ACTIVE DEMAND MANAGEMENT IN MV NETWORK OPERATIONAL PLANNING: AN INDUSTRIAL METHOD FOR THE SELECTION OF FLEXIBILITY OFFERS TO SOLVE TECHNICAL CONSTRAINTS

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ABSTRACT

In order to handle the impact of Distributed Energy Resources, new usages and demand-side management, more flexibility is required from the grid, particularly on a local scale. A new market mechanism has been designed in France to address this specific problem. It aims at helping Enedis, the French Distribution System Operator (DSO) to solve technical constraints (voltage contractual requirements, thermal constraints in lines or transformers) by making flexibility offers available on a flexibility platform.

This paper presents a tool designed by EDF R&D to help the DSO select the relevant flexibility offers in order to solve or at least reduce the expected technical constraints while minimizing the overall cost.

This tool is to be integrated into Enedis' operational Distribution Management System to be used in a fully automated process, from the day-ahead constraints' detection and offers' selection in operational planning to the real time flexibility activation.

INTRODUCTION

The increasing deployment of Distributed Energy Resources (DER) such as wind farms on the Medium Voltage (MV) network or solar panels on the Low Voltage (LV) network is strongly challenging the Distribution System Operator (DSO). This situation is amplified by the arrival of new usages like electric vehicles or storage. These changes add more variability and introduce bidirectional power flows, which can potentially lead to congestions or contractual voltage constraints on the MV network.

The impacts of DER and new usages have to be addressed in order to limit the investments on the grid. Thus, more flexibility -capability to adapt demand and injection flows of electricity- is required to postpone the reinforcement of the network ([1], [2]). Over the last decades, new market mechanisms have been set up in France. However, they mainly deal with the problem of supply-demand balance. There is no mechanism on a local scale, which intends to solve technical constraints on the MV network.

A new market mechanism has been designed to solve thermal and voltage constraints on the French MV network. Offers made by flexibility aggregators are submitted on a flexibility platform. If necessary, the DSO selects a combination of flexibility offers to solve the anticipated constraints.

This paper presents an algorithm designed by EDF R&D to help the DSO select an optimal combination of flexibility offers to solve or at least reduce technical constraints while minimizing the total cost. After describing the overall operational planning process, the algorithm used to select offers on the market mechanism will be explained.

OPERATIONAL PROCESS FOR THE SELECTION OF FLEXIBILITY OFFERS TO ADDRESS CONSTRAINTS

This part describes the operational time process, during which the algorithm is called.

The operational process begins one day ahead when the DSO performs a load-flow calculation based on consumption and production forecasts to detect potential constraints. If so, the DSO can call technical levers to solve these anticipated constraints. The use of flexibility offers is one of them. Each lever can be used to solve all or part of the constraints. A global merit order is established in order to select the most relevant levers for the expected situation. This global merit order depends, amongst other information, on the kind of constraints addressed and on the cost of these technical levers.

To solve the constraints for which it has been called, the flexibility offers' lever looks for an optimal combination of offers on a local flexibility market (see Figure 1 below). This market contains the available offers proposed by flexibility operators (aggregators). Specific characteristics are required to define these offers appropriately (cf. p2). Based on the available offers and their characteristics, as well as the anticipated constraints, the selection algorithm determines the optimal combination of offers.

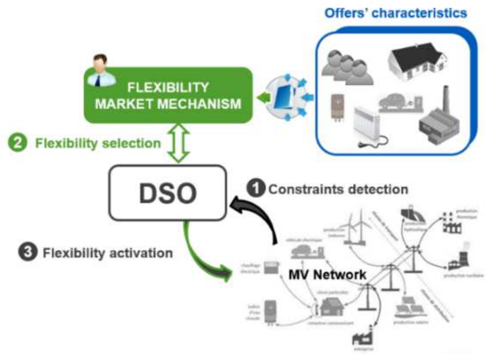

Figure 1: Flexibility offers time process

Once selected, flexibility offers can be activated by the DSO. If so, these activations are notified to concerned aggregators with a given notice period to allow sufficient time between information and effective activation.

The selection algorithm can be restarted closer to real time to take into account new consumption or production forecasts, new topological event on the network as well as new offers on the local market.

DESCRIPTION OF THE SELECTION ALGORITHM

Purpose

The main purpose of the algorithm is to find the best combination of flexibility offers to solve the detected constraints on the MV network while minimizing the overall cost. The algorithm can also exploit the offers' activation time periods -which are not explicitly defined- in order to optimize the offers' impact.

The technical constraints which are considered in this algorithm are <u>the contractual voltage constraints at the nodes of the MV network and the thermal constraints in lines and transformers.</u>

General Overview

The algorithm can be divided into four steps:

- Step 1: identify the useful offers. The algorithm selects the offers which can help reduce the constraints detected on the network.
- Step 2: set useful offers' time frames. The time frame during which each useful offer will be activated, if selected, is defined in order to maximize its expected impact on the constraints.
- Step 3: express the associated linear programming problem. This step puts into equation the problem of finding the best flexibility offers' list to solve the existing constraints while minimizing the overall cost of the selected offers.
- Step 4: solve the optimization problem. Two methods are used to solve the previously defined optimization problem.

Flexibility offer characterisation

In this algorithm, a flexibility offer is characterized by:

- A definition time period divided into several time steps.
- A time step resolution (half hour multiple).
- A power time series on the definition time period.
- A flow direction, which indicates the type of power variation (increase or decrease).
- Minimal and maximal activation durations (half hour multiple).
- A power modulation cost for each time step.

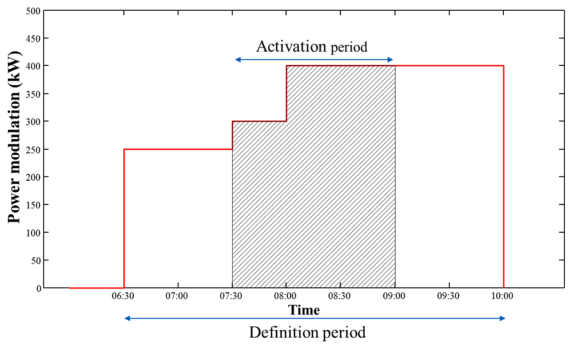

Figure 2: Power time series of a flexibility offer

The activation period, time interval during which the flexibility offer will inject power on the network if activated, is not explicitly defined: it can be set within the definition time period as long as minimal and maximal activation durations are respected (see Figure 2 above). Thus, the algorithm not only aims to select the best offers' combination in order to solve anticipated constraints, but also to determine the most appropriate activation period of each selected offer to optimise its impact on the constraints

Throughout this document, an offer will have a positive impact on a constraint if its activation reduces the amplitude of the considered constraint. Similarly, an offer will have a negative impact on the constraint if its activation increases the amplitude of the constraint.

First step: identifying useful offers

This step aims to identify relevant offers which will have a positive impact on the anticipated constraints. These offers will be called useful offers within this document.

An offer is useful if it complies with three criteria:

- A spatial criteria: the electrical connection point where the power is injected must let the concerned offer have an impact on at least one constraint on the MV network.
- A temporal criteria: the offer which respects the spatial criteria must also have a common time step with the associated constraint.

- A “type of impact” criteria: if the offer respects both the spatial and temporal criteria, its impact must be positive on at least one constraint on at least one time step.

At the end of this step, the algorithm has detected all the flexibility offers which respect these criteria.

Second step: setting useful offers’ time-frames

The second step consists in determining the optimal activation period of each useful offer: indeed, as explained previously, the activation period is not explicitly defined.

The algorithm sets the activation period of each useful offer in order to maximize its positive impact on the constraints. This is done without consideration of power or cost of the flexibility offers but only by taking into account their kind of impact (positive or negative) on the constraints.

Let us define the following set:

$$\mathrm{E} = \{(c, t_c), c \in C, t_c \in T_c\}$$

Where:

- C is a set containing the different constraints on the network.
- T_c is a set containing the time steps associated to the constraint c.

The useful offers have a positive impact on at least one element of E. The second step distinguishes two kinds of useful offers:

- The offers with a strictly positive impact: it corresponds to the offers which have, at a time step, at least one positive impact on one constraint without having a negative impact on the other constraints at the same time step.
- The contentious offers: offers which have, at a given time step, a positive impact on one constraint as well as a negative impact on another constraint.

The time frames of the offers with a strictly positive impact are determined in the first place. Then, the time frames of the contentious offers are set. The algorithm ends when all the useful offers’ time frames have been determined.

To do so, the algorithm considers the pairs (c,t) successively. At each iteration, this process encompasses 3 stages:

- During one iteration i, the algorithm finds the priority pair (c_i, t_{c_i}) of the set E. The priority pair is determined by considering the pairs for which useful offers to be positioned have a positive impact on their respective time steps. Among them, the pair (c_i, t_{c_i}) which has the less useful offers positioned with a positive impact on the time step t_{c_i} is the priority pair.
- Once the priority pair (c_i, t_{c_i}) is defined for the iteration i, the algorithm chooses one of the useful offers to be positioned which has a positive impact on c_i during the time step t_{c_i}.
- Finally, the algorithm defines the time frame of the chosen useful offer. The useful offer is positioned on the time step t_{c_i} associated to the priority pair. The time frame is then extended on the adjacent time steps as long as the minimal time duration is not respected or as long as the useful offer has a positive impact on these connected time steps. An order is established between the connected time steps to give priority to the couple $(c_{con}, t_{c_{con}})$ which has the less useful offers positioned on the time step $t_{c_{con}}$. The extension stops when the maximal activation duration has been reached or when the considered useful offer has no more positive impact on the connected time steps.

Third step: expressing the associated linear programming problem

The third step aims to express the useful offers’ selection problem. It can be represented by the following linear optimization problem:

$$\min_{x \in M_{n,1}(\mathbb{R})} \; f^T x \quad such\ as \begin{cases} Ax \leq b \\ \forall\, i \in [\![1\ n]\!], x_i \in \{0,1\} \end{cases}$$

Where:

- $n \in \mathbb{N}^*$ is an integer representing the number of useful offers
- $f \in M_{n,1}(\mathbb{R})$. $\forall i \in [\![1\ n]\!]$, f_i represents the overall cost associated to the offer i. The overall cost depends both on the offer’s price and on the power injected on the network.
- x is a boolean vector representing the useful offers. $\forall$ i $\in [\![1\ \mathrm{n}]\!]$, x_i equals 1 if the offer is activated and 0 if not.
- $A \in M_{p,n}(\mathbb{R})$ and $b \in M_{p,1}(\mathbb{R})$ are associated to the p limits that have to be respected by the offers. An interpretation of the matrices A and b is exposed below.

Matrices A and b interpretation

The matrices A and b represent the material and contractual limits which must be respected by the elements of the network (nodes, lines and transformers) at each time step to avoid the presence of technical constraints.

The number of columns in A represents the number of useful offers. The number of lines of A and b is linked to the number of topological elements impacted by the offers at each time step of the considered time period.

Thus, a coefficient $a_{i,j}$ of the matrix A represents the impact of the offer j on a pair (e, t) associated to the index i, where e is a topological element impacted by the useful offers during the time step t.

Determination of the pairs (e, t) impacted by the useful offers

The pairs (e, t) impacted by the useful offers are determined by considering each time step of the time period.

For one of these time steps t, the topological elements impacted by the offers are:

- All the lines or transformers upstream from at least one useful offer which can be activated during this time step t.
- All the nodes of the feeder on which at least one offer can be activated during this time step t.

Expression of the matrices A and b coefficients

The material or contractual limits which have to be respected by each pair (e_j, t_{e_j}) previously determined can be represented with the following inequalities.

<u>Case of material limits for lines or transformers:</u>

The power flowing through the lines or transformers must be limited to avoid material destruction. Thus, for a given time step t and for a given line or transformer, the following inequality must be respected:

$$\left| \sum_{i \in Offers_{downstream}} P_{i,t} \cdot x_i + P_t \right| \leq \sqrt{S_{max}^2 - Q_t^2}$$

Where:

- $P_{i,t}$ is the active power variation induced by offer i at time step t.
- P_t and Q_t are the active and reactive powers flowing through the line or the transformer without any offer's activation at time step t.
- S_{max} is the maximal apparent power permitted for the considered electric installation.

The previous inequality is equivalent to the following inequality system:

$$\begin{cases} \sum_{i \in Offers_{downstream}} P_{i,t} \cdot x_i \leq \sqrt{S_{max}^2 - Q_t^2} - P_t \\ - \sum_{i \in Offers_{downstream}} P_{i,t} \cdot x_i \leq \sqrt{S_{max}^2 - Q_t^2} + P_t \end{cases}$$

Which gives the coefficients of the matrices A et b for a considered pair (e_j, t) associated to a line or a transformer:

$$\boxed{\begin{aligned} a_{j,t,1} &= (P_{1,t} \ \cdots \ P_{i,t} \ \cdots \ P_{n,t}) \\ a_{j,t,2} &= -a_{j,t,1} = (-P_{1,t} \ \cdots \ -P_{i,t} \ \cdots \ -P_{n,t}) \\ b_{j,t,1} &= \sqrt{S_{max}^2 - Q_t^2} - P_t \\ b_{j,t,2} &= \sqrt{S_{max}^2 - Q_t^2} + P_t \end{aligned}}$$

<u>Case of contractual limits for nodes:</u>

The voltages associated to the different nodes of the network must respect contractual limits. Thus, for a given node k and a given time step t, the following inequality must be respected:

$$U_{\min}^k \leq \sum_{i \in Offers_{on\ the\ feeder}} U_{i,t}^k \cdot x_i + U_t^k \leq U_{max}^k$$

Where:

- U_{min}^k and U_{max}^k are the contractual voltage limits for the considered node.
- U_t^k is the voltage at the considered node at time step t without any activation of the useful offers.
- $U_{i,t}^k$ is the voltage variation induced by offer i at time step t.

$U_{i,t}^k$ is assumed to be equal to :

$$U_{i,t}^k = \frac{-R_{i \to k}}{U_{BB,t}} P_{i,t}$$

Where:

- $U_{BB,t}$ is the bus bar voltage at the time step t
- $R_{i \to k}$ is the resistance of the network portion common to paths $bus\ bar \to i$ and $bus\ bar \to k$
- $P_{i,t}$ is the active power coming from the offer i at the time step t

The previous inequality is equivalent to the following inequality system:

$$\begin{cases} \sum_{i \in Offers_{on\ the\ feeder}} \frac{R_{i \to k}}{U_{BB,t}} P_{i,t} \cdot x_i \leq U_t^k - U_{\min}^k \\ - \sum_{i \in Offers_{on\ the\ feeder}} \frac{R_{i \to k}}{U_{BB,t}} P_{i,t} \cdot x_i \leq U_{max}^k - U_t^k \end{cases}$$

Thus, this system gives the coefficients of the matrices A et b for the considered pair (e_k, t):

$$a_{k,t,1} = \left(\frac{R_{1\to k}}{U_{BB,t}} P_{1,t} \quad \cdots \quad \frac{R_{n\to k}}{U_{BB,t}} P_{n,t}\right)$$

$$a_{k,t,2} = -a_{k,t,1} = \left(-\frac{R_{1\to k}}{U_{BB,t}} P_{1,t} \quad \cdots \quad -\frac{R_{n\to k}}{U_{BB,t}} P_{n,t}\right)$$

$$b_{k,t,1} = U_t^k - U_{\min}^k$$

$$b_{k,t,2} = U_{max}^k - U_t^k$$

Fourth step: two ways for solving the optimization problem

The purpose of the last step is to solve the optimization problem defined previously. The algorithm implemented uses two complementary methods to determine the best combination of useful offers:

- A generic method calling a Branch & Bound algorithm. This method finds, if it exists, the best combination of offers to solve all the anticipated constraints on the network.
- A heuristic method, called if no combination of offers is able to solve all the constraints. The heuristic method will find a partial solution by activating the useful offers gradually to reduce the constraints on the network.

This document will only present the heuristic method.

Priority list method based on the increasing cost of the useful offers

The heuristic method proposes an approximate resolution of the optimization problem. It is based on observing the impact of each useful offer from the cheapest to the most expensive.

After ordering the offers according to their cost, the algorithm considers the impact of each offer, starting with the cheapest. An offer is selected if:

- It reduces at least one constraint.
- It does not worsen or create other constraints on the network.

Whenever an offer is selected, the linear inequalities system is updated in order to take its impact into account.

The heuristic method stops when either:

- All the offers have been considered.
- Or all the constraints have been solved.
- Or a maximal cost has been reached by the activated offers.

CONCLUSION AND PERSPECTIVES

This document has presented a selection algorithm designed to help the DSO choose the best combination of flexibility offers in order to solve technical constraints.

After identifying the relevant offers which can have a positive impact on the constraints, the algorithm determines each useful offer's time frame to maximize its expected impact. Afterwards, the algorithm selects the best combination of offers to solve as many constraints as possible while minimizing the overall cost of flexibility activation.

This tool is integrated into Enedis' operational Distribution Management System (DMS), to be used in a fully automated process, from the day-ahead constraints' detection and offers' selection in operational planning to the real time flexibility activation. An experiment will take place in 2017 on a real MV network within the *Smart Grid Vendée* demonstrator project.

While currently focused on the MV network, this work paves the way for the development of LV network management tools. The flexibility brought out at the LV level by DER and new usages, such as PV panels and electric vehicles, is indeed being investigated in several studies and demonstrator projects.

REFERENCES

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