Grid capacity issues with distributed generation *A German case study*

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***Abstract*—The purpose of the project was to investigate how a high penetration of solar power (PV) affects the electrical grid on a distribution level concerning active power and investigate different measures for avoiding overloads and overvoltages, using a simulation model and grid data received from E.ON. The studied measures are battery storages of different technologies, load shifting and biomass power plants.The simulations were done in the simulation tool DIgSILENT PowerFactory.**

The results showed that implementation of battery storage and load shifting will balance the grid and less power will be delivered to or taken from the transmission grid. Load shifting is very hard to analyze and utilize but assumed to have low capital costs. Load shifting in households is also a very immature technology. Storing energy is the most effective measure for balancing the active power because of the valuable property to store energy and use when it is needed. But the costs of battery storages are high even if no costs of power electronics were included and also the total energy losses will be higher. Implementation of a 10 MW biomass power plant will balance the active power while low production of PV and high demand.

***Index Terms*—Power systems, energy storage, PV, load shifting.**

I. Introduction

CLIMATE change is more evident than ever as reflected in The European Union environmental directives which say that the carbon emission must be reduced by 20% and 20% of the used energy must come from renewable energy sources until 2020. German government has also made a decision to close the nuclear power plants until 2022 and in long term replace them by renewables.

Since the installed PV capacity is not homogeneously spread across Germany, some regions are already experiencing a very high PV penetration of more than 200 kWp km^2 compared to the nationwide average of 39 kWp km^2. In these regions, the increasing power feed-in may result to high local voltage magnitudes which might give rise to demanding grid reinforcement actions, causing in an increment of the whole PV grid integration expenses in Germany [1]. One of the biggest challenges in the reconstruction to an energy system with a larger part of renewable energy is the expansion of both the distribution grid and transmission grid. To be able to transfer large amount of energy from regions with energy excess to regions with deficit, large investments are needed to enhance the transmission grid.

II. Grid capacity measures

A. Energy Storage

Energy storage means an energy conversion process that converts different forms of energy (e.g. chemical, thermal, mechanical energy) into storing forms of different media. For energy storages, when needed, the stored energy can be converted in electrical energy and fed in to the grid.

1) Li-ion Battery Storage: Li-ion batteries are primarily used as medium-term (a few hours) storage, but can also be used as short-term (a few minutes) storage. The Li-ion batteries are the most important battery storage technology in the portable application area (cell-phones, laptops). In the US, the Li-ion battery storage is already used in some areas where the grid is very weak [2].

2) Lead-Acid Battery Storage: Its mainly used in short-term (a few minutes) and medium-term (a few hours) energy storage applications. The lead-acid battery technology has the largest installed capacities all over the world (mostly due to car batteries) and many existing have been in operation for up to 20 years [2].

3) Vanadium Redox flow battery storage: The active material in the redox flow batteries is made up of salt and dissolved in a fluid electrolyte which is stored in tanks. In vanadium Redox flow batteries, the electrolytes are based on Vanadium. The higher required energy density is the bigger the size of the tank needs to be. The main advantage of the Vanadium Redox Flow battery is its independent scaling of power density and this type of batteries offers a big potential for relatively cheap weekly storage [2].

B. Load Shifting

The process of shifting loads from peak periods to off-peak periods is called load shifting. The main purpose for the customer is to take advantage of the low electricity price in the off-peak hours when using heavy load consumption units. Load shifting can be implemented in a number of ways. For example using Demand Response Programs which shifts loads by controlling the functions of e.g. refrigerators, water heaters and air conditions at peak hours. Energy storage is also an important feature of load shifting, for example pumped hydro facilities pumps water from low reservoir into higher one during off-peak hours, and then reverses the flow during peak hours to generate electricity. In the simulation model it is assumed that 50 % of the households have one of the controllable loads available for control.

C. Biomass Power Plant

Biomass power plants generate carbon neutral[1] electricity from renewable organic waste that would otherwise be dumped. The generated energy is called *bioenergy*.

[1]Carbon neutral is a term used to describe fuels that neither contribute to nor reduce the amount of carbon dioxide into the atmosphere [3]

Its unlike the other renewable energy sources like wind and solar which only produces electricity when the wind is blowing or the sun is shining. The biomass power plant implemented in the simulations i producing 10 MW electricity.

III. Simulations

The goal of the simulations is to with help of implemented measures be able to not exceed the voltage limits set by grid codes. The grid model is medium-voltage to low-voltage model. In the model three of the low-voltage grids have detailed models, where every household is represented by a load. The load for the low voltage grids that are only represented as load or a load combined with a PV generator has been dimensioned after the size of the transformer that connect the low-voltage area to the medium-voltage.

The grid model is treated as an isolated medium voltage grid with only one connection point to the transmission grid. The connection contains two transformers with a transfer capacity of 75 MVA.

Two scenarios have been investigated. Scenario 1 describes the current situation in the area and scenario 2 describes a future situation where the PV installation in the area have increased with 30%.The increased PV penetration has been done in the low voltage areas with low production from PV For every scenario worst case load and production profiles have been chosen. The most interesting worst case scenarios are High load & Low Production and Low load & High production.

IV. Results

Battery nr	kW
1	130
2	125
3	300
4	120
5	120
6	70
7	50
8	70
9	30
10	60
11	20
12	50
13	70
14	30
15	1100

TABLE I
Installed batteries in the grid to avoid overloadings on transformers and cables. The batteries were dimensioned from the High Production & Low Load profile.

Figure 1 shows the loading of the transformers in the grid model between low voltage areas and medium voltage areas (secondary substation) for the High production & Low load profile. 14 of the transformers have a loading over 100 % for the base case, as the batteries are dimensioned to prevent overloading all the overloaded transformers are reduced by the battery implementation. The load shifting implementation reduces 7 of the overloaded transformers. Some of voltages in grid are higher than 10 % above nominal voltage. They are

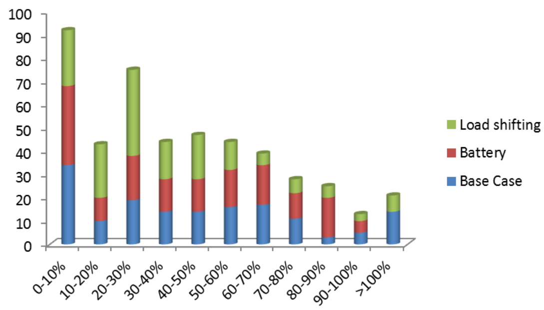

Fig. 1. The loading of the transformers for base case, battery and load shifting.

all located in the low voltage areas and are reduced by both the battery and load shifting implementation. Figure 2 shows

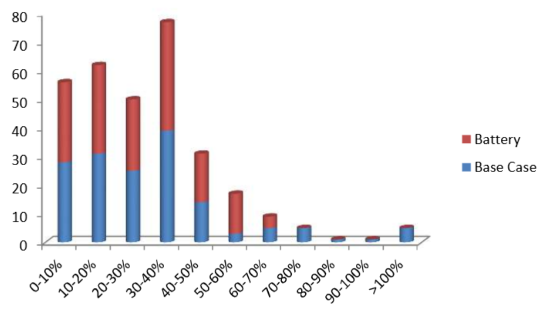

Fig. 2. The loading of the transformers for with batteries implemented.

the loading of the transformers at secondary substation in the grid for the High production & High Load profile. Despite the high load, five transformers are still overloaded. They are all reduced by the battery implementation. The batteries reduce the loading of the transformers such that none are more loaded than 70% because all the batteries are charging with full capacity.

Following figures shows a 24 hour simulation with the base case (red) and a case with a combination of all the measures used (blue). Figure 3 is a sunny day and figure 4 is for a cloudy winter day. In the figure 3 the arrows illustrate which measures that create the difference in power delivery between the base case and the mixed combination case are used. For

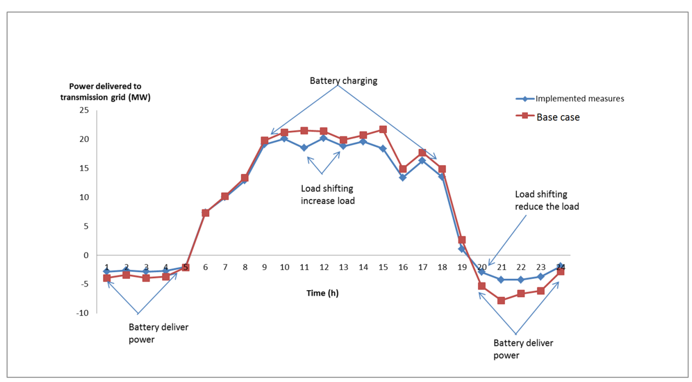

Fig. 3. 24 hour simulation for a sunny day, base case red and combination of different measures blue.

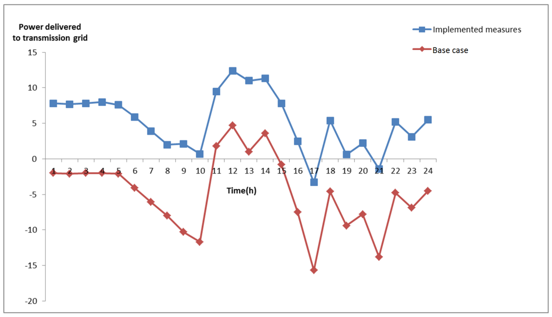

Fig. 4. 24 hour simulation for a winter day, base case red and combination of different measures blue.

the summer day there are no bigger differences between the two graphs. But it is enough to prevent the transformers to not be overloaded. The load shifting also reduces the highest production peaks. The simulation also shown that transformers were overloaded for long time during a day with a lot of PV production, even if the loads were hourly averages.

V. Conclusion

Large integration of PV into the distribution network will lead to high voltages and overloading, especially in the low-voltage side and the secondary station. At the primary station, the results from the case study, showed no signs of problems related to grid capacity issues.

From a DSOs point of view, the easiest and most profitable to implement larger energy storages close to the transformers and to be able to avoid over loadings, it should be done at the low-voltage side. It is difficult to compare the cost of battery storage and load shifting where there are no costs for implementation of load shifting available yet. Battery storages and load shifting does not fill the same purpose. With a 30% increase of PV, the voltages may increase in the grid and then also in the medium-voltage areas. If the increment is carried out in areas that already have a high PV integration, then over loadings will also arise for more transformers. Either the increment of PV should be limited, grid strengthening carried out or battery storage should be implemented to utilize the produced electricity. Battery storage provides unlike from grid reinforcement effect on voltages but may be needed in large capacities. How battery storages should be dimensioned, economical aspects should also be taken into account and that have been outside the scope of the Thesis.

Next follows some advantages and disadvantages regarding each technique based on simulations, interviews and literature studies:

A. Battery Storage

- Efficient for power balancing purposes
- Implementation of battery has higher costs than to strengthen the electrical grid.
- Might lead to higher revenues in the spot market.

B. Load shifting

- Works to partially reduce the problems of overloading.
- Uncertainty about how the financing and the implementation should be realized.
- Unproven

C. Biomass power plant

- Possibility of controllable power generation
- High capital costs

References

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