DECONGESTION OF THE DISTRIBUTION GRID VIA OPTIMIZED LOCATION OF PV-BATTERY SYSTEMS

Jurgen VAN RYCKEGHEM
Ghent University – Belgium
Jurgen.VanRyckeghem@Ugent.be
Johan RENS
North-West University – South-Africa
Johan.Rens@nwu.ac.za

Thijs DELERUE
Ghent University - Belgium
Thijs.Delerue@Ugent.be
Jan DESMET
Ghent University - Belgium
Janj.Desmet@Ugent.be

Agknaton BOTTENBERG
Ghent University - Belgium
Agknaton.Bottenberg@Ugent.be

ABSTRACT

In order to achieve the energy targets for 2020, further integration of RES (renewable energy sources) is required. Hence, the need to investigate possible solutions to achieve a reliable network without loss of production. An optimization method is defined for integrating a residential solar-battery system. Based on the results of this research, it could be concluded that small battery storage systems of ± 1kWh/MWh consumption creates a considerable increase of both self-consumption and self-sufficiency ratio. Integrating a larger capacity will not contribute to a proportionate increase. Also an evaluation of centralized and decentralized storage systems is performed.

I. INTRODUCTION

During the last few years, the integration of decentralized production has introduced new challenges for the electrical distribution grid. Further integration of RES (renewable energy sources) is required in order to achieve the Flemish energy targets for 2020. In comparison to 2014, the objective for solar energy has increased by 31% (from 2.670 GWh to 3510 GWh), for wind the ambition is 39% higher (from 2094 GWh in 2014 to 2913 GWh). For residential buildings, the simultaneity of solar is 1 on a specific feeder. In the meantime study results of the Belgian distribution grid operator point out that the simultaneity of consumption for low voltage grids (LV-grids) is 0.25 à 0.3, which leads to local unbalance in specific low voltage feeders. Another issue is the voltage at the transformer, which can be as high as 240V or higher to ensure that the voltage level is within range for the whole LV-grid. This combination leads to voltage congestion on moments of high PV production and failure of the decentralized production unit, which has to comply with the EN50160 standard *[1]*. The distribution grid faces major challenges to deal with this new scenario, hence the need to investigate possible solutions to achieve a reliable network without loss of production and further integration of RES production. In addition to this, when the capacity tariff policy for Flanders comes to effect (at the earliest starting in 2019, based on a fixed price for the use of the distribution grid, determined by the connection capacity and no longer based on consumption), a smaller connection capacity will lead to financial gain. An optimized system benefits the distribution system operator (DSO) as less energy flows out and into the LV-grid.

II. METHODS TO MITIGATE GRID CONGESTION PROBLEMS

Different control strategies to decongest the LV distribution grid are available. In a previous work, various control strategies have been discussed from which some are easily implemented and/or more advantageous than others. The effectivity of reactive power control remains limited in low voltage feeders because of their high R/X ratio. Active power limitation on the other hand, leads to waste of production on moments when overvoltage occur, due to the curtailment of PV power *[2]–[4]* Online tap changers (OLTC) with different control algorithms can also be implemented *[5],[8]* . These transformers are already used in MV grids, and preliminary tests shown promising results for LV-grids. On the other hand a broad adoption of OLTC capable transformers in LV-grids could be cost prohibitive. A last strategy is active power management. This can be done by integrating storage to the system and/or by demand side management control algorithms applied on flexible, deferrable loads *[9]*. This paper focuses on the active power management, more specifically decreasing the grid congestion by implementing local battery storage in residential buildings or in the LV-grid.

III. SIZING A RESIDENTIAL SOLAR-BATTERY SYSTEM

The optimal capacity of battery storage has to be evaluated in order to achieve a cost-effective and technical optimization, which results in a reliable system. Battery storage sizing estimation methods are evaluated *[6,7]*. Data regarding solar panel yields and load profiles of Belgian households has been obtained from the smart meter pilot project 'Leest and Hombeek' where 4300 smart electricity and gas meters have been installed.

Definitions

Self-consumption

The self-consumption ratio (F_C) represents the share of the generated solar energy that is instantly consumed in the household. It is expressed by the ratio of the consumed

own PV-energy E_{EV} to the total generated energy E_{PV} produced by the solar panels. In case of feed-in tariff, the self-consumption ratio can be seen as the economic efficiency of the plant.

$$F_C = E_{EV} / E_{PV} \qquad (1)$$

Self-sufficiency

The self-sufficiency ratio (F_V) represents the share of the demanded energy that immediately can be supplied by the local (PV) production. It is expressed by the ratio of the energy supplied by the own local production E_{EP} to the total demanded energy E_1.

$$F_V = E_{EP} / E_1 \qquad (2)$$

For typical PV-installations, the self-produced energy is equal to the PV-energy that instantaneously is demanded by the load, and thus equal to the own consumed energy. Where the self-consumption is a measure of the value of a generated kWh, the self-sufficiency is related with the kWh consumed from the grid stands for the value of a kWh paid. When integrating storage, also the battery system has to be considered, consequently the need for self-consumption and self-sufficiency no longer depends exclusively on the instantaneous production and consumption.

Evaluation of the self-consumption and self-sufficiency with variable production and storage

Evaluation of an individual building

For a classic PV-installation, without the integration of storage, both the self-consumption and the self-sufficiency ratios will be around 30%. In Fig. 1 the self-consumption and self-sufficiency (y-axis) are presented when varying the ratio production/consumption (x-axis) and for different battery storage capacities.
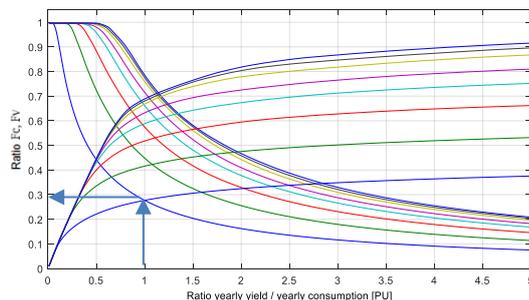
Fig. 1: Fc and Fv in function of the size of the PV-installation for different effective storage capacities from 0 to 5 kWh/MWh with a cycle efficiency of 81% for an individual building

Without storage, but with a ratio 1 for consumption/production, both self-consumption and self-sufficiency are nearly 30%. As production exceeds consumption, the self-consumption ratio gets smaller. On the other hand the self-sufficiency slowly increases and

saturates because of the seasonal behaviour of solar. When storage is implemented, both self-consumption and self-sufficiency increase. Especially when integrating small storage capacity, both ratios increase significantly. The bigger the storage, the higher the ratios. However, the rise isn't linear, even more: saturation is reached at approximately 1 to 1,5kWh/MWh effective battery storage (without integrating the depth of discharge). Optimal ratios can be obtained with relatively small storage systems. Additionally, it can be concluded that complete independency from the grid is unpractical due to the seasonal behaviour of solar and the self-discharge ratio of the battery bank. Fig. 2 shows that we can store a certain amount of power on a sunny day. But because of the small effective battery capacity of 1,5kWh/MWh consumption, the battery will be charged quickly and often, causing grid congestion in periods of overproduction. Therefore, forecasting algorithms and smart charging/discharging cycles have to be implemented to store energy when grid congestion is a risk.
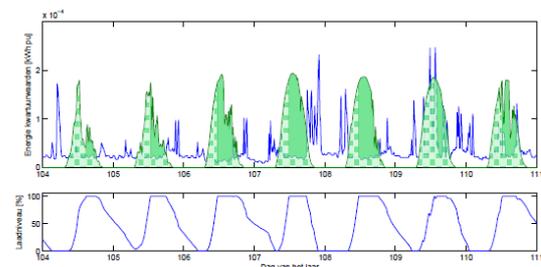
Fig. 2: Self-consumption for week 16, with an effective battery capacity of 1.5 kWh/MWh for an individual building

Next to the previous discussed optimization, battery utilization is also important to evaluate. In fig. 3, 3 different battery capacities are presented. When integrating a battery storage system of 1kWh/MWh, utilization of the full capacity for the battery bank could be achieved. A battery bank of 5 kWh/MWh, on the other hand, achieves a lower capacity utilization. This leads to the conclusion that ,from a technical and economic point of view, using a bigger battery in order to maximize both the self-efficiency and self-consumption is not preferable. In that case, the only gain would be more available capacity to reduce congestion on the LV grid in overvoltage situations.
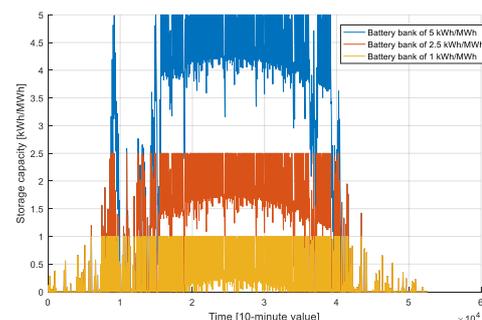
Fig. 3: Battery usage integrated in a residential household

An important remark is that 10-minute window data was used. The shorter the time interval the more precise the usage of the battery could be estimated and the usage of the bank could increase even more.

Evaluation of 25 individual buildings

To evaluate the accuracy of the results from the individual building, 25 buildings were evaluated and compared to investigate if the dimensioning is sufficiently accurate. As presented in Fig. 4, the values for optimal battery storage capacity for the residential building vary between 0.64 and 1,34 kWh/MWh, for self-consumption and self-sufficiency ratios ranging from 44% to 62%.
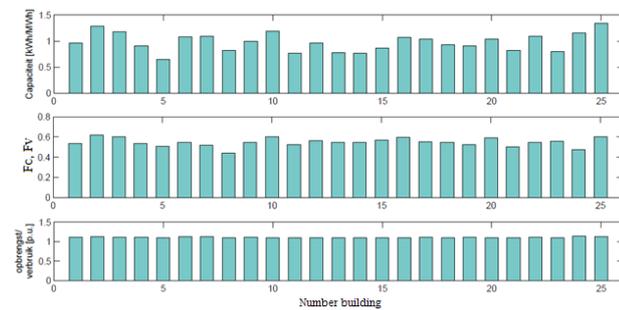

Fig. 4: Evaluation of the optimal storage capacity, self-consumption and self-sufficiency ratio and annual yield for 25 residential buildings

Much will be dependent on the load profile of the consumer. It is worth mentioning that it is not the building with the highest or smallest capacity that reaches the highest or smallest F_C or F_V, but generally with a bigger capacity, a higher F_C and F_V can be reached.

Evaluation of average load and yield profiles

Finally, the results of the 25 individual buildings will be compared with the synthetic load profile which are available on the website of the Flemish Regulator for Electricity and Gas (VREG), (average load profile on quarter base for a whole year on a connection point). Also historical solar data for averaged solar yield was used. The synthetic load profile uses historical data for forecasting the consumer profiles and make it possible for suppliers to estimate the energy needs on connections where no measurements per elementary periods exist.

The self-consumption obtained from combining these profiles is 38.15% for 2014 and 38.37% for 2017. These are higher than the previously discussed results of the individual buildings, because of the averaged character (less peaks) of the historical datasets. The optimal capacity obtained for these profiles is ±1 kWh/MWh and the yearly yield has to be 9% higher than the consumption. These parameters lead to a self-consumption of 60.7%.

IV. OPTIMAL LOCATION IN A LOW VOLTAGE DISTRIBUTION FEEDER WITH

SINGLE PHASE STORAGE SYSTEMS

The impact of location for single-phase storage systems is evaluated in order to find an optimal position along different grid network topologies. The evaluation is performed by simulation in Matlab Simulink® and also experimentally using a lab test platform, which consists of a LV-network with 18 free programmable buildings, connected to a low voltage grid feeder of ± 675m EAXVB 150mm².
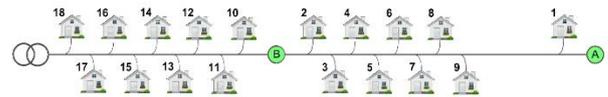

Fig. 5: Configuration example - antenna grid topology

Dimensioning of storage integration in LV-grids

Single phase injection

When integrating single phase PV-systems connected to the grid at building 18 (3 kW), building 2 (4 kW) and building 1 (4 kW), an evaluation of the voltage profile could be seen in fig. 6. The 3 PV-systems are single phased systems, connected to phase 1. On the other phases, no load is present. Because of the single phased injection, the neutral potential will shift, which is related to both the neutral impedance and the current in the cable. The resulting terminal voltage will be the sum of both vectors of the voltage drop and the source voltage.
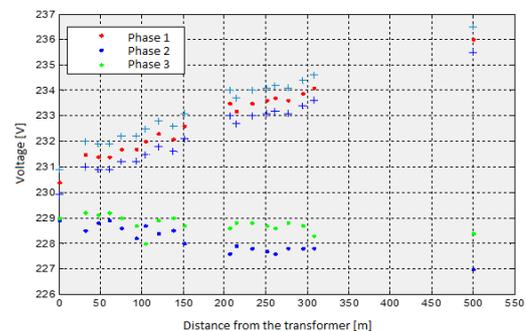

Fig. 6:Model validation - Single phase injection profile

For smaller cable sections, the inductive voltage rise could be neglected, and the voltage drop is in counter phase with the source voltage. For bigger cables, the inductivity of the cable will have an influence on the asymmetry of the phases without loads.

Fig. 6 shows a voltage rise on phase 1, and a voltage decrease on phase 2 and 3. The decrease or increase of the voltage on phase 2 and 3 will be dependent on the phase shift and the voltage drop. When evaluating the measurements with the simulations, all the simulated values are within the ±0.5V tolerance band.

Evaluation of an antenna LV-grid with storage

Both measurement and simulation give similar results. When integrating storage, a higher voltage decrease is observed as the distance between the end of a specific feeder and the transformer becomes bigger. When

integrating the same amount of storage, but on different locations, huge differences are observed. When adding the storage system at the transformer, only a voltage decrease of ±0.4V can be achieved (Rgrid =228mΩ, Xgrid = 42.7mΩ), whereas integrating storage at the end of the feeder (Rgrid =387mΩ, Xgrid = 98.6mΩ) a voltage decrease of ± 3.8V is observed. The location of centralized storage in antenna grids has to be further evaluated from techno/economical point of view. Depending on the amount of feeders, connected to the transformer, it could be more feasible to place the battery bank close to the transformer, helping to decongest multiple feeders, instead of placing multiple smaller banks at the end of every feeder.

Furthermore, there has to be taken into account that if an ideal battery storage system is implemented, the instantaneous current flows through the storage bank will be limited. Limiting the charge/discharge rate to 10-20% of its C_{20} value extends the lifetime of the system. Although, this limits the capability to absorb all production at high solar power irradiation events, resulting in limited decongestion ability, on the other hand, it extends the lifetime of the equipment. Therefore, it is important that PV-profiles are investigated with short time intervals, to estimate and evaluate the needed peak power of the system. Battery systems are best suited for load following applications, at which life cycle requirements and the ratio of peak power to stored energy are lower.
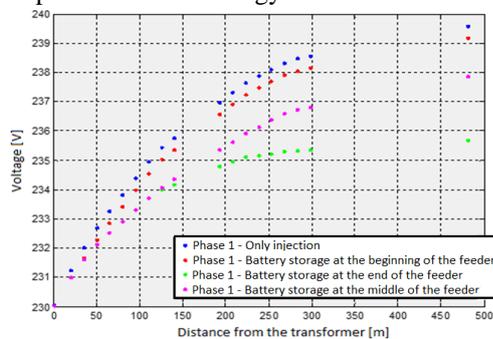

Fig. 7: Evaluation of storage location for an 30 kW PV-system

V.   DECONGESTION – DAY PROFILES

Previous chapter discussed the location of the storage system in the grid. Another factor which should be taken into consideration is the limitations of the battery system.
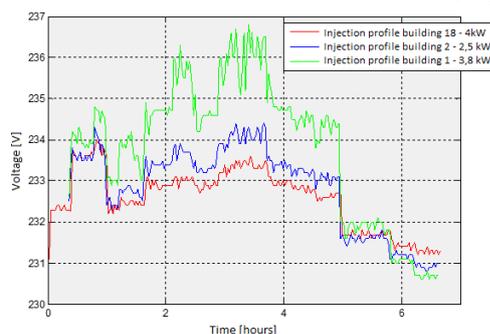

Fig. 8: Voltage profile of an LV-grid with 3 PV-systems

Measurements where performed on typical PV profiles to assess these limitations. The voltage profiles of 3 buildings were investigated (fig. 8). In those profiles, the voltage in the feeder will reach its highest voltage typically at noon.

Strategy 1 – Centralized storage

In this strategy, an investigation of centralized storage systems is performed in a network where multiple buildings are connected to the battery system. These systems could be implemented by the distribution grid operator or an aggregator that uses the stored energy to support the distribution grid, based on its needs. Because the free choice of installation, the storage system is implemented at the end of the feeder and not in the transformer house.

In this case, batteries start charging earlier and faster, compared to decentralized storage and consequently the whole system is more capable of handling a problem with respect to overproduction. Fig. 9 shows an integrated small battery capacity of 5kWh, without implementing forecasting or algorithms, decongestion is realized during peak moments. Because of the small battery system, after a few hours it will be fully charged.
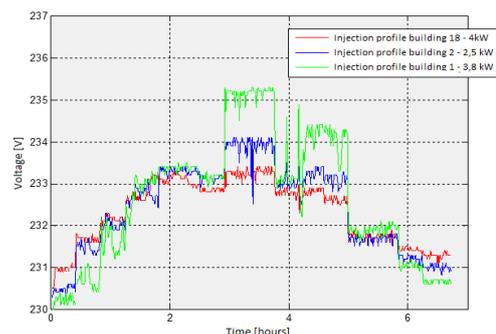

Fig. 9: Implementation of small centralized storage at the end of the feeder (building 1)

Nevertheless, even when integrating a much bigger battery storage of 5 MWh, with 200 connected buildings (combined prosumers and consumers), after multiple sunny days the same voltage congestion as before occurs. Extra control strategies are still required to ensure a reliable grid. However, huge storage banks are creating new flexible market possibilities for aggregators to decongest single distribution feeders which suffer from overvoltages. Especially with the changing flexibility market which makes it possible to integrate uncontracted reserve starting from 1MW and where clustering of SME and residential storage is possible.

Strategy 2 – Decentralized storage

For strategy 2, an ideal battery system as discussed in chapter 3 is installed for a consumer in the middle of the feeder, next to the centralized system at the end of the feeder. The different systems are compared in fig. 10.

In comparison with the centralized system, the individual system can only be used for the individual building (no

other systems can charge/discharge the battery system), which leads to longer decongestion for the individual building. There is lower voltage decongestion in comparison with the centralized system, due to dependence on the location of the storage system and the current limitations of the system. The customer obtains higher F_C and F_V and helps in the congestion management.

Fig. 10: Extra integration of decentralized storage system

Both, centralized and decentralized configurations can guarantee a certain decongestion, depending on the capacity and current limitation. Better results are realized with centralized storage because these systems could be located at the end of the distribution feeder. For ring grid topologies, this could be next to the transformer house, for antenna grid topology, new cabins have to be installed, in calculating special requirements (vibration of the road,…) for safe operation and deployment. Next to that, smart strategies can be implemented which are not or less possible for decentralized systems , since the main goals for those systems are increased self-production and greater independency.

VI.   CONCLUSION

This paper discusses the implementation of a optimized battery storage system that could be implemented at LV-grids. Different evaluation methods are considered, but generally for a residential building a battery bank of approximately 1kWh/MWh consumption would enlarge both the self-consumption and self-sufficiency from 30% in an solar system without storage, to approximately 60% with small battery capacity. Bigger storage capacity means greater decongestion of the grid, but it will not contribute to a proportionate increase of both ratios.
 In another section the influence of the location of the storage system is evaluated, which points out that integrating storage at the end of the feeder would lead to considerable decongestion, but both, decentralized and centralized systems contribute to a lower voltage congestion. Centralized systems start charging earlier and faster, compared to decentralized storage and consequently they are more capable of handling problems with respect to overproduction. Decentralized systems on the other hand use the battery system to optimize the residential building resulting in longer decongestion. Although, the voltage decongestion is lower in comparison with centralized systems due to the dependence on the location of the storage system and the current limitations of the system.

Further research on the optimization method has to be performed to substantiate the statements that were made. Next, optimal location for centralized storage in antenna grids has to be performed from techno/economical point of view, depending of the amount of feeders connected to the transformer and optimal battery location. Also the combination of battery-(BESS) and flywheel energy storage systems (FESS) has to be analyzed which can lead to optimal dynamic solutions.

VII.   REFERENCES

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