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Utilising a cluster-based power optimisation in micro grids

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Abstract. A cluster-based power optimisation is an effective solution to improve the overall performance of renewable energy systems in a low voltage grid. The system, combined with several decentralized storages could increase the possible amount of integrated photovoltaic systems in a specific low voltage grid. Furthermore, the optimisation algorithm could shift energy from the times points with very high generation to high load in the grid.

Key words
Intelligent grids, load management, supply management, energy management, Low voltage grids,

1. Introduction

With the increasing of renewable energy contributions in the electricity generation, new requirements of low-voltage grids should be considered. These days during times with large amounts of power generation combinations can occur, which allow a backflow of the energy from the low-voltage to the medium voltage grid. This leads to a higher utilisation of the operating system.
The system should be able to use produced renewable energy as much as possible so the conditions regarding to effectiveness and legal requirements are achieved [1]. Moreover, the system should not increase the grid strain.

These two conflicting objectives have been achieved by a power flow optimisation of the low-voltage grid. Hence, the supply and consumption could be controlled which is resulted in lowering the electrical strain of the grid. Furthermore, the optimisation should be able to reduce energy losses between supply and consumption [2].

The solution of the objectives has been written and added to the MATLAB-based program named MATPOWER[3]. The information about the grid structure and the load flow signals of every connected grid are such requirements of the program. The signal determines for every participant, which load it should require or supply. Thus, load supplying or demand can be determined through the signals.

For this calculation the program divides the grid into several smaller parts, which are called clusters [4]. The optimisation algorithm should balance the supply and demand of power in the clusters so the losses are minimal. Furthermore, depending on the situation, the voltage level of nodes should be decreased or increased in order to avoid the limitations of grid utilisation.

The optimisation algorithm uses the load and the grid data for the calculation. The load data contains the values of node loads for the specific points of time. The load of the nodes is determined with the information of the amount of people living in the house and the assumption of their daily usage [5]. The second data contains all the nodes of the grid. In addition, it includes the maximum voltage level of each node. Moreover, the data includes the connections between the nodes. The connections are defined by their start and ending node. Additionally, the data list the resistance, inductivity of the connection line and the rated current. This kind of data contains the position and capacity of the grid storages as well.

2. Different Supply Scenarios

Data about urban areas with a high amount of installed photovoltaic systems do not exist yet. Hence, some assumptions have to be included in the optimisation because of such a situation. The prediction of the possible supply of photovoltaic energy in the grid depends on the geographical environment where the grid is placed. It is complicated to predict the specific development of the photovoltaic systems in the area of the grid. Then, the photovoltaic energy is determined through the possible surface of photovoltaic systems in the vicinity of the grid.

The following example uses the low voltage grid of a part of the city named Chemnitz in Germany. Possible places for photovoltaic systems in an urban area are mostly the roofs of buildings. Every other space is in most cases already occupied. It should be mentioned that in the example, photoactive streets or pavements or other additional systems are not considered. In this example the size of the roof surface of all buildings which are connected to the grid, have been remarked. A classification of usual building types is used in order to determine possible places, including information about roof leaning and other characteristics. Aerial photographs have also been taken and additionally an empirical factor has been included for effects like shadowing, module form and other reducing influences. The result is the size of the usable surface of the building. The value is used to calculate the specific generation power of the building. For this example a typical power characteristic of a photovoltaic system was assumed for all buildings in the area. It is resulted in a matrix which can be used to calculate the generated power for every insolation. The used data of insolation for the calculation is selected from a one year measurement in this area. The amount of generation is set off against the consumption value of the building.

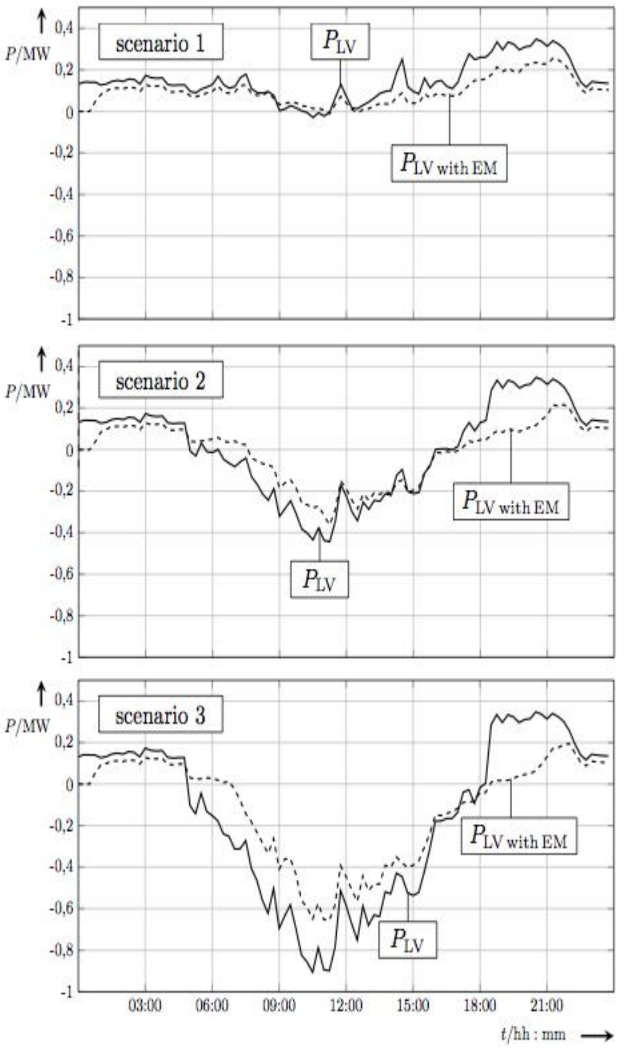

Fig. 1. daily progression of the power of the low voltage grid transformer without energy management (P_{LV}) and with it (P_{LV} with EM) in three different scenarios of photocoltiac system integration

Fig. 1 shows the results of the optimisation for one day in summer. In addition, it shows the results for three different states of photovoltaic energy integration. In the first diagram 15 % of all buildings have the photovoltaic system on the roof, which has occupied the maximum possible space. The second diagram represents 50 % and the last one depicts a saturation of 85 %.

In the first diagram the effect of electrical power generated is low. There is just a small reduction of the power around midday. The second and the third diagram display a greater effect of the photovoltaic power generation on the grid.

The diagrams also show the effects of the optimisation. The size of the storage is 10 kWh for each node. In the first diagram the optimisation algorithm reduces the load slightly during the day. In the evening, however, the load has been noticeably decreased. In the second diagram the optimisation algorithm declines the generated power, which has to be transmitted to the higher voltage grid during the day. In the evening, the load peak has considerably been fallen down. Consequently, the third diagram illustrates even a stronger relative effect, although the absolute value of generation and loads are higher. The result of the optimisation algorithm is a shifting of the energy from the midday to the evening. This is a very useful approach because the grid does not need to exchange a lot of supplied or demanded power with the higher voltage grid.

3. Composition of the grid load

In order to explain the effect of the optimisation more, the following example demonstrates the modification, which occurs to the generation and consumption of the grid. The scenario is identical to the second scenario of Fig. 1.

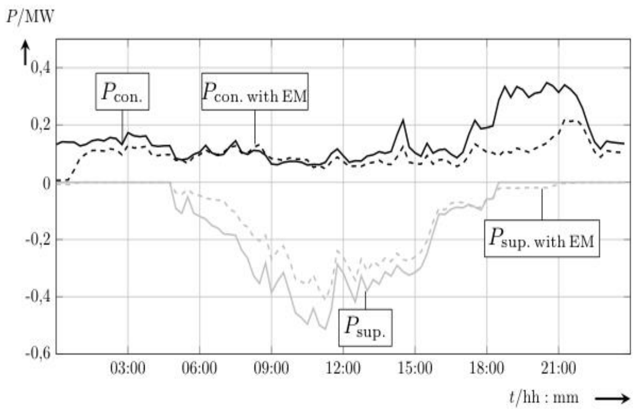

Fig. 2. daily progression of the consumed power ($P_{con.}$) and the supplied power ($P_{sup.}$) for the second scenario with and without the energy management

Fig. 2 shows the load and the generated power of the grid with and without the optimisation. At the beginning of the day, the optimisation algorithm reduces the load of consuming nodes with the rest of the stored energy from the last day. After consuming the energy, first, the optimisation algorithm reduces the load slightly. As soon as the generation reaches to a certain amount, the load of the consuming nodes is slightly increased by the algorithm. At this time the storages are charged. After the midday the optimisation algorithm reduces some load peaks. In the evening the load of the consuming node is drastically reduced till the total discharge of the storages.

The generation shows an adequate effect. After sunrise the optimisation algorithm reduces the amount of the generated power in the grid. The storages are charging during this time. Some storages supply energy to other nodes of the grid after sunset. The utilisation of the grid generation and consumption is decreased as well. Some nodes increase their load in order to consume the generated energy of attractive nodes, which is generated with a high power. Mostly in the evening, some nodes supply energy for active other nodes, which need to consume energy. The amount of stored energy during the day is as high as the amount of provided energy in the evening.

4. Variation of the storage sizes

The storages of the nodes are important for the result of the optimisation. Without them the optimisation algorithm would only shift the power from the supplying to the consuming nodes. Every generation or load, which is above or under the possible distributed power, would be cut off from the optimisation. The reduction of the generated power is prohibited by some laws. This problem could be solved with the adjustment of the specific laws, if it is necessary. The downregulation of the consumption is not possible. It would create a state of not supplying energy for some users of the grid. It is important to avoid this situation. Therefore, an optimisation without storages is useless most of the time. The storages provide a range where the optimisation algorithm could work. Furthermore, they permit the system to shift the generated energy from the midday to the evening consumption.

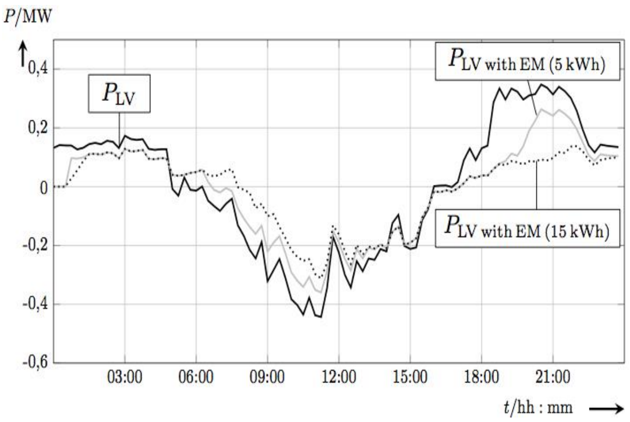

Fig. 3. daily progression of the power at the low voltage transformer (P_{LV}) without energy management and with energy management including different storage capacitys ($P_{LV \text{ with EM } (5 \text{ kWh})}$, $P_{LV \text{ with EM } (15 \text{ kWh})}$)

Fig. 3 depicts power in the grid with two different storage capacity at each node; 5 kWh and 15 kWh. The scenario is also identical to the second scenario of Fig. 1. Case 1 shows how the generated power is reduced during the day. During the first hours in the morning, in this case, the generation is reduced to transmit less power to the higher voltage grid. With one 15 kWh storage at every node, the generated power is plainly higher and the process continues approximately till midday.

At the beginning of the evening, case 1 reduces the power, which the higher voltage grid has to provide. But during the process the charge of the storage is used up. The consumed power increases drastically during the later hours. In case 2 the capacity of the storages is big enough to reduce the complete spike in the evening. Afterwards, the remaining charge is sufficiently large enough to decrease the grid load further.

5. Different amount of storage systems

The effectiveness of the optimisation algorithm depends on the amount of nodes, which follow the guideline of the optimisation. In addition it is related to the number of connected storages at the same time. The following example shows the influence of the amount of storages in the grid. The levels of saturation of storages are 30 %, 50 %, 70 % and 100 % of all nodes of the grid. The scenario is also identical to the second scenario of Fig. 1. The capacity of each storage is 10 kWh. The nodes, which have storage, have randomly been determined for each case.

Fig. 4 and Fig. 5 illustrate the effect of the four different cases of storages in the grid. In the case, where 30 % of the nodes have storage, the amount of power that is transmitted to the higher voltage grid, is slightly reduced. In the 50 % and 70 % cases the power generation is further reduced during the daytime. In the evening the reduction of the load depends on the amount of storage, which is available. The high amount of storage in the cases of 70 % or even 100 % leads to a peak reduction. Although, lower saturations have an effect on the load reduction as well.

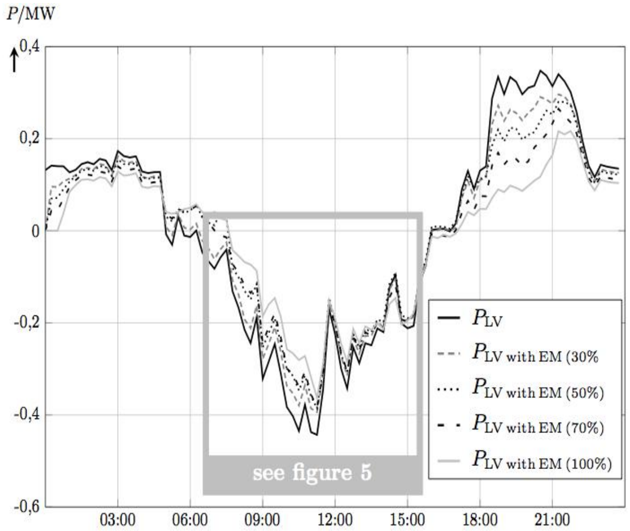

Fig. 4. daily progression of the power at the low voltage transformer (P_{LV}) without and with energy management including different percentages of integrated storages systems in the grid ($P_{LV \text{ with EM } (30\,\%)}$, $P_{LV \text{ with EM } (50\,\%)}$, $P_{LV \text{ with EM } (70\,\%)}$, $P_{LV \text{ with EM } (100\,\%)}$)

The amount of reduction of the peak depends on the distribution of storage and generation. In several cases some clusters have an amount of generated or demanded energy, which is clearly higher than the potential storage capacity. These situations result in an ineffective distribution between the nodes of the cluster. The optimisation algorithm is very ineffective in these cases. Apart from this situation this situation, the optimisation algorithm provides useful results for the clusters with an approximate equal number of generators and storages.

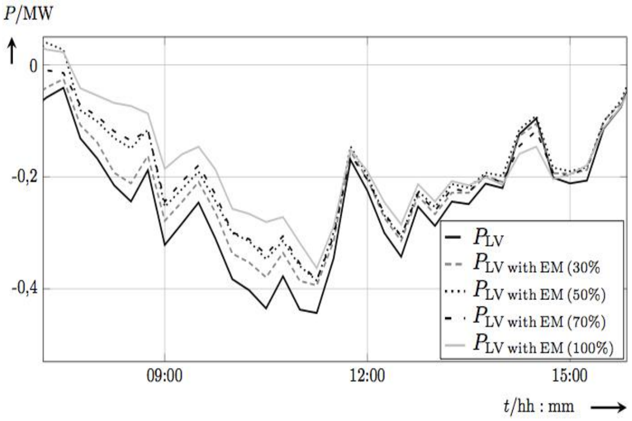

Fig. 5 daily progression of the power at the low voltage transformer (P_{LV}) without and with energy management including different percentages of integrated storages systems in the grid ($P_{LV\text{ with EM (30 \%)}}$, $P_{LV\text{ with EM (50 \%)}}$, $P_{LV\text{ with EM (70 \%)}}$, $P_{LV\text{ with EM (100 \%)}}$)

6. Conclusion

The developed cluster-based power optimisation is a good method to manage the differences between supply and consumption in a certain electrical grid. The subdivision of the grid nodes in several groups, which are appropriate to work with together, enables the system to decrease the peaks of generation and consumption power for the entire electric grid effectively.

In the case of very high extension of photovoltaic energy, the optimisation algorithm is capable of reducing the generation peak drastically compared to decentralized storages. The amount of photovoltaic power that could be integrated in the current electric grid is increased in this way. Furthermore, the algorithm decreases and saves the power, which would be required in the evening from the higher voltage grid. Therefore, the system could increase the overall efficiency of unsteady energy suppliers like photovoltaic systems.

The effectiveness of the optimisation algorithm depends on several aspects. It is fluctuated due to the amount, the power and the distribution of the generating systems. Also, the algorithm combined with certain amount of storages would deliver more reduction of power peaks in the grid. Although there is a variation in the optimal capacity and saturation for every electrical grid, a higher amount of decentralised storages with a normal capacity of 10 kWh would lead to a very promising result.

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