PROJECTION OF RESULTS ON TOTAL AÜW AREA

The projection of results is done by classifying the respective LV grids by an "Infrastructre Index". This index takes into account the existing system equipment including the number of RMU and line lengths as well as the density and number of households. MV grids have been characterized by their line length. In Figure 5 the investment cost in order to realize the 70-50-50 target are shown. The calculation includes the replacement and further utilization of equipment.



	Scenario 1	Scenario 2	Scenario 3
Conventional Network Extension	83 Mio. €	35 Mio. €	57 Mio. €
Battery Storage	>> 100 Mio. €	>> 100 Mio. €	
Load Management	~ 83 Mio. €		
Smart Grid Components	> 20 Mio. € (*)		

(*) depending on type of solution

Figure 5: Comparison of investment cost per scenario

CONCLUSION

Until now, conventional network extension has been executed for maximum load scenarios. In case of an excessive share of renewable generation this planning procedure has to be adapted to maximum generation scenarios on several days in a year. The outcome of the study shows that:

Future renewable generation should be integrated directly into the medium or high voltage network; given that no further subsidies for other technologies is provided.

More importantly, smart grid components prove very effective but would require communication infrastructure in order to consider the control influence on MV and LV networks. Finally, in order to make the application of smart grid components and battery storage economically viable, they have to be considered in the future German regulation system.

REFERENCES

[1] Technical Guideline BDEW, „Erzeugungsanlagen am Mittelspannungsnetz“, 06-2008.

[2] Technical Guideline VDE-AR-N 4105, „Eigenerzeugungsanlagen am Niederspannungsnetz“, Richtlinie für Anschluss und Parallelbetrieb von Eigenerzeugungsanlagen am Niederspannungsnetz“, 08-2011.

[3] G. Kerber, R. Witzmann, „Loading Capacity of Standard Oil Transformers on Photovoltaic Load Profiles“, World Renewable Energy Congress, 2008.