OPTIMISED OPERATION STRATEGIES FOR ENERGY STORAGES IN LOW-VOLTAGE GRIDS WITH A HIGH DEGREE OF DECENTRALIZED GENERATION

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ABSTRACT

With the assumption that photovoltaic power plants will use all available roof areas in the future, it is not possible to integrate the entire PV potential in today's low-voltage distribution grids. Due to the enormous feed-in of fluctuating electrical power in low-voltage grids by small-scale photovoltaic plants, transformers and cables can reach their loading limits. Moreover, the grid voltage can exceed permissible thresholds. In this paper the maximum feed-in that low-voltage energy distribution networks can be supplied with is being evaluated. The simulations are based on statistically firm reference networks for various settlement types. The results show that it is not possible at present to integrate the entire potential of photovoltaic power plants in the distribution grids. Local energy storages, which save the surplus generation, can be an alternative to grid reinforcement and can be essential for a stable and efficient energy network in the future. In this context the minimal storage capacity necessary to fully integrate the photovoltaic plants is being evaluated. Optimisation methods using weather forecasts can lead to a more efficient usage of energy storage systems and enhance the self-consumption of the local energy generation.

INTRODUCTION

Due to governmental promotion there is a fast growing amount of decentralized power units in Germany. Especially in high solar gain periods, when solar plants feed at their highest power levels into the grid, while the power consumption is fairly low, reverse power flow may occur. With the assumption that small-scale photovoltaic power plants will use all available roof areas in the future, it is not possible to integrate the entire PV potential in today's low-voltage distribution grids. In cases of increasing feed-in of fluctuating electrical power in low-voltage grids, transformers and cables can reach their loading limits. Moreover, the grid voltage can exceed permissible thresholds.
As a consequence grid reinforcement is required to increase the transmission capacity, resulting in additional cabling and higher investment cost, even if the additional grid capacity is only being used for a few operating hours per year. Local energy storages, which save the surplus generation, can be an alternative to grid reinforcement and can be essential for a stable and efficient energy network in the future.

In this paper different scenarios for the optimal usage of energy storage systems in low-voltage distribution networks with a high degree of decentralized generation are being developed and evaluated. The attention is mainly directed towards roof-mounted PV power plants in suburban areas, villages and rural areas, which are most critical for PV feed-in. The simulations are based on statistically firm reference networks for low-voltage distribution grids and various settlement types.
The concept described in this paper uses optimization and forecast methods to reduce the storage capacity and to enhance the self-consumption of the local energy generation at the same time. Self-consumption is very attractive under actual feed-in tariff system.
Therefore estimations of the local energy consumption of the customers and the assumed energy feed-in of the PV power plants can lead to a lower amount of energy that has to be purchased. Due to this the local weather forecasts will be interpreted as well as the feed-in of the decentralized photovoltaic plants of the past few days. Thus also the inaccurateness of the weather forecast and the additional required storage capacity for the balancing energy has to be estimated.
The concept described in this paper can be applied not only on separate storage units; it is rather an independent algorithm that can also be used in electric vehicles or similar with spare modifications.

LOW-VOLTAGE REFERENCE NETWORKS

The simulations are based on statistically firm reference networks for low-voltage distribution grids (Figure 1). These typical networks have similar characteristics to approx. 50 % of real distribution grids (see [1]). Instead of a variety of real networks, only few typical reference networks must be examined in order to obtain reliable conclusions.

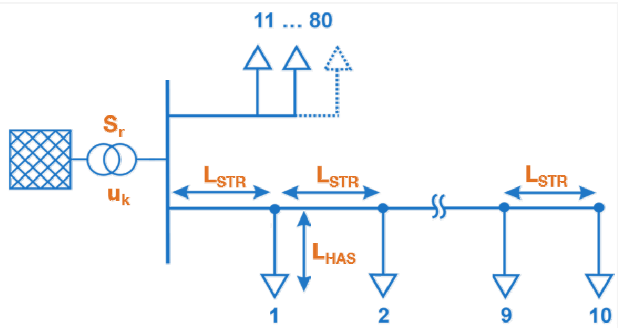

Figure 1: Typical Low-Voltage Reference Network

Former studies showed that suburban areas, villages and rural areas are most critical for PV feed-in. The attention was therefore mainly directed towards roof-mounted PV power plants in these areas. In town centres and industrial regions, the electrical power consumption is assumed to be higher than the possible supply of PV plants. Problems due to decentralized and fluctuating generation are not expected.

POTENTIAL OF ROOF-MOUNTED PV POWER PLANTS

The usable surface area on rooftops of different regions was statistically evaluated in [2]. According to these results the average photovoltaic potential of each settlement type can be estimated as seen in Table 1:

Table 1: Average Photovoltaic Potential

	rural area	village	suburban
residential buildings	13,7 kW_p	12,5 kW_p	8,7 kW_p
agricultural buildings	53,9 kW_p	47,3 kW_p	-

The impact of an increasing decentralized feed-in was examined using a commercial simulation program. At each rooftop a photovoltaic power plant was assumed. Its nominal power was gradually incremented up to the maximum potential.

LIMITS OF GRID TRANSMISSION CAPACITY OF LOW-VOLTAGE DISTRIBUTION GRIDS FOR DECENTRALIZED GENERATION

The theoretical photovoltaic roof potential cannot be achieved with the transformers and cables which are currently installed in the reference grids. Considered limitations of the grid transmission capacity of low-voltage distribution grids are:

- Voltage increases due to fast load and generation changes have to be less than 2 % (or 3 % in the future) of the nominal grid voltage U_N on each connection point [3].
- Conventional limitation criteria:
    - The loading of each transformer is less than its rated apparent power S_{Tr}.
    - Distribution lines can be loaded till their thermal limiting current I_{th}.
    - Voltage increases/decreases are limited to a maximum of ±10 % of the nominal grid voltage U_N.

- To increase the permissible feed-in of PV plants the following measures for extended limitation criteria can be taken into account:
    - Thermal reserves of the transformers can be used till 150 % of its rated apparent power S_{Tr} [4].
    - In case the permissible voltage rise is exceeded, reactive power compensation of the inverters in addition to the active power feed-in could be integrated. By forcing a feeding with $\cos(\varphi) = 0.9_{ind}$ the voltage rise in the grids can be reduced successfully.

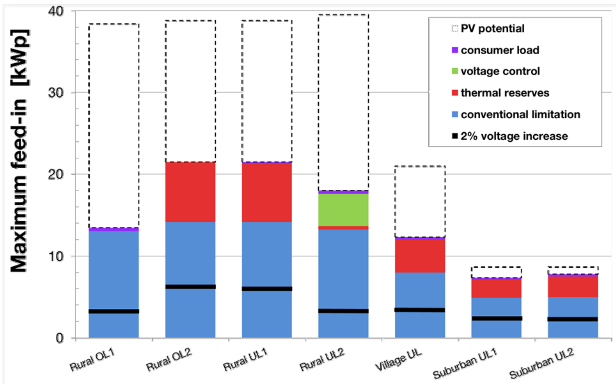

Figure 2: Average Photovoltaic Potential (White) and Limits of Grid Transmission Capacity for Several Reference Grids

The evaluation of the calculations provides the maximum feed-in that each energy distribution network can be supplied with (Figure 2). Depending on the network topology, an average supply of 2.3 kWp (suburban) to 5 kWp (rural networks) can be accepted at each house service connection. With more feed-in the voltage rise at a node exceeds 2% of the nominal grid voltage.

To ideally exploit the existing network infrastructure, the limit of the voltage rise was not considered. The average size of PV plants increases up to 5 kWp (suburban) or 14 kWp (rural) per house service connection without any further efforts. Standard oil-immersed transformers can be overloaded to a maximum value of 150 % of its nominal power in conjunction with feeding of PV power plants, without affecting the aging process. This induces an average plant size that is in some grids approx. 1.5 times the original value. Furthermore, the permissible feed-in increases if the consumer load of about 0.2 kW to 0.5 kW per house service connection is considered.

These results show that it is not possible to integrate the entire potential of photovoltaic power plants (white bars in Figure 2) in the low-voltage distribution grids at present. The distribution network has to be strengthened to increase the permissible feed-in of PV plants.

DECENTRALIZED ENERGY STORAGES

Local energy storages, which save the surplus generation, can be an alternative to grid enforcement and can be essential for a stable and efficient energy network in the future. Energy storage can help to keep the balance between energy supply and demand. Furthermore it can contribute to limit the losses in the system by reducing the transmitted power. These storage systems have to be placed near to the power generators to optimize the load flow.

Development of a simulation tool

A simulation model was designed using minute-based household energy consumption from standard load profiles and real PV production data for a whole year (for seasonal and short-time production fluctuations, e.g. cloud-drift). Energy storages were implemented with all necessary electrical parameters of typical batteries. On every house / generation unit an energy storage is supplemented. All storage units are simulated with homogeneous parameters and sizes.

Variable parameters of the simulation model are the maximum battery sizes (power and capacity), PV system sizes (according to the above given PV potential), the given electrical structure (i.e. typical reference grids) and used control strategy for the storage system.
All loads, generation and storage elements were simulated together with the electrical structure of the reference grids in a commercial load flow calculation program in several scenarios for a whole year. The overall aim of the control strategy is to meet the given limits of grid transmission capacity (see above).

The optimum capacity of a storage system to fully integrate the photovoltaic plants is being calculated for each reference network, scenario and PV penetration. Different approaches are made using optimization methods to reduce the required storage capacity and to enhance the self-consumption of the local energy generation at the same time.
Therefore estimations of the local energy consumption of the customers and the assumed energy feed-in of the PV power plants can lead to a lower amount of energy that has to be purchased. Local weather forecasts will therefore be interpreted as well as the feed-in of the decentralized photovoltaic plants of the past few days.
Depending on the existing energy reserves and the assumed load in the storage units the discharge power is varied.

Storage demand

As a result of the optimised control strategy the necessary storage units can be dimensioned smaller. According to these estimations, the power units of the storages are best chosen in the range from 60 % to 85 % of the respective PV plant size. Storage capacities for about 2.5 to 4 full load hours are sufficient for the best exploitation.

Higher charging rates on days with low feed-in help to increase the efficiency of the storage systems. Even on these days the local demand can mostly be covered with the help of the existing storage reserves. Energy delivery from higher voltage levels to low-voltage grids can be reduced at about 500 kWh to 3,000 kWh per year and household.

WEATHER FORECASTS

A new model was designed using global weather data. With this model the expected irradiation and the resulting PV feed-in for one to three days in the future were calculated.

Forecast errors

The quality of the forecasts depends highly on the forecasting method, the data quality and the forecast horizon.
Comparing with measured irradiation data, the forecast system provides quite exact results on clear-sky days. On cloudy days the predicted feed-in of the PV power plants is often estimated higher than the measured data. This error results in inaccurate raw data of the global forecast model. Compared to the measured data the average error of the weather forecasts for the next day is 32.5 %. The relative forecast error decreases with rising maximum feed-in predicted for the following day.

Forecasts for more than one day increase the error, e.g. forecasts for two days imply an average error of about 39 %, and 47 % for three days.
These results match with [6].

Storage demand for balancing forecast errors

In these studies, the storage system can also be used for balancing forecast errors. With the above identified average errors, the storage demand increases only at about 10 %. This value is depending on the PV penetration in the low-voltage grid. The higher the installed PV plant size the lower the relative impact on the storage capacities. Forecasts for more than one day do not further affect the size of the storage systems.

By considering weather forecasts the self-consumption of local energy generation can be further increased at about 600 kWh per household and year.
The power units of the storage systems do not significantly increase by considering forecast errors.

CONCLUSION AND OUTLOOK

The rising share of solar power in the low-voltage grids will lead to the point where the electricity that can be generated from solar power plants will at times exceed demand in the grid.

Technically it is not a problem to dump the electricity and make sure the electricity provided to the grid does not exceed demand. A way out of this is the storage of energy. Storage allows energy shifting from peak production to peak load and thus maximizes local self-consumption of regenerative generation. Further benefits of energy storage for PV power plants are back-up against outages/interruptions.
With the storage methods shown in this paper higher reliability, increased and controllable power quality and less problems in low voltage grids can be achieved. Thus, the capability to accept, integrate and transmit higher quantities of decentralised generated power can be improved. Thus also the inaccurateness of the weather forecast can be balanced.

According to these results a weather forecast system is highly recommended for the objective of a high share of self-supply with renewable energies. Especially by considering days with low PV feed-in an efficient exploitation of the investment in energy storages is assured.

The technology described in this paper is currently under development and being further optimized. In the next working steps the costs-benefits of using energy storages and different forecast horizon are being analysed.

REFERENCES

[1] Georg Kerber, Rolf Witzmann: "Statistische Analyse von NS-Verteilungsnetzen und Modellierung von Referenznetzen", ew, vol. 107 (2008), nr. 6, pp. 22-26
[2] Martin Lödl, Rolf Witzmann: "Abschätzung des Photovoltaik-Potentials auf Dachflächen in Deutschland", 11. Symposium Energieinnovation Alte Ziele - Neue Wege, Graz/Austria, 10.-12.2.2010
[3] "Richtlinie zum Anschluss und Parallelbetrieb von Eigenerzeugungsanlagen am Niederspannungsnetz", VWEW Energieverlag, Frankfurt am Main, 2001
[4] Georg Kerber, Rolf Witzmann: "Loading Capacity of Standard Oil Transformers on Photovoltaic Load Profiles", World Renewable Energy Congress X, Glasgow/Scotland, 2008
[5] Mirko Bodach: „Energiespeicher im Niederspannungsnetz zur Integration dezentraler, fluktuierender Energiequellen“, Technische Universität Chemnitz, 2006
[6] Elke Lorenz: „PV Leistungsvorhersage für eine effiziente Netzintegration“, VWEW-Fachtagung Photovoltaik und Netzintegration, 2008