LV4MV: A CONCEPT FOR OPTIMAL POWER FLOW MANAGEMENT IN DISTRIBUTION GRIDS, USING DER FLEXIBILITY

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ABSTRACT

This paper introduces a concept for optimal power flow management in distribution grids, using DER flexibility. The LV4MV concept leads on a release of the admissible MV voltage range, in order to increase the number of suitable DER available dispatches at the LV level, willing at the end to reduce the constraint management costs of both MV and LV levels and to encourage the penetration of DER down to the lowest level of the grid. It aims to help the DSO to benefit of the available LV flexibility to solve voltage constraints on the both MV and LV levels. The method to identify the MV admissible voltage range for nodes where only LV network is connected is presented, taking into account the downstream LV flexibilities, if available. Test results concerning a LV unbalanced distribution system are then displayed, for different scenarii of LV flexibility. Finally, developed at the European scale within DREAM FP7 project, LV4MV implementation requirements and architecture are discussed.

INTRODUCTION

One step toward LV network automation

The large penetration of Decentralized Generation (DG) among the distribution grids engenders, among other impacts, a modification of the voltage profiles on both the Low and Medium Voltage levels (LV & MV levels) [1]. To cope with these resulting voltage deviations, the Distribution System Operators (DSO) can either use network reinforcement, or voltage regulation through management of local active and reactive powers of the Distributed Energy Resources (DER), including DG, storage and controllable loads connected to both MV and LV levels. While the automation of the distribution grids focused mainly on the MV grids [2]–[4], this new challenge of voltage deviation should encourage the DSOs to think at a partial automation of the LV grids.

Short-term local flexibility offers

With the growth of automation in distribution grids, networks are becoming more and more active [5]-[6], meaning that active and reactive powers management is possible via controllable sources and loads in order to solve constraints in the grid. This is possible through the activation of end users' flexibility at both demand and supply side. On an individual level, flexibility is the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system. The parameters used to characterize flexibility include the amount of power modulation, the duration, the rate of change, the response time and the location [7].

The day-ahead and intraday processes lead to an optimal plan of energy balance and to the knowledge of available flexibility offers which can be used for constraint management. Thanks to a decentralized approach, after the clearing of the both wholesale and balancing markets, distribution networks remaining flexibility services could allow the DSO to tackle network constraints up to the time of operation, maintaining reliability and quality of service and encouraging the increase of the rate of penetration of DER until the lowest levels of the grid. The LV4MV, a concept for optimal power flow management in distribution grids using DER flexibility, has been thought as a pre-operational service for DSOs, permitting operational planning.

Proposed solution

The LV4MV concept leads on a release of the admissible MV voltage range, to increase the number of suitable DER available dispatches at the LV level, willing at the end, to reduce the constraint management costs of the both MV and LV levels. LV4MV aims to help the DSO to benefit of the LV flexibility available on a given LV network to cope with voltage deviations appearing on both MV and LV levels.

According to EN 50160, it is recommended that, under normal conditions, the variations range of the r.m.s. magnitude at the supply terminals for LV and MV levels should be Un ±10% for 95% of a week, where Un is the nominal voltage [8]. In practice the r.m.s. value could be determined over a fixed interval of 20 milliseconds and the basic measurement could be made by determining the average of these values over a period of 10 minutes. While EN 50160 gives general limits for public supply networks, various European countries commit to additional rules governing supply conditions.

Until now in Europe, based on a "fit-and-forget" approach, the DSO currently guaranties voltage margins in MV level in order to ensure the operation in LV level. For example in France, the voltage at each MV network connection point should be within the range of Un ±5% [9]. This might lead to suboptimal operation of the system network, adding operational constraints for the DSO. The LV4MV concept has been designed to release these constraints, taking advantages of active distribution networks.

CONCEPT

Identification of the MV admissible voltage range interval

The LV4MV concept aims to dissociate the MV and the LV levels via the management of the LV DER available dispatches. The objective of LV4MV is to determine the constraint-dependent admissible voltage range for each MV node where only LV network is connected, considering the downstream LV flexibilities, if available. Let $[V_{i,adm\,min}\,;V_{i,adm\,max}]$ the MV admissible voltage range interval at the i^{th} node of the considered MV distribution network, assuring that all LV nodes fed by this connection point are respecting the LV admissible voltage constraints. At a given time interval, for each MV node where only LV network is connected and no MV consumer, it is possible to determine several MV admissible voltage range intervals, depending on the state of activation of downstream LV flexibilities. Hence, a table including the different voltage range intervals and their corresponding price of LV flexibilities activation can be constructed for each considered MV node.

Therefore, instead considering a fix MV voltage range for all the MV nodes, it enables to increase the degree of freedom of those where only LV networks are connected: at these nodes, the voltage at the MV/LV transformer might be outside of the MV admissible voltage range commonly used in network planning, while all LV nodes fed by this connection point are respecting the LV admissible voltage constraints.

Optimization of the MV grid operation with more precise voltage constraints

Thanks to this increase of degree of freedom of the MV nodes, it will be easier to optimize the overall MV grid operation. This global economic and technical optimization should take into account the OLTC position of the HV/MV transformer but also the cost of activation of MV and LV flexibilities. The acquired precision on the voltage range constraints will help the DSO to plan and operate the network in a more accurate way and to realize benefits on flexibilities' activation.

ALGORITHM

In the present article, the voltage variations range are respecting grid codes: the MV end users voltage variations range is set at Uc ±5% and the LV voltage variations range is set at [Un -10%; Un +10%]. Figure 1 presents the flowchart of the initialization step of the LV4MV, performed for each MV node where only LV network is connected, and for each dispatch of downstream LV flexibilities. Vref is the current standard voltage at the secondary part of the MV/LV transformer under normal conditions. It is stored in the variable V0 for the initialization of the algorithm.

After performing a first unbalanced three-phased loadflow on the downstream LV network, three situations might appear: case 1 corresponds to a situation where voltage at each LV node is included in the LV voltage variations range, whereas cases 2 and 3 correspond respectively to a LV under-voltage situation and to a LV over-voltage situation.

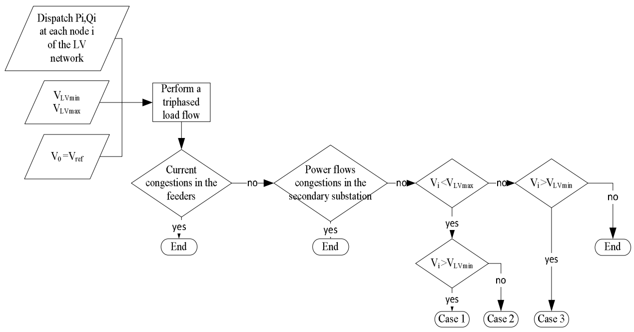

Figure 1- Initialization flow-chart of LV4MV

The next step consists in the computation of the MV admissible voltage range interval. The algorithm corresponding to case 1 is presented in figure 2. Cases 2 and 3 are not presented here due to high similarities.

The algorithm consists in computing the admissible voltage limits $V_{adm\,min}$ and $V_{adm\,max}$ at the secondary part of the MV/LV transformer, assuring that all downstream LV connection point are respecting the LV admissible voltage range. In order to determine the voltage $V_{adm\,max}$, the first step is the computation of the minimal voltage deviation ΔV_{max} between the highest voltage of the LV network and the admissible LV maximal voltage. The second step consists in increasing the voltage at the secondary part of the MV/LV transformer of ΔV_{max} value and to test thanks to a unbalanced three-phased load flow computation, if all the LV connected points are still respecting the LV admissible voltage range. This procedure is repeated until a detection of LV voltage deviation or a critical threshold of ΔV_{max}. The determination of $V_{adm\,min}$ is roughly based on the same sequence.

The computation of the applied offset voltage corresponding to the deviation between the nearest voltage of the LV network and the LV voltage limit permits to gain CPU time doing less load flow computations than when performing iterations based on small step increases.

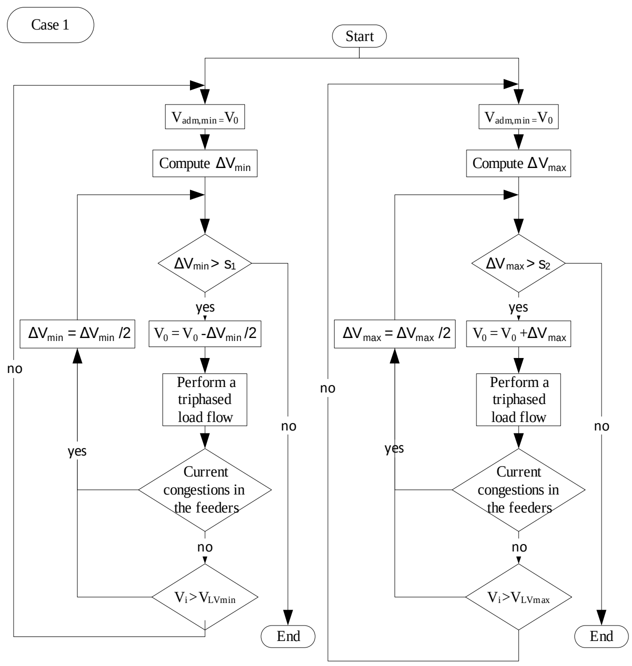

Figure 2 – LV4MV flowchart corresponding to case 1

SIMULATION RESULTS

Test Network

The LV4MV is applied at a random MV node, which would be only connected to a real three-phase unbalanced 12-nodes LV grid, composed of one feeder. No MV end user is connected to this node. Figure 3 shows the considered LV distribution system. Table 1 presents the lines characteristics of the considered LV network.

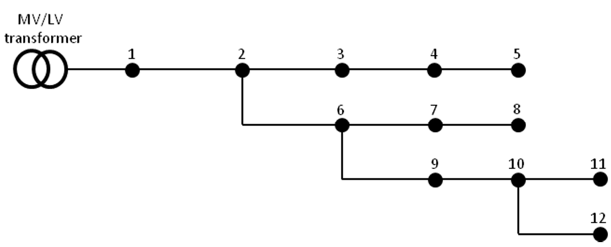

Figure 3 - Considered unbalanced 12-nodes LV network

Table 1 - Mutual and Self impedances of the considered network (mΩ)

Z(L1)	0,7 + 1,2 i	0,1 + 1,0 i	0,1 + 1,0 i	0,1 + 1,0 i
	0,1 + 1,0 i	0,7 + 1,2 i	0,1 + 1,0 i	0,1 + 1,0 i
	0,1 + 1,0 i	0,1 + 1,0 i	0,7 + 1,2 i	0,1 + 1,0 i
	0,1 + 1,0 i	0,1 + 1,0 i	0,1 + 1,0 i	0,9 + 1,2 i
Z(L2)	10,5 + 18,6 i	1,2 + 16,7 i	1,2 + 16,7 i	1,2 + 16,7 i
	1,2 + 16,7 i	10,5 + 18,6 i	1,2 + 16,7 i	1,2 + 16,7 i
	1,2 + 16,7 i	1,2 + 16,7 i	10,5 + 18,6 i	1,2 + 16,7 i
	1,2 + 16,7 i	1,2 + 16,7 i	1,2 + 16,7 i	15,0 + 18,9 i
Z(L3)	42,8 + 75,5 i	4,7 + 67,7 i	4,7 + 67,7 i	4,7 + 67,7 i
	4,7 + 67,7 i	42,8 + 75,5 i	4,7 + 67,7 i	4,7 + 67,7 i
	4,7 + 67,7 i	4,7 + 67,7 i	42,8 + 75,5 i	4,7 + 67,7 i
	4,7 + 67,7 i	4,7 + 67,7 i	4,7 + 67,7 i	60,9 + 76,9 i
Z(L4)	21,7 + 38,3 i	2,4 + 34,4 i	2,4 + 34,4 i	2,4 + 34,4 i
	2,4 + 34,4 i	21,7 + 38,3 i	2,4 + 34,4 i	2,4 + 34,4 i
	2,4 + 34,4 i	2,4 + 34,4 i	21,7 + 38,3 i	2,4 + 34,4 i
	2,4 + 34,4 i	2,4 + 34,4 i	2,4 + 34,4 i	30,9 + 39,1 i
Z(L5)	1,3 + 2,3 i	0,1 + 2,1 i	0,1 + 2,1 i	0,1 + 2,1 i
	0,1 + 2,1 i	1,3 + 2,3 i	0,1 + 2,1 i	0,1 + 2,1 i
	0,1 + 2,1 i	0,1 + 2,1 i	1,3 + 2,3 i	0,1 + 2,1 i
	0,1 + 2,1 i	0,1 + 2,1 i	0,1 + 2,1 i	1,9 + 2,4 i
Z(L6)	43,5 + 76,7 i	4,8 + 68,7 i	4,8 + 68,7 i	4,8 + 68,7 i
	4,8 + 68,7 i	43,5 + 76,7 i	4,8 + 68,7 i	4,8 + 68,7 i
	4,8 + 68,7 i	4,8 + 68,7 i	43,5 + 76,7 i	4,8 + 68,7 i
	4,8 + 68,7 i	4,8 + 68,7 i	4,8 + 68,7 i	61,8 + 78,1 i
Z(L7)	18,1 + 16,9 i	1,0 + 14,6 i	1,0 + 14,6 i	1,0 + 14,6 i
	1,0 + 14,6 i	18,1 + 16,9 i	1,0 + 14,6 i	1,0 + 14,6 i
	1,0 + 14,6 i	1,0 + 14,6 i	18,1 + 16,9 i	1,0 + 14,6 i
	1,0 + 14,6 i	1,0 + 14,6 i	1,0 + 14,6 i	13,1 + 16,6 i
Z(L8)	36,9 + 65,0 i	4,1 + 58,3 i	4,1 + 58,3 i	4,1 + 58,3 i
	4,1 + 58,3 i	36,9 + 65,0 i	4,1 + 58,3 i	4,1 + 58,3 i
	4,1 + 58,3 i	4,1 + 58,3 i	36,9 + 65,0 i	4,1 + 58,3 i
	4,1 + 58,3 i	4,1 + 58,3 i	4,1 + 58,3 i	52,5 + 66,3 i
Z(L9)	73,0 + 128,7 i	8,1 + 115,3 i	8,1 + 115,3 i	8,1 + 115,3 i
	8,1 + 115,3 i	73,0 + 128,7 i	8,1 + 115,3 i	8,1 + 115,3 i
	8,1 + 115,3 i	8,1 + 115,3 i	73,0 + 128,7 i	8,1 + 115,3 i
	8,1 + 115,3 i	8,1 + 115,3 i	8,1 + 115,3 i	103,8 + 131,2 i
Z(L10)	26,5 + 46,7 i	2,9 + 41,9 i	2,9 + 41,9 i	2,9 + 41,9 i
	2,9 + 41,9 i	26,5 + 46,7 i	2,9 + 41,9 i	2,9 + 41,9 i
	2,9 + 41,9 i	2,9 + 41,9 i	26,5 + 46,7 i	2,9 + 41,9 i
	2,9 + 41,9 i	2,9 + 41,9 i	2,9 + 41,9 i	37,7 + 47,6 i
Z(L11)	26,0 + 45,8 i	2,9 + 41,0 i	2,9 + 41,0 i	2,9 + 41,0 i
	2,9 + 41,0 i	26,0 + 45,8 i	2,9 + 41,0 i	2,9 + 41,0 i
	2,9 + 41,0 i	2,9 + 41,0 i	26,0 + 45,8 i	2,9 + 41,0 i
	2,9 + 41,0 i	2,9 + 41,0 i	2,9 + 41,0 i	36,9 + 46,6 i

Load modelling

The static characteristics of the load can be classified into constant power, constant current and constant impedance load, depending on the power relation to the voltage [10]. Considering the network data, the constant power characteristic is applied for load modelling.

Table 2 – Phases repartition of residential customer profile characteristic at the different nodes

Node	Phase 1	Phase 2	Phase 3
4	1	1	1
5	5	4	1
6	2	2	2
8	3	3	3
10	1	0	0
12	3	3	4

In order to simulate different power patterns, the French residential customer profile characteristic for a standard weather condition of the 3rd Thursday of January [11]-[12] has been applied several times on the different phases at some nodes of the considered LV network (table 2). Assuming that the mean annual consumption per house in 2013 in France is 4113kWh [13], the active power withdraw value of a typical end user is computed for each half-hour. The power factor for residential customer has been set to 0.95.

LV4MV results

The LV4MV algorithm has been performed for different activations of LV flexibilities in the 12-nodes network, at different time of the day. The different cases of available flexibilities are listed below:

- Scenario 0. Initial case: without activating any flexibility
- Scenario A. 30% decrease of consumed power on phase 1 at node 5
- Scenario B. 25% decrease of consumed power on phase 3 at node 12
- Scenario C. 17% decrease of consumed power on each phase at node 8
- Scenario D. 50% decrease of consumed power on phase 1 at node 10

Table 3 presents the results of the LV4MV algorithm applied for different scenarii of activation of LV flexibilities, at 3.00 pm and 7.30 pm respectively.

Table 3 – LV4MV results (3.00 pm, 7.30 pm)

Time	3.00 pm		7.30 pm	
Scenario	Vadm_min (pu)	Vadm_max (pu)	Vadm_min (pu)	Vadm_max (pu)
0	0,94	1,1	0,95	1,1
A	0,94	1,1	0,95	1,1
B	0,93	1,1	0,95	1,1
C	0,94	1,1	0,95	1,1
D	0,94	1,1	0,95	1,1
A, B	0,93	1,1	0,95	1,1
A, C	0,94	1,1	0,95	1,1
A, D	0,94	1,1	0,95	1,1
B, C	0,93	1,1	0,95	1,1
B, D	0,93	1,1	0,94	1,1
C, D	0,94	1,1	0,95	1,1
A, B, C	0,93	1,1	0,95	1,1
A, C, D	0,94	1,1	0,95	1,1
B, C, D	0,93	1,1	0,94	1,1
A, B, C, D	0,93	1,1	0,94	1,1

Depending on the load of the network and the activated flexibilities, it is possible to find the MV admissible voltage range at each MV node, which guarantee that all downstream LV connection points are respecting LV voltage constraints. In some of these scenarii, table 3 shows that MV admissible voltage ranges are larger than the one commonly assumed for network planning. Others situations might lead to stricter MV voltage ranges, the benefit of this algorithm would stay to get more information for real-time network operation.

Figure 4 shows the three-phases voltage profile along the downstream LV network at 3.00 pm, when scenarii A,B,C and D are applied, and with a reference voltage V0=0.95pu at the secondary part of the MV/LV transformer.

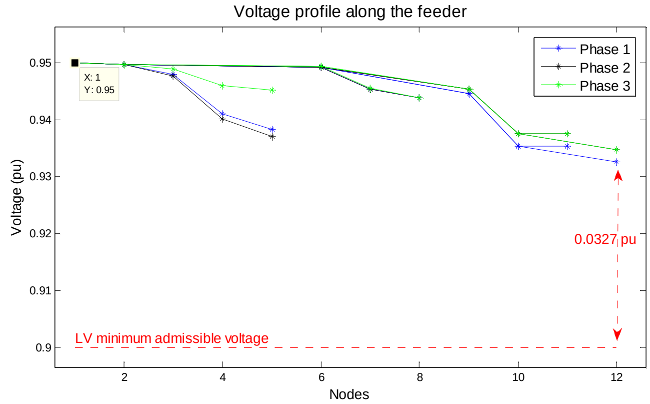

Figure 4 – Three-phases voltage profile along the LV network (3.00 pm, scenario A,B,C,D, V0=0.95pu)

According to LV4MV computations, the voltage at the secondary part of the MV/LV transformer can be set down to 0.93pu, ensuring that LV voltage constraints will be respected for the whole downstream LV network. However for V0=0.92pu, LV voltage constraints are not respected anymore.

Influence on voltage profile of a LV flexibility activation

In term of power decrease need, an end user's flexibility activation corresponds either to a consumption reduction of a controllable load, or to a production increase assuming that some reserves have been pre-contracted. Mathematically, it can be represented as a single-phase consumed power reduction at one node. Figure 5 illustrates the scenarii A and D applied on phase 1 simultaneously at 7.30 pm, which is a 30% decrease of consumption at node 5, coupled with a 50% decrease of consumption at node 10.

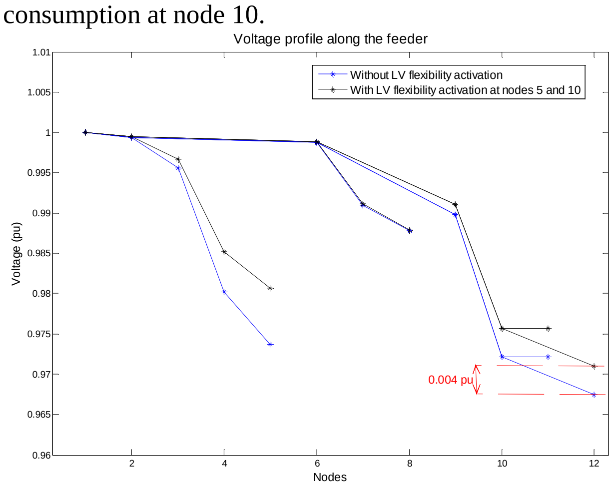

Figure 5 – Voltage profile on phase 1 along the feeder at 7:30 pm with and without LV flexibilities activation

Figure 5 shows that a LV flexibility activation could have a large impact on voltage profile. This impact on voltage profile is larger when the network is highly loaded and when the flexibility is located at the end of a line. The activation of LV flexibilities will permit to increase the determined MV admissible voltage range intervals. The LV4MV is performed for each LV flexibilities offer and combinations, which are tested in merit order. Therefore, the logic is combinatorial and might not be optimal. A method based on the sensitivity analysis of local flexibilities for voltage regulation [14] completes this algorithm step, in order not to test every combination of available LV flexibilities but to sort them by economic and technical impacts. It will be then possible to compare the cost of LV flexibilities activation with the benefit in operation of the entire MV grid.

IMPLEMENTATION

Requirements

Technically, LV4MV requires the processing of independent load-flow calculations for LV networks and then Optimal Power Flow (OPF) calculations for MV networks. It requires also the monitoring of the voltage values among the LV feeders thanks to Customer Energy Management System (CEMS) or Advanced Metering Infrastructures (AMI), the forecast of non-controllable loads and already trade DER programs and finally the gathering of DER bids, willing to support the grid for constraints management.

Implementation architecture

Developed within the FP7 DREAM project [15], this mechanism rests on a distributed mode of network operation, with an architecture where functionalities are distributed among the whole system network. The distribution of intelligence permits a repartition of computations among the network and avoids the reporting of all the data at a centralized level. This permits also to better consider all the available DER flexibilities down to the lowest level of the grid. Hence, assuming that RTU are installed in primary and secondary substations, the LV4MV algorithm could be embedded and performed at every secondary substation in order to facilitate the optimization and the operation of the entire considered network, completed in primary substations. Figure 6 presents the infrastructure to be deployed on targeted MV and LV flexible networks in order to benefit of the LV4MV concept.

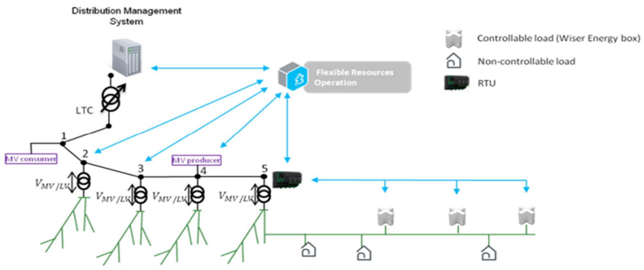

Figure 6 – Infrastructure to be deployed on MV and LV flexible networks to benefit of the LV4MV concept

CONCLUSION AND PERSPECTIVES

A method to identify the MV admissible voltage range interval of nodes where only LV network is connected, taking into account the downstream LV flexibilities if available, has been presented and tested. Results shows that MV admissible voltage ranges might be larger or stricter than the one commonly assumed for network planning, depending on downstream LV flexibilities. The interaction between the LV4MV algorithm performed at each secondary substation and the optimization of the overall MV grid operation will be discussed in future work. This global economic and technical optimization will take into account the OLTC position of the HV/MV transformer but also the cost and performance of activation of MV and LV flexibilities, determined thanks to a method based on the voltage sensitivity analysis of local flexibilities.

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