SENSITIVITY OF LV GRID PLANNING TO LOAD MODELLING

Pierre LAIZE^{1,2}, Raphaël CAIRE², Marie-Cecile ALVAREZ-HERAULT², Aurel GARRY¹, Luc GLORIEUX¹, Mathieu CAUJOLLE¹

¹EDF R&D, Palaiseau, France

²Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, Grenoble, France
pierre.laize@edf.fr

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Abstract

In this paper, we propose an approach to deal with the impact of uncertainties on the decision criteria used by a planning operator. These uncertainties come from the models applied to network components and their associated assumptions, and they create discrepancies between the results of the studies in the literature. As there is no scientific consensus, network actors continue to keep and develop their own philosophy. The method we propose uses a Global Sensitivity Analysis to characterize the impact of any model on the decision criteria: we consider here the active and reactive powers of customer consumption and solar panel production, as well as the conductor impedances. We test several modelling hypotheses and assess their impact on a French low voltage network. Thanks to this work, we are able to measure the dependence of the decision criteria on the models considered in the LV grid planning process.

1. Introduction

The purpose of electric grid planning is to determine the best trade-off between the investment cost and the quality of the power supply. To this end, Distribution System Operators (DSO) usually define a few extreme but realistic scenarios, and check through network computations, like load flow, that the electric constraints defined in grid codes such as EN 50160 and IEEE 1159 are limited. This process requires to model a set of main predictor variables like the active and reactive powers of loads and generators, atmospheric conditions, conductor impedances, etc. on the time horizon considered. All these variables display high level of uncertainty, because of the limited LV grid observability, or the random nature of the process considered. The model chosen and the scenarios defined by DSOs are driven by the risks he is willing to take regarding electric constraints.

As there is no standardized method for risk analysis at a planning level, it is difficult to compare DSO planning strategies in different countries. But, expansion and planning studies generally assume independency of uncertain variables to perform their investment choices (as [1]). Their decision criteria are intrinsically linked to the modelling of the variables they consider.

In the last decade, the integration of flexibility solutions in grid planning has been a hot topic for research. In our state-of-the-art analysis, we noticed discrepancies from one study to another when assessing the interest of various solutions, as illustrated in Table 1. This is becoming increasingly problematic because of the increasing number of new equipment and flexibility services on the grids. A review of the definitions of input models is thus required.

This paper focuses on a **methodology to characterise the impact of the input models on LV grid planning decision criteria**. It aims to inform the planning operator of the effects of these model choices. With this information, he will be able to decide how to set a variable in order to improve its computation performance. Properly integrating flexibility solutions in planning processes may lead to a combinatorial explosion of reference scenarios, to consider temporality (load shedding, storage, etc.) or availability. While most studies rely upon the use of Monte-Carlo evaluation [2], our option is to identify, through Global Sensitivity Analysis (GSA), where are the main sources of uncertainties to optimize this evaluation. Our research focuses on GSA to analyse hypotheses effects, characterize model uncertainties and provide information on the robustness of a system sizing.

In this paper, we describe the GSA method and its possible application to grid planning problems. Our methodology is presented and then illustrated on a LV network. Finally, we propose hypotheses for modelling input variables.

Table 1: State of the art discrepancies on the value of flexibility solutions in grid planning (+++ means very suitable, – means unsuitable while / means not studied)

	On Load Tap Changer (OLTC)	Demand Response (DR)	Reactive regulation	Active power curtailment
[3]	+++	+	++	-
[4]	+	/	+++	++
[5]	+	/	+++	-
[6]	+++	/	/	++
[7]	-	++	+++	+

2. Methodology

In this section, we propose a framework to assess the modelling assumptions used in LV grid planning process in order to compare their multiple uncertainties.

The purpose is to identify the impact of each variable on voltage dispersion, and in particular the violation of boundaries related to Power Quality or grid assets limits. This information could guide the planning operator both in his modelling and in his investment choices.

2.1. Global Sensitivity Analysis

When using GSA, we aim to overcome the limitations of local sensitivity methods [8], considering the whole variation range of the p inputs. Our objectives [9] when using GSA are to:

- Identify and prioritize the most influential inputs,
- Identify non-influential inputs in order to set them to their nominal values,
- Map the output behaviour as a function of the inputs by focusing on a specific domain of inputs if necessary.

Figure 1 summarizes the GSA approach that we use to frame our mathematical modelling.

Figure 1: Steps of the proposed uncertainties study [10]

When applied to a grid planning study, the transposed GSA method can be decomposed in the following steps:

Step A: Problem specification

- $G(\underline{x}, \underline{d})$ model corresponds to a load flow calculation
- Variables $\underline{x}$ are the uncertain input variables of the model, like consumption, production, conductor characteristics, etc.
- Variables $\underline{d}$ are the fixed input variables, like the network topology, power subscribed, etc.
- Outputs Y are derived from the load flow results. They are the performance indicators (voltage drop, losses, current, etc) chosen by the planning operator.

Step B: Quantification of the uncertainty sources

In this step, we define the distribution assumptions for $\underline{x}$ variables. Their distribution can be a statistical law like the

normal or the Weibull distribution, or it can be derived from measurements.

Step C: Propagation of the uncertainties

This step provides us the statistical information of Y : we see how the performance indicators of the system (Y) respond to the uncertainties of variable $\underline{x}$. To achieve this, we simulate several time the model G , with each time, variations in its input values.

Step C': Global Sensibility Analysis

GSA informs about the robustness of the system model by characterizing its uncertainty through statistic modelling. To perform GSA, several mathematic methods can be used like FAST (Fourier Amplitude Sensitivity Test) [11], Morris [12], or regression [13].

2.2. GSA using Sobol indices

We choose to use Sobol indices [14] because the method is easy to understand and implement. It allows to:

- Compute sensitivity indices for each variable and for each interaction between them;
- Provide intuitive percentage results;
- Make clear the hierarchy of responsibilities;
- Calculate a confidence interval without additional simulations.

Sobol method decomposes the output variance of the system into fractions which can be attributed to input subsets. Its principle is simple: isolating the input variation on the system in order to compute the conditional variance and normalize the results by the total variance.

Its main weakness is its computation burden: Monte Carlo Simulations (MCS) [15] are performed to propagate the uncertainties. Function G execution has to be carried out a large number of times ($N > 1000$) for efficient convergence. Its principle is:

$$\sum V_x = \text{Var}(Y) \text{ and } S_x = \frac{V_x}{\text{Var}(Y)}$$

$$\text{With: } V_x = \text{Var}[E(Y | x)] = U_x - E[Y]^2$$

Then, to compute conditional variance, two random samples are generated (s_1 and s_2) to estimate U_i by $\hat{U}_i$:

$$\hat{U}_i = \frac{1}{N} \sum_{k=1}^N G(x_{k1}^{(s_1)}, \dots, x_{kp}^{(s_1)}) \times G(x_{k1}^{(s_2)}, \dots, x_{ki}^{(s_1)}, \dots, x_{kp}^{(s_2)})$$

2.3. Application to LV grid planning

To apply Sobol method to network studies, we choose to model four variables as uncertain variables. This choice comes from the general formula of the voltage drop [16] described below:

$$\Delta V = Z \times I = Z \times \frac{S}{V} = \frac{R \times P + X \times Q}{V}$$

The four variable types we consider are:

- The consumption, defined by its active power (1) and tangent phi (2), which is the ratio between the reactive power and the active power of a load.
- The production, defined by its apparent power (3). We consider the producer tangent phi is set to 0.
- The impedances of the conductors (4), modelled by their series resistance and reactance.

To obtain the general impact of each variable, we model all customers, producers and conductors as a random vector whose dimension is equal to the number of customers (resp. producers and conductors). The density function matches the assumption defined for each variable.

Through GSA, the sensitivity of the outputs to the whole set of variables is calculated. This aggregation allows us to reduce the calculation time and to focus on the impact of the general variable and its assumptions, rather than a local impact. This means that $x_{k,load}^{(s_1)}$ is a vector containing the consumption data of all loads for simulation k .

We use the Sobol method post-simulation, as G model remains the same in every load flow calculation. So, we can easily apply it to different global decision criteria (output Y), like voltage drop, current, etc, or local ones, like to each load, and even to combination operations of these criteria.

3. Study cases

3.1. LV network under study

We apply the analysis method we propose in this paper on a Low Voltage network. Its topology is described in Figure 2 and its main characteristics are provided in Table 2.

Figure 2: Topology of the LV network under study

3.2. Modelling assumptions

In this paragraph, we consider two modelling assumptions for each of the four variable types discussed before.

We model the active power of **customer consumption** by:

- Either using SMACH [17], a multi-agent platform that simulates human behaviours and generates time

series of active and reactive power consumption of the loads of a household (1a).

We simulate the 10 time steps with the highest annual total load consumption (C) to consider high level of consumption. For high level of production, the time steps simulated are defined by the production model.

- Or using consumer information and statistic law (1b) [18], [19]. We centre the statistic law on the peak responsibility factor [20] to consider high level of consumption. For high production, the statistic law is centred on 25% of the peak responsibility factor [21].

Table 2: Characteristics of the LV network under study

Starting node	Arrival node	[R_ph R_n] ($\Omega \times 10^{-2}$)	[X_ph X_n] ($\Omega \times 10^{-2}$)	Contract power
T	1	[2,9 5,4]	[1,8 1,8]	[0 6 6]
T	2	[1,9 3,9]	[1,3 1,3]	[6 0 0]
2	3	[0,4 0,5]	[0,2 0,2]	[0 0 21]
3	4	[5,7 7,2]	[2,5 2,5]	[6 6 6]
T	5	[0,9 2,0]	[0,7 0,7]	[13 4 4]
5	6	[0,0 0,0]	[0,0 0,0]	[0 9 0]
6	7	[0,5 1,0]	[0,4 0,4]	[6 6 6]
T	8	[0,6 1,3]	[0,4 0,4]	[13 4 4]
8	9	[0,4 0,8]	[0,3 0,3]	[21 6 6]

We model the **tangent phi of customer consumption**:

- By using the reactive power time series generated by SMACH (2a). Simulated active and reactive powers are correlated as they are based on real equipment measurements [17].
- With a uniform variation in the interval [-0.2; 0.4] (2b). We select this interval based on our analysis of household electric equipment measurement data. Assuming a correlation between the tangent phi of loads, a reference value is selected for all loads by simulation and then deviation is added around the selected reference.

We model the **apparent power of the production**:

- By using a PV system simulator [22] to generate the apparent power production curve (3a). We feed the simulator with the weather information as SMACH.
We simulate the 10 time steps with the most production (P) to consider high level of production.
- With a statistic law (3b) that is centred on 90% of the install power of the solar panels. This value makes it possible to simulate a high level of solar production while taking into account the variation in the location of the installations.

We consider that the installed solar power statistically follows the current national distribution available on the French DSO OpenData in the cases with a high PV penetration. The public projections of the French TSO predict a significant increase of the solar production [23]. To model this increase, we consider that up to 35% of customers of the LV grid are equipped with solar panels.

Regarding the conductor impedance Z (with $Z = R + iX$ where R is the resistance and X the inductance), our state-of-the-art analysis shows that:

- R is influenced by the material, section and temperature of the conductor. Its internal temperature depends on the current flow, the weather, etc.
- X is mostly influenced by the geometries of the underground or overhead conductors. Some studies model the reactance as an uncertain value [24].

Here, we only consider the *resistance R as uncertain* while the *inductance X remains constant* and equal to its nominal value. Thus, we model the **conductor resistance R** by:

- Using the nominal value of R supplied by the manufacturer (**4a**);
- Attributing a 25% uniform variation to R (**4b**). This value has been chosen to envelop most of the variations in the resistance [25].

3.3. Study cases definition and simulation

In this paper, we simulate four cases to highlight our methodology. Table 3 details the assumptions we use for each study case.

Case 1: Simulation with a low level of variation on each variable assuming a high level of consumption. The chosen standard deviation is 25% of the diversity factor.

Case 2: Simulation with a low level of variation on each variable assuming a high level of production;

Case 3: Simulation with a high level of variation on each variable on time steps when the consumption is high.

Case 4: Simulation with a high level of variation on each variable over time steps when the production is high.

In case 3 and 4, the active and reactive power variables are generated together. For independence necessity [14], we combine them into one variable: apparent power.

Table 3: Assumptions used in each study case

Assumptions	Case 1	Case 2	Case 3	Case 4
Active power	1b (C)	1b (P)	1a (C)	1a (P)
Tangent phi	2b	2b	2a (C)	2a
Production	3b (C)	3b (P)	3a (C)	3a (P)
Conductor	4a	4a	4b	4b

We use the Distribution Network Simulation Platform (DisNetSimPI) developed by EDF R&D on Matlab to perform the load flow computations required to carry out the study case simulations. Within its framework, we manage input and output data and apply our methodology. OpenDSS is used as internal load flow solver [26].

4. Results

The major results obtained for the four study cases are presented in Figure 3. Interactions correspond to the impact of the combination of two variables. Figure 4

shows the importance of load and production modelling on voltage distributions.

These results show that the uncertainties of the resistance or tangent phi can be neglected and modelled with fixed values. The distribution would be shifted but unchanged.

They also show that power systems are not robust to active power variation and that the results of a planning study are highly dependent on load assumptions.

In case of a constraint, the planner can decide to act:

- Either to shift the average of the distribution, for example by using network reinforcement, introducing OLTC, etc,
- Or to reduce the variance by using active power curtailment of the production or flexibility solutions such as demand response when the influence of consumption variable is high.

Figure 3: Sobol indices computed on the LV network

Figure 4: Voltage distribution on the LV network

5. Conclusion

In this paper, we **adapt and apply a GSA method** to characterise the voltage distribution observed on a LV network in several study cases. The sources of uncertainty we consider are the active power and tangent phi of the

load consumption, the conductor resistance and the apparent power of the solar production.

Using this method:

- we evaluate the impact of the input assumptions on the grid performance indicators;
- we show the importance of active power modelling of the consumption and the production,
- we justify simplifications related to tangent phi and conductor modelling.

Our methodology can be adapted to further studies such as testing alternative modelling hypotheses or defining modelling choices for flexibility solutions.

Future work is in progress in order to estimate the thresholds regarding flexibilities activations according to the risk of constraint that a DSO is willing to accept.

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7. References

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