FLEXIBILITY ACTIVATION OPTIMIZATION FOR CONSTRAINTS MANAGEMENT IN DISTRIBUTION GRIDS, USING DER FLEXIBILITY THROUGH LV4MV

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ABSTRACT

This paper presents a flexibility activation cost optimization for constraints management, using both MV and LV DER flexibility. This method, based on a metaheuristic algorithm, permits to determine the best economic activation of MV and LV flexibility opportunities in order to solve MV network constraints, while ensuring that all connected LV networks constraints are respected. Developed within a distributed approach, the idea is to dissociate the two voltage levels aiming to get a complete vision of the potential flexibility opportunities. Some results of simulations performed on a part of a real distribution network near Strasbourg are presented.

Keywords: *Constraints management, Cost minimization Distributed Energy Resources, Local flexibility opportunities, LV and MV voltage levels*

INTRODUCTION

Over the last 20 years, the penetration rate of Distributed Energy Resources (DER) in European distribution grids has largely increased [1]. This engenders, among many others impacts, a modification of the voltage profiles on both Medium and Low Voltage levels (MV & LV levels) [2]. To cope with these resulting voltage deviations, the Distribution System Operators (DSO) can think of network reinforcement, but also of voltage regulation through management of both local active and reactive powers of DER, including DG, storage and controllable loads. Many references present solutions of DER management focusing mostly on only one voltage level [3]. The large spread out of DER in distribution grids, and particularly in LV level (via Demand Side Management for example) should encourage DSO to think at using both MV and LV flexibility opportunities to avoid congestions and to keep the voltage within specified limit.

In the presented context, end user's flexibility opportunity is defined as the possibility to modify generation and/or consumption patterns at an end user node of connection for a given time (both demand and supply side), with an associated payment for this modification [4].

This article presents a flexibility activation cost optimization for constraints management, using both MV and LV DER flexibility. The objective of this method is to first, aggregate and validate flexibility opportunities in LV level, and in a second phase, to plan the best economic activation of MV and LV flexibility offers to solve the cases of MV constraints deviations, while ensuring that all LV network constraints are always satisfied. Instead of using LV flexibilities locally, the provision of them in MV level would enable a better repartition of the flexibility offers and would ensure fairer and lower prices in the MV local market.

The paper is organized as follow: in a first part, the overall concept is presented, as well as the chosen infrastructure of deployment. Then, the two different phases are detailed: a) determination of the MV admissible voltage range at the MV nodes where only LV network is connected, and aggregation and validation of LV flexibility opportunities if available at these MV nodes, and b) cost optimization for MV constraints management. Finally, some test results are presented based on simulations on a part of a real distribution network operated by ESR (Electricité de Strasbourg Réseaux).

CONCEPT AND INFRASTRUCTURE

General overview of the solution

In order to plan the best combination of activation of LV and MV flexibility opportunities, the idea is to dissociate the two voltage levels. Hence, two algorithms have been developed, which have to be performed one after the other in order to carry out the whole optimization. The first step is the execution of the LV4MV algorithm [5] which permits to determine the constraint-dependent admissible voltage range for each MV node where only LV network is connected. This first step provides an aggregated view of the downstream LV network and of its respective LV flexibility opportunities at the MV level.

The MV level optimization is the second step of the method: the objective is to determine the best economic combination of MV and LV flexibilities to be activated in order to solve the different cases of constraints violations.

The topology of the distribution grid, as well as the end users production and consumption forecasts are required as inputs of the algorithms, but also their flexibility opportunity offers. If information about downstream LV networks is not available, they are treated as MV aggregated load or generator.

Implementation infrastructure

Developed within the DREAM project, this mechanism relies on a distributed mode of network operation. Functionalities are distributed among the whole system network thanks to a Multi-Agent System (MAS) deployment through the installation of advanced Remote Terminal Units (RTU). MAS architecture has several advantages for the development of smart grids [6]. First of all, it enables to specify and to simplify the communication process: the specification of the information exchanges permits to reduce communication needs. Moreover, in a practical point of view, the deployment of MAS for smart grid is a businesslike architecture: the deployment is very scalable and adaptable, and can be done step-by-step. Today in Europe, the DSO currently does not have a lot of visibility on LV networks, where more and more DG are connected. While choosing a step-by-step deployment, the DSO could focus and invest first on most critical zones instead of deploying a centralized solution on the whole distribution network. The LV4MV algorithm can be performed at all the equipped secondary substations, while the MV optimization is performed at the primary substation.

THE LV4MV PROCESS: A TOOL FOR AGGREGATION AND VALIDATION OF LV FLEXIBILITY OPPORTUNITIES

As presented in CIRED 2015 [5], the LV4MV algorithm permits to have an aggregated MV vision of a downstream LV network. It allows the DSO to treat it as a flexible aggregated MV node with specific admissible voltage limits which are reflecting the downstream LV network constraints. This gives more precise information to the DSO who generally guarantees large voltage margins in MV level in order to ensure all cases of operation in LV level.

It is possible to determine several MV admissible voltage range intervals for each MV node, depending on the state of activation of downstream LV flexibility offers. Indeed, the voltage profile is mainly depending on the load state of the considered network. A highly loaded LV network will have large voltage drops along its feeders and thus, the voltage value at the secondary substation will have a restricted degree of freedom. On the other hand, a slightly loaded LV network will have a quasi-flat voltage profile. The voltage value at the secondary substation will have a large degree of freedom, still ensuring that the LV network constraints are respected.

Step-by-step LV DER activation can permit to enlarge the MV admissible voltage range. At the end of the process, the list of the possible LV activated flexibility combinations is generated, and for each combination, a new MV admissible voltage range and a price of activation is associated.

MV GRID MINIMAL COST CONSTRAINTS MANAGEMENT

The objective of this optimization is to determine the best economic combination of MV and LV flexibilities to be activated in order to solve the different cases of voltage deviations and current congestions in MV level, ensuring that all network constraints are respected in downstream LV networks. The MV network is considered as a balanced system. In this optimization, decision variables are:

- MV flexibility offers of MV controllable productions or loads (there can be multiple offers at the same node, depending on the capacity of the connected end user),
- LV flexibility combinations offers of downstream networks corresponding to new MV admissible voltage ranges and associated prices of LV flexibility activation, at equipped MV/LV transformers where LV4MV has been executed,
- OLTC position at the primary substation.

All the non-equipped secondary substations are considered as MV aggregated loads and their MV admissible voltage ranges are fixed at +/-5% of the nominal voltage value. The admissible voltage range at MV connection point of MV end users are as well set at +/-5% of the nominal voltage value.

Problem formulation

The objective function can be formulated as follow:

$$\min \sum_{i} \sum_{l} (c_{il} \times x_{il}) \qquad (1)$$

where i is the index of the MV node, l the index of the flexibility opportunity at node i, c_{il} is the cost of the flexibility activation l at node i, and x_{il} is the state of activation of the flexibility l at node i. This binary variable is either equal to 0 if the flexibility offer is not activated or 1 if the flexibility offer is activated.

The problem is ruled by the classical loadflow equations, and the constraints of the problem are:

$$\forall i \in N, \quad V_{MV\,min,i} \leq V_i \qquad (2)$$

$$\forall i \in N, \quad V_i \leq V_{MV\,max,i} \qquad (3)$$

$$\forall j \in L, \quad I_j \leq I_{j\,max} \qquad (4)$$

$$\min tap \leq x_{tap\_OLTC} \leq max\ tap \qquad (5)$$

Where N is the set of nodes, L the set of lines of the considered MV network, V_i is the voltage at the MV node i, $V_{MV\,min,i}$ and $V_{MV\,max,i}$ are respectively the minimum and maximum MV voltage admissible constraints at the MV node i. Given a node k where the LV4MV has been performed on its downstream LV network, and l the index of one LV flexibility combination activation at this node, if $x_{kl} = 1$, the associated MV voltage limits $V_{MV\,min,k}$ and $V_{MV\,\max,k}$ are updated.

I_j is the current flowing into the line j, $I_{j\,max}$ is the maximum limit of current flowing into the line j, x_{tap_OLTC} is the OLTC position, $min\ tap$ and $max\ tap$ are the bounds positions of the OLTC.

Proposed solution

The problem is formulated as an integer linear problem (ILP), as all decision variables are integers, the objective function is linear, and the constraints are quadratic (due to loadflow equations). Exact algorithms can be used to solve ILP, as cutting plane or branch and bound methods in order to find the optimal solution. However, since integer linear programming is NP-hard, the resolution time with these methods can increase exponentially. Heuristic methods can be also used to solve the problem in a reasonable time. In this particular case, a metaheuristic method based on a genetic algorithm is used to find a solution. The dedicated algorithm is dealing with both discrete and binary variables.

SIMULATION RESULTS

The flexibility activation cost optimization for constraints management is simulated on a real MV network, located in the area of Strasbourg in France, and operated by ESR. The test case is focusing on two extended MV feeders that are connected to the same substation, and that connect 14 MV consumers, 2 MV producers and more than 30MVA of LV subscribed power contracts. Load profiles are based on French profiles characteristics [7] and depend on the subscribed powers of the MV and LV end users. The scenario is representing an hour during a weekly summer day, where DG production is high. In order to create voltage deviations, some DG productions and some load consumptions have been modified. Particularly, a big load which could correspond to a large industrial site has been added in the first feeder (450 kW), and two large generating power plants have been added in the second feeder (respectively of 2.8 and 4 MWc).

Initial situation

The initial voltage profiles for two different tap positions of the HV/MV transformer are shown in figures 1 and 2. In figure 1, the tap ratio is set at 1: some under-voltages are occurring at MV nodes, and particularly at the MV connection of the industrial plant which has therefore a poor quality of supply. Keeping this tap position, the solution to release the voltage constraints would be to activate flexibility opportunities (through Demand Side Management for example) in order to decrease the loading of the first feeder.

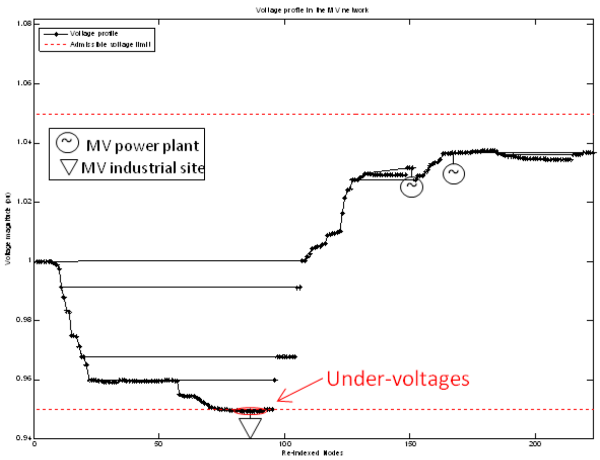

Figure 1 – Initial voltage profile without any activation of flexibility opportunities (OLTC tap: V1=1pu)

In figure 2, the OLTC is increased and the voltage at the first MV node is now at 1.014 pu. Some over-voltages are appearing in the second considered feeder at some MV nodes where only LV downstream networks are connected. Depending on these LV networks, some LV constraints could appear if a lot of DG is connected in LV level. A way to solve these possible over-voltages could be production curtailment.

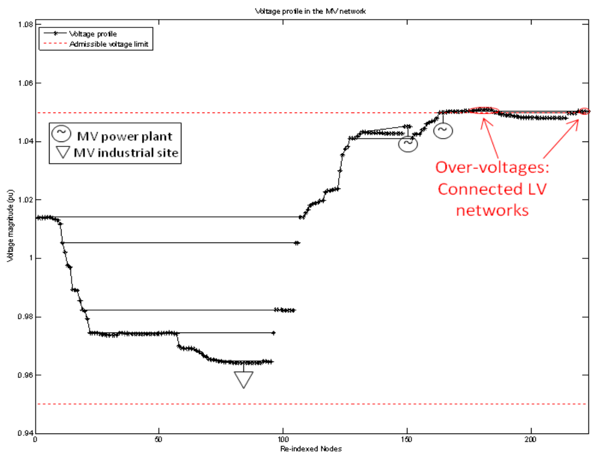

Figure 2 – Initial voltage profile without any activation of flexibility opportunities (OLTC tap: V1=1.014pu)

MV flexibility assumptions

Some MV flexibility opportunities are assumed to be available in the considered network at some MV end users connection, with an associated payment for their use. In table 1, these flexibility opportunities are presented. The best economical solution found by the algorithm set the tap ratio at 1. The lines which are highlighted in grey are the flexibility opportunities that have been selected by the optimization algorithm in order to solve MV voltage constraints, ensuring that no current congestion is happening.

Table 1 – MV flexibility opportunities

Node	ΔPcurtailment (kW)	ΔPload shedding (kW)	Activation price	
			€	€/MWh
78	0	20	0,8	40
84	0	50	7,5	150
87	0	20	0,76	38
106	0	10	2	200
120	0	10	0,34	34
134	0	10	0,36	36
145	0	50	2,25	45
150	500	0	100	200
164	500	0	80	160
211	0	20	1,9	95

In this case, the optimization algorithm finds as a solution the activation of the demand response of 40kW, with an associated price of 1.56€ for its use.

LV4MV flexibility assumptions

In a second scenario, the LV4MV is assumed to be performed at the 9 critical MV nodes, which are connected at the end of the second feeder. These nodes are directly feeding downstream LV grids where some DG are also connected. 4 of the 9 considered LV networks are producing more than consuming. Performing the LV4MV in these LV grids, it is possible to get the new MV admissible voltage ranges for these critical nodes, reflecting the loading state of the LV networks.

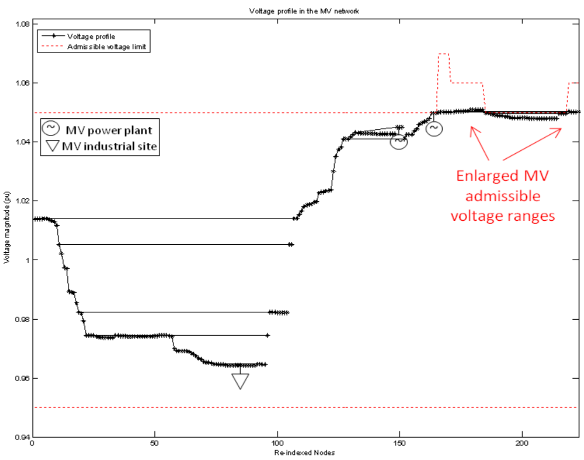

Figure 3 – Voltage profile without any activation of MV flexibility opportunities, but enlarged admissible voltage ranges at critical nodes thanks to LV4MV algorithm

Figure 3 shows the new situation of the network voltage profile as well as the new MV admissible voltage ranges at critical MV nodes. In this case, no flexibility activation is necessary. Indeed, the LV4MV permits the DSO to know that, even if the voltage value is higher than +5% of the nominal voltage at these MV nodes, there will be no voltage deviations occurrence in LV downstream networks. This example shows the benefits of coupling the optimization algorithm with the use of LV4MV at critical MV nodes, where only LV networks are connected.

CONCLUSION AND PERSPECTIVES

In this paper, a metaheuristic method has been used in order to perform a flexibility activation cost optimization for constraints management in distribution networks, taking into account LV and MV flexibility opportunities. The LV4MV method is used in order to aggregate LV flexibility offers and to reflect downstream LV networks constraints in MV level. As shown in the simulation results, LV4MV can improve the optimization in some cases, enlarging the MV admissible voltage ranges while ensuring that all LV constraints are still respected.

Until today, DSO generally doesn't take into account LV level voltage margins (applying a fit and forget approach) but with the growing share of DG in both MV and LV levels, this solution might not be always the best economic option. The LV4MV is a solution that can be gradually deployable in order to have a better aggregated visibility of the critical LV networks. This flexibility activation cost optimization is based on combinatorial algorithms and further work is currently focusing on branch and bound methods to find the global optimal solution of the problem. Some work on scalability for this method will be also done.

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