EVALUATION OF COORDINATED CONTROL OF FLEXIBILITY IN AN ENERGY COMMUNITY IN THE PRESENCE OF RENEWABLES, STORAGE AND GRID INJECTION LIMITS

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ABSTRACT

Local clusters of Distributed Energy Resources, e.g. photovoltaic residential rooftop installations, put stress on the distribution grid due to reverse flows and induced overvoltage. Current mitigation strategies incentivize storage, because it helps reducing costs due to non-net metering and curtailment reduction. However, the mitigation strategies incentivize individual storage systems and do not incentivize self-consumption between neighbours. In this, there is room for optimization, as coordination of the flexibility between houses may result in achieving the same result with less investments in energy storage systems. This aspect is investigated in this paper, by exploring the potential of local energy communities.

INTRODUCTION

The rise of distributed energy resources (DERs) is ongoing, due to their decreasing capital cost and payback time, in addition to increasing environmental awareness [1]. However, local clusters of DERs, e.g. photovoltaic (PV) residential rooftop installations, stress the distribution grid due to reverse flows and induced overvoltage [2]. In case of overvoltage, PV installations are curtailed according to a predefined setting of the PV inverter, determined by regulation [3]. Distribution system operators (DSOs) try to mitigate these overvoltage issues by abolishing net metering. For example, in Australia, the injection tariff is 0.06-0.10 AUD/kWh while electricity consumption costs 0.30 AUD/kWh for households. Reactive power control strategies and power injection limits for DERs are other means by which DSOs try mitigation, e.g. in Germany PV systems have an injection limit of 70 % of their installed capacity [4].

Incentivising storage is an effective mitigation strategy to avoid over voltages and congestions brought in by DERs that are characterised by variability and uncertainty. However, a comparison of the mitigation strategy via self-consumption and via community sharing of energy has a different impact on many aspects, e.g. the prosumer revenue and the amount of PV curtailment. This paper compares the individual optimization of flexibility versus the coordinated optimization of flexibility in a local energy community. The local energy community is defined here as a group of houses connected to the same low voltage (LV) network for which the energy flows will be controlled among each other in a coordinated manner, to optimize the result for the entire community.

This concept aims at decreasing the grid impact due to large DERs penetration rates, as well as decreasing the energy bill of the community members, by managing the flexibility available within the community and by optimizing the energy sharing and self-consumption between members.

METHODOLOGY

The paper assesses the added value of coordinating flexibility resources by increasing the utilisation of locally available flexibility and the positive effects of aggregation. The opportunity for a local flexibility aggregator is assessed, based on the captured added value and the split of this value between the aggregator and the community members.

The assessment compares the results for the optimal use of the storage flexibility at individual (prosumer) level with the optimal use of storage at a community level. For the individual usage of flexibility, the objective is to minimize the individual energy bill, while the community-level optimisation optimizes the overall energy bill of the community. Furthermore, the community-level optimization of the flexibility usage also considers effective grid constraints and locational sensitivity to voltage variations, by using a multi-period AC Optimal Power Flow (OPF) model based on the Smart Operation tool [5]-[6].

THE CASE STUDY

The quantification of the community value is assessed based upon analysing the simulation results of increasingly complex configurations. Residential prosumers that are equipped with (rooftop) PV and energy storage are simulated. A typical low voltage distribution feeder of a Belgium residential urban neighbourhood, as shown in Figure 1 is deployed for the simulation of the use cases.

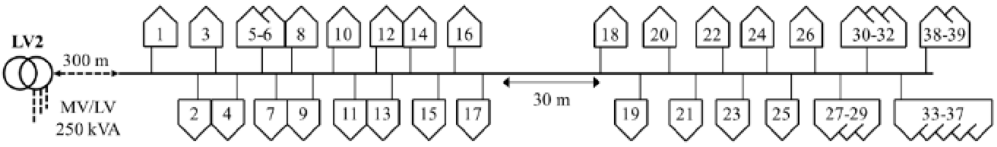

Figure 1: A typical residential urban feeder in Belgium [7]

The modelling of the prosumer

Each prosumer has several fixed and variable inputs as shown in the Table 1.

Table 1: Prosumer inputs

Fixed inputs	
Annual prosumer energy consumption	Between 600 kWh (small apartment) and 20,000 kWh (large house with electric domestic hot water storage heater)
Tariffs	Prosumers with PV have a single tariff, and prosumers without PV have a day/night tariff
Variable inputs	
PV size	Function of the prosumer's annual consumption and chosen PV penetration rate
Battery size	2.5-5 kWh
Injection limit	30-50 % of the installed PV capacity

The consumption profiles

Each household is modelled with 3 load profiles:

- **Purely electric loads** are generated by a disaggregation of the synthetic load profiles (SLP) of residential consumers in Flanders [8]. The randomization is performed in function of connection capacity.
- **Heating loads** are generated by randomizing the SLPs (Synergrid) [8]
- **Domestic hot water** (DHW) heat consumption is generated by random generated loads of showers, small and medium hot water loads with probability functions derived from typical DHW usage curves.

The PV profiles

- Each rooftop PV installation has the same power profile, scaled to its specific size. The profile data come from an existing PV installation in Belgium.

The three use cases

- **Use Case 1: no community.** All households are grid unaware and will use their own battery to optimize their own energy bill, respecting their injection limit. Doing so, the grid constraints can only be avoided by curtailing a part of the PV production.
- **Use Case 2: full community.** The households with a battery have their batteries controlled by the community manager. The community manager is grid aware and uses the flexibility of the batteries to minimize the community energy bill and limit congestions and voltage issues. If the available flexibility is not sufficient, the PV curtailment will still occur. There is no injection limit.
- **Use Case 3: partial community.** Part of the households are non-community members and grid unaware. They use their battery to optimize their individual energy bill, respecting their injection limit. Others are community members and their batteries are controlled by the community manager that uses the flexibility of batteries to minimize its energy bill and avoid grid violations. No distinction is made between the non-community and community members for the additional PV curtailment needed to avoid grid violations.

RESULTS AND DISCUSSION

The results for use case 1 are shown in Figure 2, where the percentage of PV curtailment as a function of PV penetration for various storage capacities and injection limits is depicted.

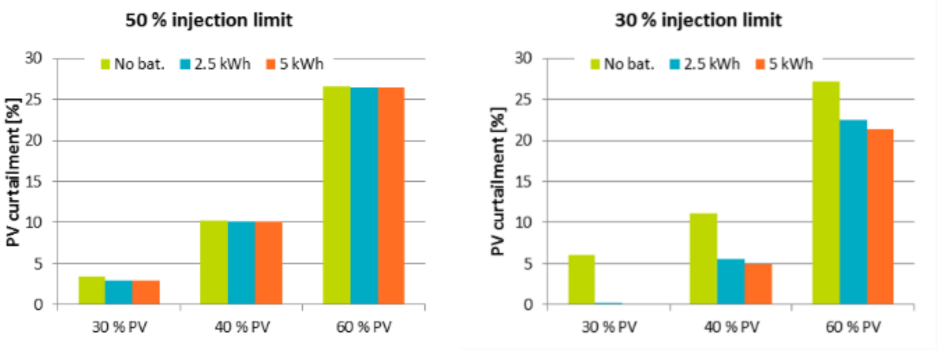

Figure 2: PV curtailment for use case 1

It shows an increasing curtailment with increasing PV penetration for a given injection limit. Additionally, stricter injection limit leads to more self-consumption reducing voltage-induced curtailment. However, there will be more local curtailment if there is no battery or if the battery capacity is insufficient. Stricter injection limits combined with larger batteries will avoid overvoltage curtailment and local curtailment for increasing levels of PV.

Figure 3 shows a detailed result of the impact of different injection limits by analysing the profiles for one household near the end of the feeder, having a 2.3 kW PV installation and a 2.5 kWh battery, for the 60 % PV penetration.

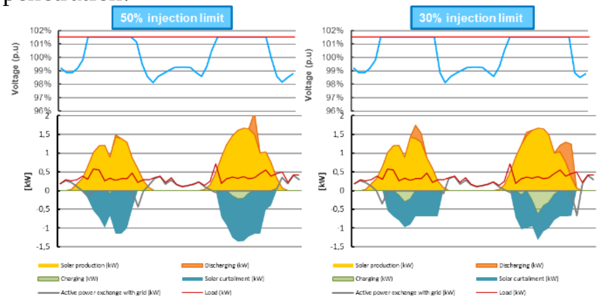

Figure 3: Profiles for one household near the end of the feeder, with a 2.3 kW PV installation and a 2.5 kWh battery, for use case 1.

When the grid voltage nears its upper limit (101.5 %), curtailment occurs. For the 50 % injection limit, batteries only have limited impact on curtailment, because there is only limited charging of batteries to avoid curtailment. However, for the 30 % injection limit, batteries can substantially decrease curtailment. For both cases, additional PV curtailment still occurs. However, the 30% injection limit needs less curtailment, because prosumers have more incentive to charge their battery. This shows that the injection limit should be matched to the PV penetration rate, to be effective.

Figure 4 shows the result of the use case 2, where percentage of PV curtailment is shown as a function of the PV penetration for various storage capacities. It shows that for high PV penetration rates, there is a strong interest to invest in batteries at community level. Even small batteries are very effective, as the community makes optimally use of the flexibility of all batteries to avoid congestion and voltage constraint violations.

For the same amount of batteries installed, a local energy community will experience less PV curtailment compared to the individual usage of the battery flexibility (use case 1). This also means that a local energy community can increase the local self-consumption of renewable energy, as less of this energy has been curtailed. However, when PV penetration is low (e.g. 30% PV), there is no value for an energy community yet.

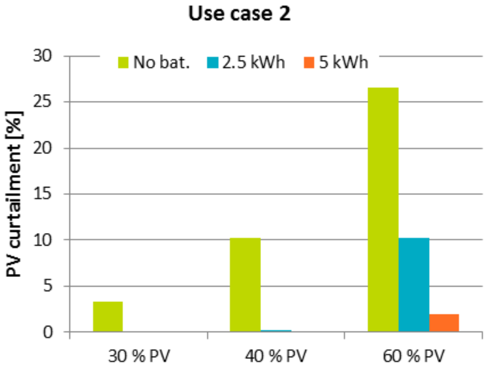

Figure 4: Percentage of PV curtailment as a function of PV penetration for use case 2.

Figure 5 shows the aggregated profile of all prosumers with 60% PV penetration and batteries of 2.5 kWh, with no injection limit. When the voltage nears its upper limit (101.5%), the batteries will all start to charge simultaneously to avoid excessive PV curtailment. This is the optimal use of batteries of the community, which avoids curtailment as a solution to avoid grid constraints. However, still curtailment occurs with the 2.5kWh battery, implying the insufficient storage capacity to avoid curtailment fully for the given PV penetration rate.

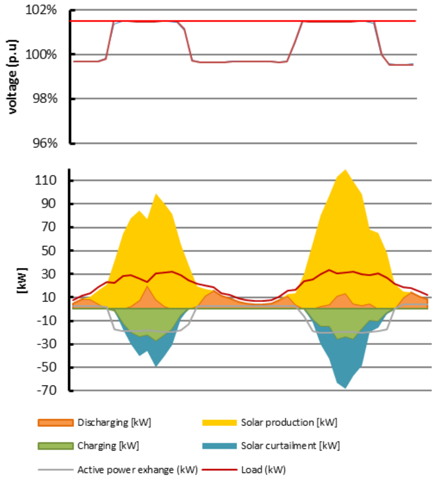

Figure 5: Aggregated profile of all prosumers with 60% PV, batteries of 2.5 kWh, for use case 2

Figure 6 shows the economic value of a community under the assumed cost parameters for various scenarios, for use case 1 and use case 2. The results show that the community with 60% PV penetration and with 2.5 kWh batteries is more profitable than the reference use case (PV without batteries). A community with 60 % PV and batteries of 5.0 kWh batteries decreases curtailment to 2% but is 21% costlier than the reference use case.

Figure 7 shows the diverse saturation levels of PV curtailment for different percentage of PV, injection limit and battery size under varied share of prosumers in use case 3.

For a given PV penetration, the following can be observed:

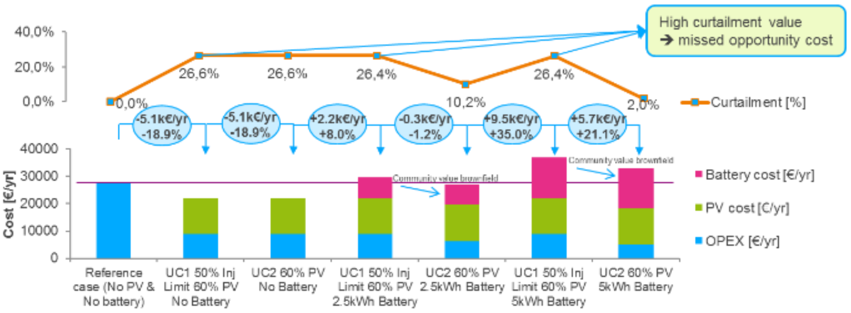

Figure 6: Comparison of curtailment and the economic value of a community for use cases 1 and use case 2.

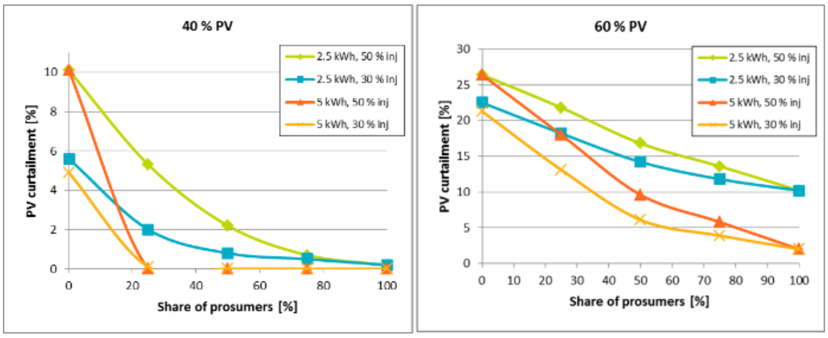

Figure 7: PV curtailment for different shares of prosumers for use case 3.

- For the same injection limit and battery size, the PV curtailment decreases with an increase in the number of prosumers in the community.
- For the same percentage share of prosumers in a community, the higher the battery size, the lower the curtailment.
- For the same percentage share of prosumers in a community, the same battery size, the lower the injection limit, the lower the curtailment.

Additionally, for a given share of prosumers in a community, battery size and injection limit, a higher PV penetration rate will lead to more curtailment.

CONCLUSION

The community aspect brings benefits for all grid users by using the available flexibility more effectively. Doing so, less flexibility investments are needed for reaching the same objective.

Less of the flexibility potential is 'blocked' for grid purposes by introducing the community aspect and more flexibility is available for capturing other value streams. These additional value streams are easier to access with a coordinated control mechanism that aggregates the flexibility of many prosumers.

An increase of the value streams is possible when the community is grid aware, i.e. having better knowledge of grid capabilities to quantify the potential of flexibility/ancillary services at any time. More flexibility at the low voltage level might be beneficial for renewable energy sources connected to the medium voltage level, which is an example of the impact stretching beyond the local level.

REFERENCES

[1] R. Fu, D. Feldman, R. Margolis, M. Woodhouse, and K. Ardani, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017," NREL, City of Co., CO, United Stated, Rep. TP-6A20-68925, 2017.

[2] C. Gonzalez, S. Weckx, N. Efkarpidis, P. Vingerhoets, T. De Rybel, and J. Driesen, "Constrained PV penetration level in LV distribution networks based on the voltage operational margin," in *CIRED 22*, 2013; pp. 1-4.

[3] "Technology compendium 3.4: PV grid integration," SMA Solar Technology, 2012. [Online]. Available: http://files.sma.de/dl/10040/PV-Netzint-AEN123016w.pdf

[4] M. Coddington, "General Overview of Interconnection Standards & Grid Codes for High Penetration PV," *presented at the Renewable Energy Training for Latin America*, 2015. [Online]. Available:https://www.iea.org/media/training/presentations/renewableenergytrainingforlatinamerica2015/Session10MichaelCoddingtonNREL.pdf

[5] Geth, F., et al.: 'The PLANGRIDEV distribution grid simulation tool with EV models'. CIRED Workshop, Helsinki, 14–15 June 2016

[6] Chittur Ramaswamy P., Del Marmol C., Schyns D, Bouchez F-X, Rapoport S., Vangulick D. "Smart Planning: an innovative tool for the investment planning of smart distribution networks" – CIRED Open Access Proceedings, IET Journal, ISSN 2515-0855, doi: 10.1049/oap-cired.2017.1042

[7] N. Leemput, "Grid-Supportive Charging Infrastructure for Plug-In Electric Vehicles," Ph.D. dissertation, ESAT, KU Leuven, Leuven, Belgium, 2015.

[8] Synergrid, Synthetic Load Profiles (SLP). Available: http://www.synergrid.be/index.cfm?PageID=16896&language_code=NED Accessed on 23/03/2018