ANALYSIS OF THE OPTIONS TO REDUCE THE INTEGRATION COSTS OF RENEWABLE GENERATION IN THE DISTRIBUTION NETWORKS. PART 1: IMPACT OF PV DEVELOPMENT IN FRANCE AND GLOBAL ANALYSIS OF CONSIDERED ALTERNATIVES TO REINFORCEMENT

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ABSTRACT

This two-part article deals with the latest results of a joint research effort by ERDF and EDF R&D to assess the cost of DG/RES integration and study innovative solutions that may help to reduce it. This paper ("Part 1") analyses the connection costs of RES in France on 2012-2020 and 2012-2030 scenarios, as well as the global savings that could be made possible by some new RES integration solutions. The companion paper ("Part 2") focuses on an innovative planning tool under development that allows searching the best option on a case-by-case basis.

INTRODUCTION

The integration of Renewable Energy Sources (DG/RES) into distribution networks impacts the way the power flows along the feeders. Grid RES connection studies allow DSO to quantify these effects and, whenever necessary the grid is upgraded to prevent current and/or voltage limit violations. Network adaptations take time and represent a cost for the community.

Moreover, the situation will worsen in the years to come since the favourable cases –feeders with some remaining hosting capacity– will become scarce as the penetration level of distributed generation increase. Several billions € of grid reinforcement will be necessary: we must develop and assess new network integration approaches to optimize these costs. Within this framework, this paper is organized in 3 parts:

1- Renewable energy scenarios and grid impact in France by 2030, taking into account various generator sizes and locations.
2- Alternative solutions to reinforcement: technical description and estimated gains.
3- Regulatory aspects.

1 - RENEWABLE ENERGY SCENARIOS AND GRID IMPACT IN FRANCE BY 2030

Development scenarios

At the end of November 2012, 3 GW of PV and 6.7 GW of wind turbines were already in operation in France. Our main scenario for the present study, shown in Figure 1 and Table 1, takes into account 8GW of PV and 14GW of wind in 2020.

The development of RES already leads to significant saturation and constraints/reinforcement of MV rural feeders due to medium size LV (36 to 250kVA) PV accumulation, and to MV PV plants between 1 and 4MW. Besides, most wind farms are expected to be connected on dedicated MV feeders.

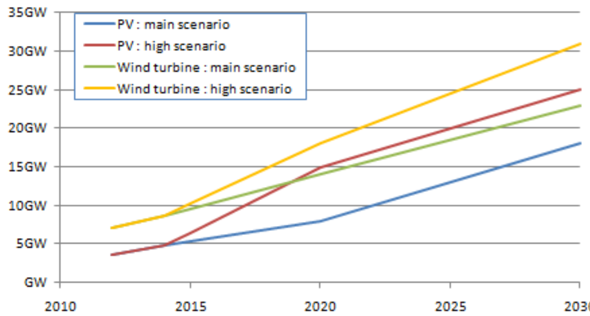

Figure 1. RES development scenarios for this study.

	2020	2030
Medium scenario	**8 GW**	**18 GW**
PV >250kVA (MV)	29%	28%
PV 36 à 250 kVA (LV)	36%	36%
PV <36kVA (LV)	35%	36%
High scenario	**15 GW**	**25GW**
PV >250kVA (MV)	27%	26%
PV 36 à 250 kVA (LV)	33%	33%
PV <36kVA (LV)	40%	41%

Table 1. Details regarding PV in our scenarios.

Network integration costs evaluation

The aim of our study is to point out differences in PV integration costs according to their size and their location. For each size of PV (small residential LV PV, medium size LV PV, large MV floor PV), the national repartition has been spread with the distribution per feeders (LV or MV) based on Poisson statistical law, under the current concentration of on each area. An area is determined by:

- Its region: for example we can note that there is a higher concentration in the south part of France.
- Urban / rural criteria: to take into account high or low load local load density, and differences in the network structure.

Size impact on costs

Figure 2 below gives the relative levels of network development/adaptation for the different sizes of PV plants under consideration. This does not include transmission network reinforcement/adaptations.

Costs have been spread between 3 different kinds:

- **Connection** to the existing network (mainly metering costs for residential PV).
- **Reinforcement** of the existing network, at the voltage level of connection, or even at the superior level (due to progressive network saturation).
- **Network creation** when reinforcement is not technically or financially valuable, new grid assets are created.

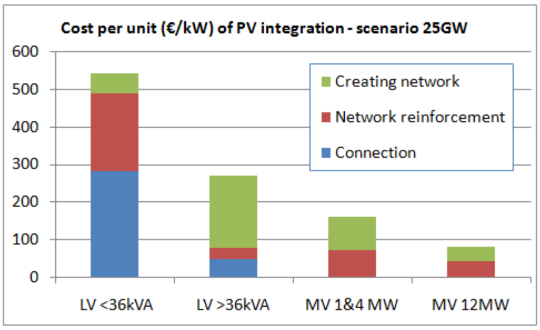

Figure 2. Average grid connection cost of PV calculated in our 25 GW scenario.

We can notice a significant scale effect for connection cost. For small PV integration, it represents about half of the total cost. This cost is mainly due to the regulatory metering system (separation of production / consumption).

Then, reinforcement concerns essentially small LV PV (impact on LV and MV feeders by accumulation) and small MV PV (impact on MV feeders). For such generation systems, there could be a strong interest in putting in place alternatives to reinforcement.

At last, there is a big issue concerning network creation, especially for large LV PV and small MV PV. We describe below in this paper means to decrease the number of new assets (feeders & substations).

Overall, due to costs scale effect, the average costs of integration of PV are around 300 M€/GW, against 100 M€/GW for wind farms (mainly 12 MW sites connected to the HV/MV substation through a dedicated feeder).

Location impact on costs

In practice, DG/RES integration costs can vary widely depending on the type of project, on the rated power of the generation plant, on the local load, on the configuration of the existing network and on the density of generation assets already connected in the area (due to saturation effect):

- Reduced costs for generation integration close to consumption: in urban areas, in the presence of strong local consumption and dense networks. Costs can then be limited to the connection in most cases (i.e. around 1k€ for a domestic installation) - no reinforcement needed.
- Higher costs for generation integration far from the loads: in areas of rather low consumption where the existing network is then less dense and with a lower capacity (grid assets often sized by voltage constraints).

On LV networks, when the PV installed capacity exceeds (alone or accumulation) about 20 to 30 % of domestic consumption of LV feeders to which they are connected or when they are connected rather far from an existing substation, it is then often necessary to strengthen the existing grid or to build new dedicated network feeders or substations for the integration of this new generation.

For example, here are some more details about our 2030 25GW scenario. We can observe that:

- 45 % of LV PV systems <36kVA are installed in rural areas, with an average cost of reinforcement of about 400 €/kW. The average cost of reinforcement in the rest of France is about 140 €/kW. Throughout France, reinforcements are caused by only 10 % of producers. These cases show a very high average cost: around 2100 €/kW.
- 66 % of LV PV systems >36kVA are installed in rural areas, with an average cost of reinforcement of about 160 €/kW. The average cost of reinforcement in the rest of France is about 100 €/kW. Throughout France, reinforcements of MV/LV substations are caused by 45 % of the producers, with an average cost of 250 €/kW.

The same effect is found on MV networks. This is due to the installation of PV generation connected directly at MV level but also because of an accumulation of LV PV connected to a same MV feeder. This phenomenon can lead to reinforcement or even to restructuring the MV network. Indeed, in our 25 GW scenario, 41 % of MV 1MW PV systems are installed in rural area, at an average reinforcement cost of 115 €/kW. The average reinforcement cost in the rest of France is about 45 €/kW. Throughout France, MV constraints are caused by around 20 % of producers, with an average cost of 390 €/kW.

The Figure 3 below summarizes the findings of this part of the study and illustrates clearly that the location of PV grid connection request have a very high impact on the grid integration costs.

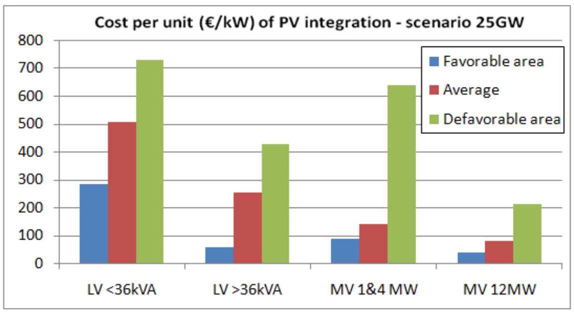

Figure 3. Impact of the location of PV systems on the average grid connection cost (scenario 25 GW).

We can conclude that "reasonable" penetration levels (i.e. hosting capacities that will keep the costs at a reasonable value) of small/medium PV systems can be defined on a case-by-case basis based notably on the characteristics of the existing network. We estimate that a rated power of generation in the range of 20 to 30 % of the local peak load is usually “reasonable” in rural area (feeders sized by voltage drops). In urban area, this value can rise up to 100 % (feeders sized by current constraints).

2 - ALTERNATIVE SOLUTIONS TO REINFORCMENT

The two main approaches for DG/RES integration that can increase network hosting capacities without reinforcement, with reduced costs and in certain cases, are basically:

1. Reactive power control
2. Active power control

Complementarily with the global approach presented herein (multi-year scenarios for France), the companion paper (see ref. [2]) focuses on an innovative planning tool under development that allows establishing, for any connection request at MV level, the merit order of the alternatives to grid reinforcement.

Local reactive power control

Description of the solution

In rural areas, network hosting capacities of DG/RES (MV and LV feeders) are often set by voltage rise limits:

$$\frac{\Delta U}{U} = \frac{R.P + X.Q}{U^2} = \frac{R}{U^2}.\left(P + \frac{X}{R}.Q\right)$$

Then, the absorption of reactive power by generators makes it possible to compensate the effect of generation on local voltages, thus increasing the hosting capacity. The absorption of reactive power can be controlled by the factor:

$$\tan(\varphi) = Q/P$$

Then, the value of tan (φ) can be:

- Set at an optimal value calculated during connection studies and maintained constant.
- Adaptive, with a reactive power vs. voltage control algorithm for example.

This solution can not only reduce the cost connection within existing feeders, but also permits to connect some 4MW producers without dedicated MV feeders, and would enable to connect LV producers > 36 kVA without dedicated LV feeders.

Method to estimate gains: fixed tan(φ)

According to the current French law, the parameter tan(φ) must be in the range [-0.35, 0.4]. We calculated the economic gain that can be achieved over 20 years by changing tan (φ) from 0 to -0.35:

- With reinforcement option only.
- With reinforcement or reactive power control solutions options possible (best solution chosen on each case).

In both cases, technical losses are taken into account, valued at 70 €/MWh.
This allows us to see the DG/RES integration cost reduction effect of the introduction of the reactive control in our 25 GW PV integration scenario.

Our statistical study, based on about 3000 MV real feeders, pointed out a possible gain of 30 % on the MV costs due to MV generators.

For generation connected at LV level, gains on MV reinforcements are about 20 to 40 %, and gains on LV reinforcement are about 10 to 20 %.
By analogy, we can estimate the gains due to LV generation between 20 % and 40 %.

On LV networks, the impedance ratios (X/R) are less favourable to this solution:

- X / R (average MV) = 0.603
- X / R (average (LV) = 0.365

By analogy with the study on MV feeders, in the light of the average differential impedance ratios, it is estimated that regulation of reactive power through constant tan(φ) should allow a constant gain twice less at LV level than at MV level, a gain of 10 to 20 % over LV network reinforcements. A statistical study based on a representative sample of LV feeders remains to be done to validate these values.

Method to estimate gains: Q=f(U) algorithms.

The previous solution reduces the costs required to connect producers (CAPEX), but induces additional losses on the network (OPEX).
Reactive power control based on voltage (Q = f (U) algorithm) is expected to further improve economic gains on losses reduction as reactive compensation that leads to losses increase will only be used when necessary. Furthermore, regarding the CAPEX effect, investments will remain the same than these required in the case of a constant tan(φ); it should also in some cases help maintain the voltage versus voltage drops (consumption). This control is simple to implement, with no substantial additional cost compared with the fixed tan(φ) approach.

ERDF is currently studying Q=f(U) controls in details: field experiments on test sites (see ref. [3]), macroscopic technical-economic study, etc.
Beyond a single generation system, future is centralized voltage regulation, including integration with other voltage control assets (notably OLTC).

Local active power control

Description of the solution

Curtailment is a punctual limitation of the active power injected on the network. Two principles exist: maximum value fixed by a connection technical study or depending on the state of the system (for example: P = f(U)). Curtailment enables to postpone reinforcement

of the network, but induces an amount of "not injected energy" (NIE) which is lost. This solution also permits to connect a higher rate of MV 4MW systems and LV >36kVA systems to existing feeders.
Finally, a study would lead to the possibility of avoiding or postponing the reinforcement / creation of substations (HV/MV and MV/LV).

Method to estimate gains: curtailment
The technical and economic optimum is highly dependent on the value of NIE: gains below are calculated with NIE valued at 70 €/MWh for 20 years.
For curtailment at a fixed value, the gain is 30 % of the MV reinforcement costs (applicable to the generation connected at LV and MV level) and 10 to 20 % of LV reinforcements.

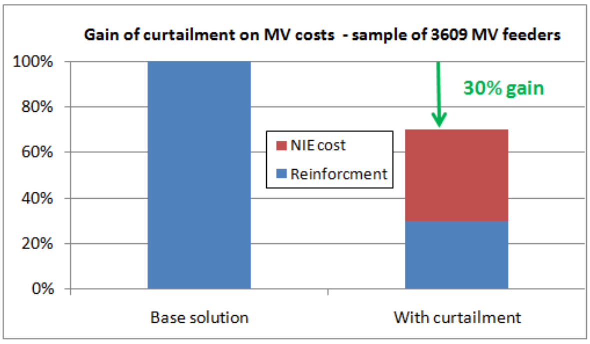

Figure 4. Average grid connection cost of PV calculated in our 25 GW scenario.

3 - REGULATORY ASPECTS

This last part gives a preliminary analysis of the regulatory aspects of the problematic. Table 2 summarizes to what extend the innovative options are compatible with the current French connection rules.

Current French technical regulatory allows solutions described in the chapters before. ERDF has already developed solutions for:

- Grid reinforcement, commonly used by ERDF for the moment in its generation connection studies,
- Production curtailment at MV level for HV n-1 constraints, where a current decoupling protection (ADA) is used if need be.

The French regulatory does not yet comment:

- Generation curtailment at MV level for HV n constraints and MV constraints.
- Generation curtailment at LV level.

ERDF is currently experimenting solutions for:

- Reactive power management at MV level (see ref. [3]),
- Reactive power management at LV level, even if it is forbidden today. A regulatory change would be necessary in order to make this solution possible to implement.

ERDF currently studies:

- Possible solution for generation curtailment at MV level for MV constraints,
- Curtailment at LV level concept.

Nothing is anticipated at this time for generation curtailment at MV level for HV n constraints.

	Technical solution	Regulatory status
Reinforcement	Current solution	☑
Reactive power management		
❖ At MV level	Experiment in progress	☑
❖ At LV level	Experiment carried out	☒
Active power management / generation curtailment		
❖ At MV level		-
HV N-1 constraints (under contingency operating conditions)	Deployed (ADA)	☑
HV N constraints (under normal operating condition)	No	-
MV constraints	Under study	-
❖ At LV level	Concept studied	-

Table 2. Analysis of the regulatory status of some DG/RES integration solutions.

ERDF is involved in a working group with producers to ensure that the value derived from the innovative options can be fairly shared among all the stakeholders: DSO, producers and consumption customers.

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