SMART GRID VENDÉE PROJECT: A DECISION-SUPPORT TOOL FOR THE MULTI-YEAR PLANNING OF ACTIVE DISTRIBUTION NETWORKS

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ABSTRACT

This paper presents a decision-support tool under development to plan the expansion stages of medium-voltage networks using local flexibilities. Currently tested in the Smart Grid Vendée project, this tool aims to help Enedis, the main distribution system operator in France, to optimally develop the distribution grid in the medium/long term. A case study based on a French medium-voltage network is presented to show how the proposed tool works and could help Enedis in the decision making process.

INTRODUCTION

With the increase in renewable energies and flexibilities, and the emergence of new methods for connecting users to the grid and managing voltage, Enedis needs to develop these new methods, test them on planning studies, and use both traditional levers (e.g., network reinforcement) and alternative levers (e.g., demand response flexibilities).
Thereby Enedis is working on the development of a new tool integrating these new methods in order to evaluate their interest. Once their interest is proven, these methods will be implemented in Enedis' planning tools to further enhance its ability to estimate the most cost effective scenario that the distribution grid should follow to answer the customers' needs.

Distribution grid planning in France

When planning the future developments of the distribution grid in France, Enedis aims at minimizing the present operating cost of the grid over several decades. As a consequence, Enedis estimates not only the changes of the electrical loads over the years but also the connections of future Distributed Energy Resources (DER) so as to determine an optimal set of measures that will result in an efficient use of the distribution grid.
In order to estimate the present operating cost of the grid, Enedis takes into account different types of costs:
- the investment costs;
- the costs associated with the technical losses;
- the operation and maintenance costs;
- the failure costs (costs associated with the Expected Non-Distributed Energy – ENDE –).

Besides, considering primary substation reinforcements, the benefits in terms of ENDE reduction are calculated probabilistically for different levels of charge and for different types of N-1 situations. The comparison of the net present costs of different reinforcement strategies guarantees that the best strategy is selected and that the reinforcement is made at the optimal date.

Development of a decision-making tool

The decision-making tool presented in this article is notably designed for the following purposes:
- to make use of the local long-term consumption scenarios developed by Enedis to represent the climatic fields of possibilities;
- to take into consideration the expected connections of large DER in the distribution grid planning;
- to model innovative levers that are under study for use in grid planning (e.g., demand response flexibilities).

This paper presents through the example of a case study:
- the operation of the tool;
- the chosen solutions to reduce computation time;
- the obtained results;
- the additional works to integrate innovative levers.

This tool, which is still under development (further work described at the end of this paper), is tested in the framework of Smart Grid Vendée studies using local flexibilities or other innovative levers.

PRESENTATION AND ILLUSTRATION OF THE FIRST RELEASE OF THE TOOL

Objectives and main steps of the final tool

Developed under DIGSILENT PowerFactory, the proposed tool aims at planning the expansion stages of a Medium-Voltage (MV) network using local flexibilities. The network study has to be conducted in six major steps:
1) Loading and processing input data;
2) Performing a probabilistic diagnosis of current and voltage constraints on the network;
3) Finding traditional flexibilities (existing reactive power and voltage controls and network adaptations);
4) Selecting manually innovative flexibilities to study (e.g., generation curtailment, demand response, etc.);
5) Finding the most effective combinations of traditional

and innovative flexibilities;

6) Providing the results.

To date, the tool includes only steps 1-3 and 6.

The illustrative study case

For the sake of clarity, the operation of the proposed tool is illustrated through a case study built from realistic data. The network under study includes a set of French primary substations. One of them is studied in normal and N-1 situations (Figure 1) whereas the others are only used to compute ENDE when a fault occurs in the first one. The network downstream of the primary substation initially includes 2 63/20-kV transformers, 14 MV feeders, 2600 buses, 57 MVA of loads, 33 MW of MV generation, and 5 MW of Low-Voltage (LV) generation dispatched over 91 secondary substations.

This network is supposed to accommodate:

- Two new MV generators, denoted A and B. Generator A is a 6-MW wind producer requesting a connection in year 1, and generator B is an 8-MW wind producer requesting a connection in year 4.
- An annual load growth of 2 % over 20 years.
- An annual LV generation growth of 5 % over 20 years.

The network variations that are defined by the user in the PowerFactory project describe different connection solutions for producers A and B as well as different possible network adaptations (Table 1).

As in [1], several sets of annual 10-minute load/generation profiles are defined to take into account the power variability of intermittent DER and thus obtain relevant probabilistic criteria.

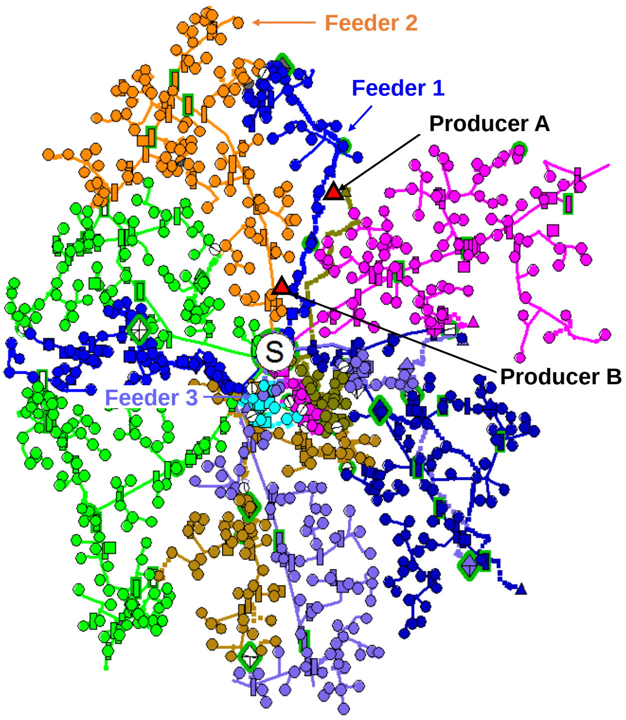

Figure 1. The primary substation "S" under study.

No.	Type	Description
1	Producer	Producer A – connection to the feeder 1
2	Producer	Prod. A – creation of a dedicated feeder
3	Producer	Producer B – connection to the feeder 1
4	Producer	Producer B – connection to the feeder 2
5	Reinforcement	Reinforcement of the feeder 1
6	Reinforcement	Reinforcement of the feeder 3
7	Transformer	Installation of a 3rd HV/MV transformer

Table 1. The considered network variations.

Computation time reduction

Computation time is mainly due to the large number of multi-period load-flow calculations required to characterize and remove the current/voltage constraints on the network. Three solutions have thus been implemented to reduce computation time.

Assumptions about DER

To reduce the numbers of network changes and of load-flow inputs, we suppose that:

- The features of new MV producers, i.e., rated power, generation type, location, and year of arrival, are known. To remain realistic, new MV producers should be added in the first five years of the study.
- All the load buses (LV generation buses, respectively) have the same annual rates of load growth (LV generation growth, respectively).
- All the network users sharing the same type (e.g., load, MV wind generation, MV photovoltaic generation, LV generation, etc.) have the same annual normalized power profiles.

Smart management of the network expansion paths

Several possible network expansion paths can be defined depending on which network variations are activated. For the proposed study case, the network can reach four **final network states** without considering network adaptations:

- Final state 1: producers A and B are both connected to the feeder 1 (variations 1 and 3).
- Final state 2: producer A is connected to the feeder 1 and producer B to the feeder 2 (variations 1 and 4).
- Final state 3: producer A is connected to a new dedicated feeder and producer B to the feeder 1 (variations 2 and 3).
- Final state 4: producer A is connected to a new dedicated feeder and producer B to the feeder 2 (variations 2 and 4).

It is possible to define a **network expansion path** for each final state. This path is composed of all the intermediate network states, called **network configurations**, required to move from the initial state to the final state. Different network expansion paths can share one or several network configurations.

To reduce computation time, a smart management of the network expansion paths including network adaptations has been put into place in three steps (Figure 2):

1) Processing the initial expansion paths without "reinforcement" and "transformer" variations:

a. Defining all the network configurations based on the “producer” variations only;
b. Processing the network configurations;
c. Building the results of the network expansion paths from those of network configurations.

2) Processing the expansion paths with “reinforcement” variations. A given feeder is assumed to be reinforced in the first year when current/voltage constraints occur on this feeder. Sub-steps are similar to those of step 1 except that “reinforcement” variations are also used to define new network configurations.
3) Processing the expansion paths with “reinforcement” and “transformer” variations. A given transformer is replaced/added in the year which is the minimum between the year when current constraints occur on this transformer and the year that minimizes the overall net present cost. Sub-steps are similar to those of step 2 except that “transformer” variations are also used to define new network configurations.

Note that all the network configurations defined in steps 1-3 will be used to build network expansion paths combining traditional and innovative flexibilities.

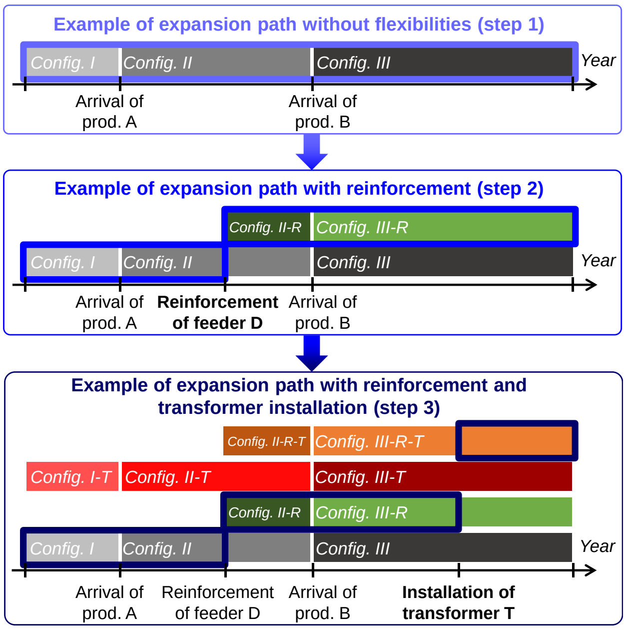

Figure 2. Example of smart management of the network expansion paths with traditional flexibilities (‘R’ and ‘T’ mean ‘with reinforcement of feeder D’ and ‘with installation of transformer T’ respectively).

Approximate load-flow calculations

The method presented in [2] has been adapted to build an approximate load-flow model. Based on a piecewise-constant interpolation, this method can be split into three steps:

1) Building an experimental design of small size (Figure 3). The space of the load-flow inputs (overall consumption, overall wind generation, overall photovoltaic generation, etc.) is entirely meshed. All the points from the annual profiles of load/generation are then positioned in this space. The experimental design is composed of the central points of the meshes including at least one point from the profiles. A weighting coefficient is computed for each point from the experimental design: this is the ratio of points from the profiles included in the associated mesh.
2) Performing exact load-flow calculations on the experimental design.
3) Interpolate the load-flow results. All the points from the annual profiles which belong to a same mesh are assumed to have the same load-flow results as the central point of the mesh. Annual mean criteria (e.g., average constraint rates, network losses and costs) are obtained by weighted sums of load-flow results.

To reach a satisfactory trade-off between computation time and accuracy, we consider:

- A single experimental design for all the years covered by the study. Only $n = m \times k$ load-flows are thus required to obtain annual mean criteria (without innovative flexibilities), where m is the number of network configurations and k the number of points in the experimental design. Note that n does not depend on the numbers of studied years and of load/generation profiles considered each year.
- Different weighting coefficients for each studied year. Thus, load/generation growths can change over years without performing supplementary load-flows.

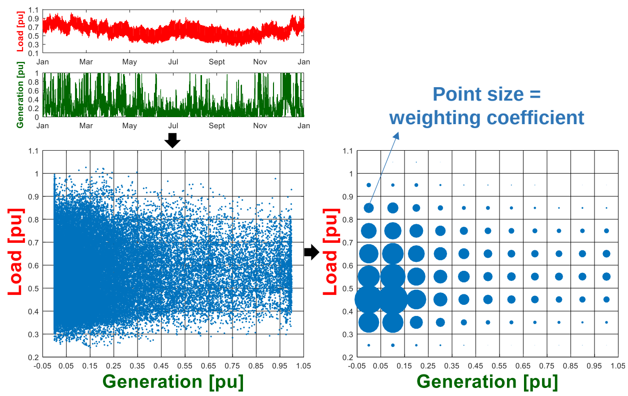

Figure 3. Experimental design building. Illustration for two load-flow inputs: load and generation powers.

Examples of results from the first tool release

Definition of the initial network configurations and expansions paths to be studied

As mentioned above, the study case has four different final network states, depending on which of the two “producer” variations is activated to connect each new MV producer to the network. This involves processing the seven network configurations detailed in Table 2 to analyze network constraints for this study case.

No.	« Producer » variations included	Covered years	Associated expansion path
I	None	0	1-4
II	1	1-3	1 and 2
III	2	1-3	3 and 4
IV	1 and 3	4-19	1
V	1 and 4	4-19	2
VI	2 and 3	4-19	3
VII	2 and 4	4-19	4

Table 2. Initial network configurations for the study case (without "reinforcement" and "transformer" variations).

Optimization of reactive power and voltage existing controls to remove voltage constraints

Apart from network adaptations, two other traditional levers are used to remove potential overvoltage caused by new MV producers: the reactive power control of MV producers and the voltage control of High-Voltage (HV)/MV transformers. The tool optimizes these two flexibilities whenever a new MV producer arrives.

Table 3 shows the power factor references of some producers for the expansion path 1, i.e., when producers A and B are both connected to the feeder 1. In this example, the references of producer A and an existing producer, called C, have been reviewed to limit overvoltage caused by producer B on the feeder 1.

	Year 0	Years 1-3	Years 4-19
Producer A	-	0.9858 cap.	0.9701 cap.
Producer B	-	-	0.9701 cap.
Producer C	1	1	0.9701 cap.

Table 3. Power factor references of MV producers for the network expansion path 1.

Probabilistic diagnosis of current/voltage constraints

Figure 4 depicts the average constraint rates over the load/generation profiles for the network expansion path 1 in year 19 (final network state). Without network adaptations, it turns out that:

- The connection of producer B on the same feeder as producer A leads to overvoltage and current constraints on this feeder from year 4.
- The load growth causes current constraints on the primary substation from year 16 and in the feeder 3 in year 19.

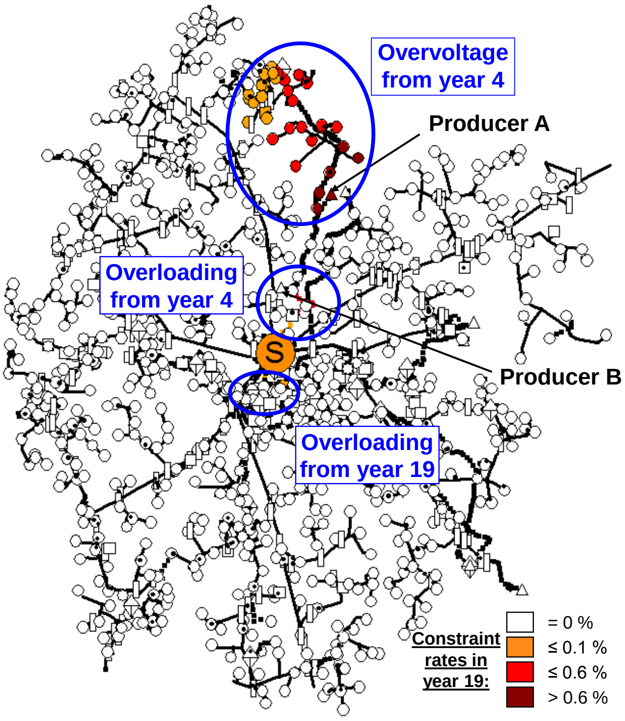

Figure 4. Average constraint rates in year 19 for the network expansion path 1.

Optimal implementation of network adaptations

Table 4 shows the optimal year of the network adaptations required to obtain the lowest net present cost (without considering ENDE for the moment) while removing all the constraints on the network for each network expansion path. In this example, feeder 1 has to be reinforced only if it hosts producers A and B, a 3rd HV/MV transformer has to be added if producer A is connected to the feeder 1, and feeder 3 has to be reinforced whatever the network expansion path.

Network adaptation	Path 1	Path 2	Path 3	Path 4
Reinforcement of the feeder 1 (variation 5)	Year 4	-	-	-
Installation of a 3rd HV/MV transformer (variation 7)	Year 16	Year 16	-	-
Reinforcement of the feeder 3 (variation 6)	Year 19	Year 19	Year 19	Year 19

Table 4. Optimal year of network adaptions.

Figure 5 depicts the annual gross costs as well as the cumulative sum of the annual net present costs for each network expansion path. For this study case, the network expansion path 3 obtains the lowest net present cost without considering innovative flexibilities.

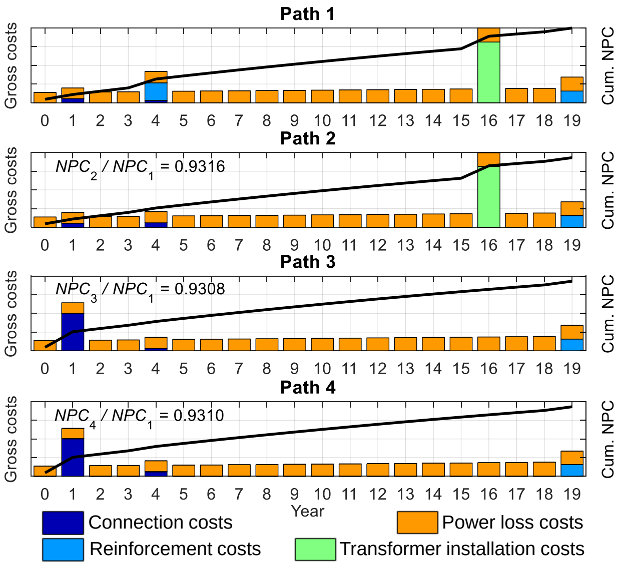

Figure 5. Annual gross costs (color bars) and cumulative sum of the annual Net Present Costs (NPC, black line).

FURTHER WORK TO CONSIDER INNOVATIVE LEVERS

Several tool developments are presented here to model innovative levers while keeping a satisfactory trade-off between speed and accuracy. In particular, these developments are compatible with the load-flow approximation method described above.

MV generation curtailment

For the sake of simplicity, all the MV generations will be assumed to be eligible for generation curtailment. For each producer, three power limitations will be defined to respectively avoid overvoltage, overloading of MV lines, and overloading of the HV/MV transformer. These power limitations will be computed only once, in year 0 for existing producers and in the year of arrival for new producers. In other words, the last producers connected to the network are the first ones to be curtailed in case of constraint. Each of the three power limitations is the maximal power that a producer can inject without causing the considered type of constraint when overall generation is maximal (or equal to the overall power limitation) and overall consumption is minimal on the studied network. In the case of constraint, the appropriate power limitations will be directly applied to all the MV producers who contribute to the constraint.

Advanced voltage control of HV/MV transformers

Advanced voltage control of HV/MV transformers consists in modifying the voltage reference of HV/MV transformers in real time to remove under- and/or overvoltage occurring on the downstream MV feeders. Advanced voltage control has two parameters: minimal and maximal possible voltage references for HV/MV transformers. Instantaneous voltage reference will be computed in two ways:

1) Voltage reference is equal to the maximal possible reference that does not cause any voltage constraint.
2) Voltage reference is computed so as to minimize the annual number of reference changes while removing voltage constraints.

Demand response flexibilities

For the moment, demand response flexibilities are not well known. Some approximations have been done to simplify their integration into the tool. To remain compatible with the load-flow approximation method described above, demand response flexibilities will be modeled at the same scale as MV feeders. To limit the number of additional load-flows, the experimental design of the approximate load-flow model will be used for computing demand response. The results of a constrained feeder/transformer at a given experimental design point will be replaced with those of the point for which generation powers are the same and load power is the closest value to the initial load power without any constraint. As in [3], an activation delay will be considered for computing ENDE when a fault occurs in the primary substation.

CONCLUSION

A decision-support tool has been proposed to plan the expansion stages of MV networks using local flexibilities. For each possible expansion path, the first tool release is able to make a probabilistic diagnosis of current/voltage constraints, optimize the existing reactive power controls of MV producers and voltage controls of HV/MV transformers, and find the optimal dates of network adaptations using the traditional planning method. Computation time has been reduced thanks to assumptions about DER, smart management of the possible network expansion paths, and approximate load-flow calculations.
Further work will focus on the computation of ENDE when a fault occurs in the primary substation and on the modeling of MV generation curtailment, advanced voltage control of HV/MV transformers, and demand response flexibilities. The last tool release will be tested in all the networks of the Smart Grid Vendée project.

REFERENCES

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