IMPACT OF BATTERIES IN THE HOSTING CAPACITY OF A GRID WITH PHOTOVOLTAIC GENERATION

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ABSTRACT

This paper analyses the impact of batteries in the hosting capacity of a low voltage grid with prosumers with photovoltaic generation installed under different scenarios. Storage location in the grid has been selected with the criterion of reducing congestion. Two scenarios have been considered: the first with current demand of consumers in the grid and the second by increasing their demand profile proportionally, whilst maintaining the daily load curve shape, until a congestion situation is reached. Simulation of increasing PV generation and storage capacity is performed until a congestion is given, resulting for the first scenario an increase of 140% of PV production is achieved with 100kWh of storage. In the second scenario 230 kWp of maximum hosting capacity can be achieved with 400kWh of storage.

INTRODUCTION

This paper analyses how the installation of batteries in a distribution grid can improve the hosting capacity [2] and mitigates the congestion effects. The study considers a low voltage distribution network, designed and planned more than three decades ago for distributing power from substation to consumers, and operated passively without any regulation. The roll out of smart meters during the last years, together with the use of a power flow simulator, offers the possibility of performing a what-if analysis with different generation and storage capacities, accurate enough to obtain results with hourly resolution [3].
The work analyses several prosumer scenarios, increasing the photovoltaic generation until a congestion situation is reached. The installation of batteries at the grid level is proposed to mitigate such congestion and at the same time that maximises the locally generated energy being consumed locally.
Next section is devoted to present the basic characteristics of the grid and available data. Also the methodology and tools, and assumptions as well, are presented in the section. In the same section, proposed scenarios for the study are described. Next, results derived from the analysed scenarios are discussed and the main achievements are highlighted in the conclusions section.

EXPERIMENTAL SET UP AND SCENARIOS

The grid under study is a 400V LV section located in Catalunya (see Figure 1). Grid topology, line parameters (impedances and lengths) and smart metering data was provided within the framework of the RESOLVD project (H2020 European project, [7]). The grid consists of a secondary substation that feeds 10 domestic consumers (contracted power around 2-3 kW, each), some of them with photovoltaic (PV) generation installed and an increasing demand to increase it. The hourly consumption and generation data, from smart meters during one year, was available and used to identify typical daily demand profiles and from them aggregations at bus (and substation) level. Study of monthly and daily profiles permitted to select July as the worst case in terms of congestion, when the highest production and lowest consumption coincides in this month. Hence, the study carried out in this paper, has considered this month; and, in particular the demand profile of the first of July.

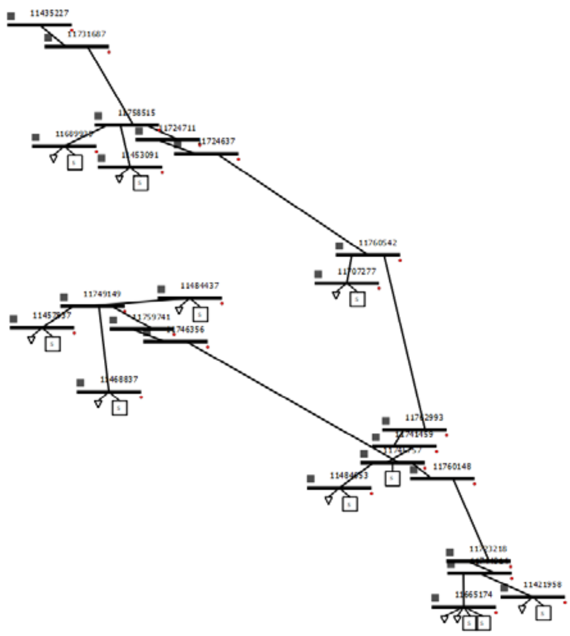

Figure 1. Schematic of the grid used in the analysis (flat lines indicate buses and triangles prosumers)

The grid under study is currently over-dimensioned and the real power flow through its branches is less than 10% of its maximum capacity. Figure 2 shows the demand curve profile in all the buses for the first of July.

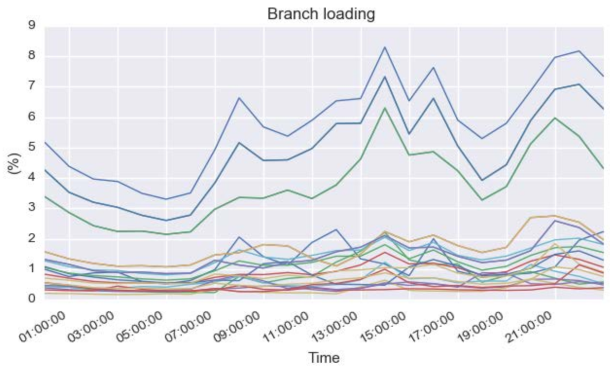

Figure 2. Branch loading on July 1st

Solar irradiation data from PVGis database, [1], was used to estimate PV generation profiles. Pilot location and an optimal inclination and orientation of solar panels for this location has been supposed.

The hosting capacity analysis is focused on the limitation given by lines and cables already installed. Thus, study focuses on congestion in branches, whereas over-/under-voltages are not considered as a limitation because the length of the lines is too short to produce these significant voltage variations.

Scenarios

Two scenarios have been considered in the analysis of storage impact:

1. Scenario 1: Current energy consumption.
2. Scenario 2: Increased energy consumption until the thermal limit of the branches (see Figure 3). In this situation, only 1 branch reaches, or exceeds, its maximum capacity during 3 hours.

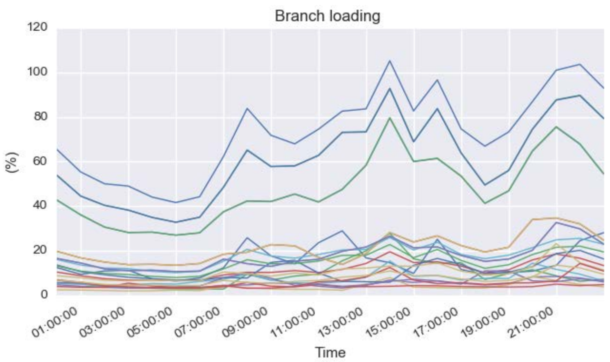

Figure 3. Branches loading without PV generation and with the increased energy consumption

In both scenarios, a linear increase of PV generation in all the prosumers has been simulated. As starting point, PV generation equals to the total contracted power at each bus has been considered. This results in a 30.5kWp of installed PV (2-3 kWp per consumer).

Battery location and operation

A single location of energy storage systems (batteries) has considered in the study and this is maintained during the whole study. The location has been decided in order to maximise its impact in terms of increasing hosting capacity. A power flow simulation was used to simulate currents in all the branches for the worst-case and compare with thermal limits, in order to identify the branches that could be affected by a congestion. Figure 3 illustrates the most overloaded branches of the grid during this situation (scenario 2). In Figure 4, the red line indicates the most overloaded branch and yellow ones indicate the next most overloaded. According to it, battery location has been set to bus #11746757 (pointed with a black arrow in the Figure 4).

For the study a battery charging-discharging power of 50 kW has been considered (this value is enough to not impose power constraints in the energy management of the battery) and its capacity has been variated to study the impact on the hosting capacity.

Simulation of battery operation has been modelled by simple rules: to charge battery if PV generation was greater than power demand and battery state of charge permits it; and, to discharge battery if power demand was lower than PV generation and battery state of charge permits it. In this regard, greater hosting capacity could be achieved with an optimal management of the battery using power demand and supply forecast such as in [4-6].

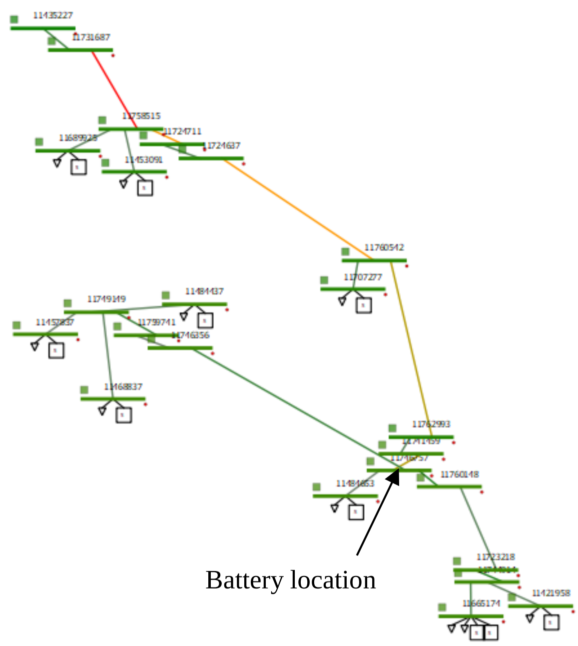

Figure 4. Grid topology with the most overloaded branches (yellow and red) and battery location

RESULTS

In the following paragraph, the results in both scenarios with increasing PV generation and battery storage are analysed.

Scenario 1

Figure 5 shows the variation of the hosting capacity according to the battery size. The figure shows that congestion problems start to appear when PV power installed reaches 100kWp. This is approximately 3.3 times the initially installed power (30.5 kWp). Then, this hosting capacity can be increased in a 16% (up to 116 kWp) when 100 kWh of battery are installed (Figure 5).

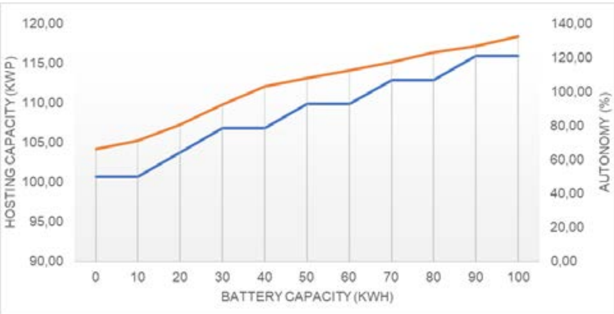

Figure 5. Hosting capacity (blue) and percentage of total consumed energy being generated locally (PV) (orange)

On the other hand, the percentage of energy demand satisfied by local PV production (plus storage management) goes from less than 70%, for 100kWp of PV power and without storage, to almost 140%, for 116kWp of PV power and 100kWh of storage. Thus, in the last situation the grid is exporting energy from the secondary substation. According to these results, the main advantage of placing a battery in the grid would be to increase local consumption of the generated energy and, eventually, contribution to the energy system as a virtual power plant. Observe that 100% of autonomy is reached with a battery sized in 40kWh. Increasing the battery capacity, allows an increase of PV generation, by avoiding congestion during peaks. Thus, increasing 2.5 times the capacity (100kWh) results in a 40% surplus of generation w.r.t local demand.

Scenario 2

In this scenario, consumption has been increased until one branch reaches its maximum capacity (Figure 3). This corresponds to 14 times the current consumption. The purpose is situate the current infrastructure in a stress situation and analyse how the appropriate combination of generation and storage can defer an investment on the infrastructure at the same time that contributes to the energy transition.

In this scenario, any presence of local PV generations contributes to reduce the congestion by reducing demand at the consumption points. Figure 6 shows this effect in terms of a reduction of the congestion hours from 3 to 2 when a total of 30.5 kWp of PV are installed (equivalent to contracted power). However, an increase PV of during low demand hours results in inverse flow that can also cause overloading in the lines. This is observed in Figure 6, when upon 170 kWp of PV, branches start being overloaded (hours per day). The same effect is illustrated in Figure 7 with the maximum loading amongst all branches in the whole day. Initially, maximum loading is reduced due to PV power, but from a certain amount of PV power it eventually increases again.

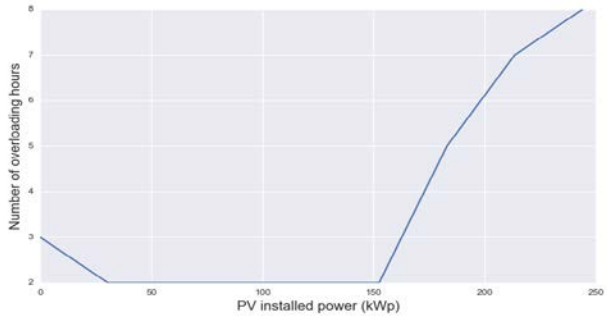

Figure 6. Number of hours where a branch exceeds its maximum capacity respect to PV power increase

Figure 6 and Figure 7 indicate that overloading appears when PV power increases over 170 kWp. The effect can be observed in Figure 8, for a total of 183 kWp of PV power installed (6 times the initial PV power). Observe that during the night and first hours of the day the loading is due to demand, whereas from 9 a.m. to 18 p.m. this is given by the PV generation, resulting in an overloaded branch in the central hours of the day (over 100%).

As in the previous scenario, the presence of storage in critical points of the grid, together with correct management strategy, can avoid congestions. Thus, assuming the same location as in the previous scenario, and the same power of 50kW, a set of simulations with increasing storage capacity have been carried out. Figure 9 shows the variation of the hosting capacity and the percentage of energy being consumed locally w.r.t demand for different capacities of the battery (0 - 500kWh). According to Figure 9, in this situation only half of the demanded power is satisfied with local PV power when no storage is present.

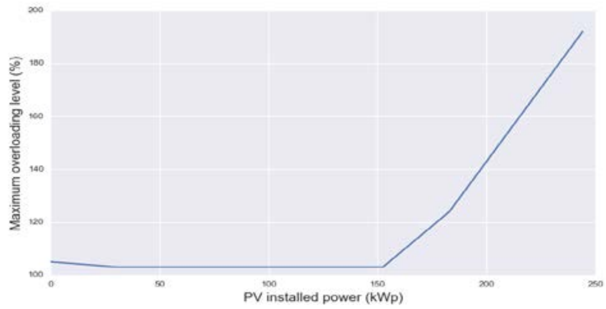

Figure 7. Maximum branch loading value respect

the installed PV power

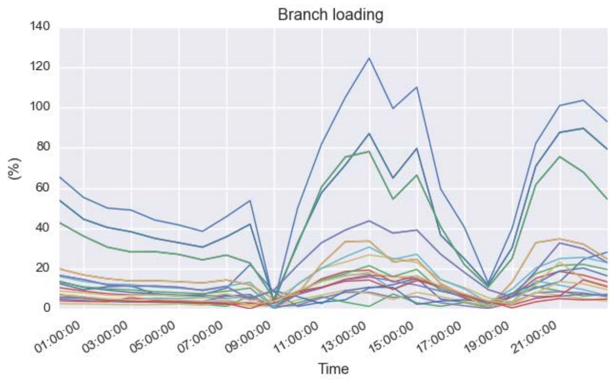

Figure 8. Branches loading in scenario 2 assuming 183 kWP of PV power

As battery size increases (from 0 to 400 kWh), hosting capacity also increases until 230 kWp (34% w.r.t to the initial situation without battery). As in the first scenario, the fact that PV generation peak is concentrated in a short time period during the day implies a high cost on storage capacity to cover the energy production during such peak. Observe that the variation of the hosting capacity is flattened for battery capacities greater than 400kWh. The reason is that battery charge-discharge power is limited (50 kW) so, in large surplus hours, it cannot absorb this surplus. Figure 10 shows the hosting capacity and grid autonomy respect to battery capacity but setting battery charge-discharge power to 70kW, which is probably more reasonable for these larger battery capacities and power surplus. The figure shows that with this new charge-discharge power, the hosting capacity and autonomy increases linearly with the size of the battery. Nevertheless, the hosting capacity increases slowly, i.e. the initial hosting capacity without storage is 170kWp and with 500kWh the hosting capacity increases up to 250kWp, which means an increase of 35%.

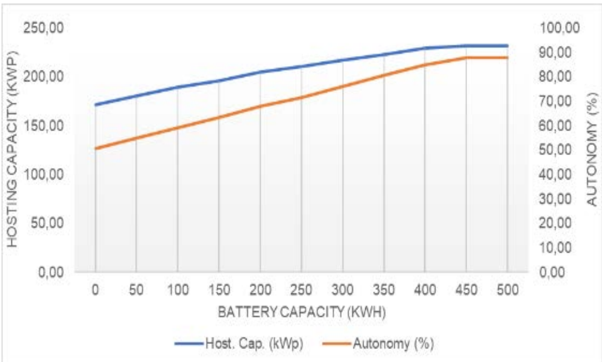

Figure 9. Hosting capacity (blue) and portion of the consumed energy which has been generated by local PV (orange) with consumption of scenario 2 and battery charge-discharge power equal to 50kW.

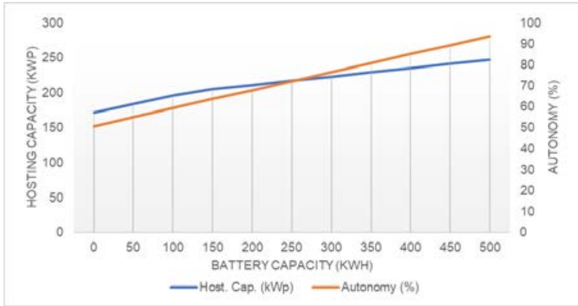

Figure 10. Hosting capacity (blue) and percentage of locally consumed PV generation (orange) in Scenario 2 with battery power 70kW.

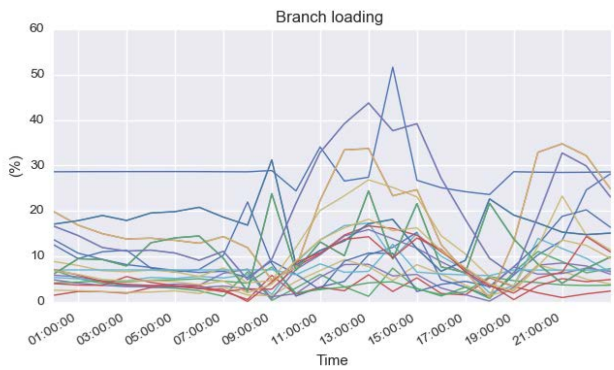

Figure 11. Grid branches loading with a battery of 50 kW and 300 kWh, and 180 kWp of PV installed power.

CONCLUSIONS

In the studied grid, over- and under-voltages are not an important issue since lines are too short to have problems, so study focus on congestions due to distributed PV generation. According to grid consumption profiles, July is the worst-case month due to highest production and lowest consumptions. Battery is allocated downstream to them most overloaded conductors in order to avoid congestion and increase grid hosting capacity.

With current consumption and 100 kWh of storage it is possible to increase hosting capacity up to 16% and reach a grid autonomy of 140%. This means that the grid would behave as a virtual power plant due to 40% of energy surplus. However, 100% of autonomy is reached with a battery size of 40 kWh so the purpose of increase battery size from 40 to 100 kWh is purely to avoid congestion problems and increase the hosting capacity to contribute to the penetration of renewable generation (PV).

Increasing consumption up to grid thermal limit means multiplying current consumption by 14. In this scenario, PV generation increase first helps to decrease grid congestion but from 170 kWp of installed PV power it increases again due to the reverse flow (from PV to substation). Battery size and hosting capacity increase linearly until 400 kWh, where a hosting capacity increase

of 34% in achieved and 230 kWp of installed PV power would be accepted without grid congestion.
From 400 kWh, hosting capacity increase is flattened because of battery charge-discharge power is limited to 50 kW and during PV generation peak hours, battery needs higher charge-discharge power to absorb power surplus.
Increasing battery power capacity, hosting capacity and grid autonomy keep increasing with the size of the battery.
Electrical storage in distribution grids would allow large amount of distributed PV generation, meaning a no limitation for prosumers or user grids to install all PV power user desires.

ACKNOWLEDGEMENTS

This work has been developed in collaboration with the European project RESOLVD of the Horizon 2020 research and innovation program (topic LCE-01-2016-2017) and grant agreement N773715. Authors want to thank the support and collaboration of Estabanell Distribució providing real data for the study.

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