ASSESSING THE FLEXIBILITY PROVISION OF MICROGRIDS IN MV DISTRIBUTION GRIDS

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ABSTRACT

This paper provides a methodology to assess the amount of flexibility that lower voltage level grids can provide at the connection point to a higher voltage level grid considering operational characteristics of installed flexibility providing units (FPU), while taking grid constraints into account. A multi-level aggregation process is introduced, with the aim to reduce the computational resources required to aggregate flexibilities of large grids. The methodology is verified using test bench grid models, in order to show its effectivity. Results show that the implementation of a multi-level aggregation reduces the complexity of the problem, while providing accurate results.

INTRODUCTION

The installation of distributed energy resources (DER) is growing at very fast rates within distribution grids, forcing grid operators to change their way to operate the grids. At the same time, this opens an opportunity to allow a more efficient operation of the grid due to the controllability of new DER units, which allow them to provide flexibility to the grid. In [1], a comprehensive definition of the term flexibility is given, from which this paper relates to the 'Physical Source' definition in LV and MV grids. Flexibility provided by DERs can be offered to provide ancillary services to the grid e.g. for congestion management, voltage control, for which increasing requests are expected at DSO level.

Microgrids (MG) can be important providers of flexibility, through its combination of flexibility providing units (FPU), such as small generation sources, storage systems and controllable loads. The flexible character of MGs make them be relevant providers of ancillary services to the grid, due to their ability to modify the active and reactive power set points of their components from the expected value, through a centralized controller.

There are different drivers for the usage of flexibility, e.g. frequency control or voltage control, but very few of them consider the grid topology during their decision-making. Therefore, a call for flexibility that may solve one grid issue may cause unexpected congestions or voltage limit violations at other sections of the grid. In this paper, a method that allows the assessment of flexibility provision of MGs to the distribution grid, while respecting grid constraints is introduced. In [2], an algorithm to aggregate the flexibility of a distribution grid was first developed. The method involves an OPF where the power flow at a DSO/TSO interconnection point is maximized/minimized. An improvement to this aggregation algorithm was proposed in [3], by means of linear optimization. The aforementioned linear algorithm is applied within this paper to aggregate the flexibility provided by all flexible components of MGs that exist in the distribution grid. The novelty relies on the application of a multi-level aggregation scheme to assess the flexibility of a distribution grid as a whole, while reducing the computational complexity and allowing a better visibility of the flexibility provision of the MGs.

The first section of the paper focuses on the characteristics of different FPUs, which can be commonly found in MV and LV grids. Afterwards, the multi-level aggregation method is introduced. A study case is then presented applying the methodology to a MV grid connected to various LV MGs. The final section provides a brief conclusion and outlook of the paper.

MICROGRIDS FLEXIBILITY PROVISION

Microgrids can comprise several types of grid utilities, which are able to provide flexibility to the power grid. This chapter introduces the concept of FPU, and then provides a set of linear models to be used in the aggregation model in order to simulate the FPUs.

Flexibility Providing Units (FPU)

Any decentralized generating unit, storage system or controllable load can be a flexibility provider, as long as its operation point can be controlled through an external signal. In this paper, the concept of FPU is applied to refer to these controllable grid utilities, considering both active and reactive power. A review on FPUs that can be found in MV and LV microgrids is presented.

Photovoltaic Generation (PV)

The integration of PV generation has seen a very large increase in MV and LV grids. The modules are connected to the grid through inverters, which regulate the provision of active power and in some cases reactive power as well. For example, newer PV generators in Germany are required to adapt their power factor up to 0.9, to provide voltage support to the grid. [4]

Wind Generation (WG)

Wind generators with doubly fed induction generators (DFIG) can control active and reactive power independently, bounded by the technical limitations of the electrical machine. Using a full-inverter allows an entirely independent control of active and reactive power, bounded by the limits of the inverter. In both cases, maximal generation depends on local wind speed. Many control techniques have been developed, that allow the regulation of the active and reactive power output, depending on the use case [5].

Controllable Loads

Demand side management has focused primarily on the control of active power consumption of industrial loads, while it is increasing its penetration into smaller customers. Every customer has its own consumption pattern, but specific *cos(φ)* limits are intended to be maintained. This can be represented as a linear relation of active and reactive power through a fix *cos(φ)* [6].

Synchronous Generators (SG)

Synchronous generators, such as low scale hydraulic generators or CHP, can control their power output through mechanical methods or through the regulation of the excitation of the generator [7].

Storage Systems (SS)

Storage systems are a key element in MGs and a mayor flexibility provider, since it allows the storage of the exceeding power load in times of high power generation through RES and then to discharge it in times of high power load demand. Storage systems are seeing an increased use in MV and LV grids. Inverter-based systems can provide reactive power in some cases [8].

Electric Vehicles (EV)

Electric vehicles are flexible by definition, as they are mobile storage systems, which can be connected to different nodes within the grid. Use cases where EVs inject energy back to the grid can be considered as well.

Reactive Power Compensation

Reactive power compensation utilities, such as capacitor banks, STATCOMs or induction coils can inject or absorb reactive power, primarily to provide voltage support to power grids.

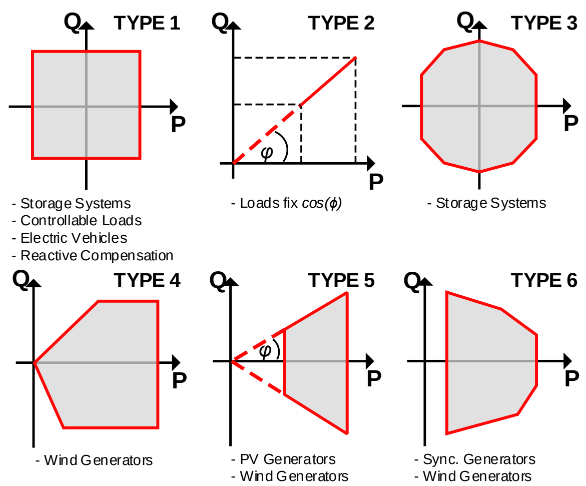

Figure 1 – Operational restrictions of six types of FPUs

Modelling of Flexibilities

Every FPU is required to operate within a specific operation range, determined by the technical features of the each unit. The operation point of RES can change e.g. due to sudden changes weather conditions or due to droop control methods, reacting to voltage or frequency changes, among others. Regardless what causes the operation point to change; it needs to stay within the given FPU limits. In [3], a set of linear models representing FPUs were defined. complemented in this paper (Fig. 1). These models provide an accurate representation of the instantaneous PQ flexibility range of typical utilities that can be found in microgrids.

FLEXIBILITY AGGREGATION METHOD

The aggregation of the flexibility range at a DSO/TSO interconnection point using nonlinear mathematical methods becomes a very complex computational problem when large quantities of FPUs are involved. This represents a challenge for grid planners, since the consideration of large amounts of FPUs is required during the planning process. The linear OPF model proposed in [3] reduces the computational burden involved in the aggregation of the grid flexibility, considering grid constraints. This paper bases on this linear model to aggregate the different voltage levels within a distribution grid, following many stages. For the mathematical description of the linear aggregation method, please refrain to [3]. First, the flexibility provided by each LV MG is aggregated at an individual basis. The obtained flexibility ranges for each MG are added to the MV grid as FPUs. This allows the aggregation of the flexibility provided by the entire MV grid to a HV grid. This allows the reduction of dimension of the problem, since the LV grids are now aggregated. Special attention needs to be given to the voltages at the connecting nodes of the MGs, since the voltage profiles of the MV grid have a strong influence on the LV grid. Fig. 2 exemplifies the proposed multi-level aggregation method.

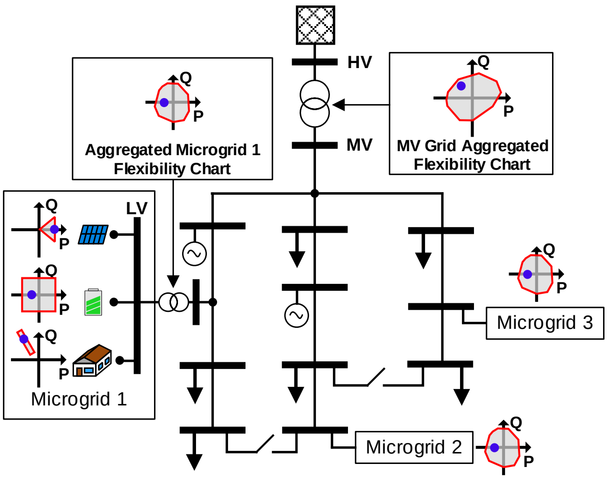

Figure 2 – Multi-level flexibility aggregation scheme of a distribution grid containing microgrids

STUDY CASE DESCRIPTION

In this section, the proposed methodology to aggregate the flexibility of a MV distribution grid with several MGs connected as subordinate LV grids is evaluated using the CIGRE test bench for European grids [9]. The CIGRE MV grid was modified to consider only the largest feeder, to which three LV MGs were integrated (Fig. 3). The LV microgrids are adaptations of the three CIGRE LV test bench models (Fig. 4). In order to simplify the modeling, a fix operation point has been adopted for the loads, while every generating unit and storage system is considered as a FPU (with reactive power capability), accordingly to the models of Fig. 1. A sum up of the considered FPU parameters grids are represented in Table I.

SIMULATION RESULTS

This section presents the results of the selected study case, together with a brief analysis of the outcomes. The multi-level aggregation was performed in two steps. First, the flexibility area of the single LV MGs was aggregated, and then by aggregating the flexibility of the entire MV grid (including the aggregated MGs).

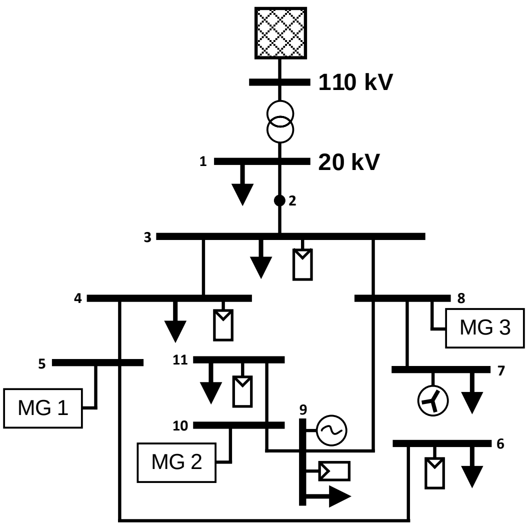

Figure 3 – Modified CIGRE MV distribution grid [9].

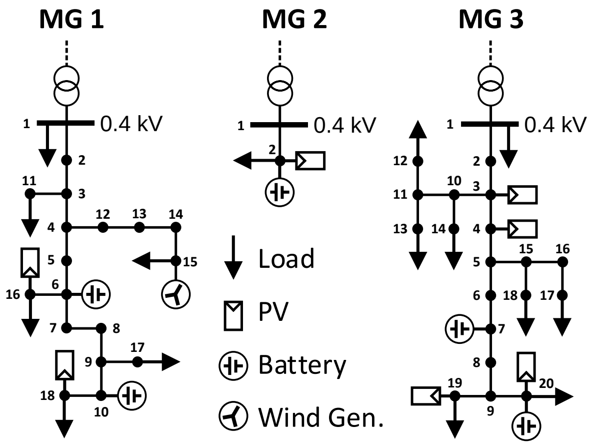

Figure 4 – Set of MGs based on CIGRE LV grids [9].

Table I: Distribution of FPUs in LV MGs

Grid	Bus	FPU Type	P_{max} kW	P_{min} kW	Q_{max} kVAr	Q_{min} kVAr
MG1	6	3	29,75	-29,75	29,75	-29,75
MG1	10	3	21,25	-21,25	21,25	-21,25
MG1	15	4	5,5	0	1,8	-1,8
MG1	16	5	4	0	1,3	-1,3
MG1	18	5	3	0	1	-1
MG2	2	5	60	0	20	-20
MG2	2	3	34	-34	34	-34
MG3	5	5	40	0	13	-13
MG3	6	5	35	0	11,5	-11,5
MG3	9	3	29,75	-29,75	29,75	-29,75
MG3	21	5	3	0	0,1	-0,1
MG3	22	5	15	0	4,9	-4,9
MG3	22	3	4,25	-4,25	4,25	-4,25

Step 1: Aggregation of Single LV Microgrids

In a first stage, each MG is considered as an individual grid. Hereby the connection to the MV grid is modelled as an infinite bus. The power flow through the 20/0.4kV transformers is aggregated taking into account the flexibility provision of all FPUs within each MG. The resulting aggregated flexibility ranges for the three studied MGs are shown in Fig. 5. Each MG offers different quantities of flexibility to the grid. In this case, MG3 (blue line) is able to provide the largest amount of negative active power flexibility, due to the curtailment of PV generation (increase of load). The power injection from the battery storage systems into the grid in all MGs allows the provision of positive active power flexibility (decrease of load).

Step 2: Aggregation of MV Distribution Grid

The aggregation of the three MGs results in non-regular convex polygons, which are established as FPUs for the MV grid. The polygons characterize the MGs as loads in the studied scenario. Adding the MGs FPUs to the MV grid model allows performing the next stage of the aggregation, using the same methodology. Fig. 6 shows the contribution of both the MGs and the connected DER to the flexibility of the MV grid. It can be observed that the wind generator connected to the MV grid impacts the flexibility areas the most, but the remarkable impact of the MGs can be perceived as well.

Comparison between Aggregation Methods

One benefit of the proposed multi-level method is the partition of a large optimization problem into many smaller ones. The grid model is split into the different voltage levels. Table II describes the resulting optimization problems, compared to the aggregation of the entire considered distribution grid in just a single step.

Table II: Size of optimization problems of one and two steps aggregation methods

Aggr. Method	Grid	Qt. Buses	Qt. FPUs	Optimization Variables	Optimization Constraints
1-Step	MV	52	20	144	962
2-Step	MV	12	10	40	226
	MG1	19	5	48	348
	MG2	3	2	10	48
	MG3	21	6	54	386

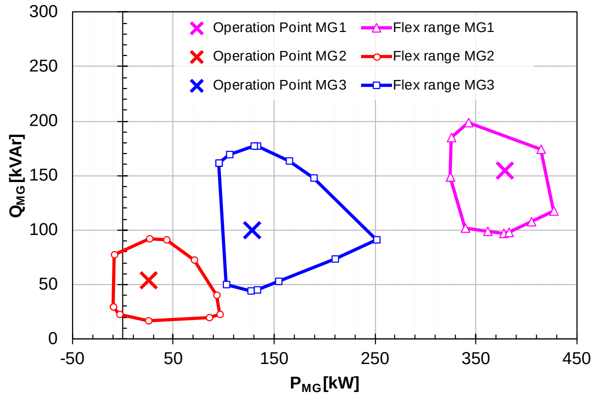

Figure 5 – Aggregated flexibility ranges of the MGs.

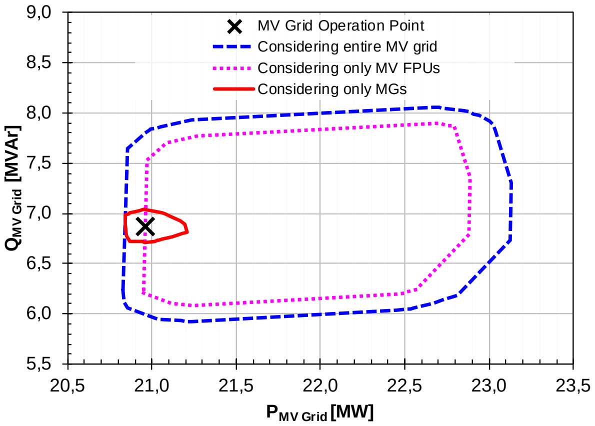

Figure 6 – Aggregated flexibility range of MV distribution grid considering RES and MGs.

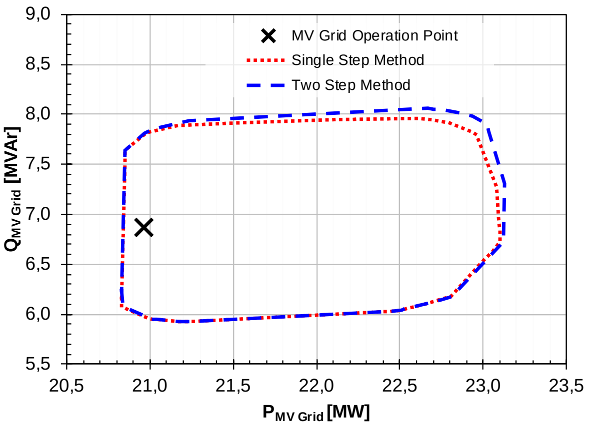

Figure 7 – Comparison of single and two steps methods.

Fig. 7 shows the flexibility areas resulting from the multi-level aggregation and by a single step aggregation. The resulting boundaries are very similar. The gap in the upper right corner of the polygon occurs due to under-voltage violations within MG1 and MG3. These violations cannot be properly detected during the multi-level aggregation, since the voltage at the slack nodes of every MG is preserved constant during the aggregation process. During the single step aggregation, the voltage at the transformers sway, causing the downstream voltage profiles to vary as well. This may trigger voltage limit violations under certain conditions. This simplification may cause an overestimation of the flexibility boundary in scenarios with voltage issues.

CONCLUSIONS

In this paper, a method to aggregate the flexibility provision of power grids at different voltage levels was introduced. The method performs a multi-level aggregation of flexibility of FPUs within the grid, beginning from the LV level. By performing the aggregation in many stages, the influence of each smaller grid section on the overall grid flexibility can be observed. In cases of LV MGs, the method allows an independent assessment of the flexibility provision of each MG, thus strongly reducing the computational complexity of the overall problem. Some issues with grids presenting voltage violations were identified and techniques to solve these issues are being currently researched. Future work will focus on the assessment of larger grids using the proposed methodology, in order to identify more use cases for the studied technique.

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