Evaluation of PV curtailment option to optimize PV integration in Distribution Network

Christophe GAUDIN
ERDF – France
christophe.gaudin@erdfdistribution.fr

Andrea Ballanti
University of Cagliari – Italy
andrea_ballanti@libero.it

Emilie Lejay
ERDF - France
emilie.lejay@erdfdistribution.fr

ABSTRACT

Due to present regulatory framework, connection studies and scheme for generators (PV, Wind...) are designed to guaranty that all capacity can be injected in the feeder any time of the year in normal operation.
Any injection above the connection capacity of the contract is forbidden. This can result in grid adaptations (reinforcements or heavier structural modifications) triggered by short duration constraints.
It is thus rational to look for alternative solutions with better costs. Among those active curtailments (reduction of active power injection during short periods) appears to have interesting features and possible drawbacks: we develop this idea further in this paper for MV PV generation.

INTRODUCTION / CONTEXT

Today 2.3 GW of PV have been installed in France and our main scenario is an expected 8GW target in 2020.

Type of PV	N° per year ; avg unit power	PV scenario in 2020
Residential 3kVA	935 000 3 kW	2,8 GW
Medium size 36 – 250kVA	19 000 ; 50 kW 11 000 ; 180 kW	2.9 GW
>250kVA up to large floor 10MW installations	600 ; 1 MW 360 ; 4 MW 20 ; 12 MW	2,3 GW

This leads today to significant saturation and constraints/reinforcement of MV rural feeders due to medium LV PV accumulation and 1-4 MW MV PV plants

PV integration is a strong issue for ERDF :
In a precedent Cired 2011 (paper 0879), we have already shown that PV generation will have a major impact on existing grids, especially, in rural areas

1. With PV integration costs levels :
   - 300-500M€/GW for small/medium LV PV and several MW PV installations
   - 100M€/GW for large PV installation of 10MW as for wind power plants
2. Reactive power compensation/regulation benefit was a 20% - 40% PV capacity increase (underground cable or overhead line)

The purpose of the paper is now to introduce and assess a new solution to further optimize PV integration in Distribution Network: PV active curtailment above classic connection capacity depending on voltage and load condition.

PART I : CURTAILEMENT PRINCIPLE, ILLUSTRATION ON RURAL FEEDER

Today PV integration capacity is defined to guaranty injection power anytime time in normal operation taking into account voltage management rules in the Distribution network.

This is illustrated, for one feeder, on the following graph:

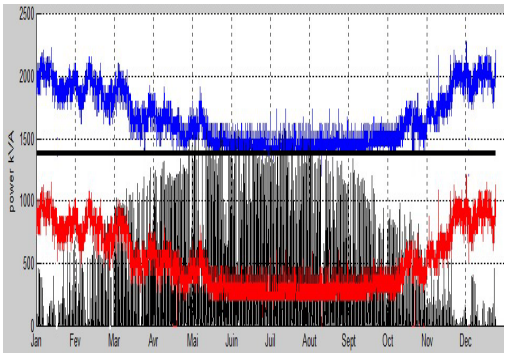

Figure 1: PV power at power capacity (black); load (red) ; PV feeder capacity (black line); PV feeder dynamic capacity (blue)

Depending on the MV feeder load level, when the load is above annual minimum load, it is possible to allow the PV system to inject more than the today 100% guaranty connection limit defined by minimum load (in normal operation)

The principle proposed is a PV power active curtailment taking into account the dynamic injection capacity of the feeder due to the current load level (blue curve).

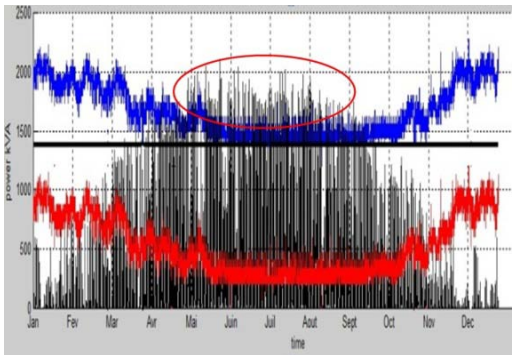

Figure 2: PV power at 130% of power capacity (black); load (red); PV feeder capacity (black line); PV feeder dynamic capacity (blue)

For a PV plant larger (130%) than its connection capacity:

- With the Active curtailment proposed only the production (in red circle) above dynamic connection capacity (blue curve), is lost/non produced to avoid network constraints
- Basic curtailment PV above 100% time connection capacity (black line) is also already possible for the producer: all production above black line level is then lost

It is interesting to note the typical seasonality of the charge curve in France: the curtailment appears only in the summer periods.

The following figure shows the energy not produced (orange) and the PV profile (dashed red line) with the active power curtailment in the worst summer days.

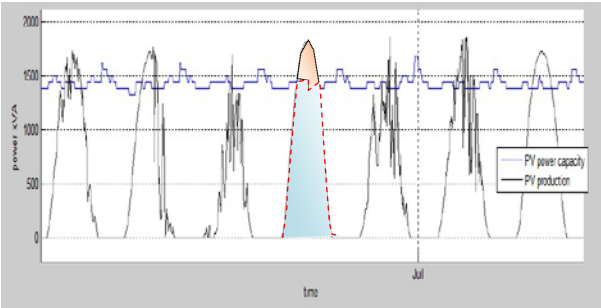

Figure 3: Zoom of figure 2 in a week of May

As we can see the reduction is limited even though the PV production is 1.3 times the power capacity in this example.

Curtailment level effect on PV capacity increase

We can then estimate the PV curtailment level (energy not produced) for different PV increase penetration level above normal connection capacity as shown the following figure:

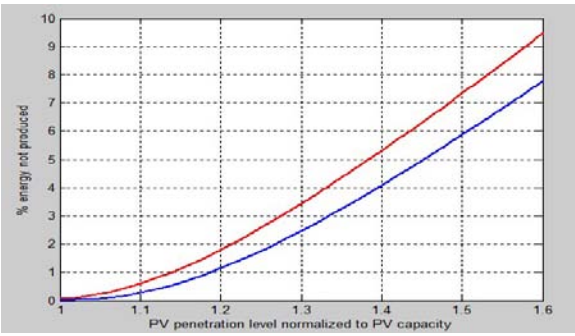

Figure 4: PV Energy not produced for each PV level penetration (red: basic curtailment; blue: active curtailment)

We can note in this case that active curtailment

- allows a significant PV capacity increase (+45%)
- with a small /energy lost (5%)

It should be also noted that due to the shape of annual PV production curve (figure 2) versus load curve, the basic curtailment of PV to its connection capacity (black line) results also in a relatively small losses of production energy and can allow installing bigger PV than the connection capacity.

So Active curtailment is more efficient by offering 'network flexibility' than a basic curtailment to the standard connection capacity, by adding about 30% of possible increase capacity versus basic limitation to connection capacity. This means also that for the same capacity increase, active curtailment needs one third production energy lost versus basic limitation.

Curtailment Effect on Network losses

The increase capacity for PV injection due to curtailment (above connection capacity) has one drawback. Since feeder reinforcement is not done/avoided, the production increase leads then also to feeder network losses increase as shown hereunder:

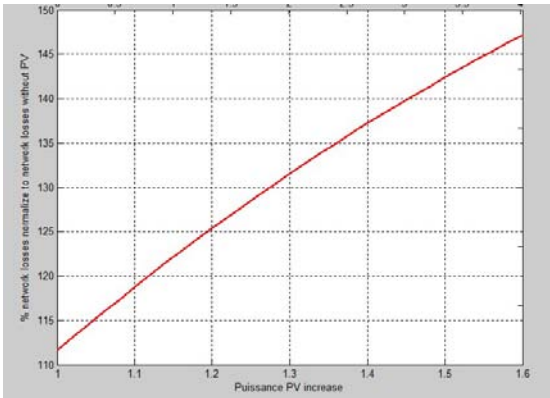

Figure 5: Network losses with active curtailment (red) for different PV levels above connection capacity

Figure 5 shows that PV integration

- at the connection capacity limit increases network losses in the feeder (+12% compared to losses without PV)
- above connection capacity limit the curtailment increases further more the network losses.

Active curtailment allows an increased network capacity to integrate more PV, but creates a trade-off situation between:

- **Savings on network adaptation /reinforcement costs**
- **Costs of PV production lost** and distribution network **technical losses increase**

NATIONAL CURTAILMENT EFFECT BASED ON A STATISTICAL APPROACH

First of all it is important to remind that the first level of PV network integration optimization is clearly to install PV close to load, in areas /feeders with sufficient load, and that any other technical tool is only a second best solution.

The main drivers for such an approach is:

- Minimum existing Load level
- load density and 'strength' of feeders at connection point (ΔU/MW) (short large section with dense consumption feeders are preferable to long thin with low density consumption feeders)
- These are 2 key parameters in the PV connection capacity as illustrated in the figure 5

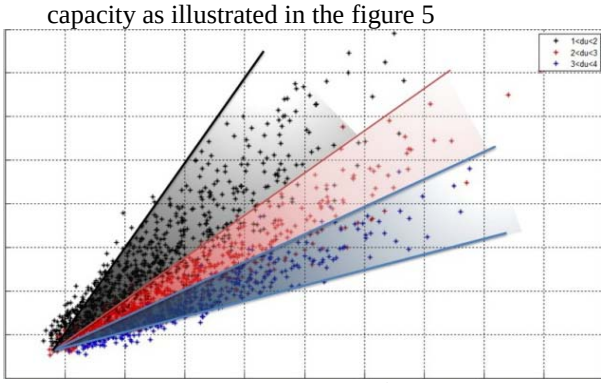

Figure 5: PV capacity (y axis) depending of minimum load (x axis) for different feeders strength (blue, red, black)

Active curtailment could allow a further optimization by extending PV network integration capacity.

National results of active curtailment on PV capacity increase

We have applied the methodology presented in part I on large set of more than 3000 rural feeders (one third of all rural feeders) who are the most sensitive ones for MV PV development to deliver a representative/global estimation of PV active curtailment effect in French rural network.

The global effect/gains of curtailment on Feeders capacity is given in the following figure:

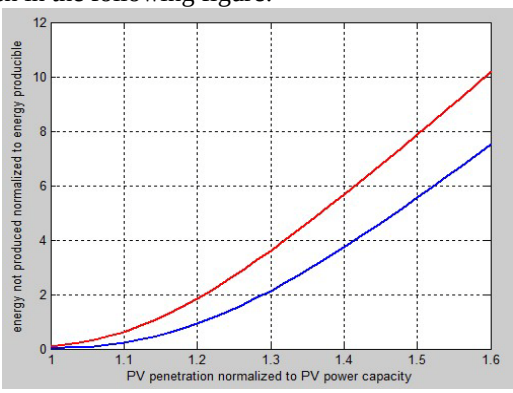

Figure 6: Energy PV not produced for each PV level penetration with basic curtailment (red) and with active curtailment (blue)

These curves are average values of a greater variety of situations but the slow initial increase is always present for all feeders. In fact with active curtailment, a third key factor appears: time correlation of load and production

National results of active curtailment on technical network losses increase

The follow figure shows the average network losses:

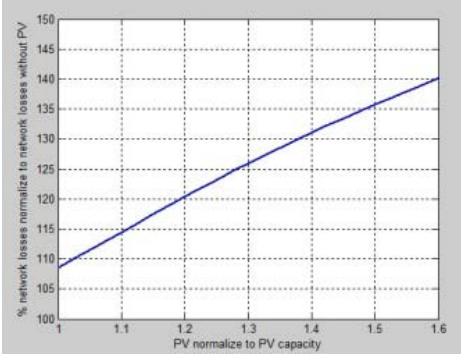

Figure 7: Network losses with active curtailment national average normalized to feeder PV capacity

This is again an average figure and different speed of losses increase happens on the feeders.

The following figure can help to understand when the energy is curtailed and the volume repartition of energy losses: mostly in the summer and in the afternoon

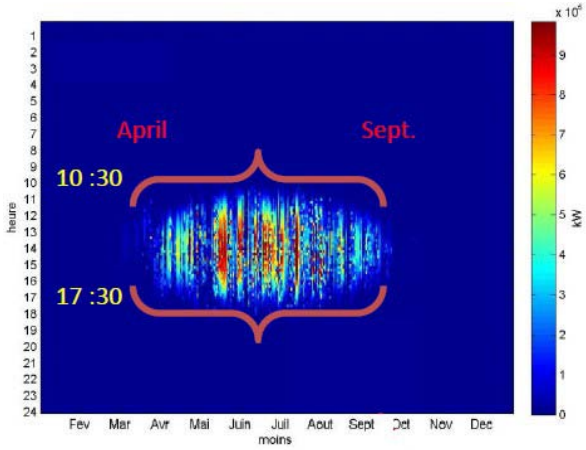

Figure 7: Colour map about PV energy not produced with a PV penetration level of 1.5 times the power capacity

For the network losses which are globally increasing, we can observe in the following figure:

- load network losses in winter and some reduction on winter midday due to PV
- additional PV network losses summer afternoons.

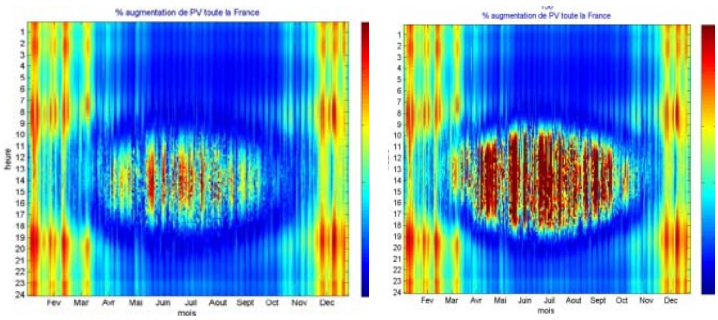

Figure 8: network losses (y axis : hour, x axis : month/day)

- left side : with PV at connection power capacity
- right side : with PV at 1.5 connection power capacity

PART III : Comparison/analysis on networks cost savings for PV integration :

In first step, we have estimated PV integration cost on MV network: the same methodology presented in Cired 2011 ERDF paper 0879 was used for our today 8 GW PV scenario in 2020: statistical distribution of PV on feeders, constraints and cost calculation.
Again costs of MV reinforcement and associated losses were significant.

In a second step, active curtailment was considered. For each rural feeder, we have calculated the optimal solution in NPV approach, between curtailment and reinforcement (losses are included in each case).

For 80% feeders, active curtailment remains the optimal solution vs. reinforcement till PV capacity extension reaches around 130-160% of present PV connection capacity. This for an average 5% curtailment/ PV production losses (with a 70€/MWh value)

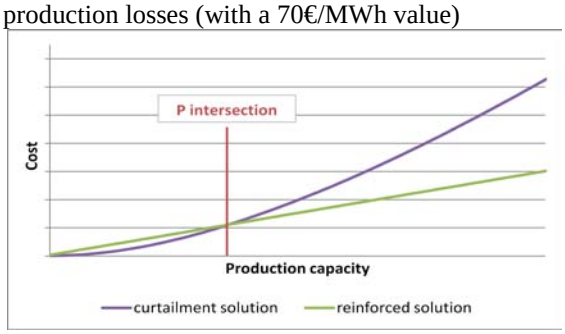

Figure 9 : curtailment vs reinforcement costs

For rural feeders, active curtailment solution was estimated to allow about 30% of PV network integration savings in comparison to an exclusive reinforcement strategy (taking into account cost of production and additional network losses).

CONCLUSION

PV network integration is a more than ever important issue for DSOs. In France alone the present regulation of PV incentives should lead by 2020 to 8GW scenario (above 5GW initial governmental plan) with possibly billions € network costs expected.

Therefore any opportunity for integration Optimization is strongly needed.
The first PV network integration optimization driver is simply to install PV where there is sufficient existing load. It remains difficult however, because incentives are not taking this parameter into account and billing rule for networks only reflects partially the costs of a remote implantation. Voltage management tools are being studied.

Active curtailment could then provide an additional efficient PV network integration optimization mean (further step after the reactive regulations): it can reduce by 30% PV total integration cost including network losses increase for around 5% production energy losses.

However it raises two interesting questions:

- How does it rate against other solution such as reactive power regulation (being it local or centralized)?
- How can we make it possible within existing regulatory framework that is focused on unconditional connection schemes?

At first glance it seems that local or central regulation of reactive power comes first among the possible strategies. Active curtailment would then be activated when reactive compensation is no longer sufficient to avoid upper voltage constraints. However this intuition needs to be further analyzed.

Second Production connection contracts strategy will have to evolve.
The present regulatory framework although not preventing formally curtailment is more focused on non contingent connection schemes. Thus smarter solutions shall either progress under a contractual agreement raising the issue of costs and benefits sharing between operators, and/or through an adaptation of the regulatory framework, shifting from an obligation to minimize costs for generator to an optimization of social costs