USING LV DISTRIBUTED GENERATION'S REACTIVE POWER FOR VOLTAGE REGULATION

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ABSTRACT

This paper deals with voltage regulation on distribution networks. It focuses on how Low Voltage (LV) producers' reactive power can help to prevent voltage constraints in order to better integrate Distributed Generation (DG) on LV distribution networks. A technical study was conducted on LV networks to evaluate the impact of innovative tools on voltage issues and LV losses. After reminding the context that Enedis has to face, this paper presents the methodology and the results of the study. Some prerequisites for a possible future large-scale implementation of this kind of solution are listed.

CONTEXT

Since 2009, Distributed Generators (DG) connected to French networks have known a substantial increase, essentially caused by the huge development of small and medium size photovoltaic plants (PV), reaching more than 3 GW at the end of 2016. To meet French and European target, the number of DG connected to LV networks is expected to continue to increase in the next years, until it reaches more than 4,5 GW in 2020 and approximately 8 GW in 2030.

In order to reduce connection costs of PV connected to low voltage networks, Enedis studies cost-effective alternatives to network reinforcement, using reactive power regulation by the PV plant. Indeed, the use of reactive power to solve voltage constraints is already used on MV feeders having both consumption and MV generation. Besides, since February 2016, a new solution based on a self-adaptive regulation of reactive power (Q=f(U)) is proposed to DG connecting to MV networks.

Now that this solution has been deployed on MV networks ([1], [2]), Enedis wants to assess the benefits of this solution for LV networks.

Thus, this paper presents the cost-benefit analysis of local reactive power regulation for DG connected to LV networks. The study was carried out at the society costs level, meaning that every cost is taken into account: network reinforcement, network losses and extra costs for the implementation of the regulation solution.

METHODOLOGY

Comparison between different kinds of reactive power regulation

Three different situations of regulation are analyzed. The reference case BaU (Business As Usual) corresponds to DG (Distributed Generation) having no reactive power absorption (the ratio between reactive and active power TanPhi=0). Then a *TanPhi* solution (constant *TanPhi=-0.33*) and a *Q=f(U)* solution (reactive power/voltage characteristics with a deadband) are studied.

For the *Q=f(U)* solution, parameters are set so that the maximum reactive power that can be absorbed by DG is the same as the *TanPhi* solution. Hence it is considered that the impact on constraints is the same for both solutions insofar as constraints are studied with maximum power for DG which is the situation with maximum absorption of reactive power for the *TanPhi* solution. However with the *Q=f(U)* solution, the deadband and the fact that the reactive power absorption depends on the voltage allows DG's reactive power to be used in a different way. That is why the impact on losses is expected to be different.

In order to evaluate the impacts of reactive power regulation on network management, three aspects are studied: the reduction of networks constraints and especially voltage constraints, the impact on network losses and the cost of the equipments required to implement this kind of solution.

Generation and consumption

The study is based on scenarios of generation and load evolution for the year 2020, using French real LV networks. Four generation cases are therefore considered. They consist in connecting the following PV units for each network:

- Case 1: 1 PV unit of 6 kVA (single-phase)
- Case 2: 2 PV units of 6 kVA (single-phase)
- Case 3: 3 PV units of 6 kVA (single-phase)
- Case 4: 1 PV unit of 100 kVA (3-phase)

The capacity of PV units has been chosen considering the existing generation. Indeed, statistics on big generation (>36 kVA) shows that a 100 kVA unit is a fair representation of this category while 6 kVA comes from statistics on small generation (<36 kVA) and the trend to ask for bigger connection power that has been observed.

For each case of generation, several draws are performed regarding the exact location of new DG on the network.

The evolution of the load is set to 0%.

Evaluation of benefits

The main benefit expected from reactive power regulation is the reduction of voltage constraints caused by the connection of new producers. However the absorption of reactive power by DG may also create more reactive transit in the network, potentially leading to a rise of current constraints in the cables and transformers when generation is high and consumption is low.

To evaluate the impact on constraints, an electrical power flow was therefore launched on each network for each draw using Erable, an Enedis tool developed from DIgSILENT PowerFactory® software. The simulated state of the network represents a situation where there is maximum generation and minimum consumption. In this situation, given the tap of the MV/LV transformer, the fact that the MV side of the MV/LV transformer is considered at its maximum voltage (1.05 p.u.) and the margin considered for the voltage rise in connection cables, the maximum allowable voltage rise on the LV network is equal to 1%.

Evaluation of the costs

Cost of solutions

For the *TanPhi* solution, no additional costs were taken into account, as every LV PV plant is naturally able to fix a ratio between its reactive and active power.

For the *Q=f(U) solution*, a benchmark of the various existing equipments able to implement a reactive power / voltage characteristic with a deadband has led us consider overall cost of 1 k€ for this solution (control equipment + installation and wiring).

Impact on LV losses

To evaluate the potential of a LV *Q=f(U)* solution compared to a *TanPhi*, the losses obtained with both regulations must be assessed in simulation. Indeed, the transit of reactive power could lead to an increase of LV lines losses and MV/LV transformer losses.

A simulation tool is developed in Python language by EDF R&D. The tool controls Erable in engine mode to calculate unbalanced load-flows.

Each LV network being simulated separately, a hypothesis is made for the MV voltage on the primary side of the MV/LV transformer. However, this voltage is likely to vary greatly, and computing time constraints prevent from running prior MV simulations. A conservative hypothesis was made, simulating for each time step the highest and the lowest voltage on the MV feeder, giving an envelope on the LV simulation results.

The simulation tool uses as inputs PV and load profiles, at a 10-minute time step. The PV profiles are measurements from real LV PV sites. The load profiles are generated. Indeed, LV loads are not monitored in France. The generation of LV profiles for each LV load takes into account the **specificity of these loads (type of load, contractual power)**. The 10-minute profiles are generated for a series of “reference days”, chosen in each season, with a repartition of working days and weekend days. The dates of those “reference days” are given as an input to the profiles generator. The dates are used to calculate a **“normal temperature”** for those days (from historical data), and to find the type of day (**working days** or **weekend days)**. Finally, the profiles are created using all this information, making them reliable and close to realistic values.

The same days are used for generation profiles (extracted from measurements) and load profiles (generated by a script).

After importing the input data, the script simulates the scenarios of generation and load for the year 2020 (connection of new generator(s), rate on consumption).
Then, the voltage regulation configurations are activated.

The 3 configurations of regulations (BaU, *TanPhi*, *Q=f(U)*) are simulated using unbalanced load-flows, for each 10-minute step of the “typical days”.

RESULTS

A strong reduction of LV constraints

The analysis on constraints was run on about 74 000 LV French networks (about 9% of total French LV networks). Figure 1 represents the results on these networks. A few networks already had some constraints before the arrival of new DG and they have been removed from the analysis.

First, these results show that a significant part of the networks will face constraints in the future if no regulation is implemented. Logically the share of networks in constraints will be quite lower for case 1 (only one additional 6 kVA producer) than case 2, 3 and especially 4 (one additional 100 kVA producer) where there is only 3% of the network in the sample with enough hosting capacity. Moreover, when focusing on networks in constraints with and without reactive power management, case 1, 2 and 3 see an improvement of about 15% to 28% whereas case 4 has only a 4% improvement.

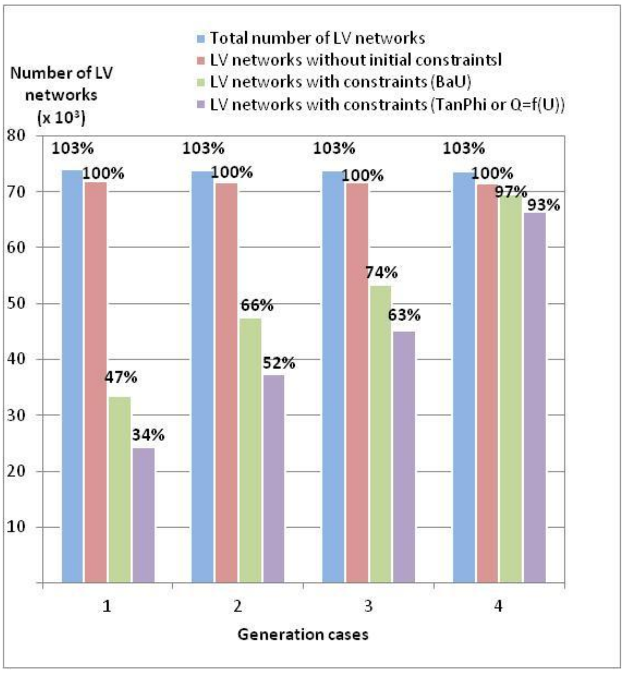

Figure 1- Impact of reactive power regulation on network constraints for 74 000 LV networks

Nonetheless there are some important points to notice with these first results. First of all, if there are thermal constraints, reactive power absorption will not be able to reduce them. In some cases, it could even create new constraints. Furthermore, a network can be constrained in BaU and with regulation but it does not mean that there is no improvement since there might be fewer feeders in constraints. This is particularly true for case 2 and 3 where there are several DG units that might be located on different feeders of the same LV network. To have a better understanding of the impact, Figure 2 gives some details about the LV feeders that were in constraint while Figure 3 focuses on the MV/LV transformers.

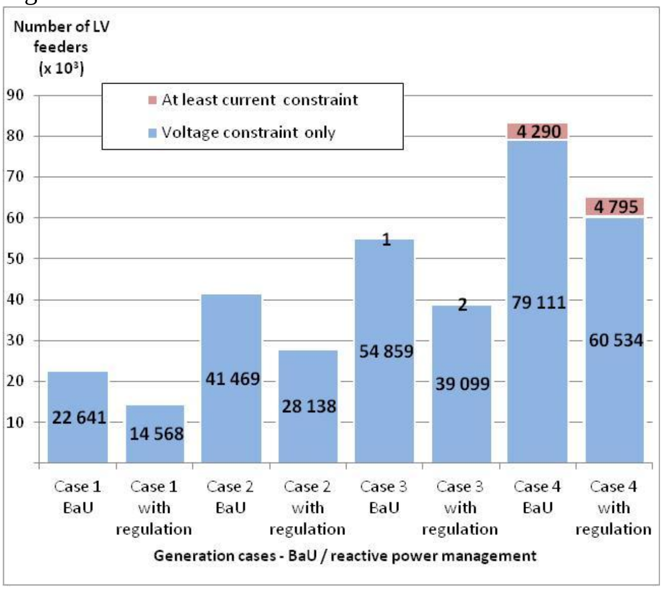

Figure 2- Results on LV feeders for each case

For the feeders, the limit of hosting capacity is reached because of voltage constraints essentially and current starts to be an issue with the connection of big producers (case 4). In this case, the regulation creates some additional constraints due to the transit of more reactive current in the network. These details by feeder confirm the positive impact of the regulation for all configurations (case 1, 2, 3 and 4).

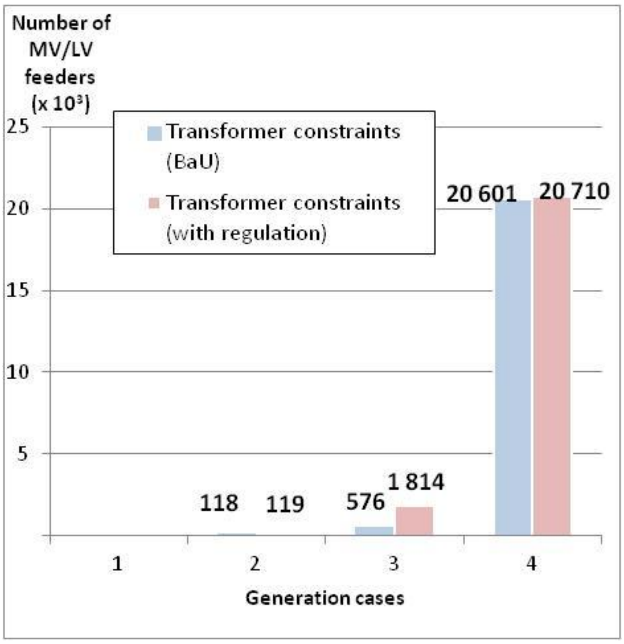

Figure 3- Results on MV/LV transformers for each case

Figure 3 shows that transformer constraint is mainly an issue for large producers (case 4). This is consistent with the fact that a pretty big share of the transformers that are in the sample have an installed capacity that is below 100 kVA.

At the end, for each LV network, a probability of occurrence is attributed to each Generation Case depending on the geographical situation of the network and a Poisson's law. It eventually gives the global results for 2020 for all the networks included in the sample.

Table 1- Results for year 2020 on 74 000 LV networks

LV constraints	BaU	Reactive Power Management	Improvement
LV feeders	3 370	2 375	30%
MV/LV transformers	193	196	-1%

The impact on losses depends on the solution

The losses simulation tool was tested on the 80 LV networks of a French MV feeder. These first simulation results give an example of comparison between the 3 voltage regulation configurations, on a small sample of

LV networks. The study will be carried on a larger scale of French LV networks.

The mean reactive energy absorbed by generators for the 80 LV networks over a year is shown on Figure 4.

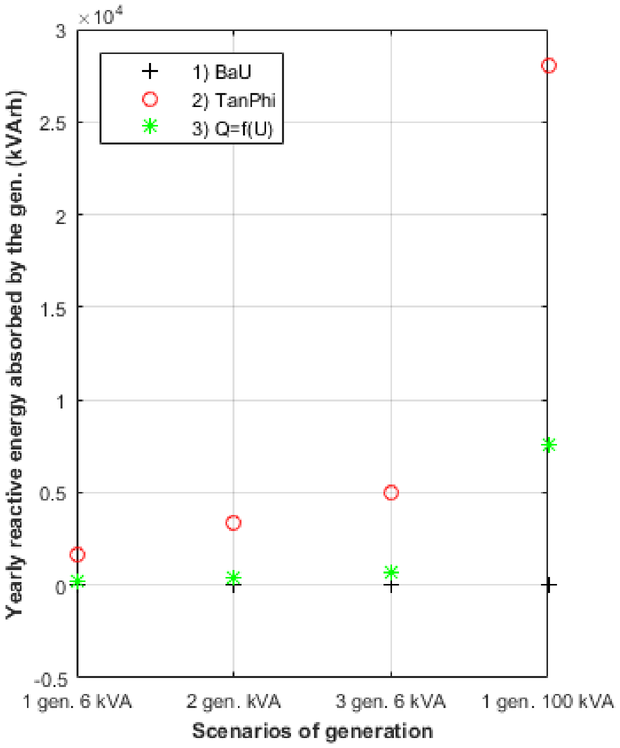

Figure 4- Comparison of the reactive energy absorbed for each voltage regulation configuration

The worst reactive power solicitation is *TanPhi* for all cases of generations, while the *Q=f(U)* solution requires less reactive power due to the deadband, as expected. The gap is bigger with the connection of a 100 kVA generator.

Furthermore 6 networks remain in constraints with both regulations. In these cases, the network reinforcement would be necessary. These 6 networks are therefore removed from the sample for the rest of the losses study.

The first results in terms of mean active losses on the 74 remaining networks LV networks are described on Table 2.

Table 2- Comparison of the yearly active losses for each voltage regulation configuration, on the remaining 74 LV networks

Yearly losses	**Connection of 6 kVA gen.** *Δ (%)*	**Connection of a 100 kVA gen.** *Δ (%)*
1) BaU	**Reference**	**Reference**
2) TanPhi	**+0.53%**	**+6.08%**
3) Q=f(U)	**+0.08%**	**+1.33%**

For small power generation, the *TanPhi* solution 2) leads to a small increase of about 0.5 %, that can be reduced using *Q=f(U)*. For the connection of a new 100 kVA generator however, it shows that the *Q=f(U)* solution leads to a huge reduction of losses compared to *TanPhi*. A simulation on a larger scale of LV networks is necessary to confirm this trend.

Summary of results

Figure 5 gives a summary of the main results obtained in this study. The *TanPhi* solution is rather effective to reduce voltage constraints caused by DG integration. The

Analysis	BaU	Tan phi = -0.33	Q=f(U)	Conclusions
LV constraints	The base for possible benefits is important C_{LV}	About 30% of improvements ≈ 0.7 x C_{LV}	About 30% of improvements ≈ 0.7 x C_{LV}	○ Positive impact ○ Not dependant on the kind of solution
Losses on LV networks	L_0	P < 36 kVA : small rise P > 36 kVA : significant increase of losses	Enable to come back to a situation similar to BaU ≈ L_0	○ Not a big issue for small producers ○ The impact is more important for large producers for which Q=f(U) would provide actual benefit
Cost of the solution		0	≈ 1 kEuros (internal estimated value)	

Figure 5- Summary of the results of the study

first results regarding losses show that losses are not a big issue for small producers. So *TanPhi* is likely to be the best solution for them since there is no cost of implementation. For big producers, the issue on losses seems to be more relevant and *Q=f(U)* is therefore more likely to be a better solution. Nonetheless this conclusion will need to be supported by further results on a larger scale. It will allow a more detailed comparison between the benefits on the losses and the costs of implementation.

PREREQUISITE FOR AN INDUSTRIALISATION

Such a smart grid solution, that is to say a local voltage regulation using the reactive power of the MV generators has been industrialised in February 2016 at Enedis. This industrialisation has been made possible by the legislative framework, and in particular the fact that the 23rd April 2008 order allowed such a MV voltage regulation.

In order to be able to industrialise such a smart grid solution for low voltage networks, and decide in which cases the best solution (*Q=f(U)* or *TanPhi*) would be deployed, a certain number of prerequisites should be met:

- launch on-site experimentations, in order to assess the technical feasibility of these solutions on real PV plants connected to LV network : such an experiment on Q=f(U) is planned in 2017 on a 160 kW PV plant;
- conduct industrial policy and cost-benefits analysis;
- propose changes in the regulatory framework;
- ensure the overall consistency and the integration of the solution in our planning tool and the billing information system;
- prepare the integration of smart solutions within business activities in terms of human resources, processes, and organisations.

REFERENCES

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