OPTIMIZING LOW VOLTAGE DISTRIBUTION NETWORKS WITH HIGH FEED-IN OF RENEWABLE ENERGIES

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Scope of the project

The rising share of decentralized photovoltaic systems leads to increasing requirements for network operating resources and the management of low voltage networks. Several flexibility options are available to supply system services like voltage control and reducing the overload of resources. All flexibility options are characterized by a range of various technical and economical parameters. These parameters determine an option's role in the technical model and allow different options to be combined in a cost function to achieve low-cost-solutions. The aim of this project is therefore to evaluate and compare different combinations of flexibility options for application in low voltage networks. In particular, battery storage technologies are compared to evaluate the „best-available"-technology for different purposes.
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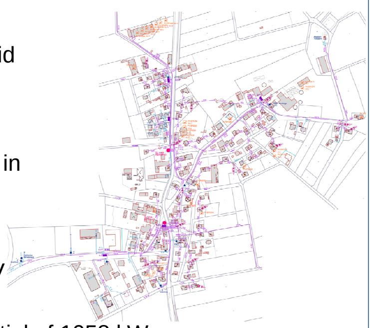
Approach and Results

Test networks and solar roof potentials



Two different test networks build a sound basis for the grid simulation. Roof potential measurements deliver input parameter for setting the boundaries for PV expansion in the reference networks.
The network plan on the left side shows the test network Hittistetten with 1162 kWp PV installed on 59 roofs which have an estimated roof potential of 1058 kWp.

Battery technologies and applications

Different battery technologies are compared for application within households to evaluate the "best-available"-technology for increasing self-consumption. The evaluation includes techno-economical data as investment costs, efficiency, P/E ratio for Lithium-Ion, Lead-acid, High-Temperature (NaS/NaNiCl$_2$)and Redox-Flow-batteries. The data has been selected through intensive literature research.
Using an advanced load profile simulator [4], 15 distinct household load profiles were simulated in 6 min resolution for ten representative days of the year 2012. These "net-grid-injection" profiles were then combined with different PV (0, 5, 7.5, 10 kWp) and battery (0, 5, 10 kWh) installations, for a total of 150 pre-computed load profiles. A series of algorithms were subsequently developed to analyze the related benefit potential of delayed storage charging to target instances of excess PV production depending upon the grid injection cap [1].

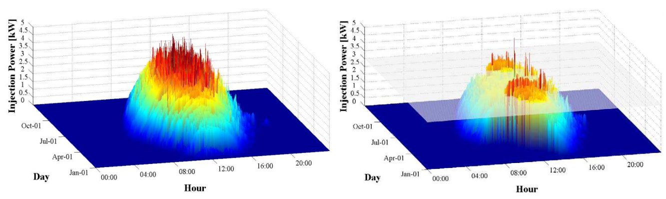


Figure 1.1 Profile Grid Injection Duration Curve without and with delayed charging.

Network expansion

Network operating resources are technically simulated within the network simulation tool Power-Factory (DIgSILENT).
Cost parameters for the different types have been taken from [2] and [3], and validated by discussion with the cooperative partner SWU Netze GmbH.

Grid simulation and Optimization

Methodical Approach:

Typical standardized low voltage grids for rural, village and suburban settings [3] are simulated using DIgSILENT PowerFactory. Load profiles for the households are assigned randomly from the pre-generated load profiles, such that prescribed PV penetration rates and battery installations are fulfilled.

An Evolution Strategy is then employed to optimize grid costs, taking into consideration all grid stability requirements. The results are then validated with real data sets from two different test networks within the low voltage network of SWU Netze GmbH. The optimization routine is indicated in the flowchart (Figure 2.1) .

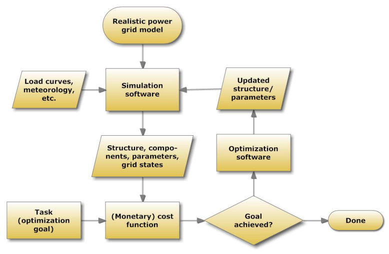


Figure 2.1 Optimization routine.

First results:

Local (household) level: Starting from the PV generation, the local consumption is subtracted and the storage operated with delayed charging. Delayed charging is optimized to reduce injection above a defined „grid injection limit". The resulting grid-injection duration curves are displayed in Fig. 2.2.

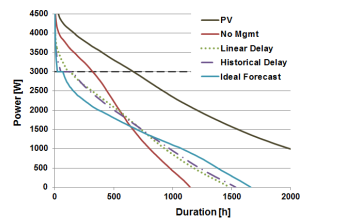


Figure 2.2 local duration curve for injected power [1] with delayed charging variants to reduce peak injection.

Grid level: a network structure typical for a village in Germany with 57 household [3] is analysed. Applied randomly to these households is one of 15 different household load profiles [4]. The effects of PV injection, the use of storage and „peak shaving" onto the network voltage levels are shown in Fig. 2.3. The following simulation steps are used:

- The annual local „net-grid injection" profiles are calculated in MATLAB at a 6-min resolution with the 15 profiles and varying capacities of PV and storage; optimized delayed charging being applied to storage.
- Extracted from the resulting full year profiles is a single selection of 10 days for all profiles, which after scale-up show a similar duration curve as the 365 days. This is achieved through a suitable mix of days, seasons and weather conditions (cloudy, full sun-shine and cloudy morning).
- The „net-grid injection" profiles of those 10 days are fed into the grid analysis tool Power-Factory
- The occurrence of voltages of all nodes are sorted by magnitude and plotted as voltage duration curves of Fig. 2.3 and 2.4.

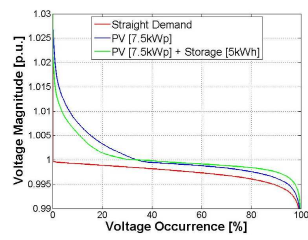


Figure 2.3 duration curve of the observed voltages for 57 households without PV, with PV and with storage.

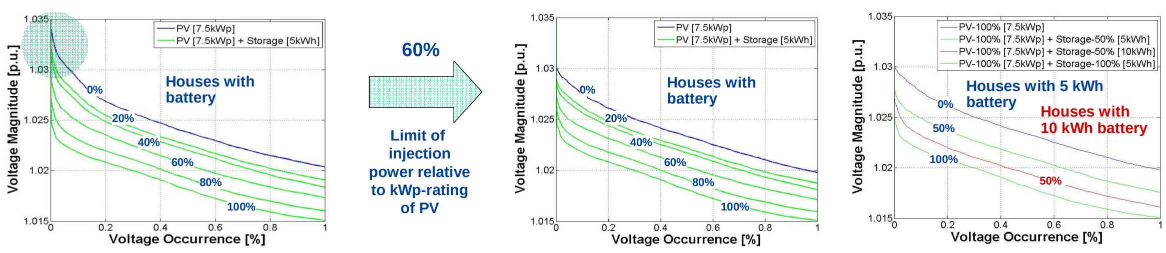


Figure 2.4 details of duration curve with different levels of storage penetration and with „peak shaving".

An example optimization run is shown in the graph below (Figure 2.5) . Evolution strategies rely on a population of grids, each member of which is evaluated with a cost and stability based fitness function. The best of these grids are selected as parents for a new generation of grids, which is spawned by mutation and recombination. This graph shows the development over an optimization run of average fitness and spread of the population, as well as the best grid found.

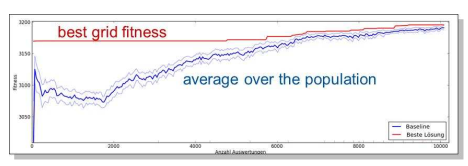


Figure 2.5 Example optimization run.

Conclusion

The aim of the study is to determine technically and economically optimized combinations of flexibility options for different shares of PV in low voltage networks. The poster presents the approach and a snap shot of first results. Application of delayed charging increases the usefulness of local storage in terms of grid relief. Capping remains necessary to avoid excessive voltage levels. An algorithm to optimize the network based on evolution strategies and guided by the fitness of populations is implemented and applied.

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