COMPREHENSIVE FRAMEWORK FOR PV INTEGRATION WITH AN OLTC IN A RURAL DISTRIBUTION GRID WITHIN THE SMAP PROJECT

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ABSTRACT

This article describes the generic methodology used in the SMAP project in order to simulate and compare different solutions to improve the insertion of PV production in the LV grid. We introduce the specific framework and the key parameters used to define the studies. We then apply this generic methodology to the assessment of a specific solution: equipping the MV/LV substation with an "On Load Tap Changer" (OLTC). We also compare this solution with a local reactive power control mechanism. The comparison is performed using two different scenarios for the evolution of production and consumption.

INTRODUCTION

The smart grid demonstrator SMAP (SMArt grid in natural Parks) offers the opportunity to study in detail the low voltage (LV) grid of a specific rural area in France, both by means of on-site experimentations and simulations. The goal of this study is to improve the insertion of Photovoltaic Distributed Energy Resources (PV DERs) in the rural grid of the village "Les Haies" thanks to solutions that could avoid grid reinforcement. One of the main features is the on-site testing of a MV/LV transformer with an On Load Tap Changer (OLTC). Another key element is that we perform comprehensive long-term Monte-Carlo simulations in order to get global insight about the value of the OLTC over a long duration and across two different future scenarios.

In this paper, we will describe how we designed a simulation framework to study the performances of an OLTC in a rural distribution grid. Then, we compare the obtained results with two other cases: a simplified reinforcement procedure consisting in upgrading the sections of lines or changing the MV/LV transformer, and then a local reactive control with a Q(U) droop function.

COMPREHENSIVE FRAMEWORK

LV rural grid

LV grids present a great diversity with numerous factors and they are affected in many ways by PV DERs integration [1]. We modelled here six real-world rural LV grids from the village "Les Haies" in France. The data was provided by Enedis, the main French DSO. As a result, we have access to many characteristics of the grids and their elements, such as the characteristics of the MV/LV transformer, the lines or the loads directly under the software PowerFactory of DIgSILENT.

Studied elements

Simulation is a very flexible mean of investigation, since it offers the opportunity to access and modify a great number of parameters. In this study, we focus on the following elements:

- **External Grids**, modelling the medium voltage (MV) grid.
- **MV/LV Transformers**, with their real technical properties. We mainly modify the tap positions and/or rated power (in case of reinforcement). We also check the voltage and thermal ratings.
- **LV Lines**, with their technical properties and π model parameters. We modify the lines in case of reinforcement, and we verify the voltage and thermal ratings.
- **LV Loads**, with their connection characteristics and load curves.
- **LV PV** (using an "ElmGenstat", an element available in PowerFactory), with their connection characteristics and production curves.

On site, we have access (specifically in the SMAP project) to the following elements:

- Voltage sensors on the MV side of the MV/LV substation.

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- A MV/LV transformer equipped with an OLTC.
- Smart meters, with access to voltage and power measurements from participating customers.
- A communication grid using "Power Line Communication" (PLC) and/or "General Packet Radio Service" (GPRS) between the above-mentioned elements and a data concentrator (cf. fig. 1). The full description is available in [2].

In this context, we are able to modify and study the influence of all those elements on the hosting capacity of the grid in term of PV insertion, and to compare them through different scenarios and different technical solutions (reinforcement, OLTC, etc.).

We use two scenarios adapted specifically to the six rural grids: one with high PV DERs insertion, based on the data of the négaWatt [3] scenario, and another one with lower PV DERs insertion, based on the current local trend (mainly from the "National Institute of Statistics and Economic Studies", Insee).

Power Consumption

We evaluated the consumption from 2016 to 2050, with a focus on the evolution of consumer uses: heating, water heating, efficiency and general consumption. In order to cope with the necessary uncertainties [1, 4, 5], we generated random load curves and proceeded with long-term Monte-Carlo simulations. Here, the uncertainties come from the evolution of uses, the amplitude of the uses and the connection phase (for single-phase consumers). On site, we experimented with power consumption measurements from the smart meters and some change of uses from the consumers. However, we do not use these data here.

Power Production

We also evaluated the expected PV production from 2016 to 2050 in the village, using an estimation of the solar potential calculated by the model "Épices" [6] from Hespul. Each year of calculation, we define a target for PV production, and we add new production sites accordingly to the solar potential. Uncertainties can come from the completion of the target, the geographical position of the added sites, the yearly production and from the connection phase (in case of single-phase generators). The PV inverters are here fully controllable in both active and reactive power, with a nominal power equal to the total watt-peak of the installed PV DER. On site, we benefit from inverters' measurements with a 15min time step.

Solutions to improve PV DERs insertion

Base case. First, we define a base case in order to compare the different solutions tested. We created a simplified algorithm to "reinforce" the LV grid: when, during the simulations, we detect a grid constraint (voltage or thermal) [1, 7], we try the following reinforcements:

- Increase the cross-section of the lines between the constraints and the MV/LV substation, starting from the transformer.
- Increase the rating of the transformer.
- Create a new feeder.

These actions can be cumulated multiple times over the long-term studies for the two scenarios. With the exact same parameters and the same randomization, we then repeat the simulations with the addition of a new "solution", such as the OLTC. We can therefore compare the obtained results, such as the cost of reinforcements or the calculated losses. We must note that this reinforcement algorithm is simplified; we may lose accuracy when a complex reinforcement would be needed, such as the creation of a new MV/LV substation.

OLTC. One of the main tested solution in the SMAP project is that one of the MV/LV substation is equipped with an OLTC. In this project, the transformer automatically changes taps in order to maintain the voltage in a set band (+/- 8.5% in calculations, and only +/- 4% on-site in order to see more tap changing) and does nothing otherwise. The installed OLTC is a 9-taps transformer with an additional voltage per tap of 1.5%, (ranging therefore

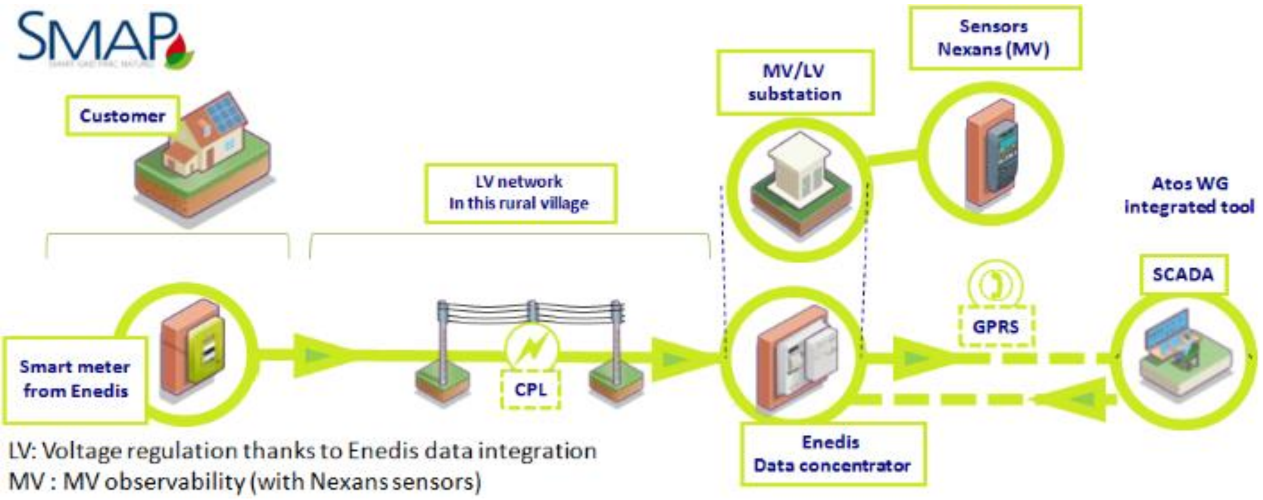

Fig.1. Smart meter integration for Voltage regulation in SMAP project with an OLTC

from -6% to +6%). This substation feeds a LV network equipped with smart-meters: we select a few of these meters as voltage sensors sending voltage data to the substation where they are used to provide an image of the maximum and minimum voltage of the grid. The OLTC is then able to modify the voltage of the distribution grid in order to remain between given setting values.

Decentralized control Q(U). For a better understanding of the performances of the OLTC, we compare it to another smart grid solution to improve PV DERs insertion. We chose here a decentralized control of the reactive power of PV inverters with a Q(U) droop function. We reuse here the work detailed in [2].

Here, we are able to compare, using simulations, the performances of these solutions. We can then verify with on-site test the feasibility of the solutions and their coherence.

SIMULATIONS

Static load Flow

For this study, we want to calculate and analyse results to provide relevant inputs to grid interconnection studies and grid planning. We mainly focus on the detection and resolution of voltage and thermal constraints along the two former scenarios. With the use of the software PowerFactory, we realise an AC unbalanced load flow calculations with a 10 min time step.

We implemented multiple scripts in "dpl" (digsilent programming language) to perform the following algorithms:

- Loop trough the LV grids.
- Loop trough the random variables of each study (at least 50 loops): modify the consumption and the PV DERs production.
- Loop trough the different time scales of the scenarios: 35 years (2016-2050), 8 typical days (one workday and one weekend day for each season), 145 time steps (10 min).
- Specific loops depending of the case: reinforce the grid, change the transformer tap position or control the reactive power of PV inverters.

Cost-Benefit Analysis

Thanks to the calculations, we are able to do a cost-benefit analysis. Enedis provided cost values for the SMAP project, both "capex" (capital expenditure) and "opex" (operational expenditure). Here, we consider the following:

- **Capex**: new equipment for reinforcements and/or the OLTC, with a 40 years depreciation time. We neglect any capex for the inverters for the reactive control in this study.
- **Opex**: losses in all cases, maintenance cost for the OLTC and eventually the non-injected production due to the Q(U) solution.
- **Discount rate**: 4.5%, from 2016 to 2050 [8].

As we want to study cost differences, costs that are common to every case are not considered here.

APPLICATION TO THE OLTC

For this example, we use the described simulations and show results from the SMAP project for one of the six grids. We choose here the one that is equipped with the on-site OLTC. This grid represents 44% of the total solar potential of "Les Haies".

High PV insertion scenario

This scenario estimates a PV production of around 335 MWh/year. We attain this value linearly from 2016 to 2050 with a final value chosen randomly from 168 to 335MWh/year. We obtain some major results shown in the next figures.

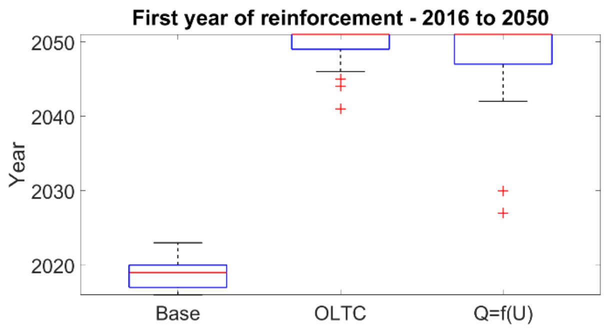

Fig. 2. Box-plot of the first year of reinforcement for a scenario of strong PV integration. Boxes contain 50% of 50 iterations of varying production and consumption. Values at 2050 means that no reinforcements were needed over the timeframe.

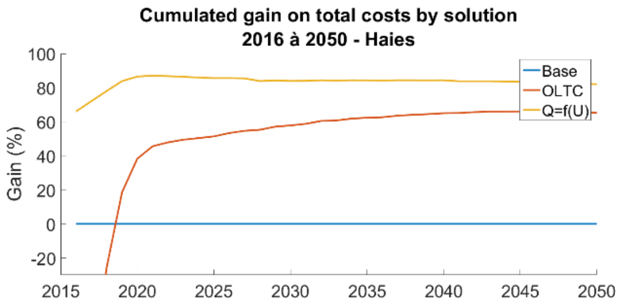

Fig. 3. Cumulated gain on total costs by solution for a scenario of strong PV integration for the main grid of "Les Haies". The gain here is the variation of the costs between the base case study and the use of a solution.

In this framework, the obtained results show a clear advantage of the use of an OLTC over the base case. We could delay the first year of reinforcement from mainly 2019 to past 2050, with a notable impact on the associated costs. The first years, we have a negative gain because of the high capex in 2016 considered for the addition of an OLTC. However, we hit positive gain from 2019 onwards with a final value of 65% in 2050 on the studied grid.
If we compare these performances to the Q(U) solution (cf. fig.2), we can see that it competes similarly for the first

year of reinforcement, both mainly past 2050. But the OLTC shows less gain than the Q(U) controller on this grid, the latter achieving a gain of 82% ultimately.

Low PV insertion scenario

The second tested scenario estimates a PV production from 50 to 100 MWh/year and a superior consumption. As a result, the cost of the needed reinforcements to insert the PV production is also reduced and could influence the potential gains of the tested solutions.

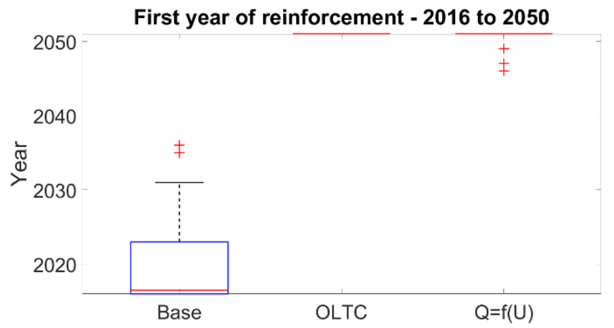

Fig. 4. Box-plot of the first year of reinforcement for a scenario of low PV integration. Boxes contain 50% of 50 iterations of varying production and consumption.

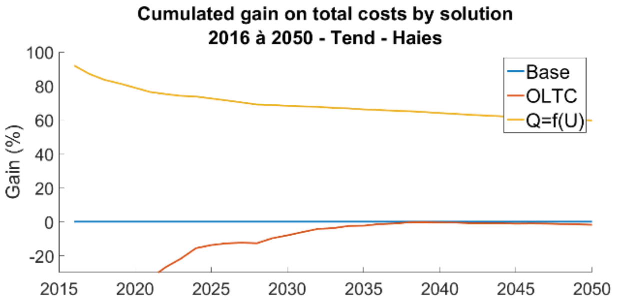

Fig. 5. Cumulated gain on total costs by solution for a scenario of low PV integration for the main grid of "Les Haies".

These results show that, compared to the base case, the OLTC still delay reinforcements greatly, as we have here zero reinforcement expected from 2016 to 2050. The Q(U) have similar performances, although in some rare cases reinforcement does occur in the last years of the studied period. However, the OLTC performs poorly on this scenario if we consider the costs. The solution barely manage to compensate the initial capex with a gain of -2%, being then less interesting than the reinforcement, whereas the Q(U) in the same context cumulate a gain of 60%.

On-site tests

The installed smart meters permitted a reliable supervision of the LV grid: we recorded less than 0.4% of failures over 7.2 million real-time measurements. During the tests, the OLTC managed to maintain the voltage of the studied rural grid between the desired levels (+/- 4% for SMAP, cf. fig.6), in response to variations from both LV and MV grids. We measured 47 tap changes from 30/04/2018 to 10/06/2018.

CONCLUSION

Considering these results, the economic value of the OLTC shows, for the six LV grids studied, high sensitivity to the scenarios of production and thus poor economic "robustness" despite acceptable technical performances to avoid reinforcements in this situation. On site, the tests were successful: we verified the feasibility of the simulated OLTC operation and its potential effect on a real grid. As a result, this solution have been experimentally verified. It could thus potentially help increasing some DERs (PV) insertion in some cases. But, its high cost and high sensitivity, especially compared to other solutions (such as the Q(U)), make it a solution to choose with care and to use in specific situations.

PERSPECTIVES

This article describes the methodology used in the SMAP project in order to simulate and compare different solutions to improve the insertion of PV DERs in the LV grid. We applied this methodology to the use of an OLTC in the specific context of SMAP. However, the methodology and developed framework can be reused for further studies. It is possible to carry out the same studies and comparison with more refined or different scenarios, solutions or costs. This was realized in particular in the framework of the SMAP project where other "smart grid" solutions were considered. Thanks to the flexibility of the methodology, and of software tools that were developed to implement it, we are also able to enlarge the scale of the study to more than one hundred additional real-world LV grids.

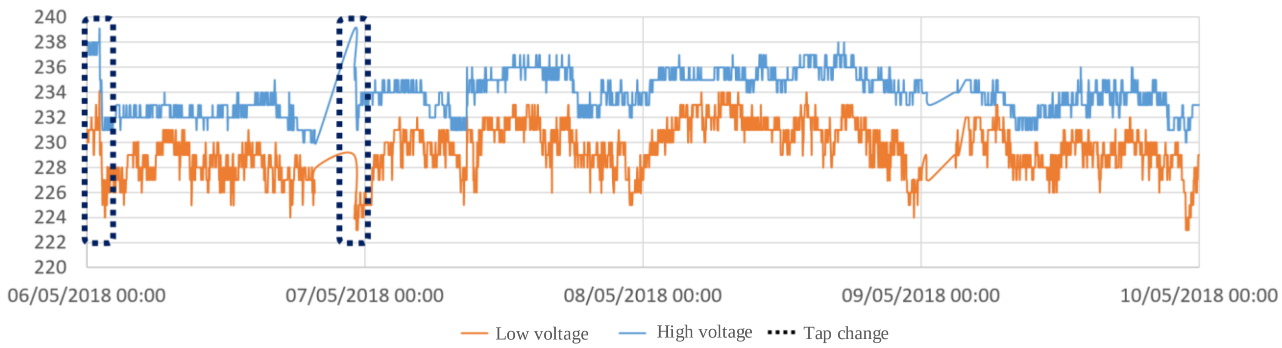

Fig. 6. Maximum (red) and minimum (blue) voltage measurements on the studied rural LV grid from "Les Haies" between 06/05 and 10/05. We can verify the voltage level between +/- 4% thanks to two tap changes.

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FURTHER QUESTIONS?

More information is also available at http://www.centralesvillageoises.fr/web/guest/projet_smap.