IMPACT OF FLEXIBILITY LOCATION IN MV DISTRIBUTION – THE NICE SMART VALLEY CASE STUDY

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ABSTRACT

Nice Smart Valley (NSV) is the French demonstrator of the European H2020 project INTERFLEX, aiming to operate the electric power system on a "local" scale through the use of flexibilities. This article presents, though simulation results, the impact of the localization of flexibility on volumes used to solve the electrical constraint(s). Two methods were used to assess the volumes of useful flexibility. The first one is based on the activation of homothetic flexibility all over the "useful" location. All flexibilities participating in the resolution of a constraint contribute in proportion to their original consumption. The second is based on "worst" and "best" combinations of flexibility placements. The results showed that on the three MV-grids of NSV the placement of flexibility may have a slight impact on the volume of useful flexibility whereas for voltage constraints, the placement of flexibility has a strong impact on the volume of useful flexibility.

INTRODUCTION

Energy transition leads DSOs to the biggest changes since several decades. Most of the distributed energy resources (DERs) – biggest hydraulic power plants excluded – are being connected to the MV or LV grids leading the distribution grids to have more and more bidirectional power flows. The raise of electric vehicles (EVs) also modifies the way the customers consume and could locally increase the overall consumption on MV/LV grids. For these reasons, DSOs currently analyse different options that could avoid electrical constraints without reinforcement.

One of the themes of the INTERFLEX European project[1] [1] and its French demonstrator project Nice Smart Valley (NSV) [2] is to study interactions between flexibilities[2] and DSOs.

The present article presents the results of a study assessing the impact of the flexibility location to alleviate electrical constraints on the grid. The study is conducted in the present context with the current number of EVs and DERs. The main objectives of the study are the following:

- Defining in which period the MV-grids could be constrained.
- Assessing the potential useful flexibility that would be necessary to mitigate the electrical constraints with two different methods.
- Analysing the results and the impact of the flexibility location on the useful volumes.

SCOPE

The portion of the Nice Smart Valley demonstrator's geographic scope suited to the activation of flexibility on the medium-voltage grids corresponds to a selection of areas that could potentially be under constraint should there be a high load level following a loss of supply. Only high-voltage supply losses and/or single transformer losses are discussed in this study. Indeed, results of preliminary simulations have shown that medium-voltage grids in normal configuration do not result in constraints in any of the Nice Smart Valley areas. The list of grids under N-1 emergency configuration tested in connection with the Nice Smart Valley demonstrator contains three areas. Isola and Guillaumes are two different areas corresponding to two small cities located in the same mountainous area. The HV-grids feeds two different primary substations of the city through a single line. The last area corresponds to a city feeded by a single HV-MV transformer.

HYPOTHESES

The hypotheses presented in this paper relate uniquely to a smart grid demonstrator and do not consider the current planning methods applied by Enedis. In addition, the approaches used may not be directly extrapolated to cover all grids managed by Enedis, because the scenarios tested are specific to Nice Smart Valley and are not in any way representative of all grids.

Load

The first step in the method is to define the consumption levels for each of the Nice Smart Valley areas. This is achieved by first extracting two years of net demand curves for the primary substation to which load relief is provided[3].

From these net demand curves we are able to derive two normalized six-month load duration curves for this primary substation, by dividing the data into two periods:

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[1] The InterFlex project is co-funded by the Horizon 2020 Framework Programme of the European Union.

[2] Flexibility in this context is the capacity of a customer to modify its normal consumption for a limited period.

[3] Net demand corresponds to the active power passing through the primary substation, to which is added the power injected by the producers connected to this substation. This power thus corresponds to the total net consumption by the primary substation (consumption by customers + losses).

summer[4] and winter plus the shoulder seasons[5]. As the maximum permissible currents for the cables differ depending on the temperature and therefore vary between these two periods, **it is essential to evaluate opportunities for flexibility in each period of the year studied.**

In the simulations, only the normalized load duration curve for the primary substation receiving load relief is considered. **The underlying hypothesis is that the load duration curves for primary substations in a given geographic area line up completely**.

The simulations involve the application of the same coefficient for all loads in the area, meaning that the **loads will undergo homothetic changes**. Our hypothesis is that the allocation of power between the loads always remains the same. In the current context, the tools and the large number of loads do not permit the simulation of varying load allocations over a limited time.

The idea is to simulate different load levels in order to determine the level from which the grid is under constraint. Figure 1 shows the load duration curve for the seasonal period studied.[6] The breakpoint $\alpha_{\min}$ shown below corresponds to the load level from which the grid is under constraint (service restoration rate after intervention lower than 100%) in the simulated N-1 scenario.

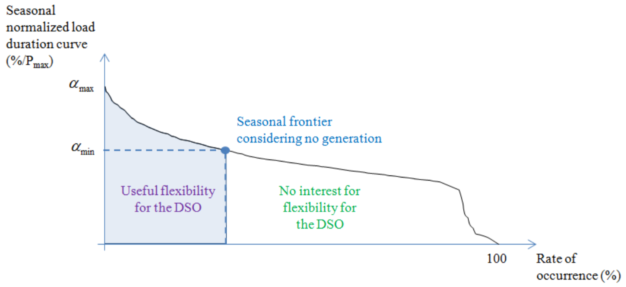

Figure 1 – Determination of the breakpoint for the seasonal period of the primary substation receiving load relief

Once the breakpoint has been determined, several load level simulations have been performed beyond this point. Given that the load level is chosen to be greater than the load threshold previously identified ($\alpha > \alpha_{\min}$), we expect to encounter one or more constraints.

Three types of constraints are studied here:

- Transformer constraint: Exceeding 125% of the transformer's nominal capacity in a emergency situation.
- Voltage constraint: Exceeding the threshold (8% for medium voltage grids) of the voltage differential in a service restoration situation at the level of at least one node in the grid.
- Current constraint: Exceeding the continuous current-carrying capacity, or ampacity, at the level of at least one section of the grid.

Generation

In this study, the generation is fixed to zero as in N-1 configuration, it is usual in Enedis not to keep the generators disconnected.

Note that the flexibility presented here may be overestimated as generators into the areas could decrease the useful flexibility.

Grid topology

We assume that the emergency configuration remains constant because the load levels entailing constraints are very high and close to the maximum. It will thus remain unchanged for all simulations at the load levels studied.

USEFUL FLEXIBILITY EVALUATION METHODS

Two methods have been performed: one heuristic which is called homothetic method and one based on a "best" and "worst" approach also called extreme method.

In the case of a voltage and current multi-constraint, the flexibility volumes will be given to resolve the constraints separately (if the voltage constraint persists after elimination of the current constraint).

Homothetic method

Current constraint

In practice, **the loads connected behind the current constraint are multiplied by a β coefficient applied homothetically**. The difference between the initial load (not using the β coefficient) and the lowered load (using the β coefficient) corresponds to the desired flexibility. Figure 2 shows the case of a current constraint at a feeder, where the desired flexibility corresponds to the difference between the consumption at the portion downstream from the constraint, before and after the constraint has been alleviated.

We therefore have:

$$P_{flex}^{I}(\alpha)=\alpha\cdot P_{\max}^{DS}(1-\beta)$$

Where:

- P_{flex}^{I} is the useful level of flexibility.
- $P_{\max}^{DS}$ is the peak demand, downstream from the current constraint location.
- α represents the load level studied via the normalized load duration curve, applied to all loads in the area.

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[4] Here considered as the period between June 1 and September 30.

[5] Here considered as the period between October 1 and May 31.

[6] The normalized load duration curve is obtained by sorting in descending order the values for the power passing through the primary substation in a given period over two years. In this case, it is determined as a function of the rate of occurrence over these two years.

- β is the maximum coefficient applied to the loads downstream from the current constraint.

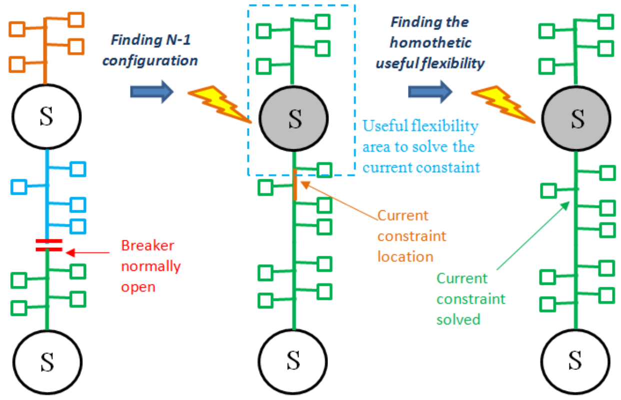

Figure 2 – Principle of current constraint resolution with flexibility framework

Voltage constraint

For a grid voltage constraint, the constraint(s) will be removed by reducing loads whose geographic location is on the whole feeder in an MV N-1 system. This is because, unlike the current constraint, the loads on an outgoing feeder all have an influence on the voltage constraint (to a greater or lesser extent depending on their position relative to the constrained zone).
Remember, too, that the current constraint has already been eliminated. When the flexible load is in the zone selected to resolve the current constraint and the voltage constraint, the total flexibility volumes will be obtained by taking the sum of the volumes for the current constraint and voltage constraint.

Figure 3 shows the resolution principle applied to voltage constraints for each constrained outgoing feeder. From a calculation viewpoint, if a limit coefficient γ is applied to the loads of the sub-zone in question, the flexibility volume capable of removing the voltage constraint (after removing the current constraint) is described by the following formula:

$$P^{U}_{flex}(\alpha)=\alpha P^{Uarea}_{\max}(1-\gamma)\cdot[1-(1-\beta)x]$$

Where:

- P^{U}_{flex} is the useful flexibility volume to eliminate the voltage constraint after eliminating any current constraint.
- $P^{Uarea}_{\max}$ is the maximum power consumed by the loads located in the selected sub-zone.
- x represents the proportion of consumption located in the flexibility search zone to remove the current constraint and voltage constraint where applicable ($xP^{Uarea}_{\max}=P^{feeder}_{\max}\cap P^{DS}_{\max}$ with x=0 if there was no current constraint or if the flexibility search zones are different).
- α represents the load level studied on the normalized monotone, applied to all the loads in the zone.
- β is the limit coefficient applied to loads downstream of any current constraint resolved previously.
- γ is the limit coefficient applied to loads in the selected sub-zone to remove the constraint.

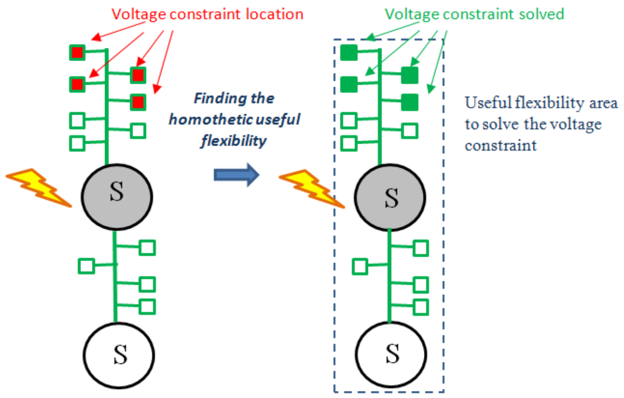

Figure 3 – Principle of voltage constraint resolution

Extreme method

We will now examine a different approach for estimating the flexibility volumes capable of removing these constraints. It concerns the search for extreme flexibility volumes on the complete outgoing feeder, in order to limit the flexibility volumes according to the maximum optimization and "deoptimization" of the location of flexibility.
In Nice Smart Valley, the extreme flexibility volumes correspond to the minimum and maximum volumes which can remove the constraint. To define them, we must first hierarchically rank the utility of load flexibility.
In *Nice Smart Valley*, the criterion for hierarchic ranking of the utility of loads to solve the voltage constraint is the voltage drop at the level of the load connection points.
A voltage profile is first simulated on the outgoing feeder under a voltage or current constraint, then a sort is performed according to the voltage drop. Then, the load with the steepest voltage drop is lowered until another load has a larger voltage drop (searches for the minimum useful flexibility volume). If this case occurs, this new load is lowered until it is replaced by another. If the load reaches zero power, the algorithm then lowers the load with the highest voltage drop according to the voltage profile. The criterion for stopping this algorithm is the disappearance of the voltage or current constraint.
The volume thus obtained is the minimum flexibility volume for which the removed loads are ideally distributed to eliminate the constraint. The same reasoning applies to determine the maximum flexibility volume capable of removing the constraint this time by sorting the loads by increasing order of voltage drops

(from the smallest to the largest). **The volume thus obtained corresponds to the flexibility most poorly distributed to resolve the voltage constraint (ΔU<8%) or current constraint (Imap(p.u.) ≤ 100%)**. NB: Imap is the maximum current capacity of a cable. More details about hypotheses are available in [3].

RESULTS

Guillaumes' primary substation

Guillaumes is a particular primary substation as it showed having four different constraints, one current and voltage constraints on two different feeders.

Current constraints

Figure 4 below shows the results of the simulations run in an N-1 configuration for various load levels of the winter & shoulder period[8].

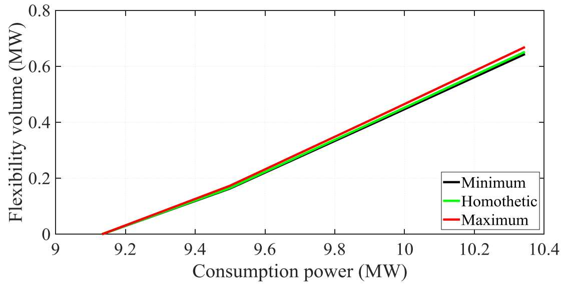

Figure 4 – Useful flexibility volume removing the current constraint (feeder #1) according to consumption levels

These curves show that the greater the consumption, the greater will be the constraint and the larger the useful flexibility volume. In particular, it can be seen that at α_{max}, the maximum useful flexibility volume is 0.67 MW, while the minimum useful flexibility volume is 0.64 MW (if all the producers are not producing). The 25 kW difference at α_{max} shows that in this specific case the location of flexibility (on feeder #2) has only very small impact on the useful flexibility volume.

Figure 5 below shows the results of the simulations run in an N-1 system for various load levels of the winter & shoulder period. The maximum useful flexibility volume is 0.685 MW and the minimum flexibility 0.474 MW if all the producers are not producing. The relatively large difference (0.211 MW, or 42% relative deviation) between the diffuse and maximum flexibility curves is due to the load distribution on the outgoing feeder. In this specific case the location of flexibility (on feeder #2) has a major impact on the useful flexibility volume.

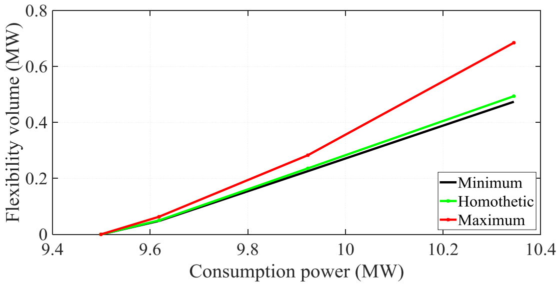

Figure 5 – Volume of useful flexibility removing the current constraint (feeder #2) according to consumption levels

Voltage constraints

Figure 5 below shows the results of the simulations run in an N-1 condition for various load levels of the winter & shoulder period, for treatment of the U constraint.

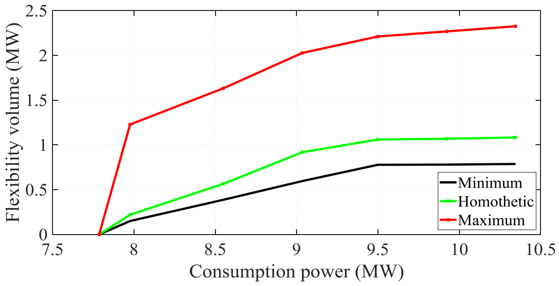

Figure 6 – Useful flexibility volume removing the voltage constraint (feeder #1) according to consumption levels

Excluding production, the maximum useful flexibility volume is 2.32 MW and the minimum flexibility 0.787 MW. The difference is 1.5 MW at α_{max}, which shows that in this specific case the location of flexibility (on the feeder #1) is of capital importance for the useful flexibility volume. Note that the sum of the flexibility volumes cannot be assessed in this case, because the flexibility scope of both constraints is not the same.

Figure 7 below shows the results of the simulations run in an N-1 condition for various load levels of the winter & shoulder period, for treatment of the U constraint.

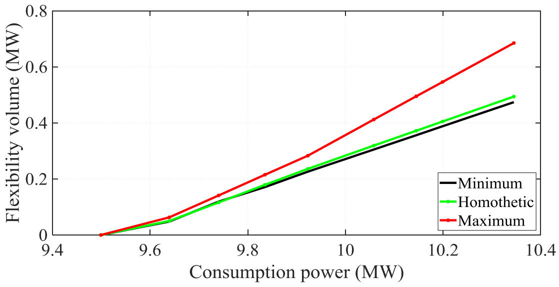

Figure 7 – Useful flexibility volume removing the voltage constraint (feeder #2) according to power levels

The maximum useful flexibility volume is 2.56 MW and the minimum flexibility 1.58 MW if all the producers are not producing. The difference is 0.98 MW at α_{max}, which

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[8] Considered here as the winter periods & the shoulder period between 1 January and 31 May and from 1 October to 31 December.

shows that in this specific case the location of flexibility has a major impact on the useful flexibility volume.

Figure 8 below shows the results for the total useful flexibility volumes[9] making it possible to remove the current and voltage constraints.

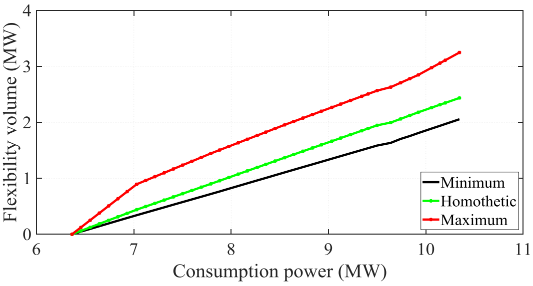

Figure 8 – Useful flexibility volume removing the current and voltage constraints (feeder #2) according to power levels

Excluding production, the maximum useful flexibility volume is 3.25 MW and the minimum flexibility 2.05 MW. The difference is 1.20 MW at α_{max}, which shows that in this specific case the location of flexibility (on feeder #2) is of capital importance for the useful flexibility volume.

Carros primary substation

Figure 9 below shows the results of the simulations run in an N-1 system for various load levels of the winter & shoulder period.

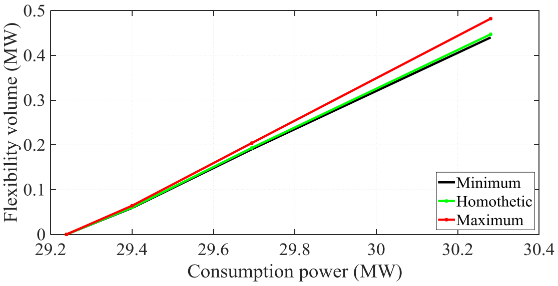

Figure 9 – Useful flexibility volume removing the current constraint (Carros) according to power levels

The maximum useful flexibility volume is 482 kW and the minimum flexibility 440 kW if all the producers are not producing. The relatively small difference (42 kW) between the maximum and minimum flexibility curves shows that the location of flexibility does not have a major impact on the volume (at no production).

Isola's primary substation

Figure 10 below shows the results of the simulations run in an N-1 system for various load levels of the winter & shoulder period. Since the HV/MV transformer's constraint is preponderant over the current constraint, the following curve therefore shows the useful maximum, minimum and homothetic flexibility volumes to remove the two constraints. The difference is 0.144 MW at α_{max}, which shows that in this specific case the location of flexibility does not have a major impact on the useful flexibility volume.

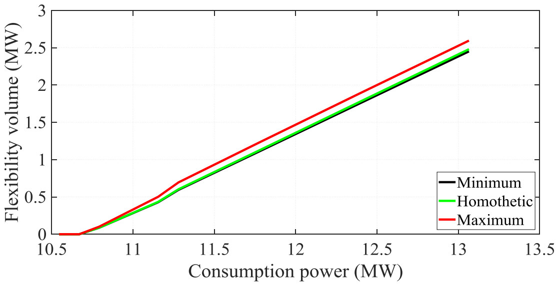

Figure 10 – Useful flexibility volume removing the transformer constraint (Isola) according to power levels

CONCLUSIONS AND FUTURE WORKS

This article presented a study done in Nice Smart Valley project aiming at assessing the impact of flexibility location on useful volumes. The impact of the location of the flexibility depends on different factors. Indeed, for current constraints the results showed the placement of the flexibility has a very small impact on Isola's MV-grid whereas we obtained a relative difference of 42% on Guillaumes' feeder #2. On these three particular MV-grids, the results also showed an interest for the diffuse flexibility as the volume seems close to the ideal placement. Note that this result highly depends on the topology of the MV-grids and the distribution of the loads. It theoretically exists grids where the homothetic volumes are closer to the maximum volume but we did not meet this case in Nice Smart Valley's areas. For voltage constraints and on the two feeders of NSV, the results showed a big impact of the placement of the flexibility on the volumes: from 63% to 190% of relative difference. These results will feed the discussions into Nice Smart Valley between the DSO and aggregators on a potential future market design and the business models related to a flexibility market.

ACKNOWLEDGMENTS

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[3] Nice Smart Valley, "Detailed Use Case planning, including the district architecture requirements and tested innovations," 2017.

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[9] The sum of the flexibility volumes is calculated in this case, because the flexibility scope of the voltage and current constraints is the same.