VOLTAGE REGULATION ON DG CONNECTED TO MV NETWORK TECHNICAL STUDY AND EXPERIMENTATIONS

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ABSTRACT

The increase in the penetration rate of Distributed Generation (DG) connected to the distribution network has a major impact on the voltage map, and results in voltage constraints that limit its integration or lead to grid investments. According to the French legislation, DG reactive power capabilities can be used to ensure that the allowed voltage range on the feeder is not exceeded.

Thus, ERDF is currently studying a local voltage regulation system based on reactive power management. Both the technical experimentation and the theoretical studies led by ERDF on this subject confirm a positive view on the local voltage regulation and have helped to build a merit order of reactive regulation laws taking into account hosting capacity and network losses. A specific electrical study method is also developed in this paper.

Eventually, the use of local voltage regulation is a cost effective alternative to network reinforcement, above all in the case of rural networks with low consumption.

CONTEXT

Due to current energy related framework, financially and technically, the penetration of Distributed Generation (DG) in distribution networks increases continuously. The chart hereafter shows the development of DG connected to ERDF's network (about 95% of the French distribution network): the installed DG capacity has grown by nearly 300% within 12 years. Mainly PV and wind farms: from nearly 5 GW in 2001 to more than 15 GW at the end of 2013.

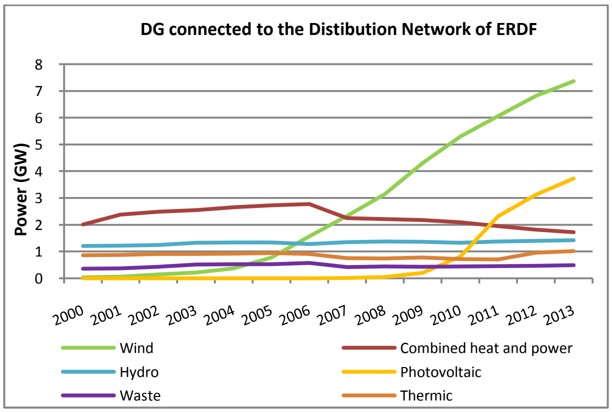

Figure 1: Evolution of DG installed capacity connected to ERDF's network since 2000

The massive development of DG connected to distribution network has enforced the French Distribution System Operator (DSO) to face new technical challenges, especially concerning voltage constraints management on the medium voltage network.

Since 2008, in order to make the best use of the DG reactive power capabilities, the French legislation allows the DSO to use it: a generator must be able to vary the ratio between its reactive and active power (called *TanPhi*) within some pre-determined limits. Currently the reactive power demand from DG is constant and doesn't take into account the real network conditions. Thus, ERDF is currently studying a local dynamic voltage regulation system based on reactive power management ([1] and [2]).

INTRODUCTION

Approved by a working group launched in 2010 between ERDF, DG producers and manufacturers, a regulation process developed by ERDF was adapted to the French Distribution Grid Code. The concept is explained in the chart below: it consists in a target value for the reactive power that is determined by a reactive power/voltage characteristic Q=f(U).

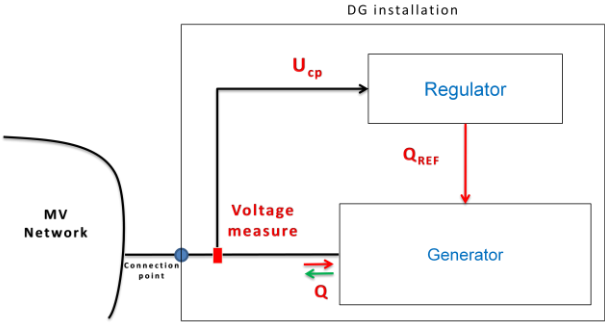

Figure 2: regulation concept
Q_{ref} – reactive power reference; U_{CP} – connection point voltage;

In order to solicit the production facility in injection / absorption of reactive power only in certain situations (those where the network is constrained by low or high voltage), the Q=f(U) characteristic includes a "dead band" (DB) (ie. Q=0) when the voltage measured at the connection point is between a certain range [$U_{DB\ MIN}$; $U_{DB\ MAX}$] (as showed in Figure 3 below).

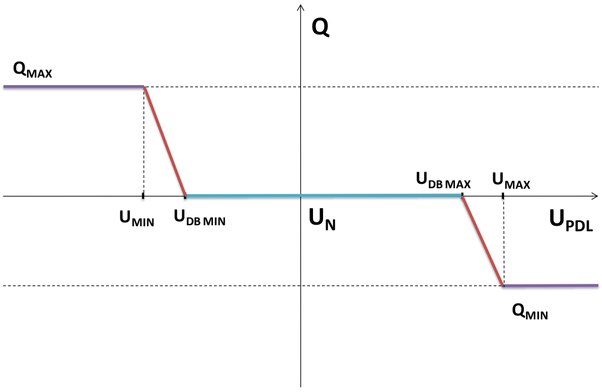

Figure 3: Q = f(U) characteristic (called *QFU*)

Thanks to electrical simulations, field experimentations and a full technical-economical analysis, the parameters of this characteristic have been adjusted in order to achieve an optimum solution for the DSO and the production facility.

TECHNICAL AND ECONOMICAL ANALYSIS

When connecting a single generator, CAPEX are decisive: a reactive power control that avoids a voltage constraint on the network is systematically preferred. When several regulation reactive power controls are in balance, OPEX (impact on technical losses) must be taken into account, but also the potential impact on future CAPEX (reinforcements needed because of a voltage constraint induced by one or more generators connected to the same feeder in the future).

ERDF carried out a technical and economical analysis in order to establish an optimal global decision graph for the choice of reactive power control laws taking into account CAPEX and OPEX.

Four laws were tested: three with a fixed level of reactive power demand (no reactive power demand: “*TP null*”, optimized *TanPhi*: “*TP Opt*” or *TanPhi* forced to the minimum value: “*TP Min*”) and a reactive power control based on voltage with dead band (Q=f(U) or “*QFU*”). These laws were tested for diverse configurations with one to three 1MW-generators randomly connected on existing networks. The results in terms of hosting capacity and losses are reported in Figure 4.

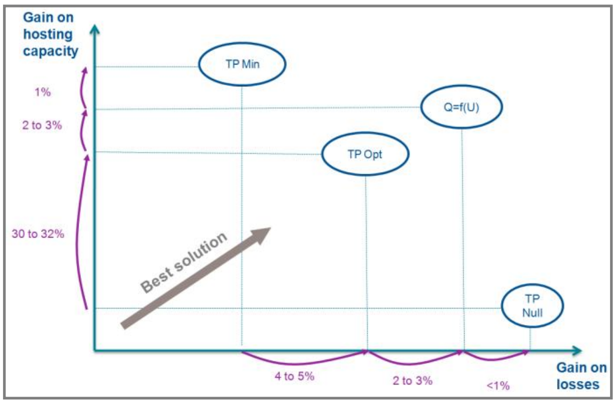

Figure 4: Merit order of reactive regulation laws regarding hosting capacity and technical losses

As shown on the graph above, the regulation laws *TP Min* and *TP null* are not acceptable for ERDF. The first one induces a permanent and strong reactive power flow which generates too many network losses. The second one is clearly not satisfying concerning hosting capacity.

As regards hosting capacity, the results may be generalized as follows (see Figure 5):

- For a single generator, all the laws are equivalent regarding hosting capacity.

- All the more generators (2, 3 ...) connected to the same feeder, all the more the gain provided in terms of hosting capacity (i.e. avoided reinforcements) decreases. **However, this gain remains more important for *QFU*** (*TP Min* being considered as the hosting capacity reference).

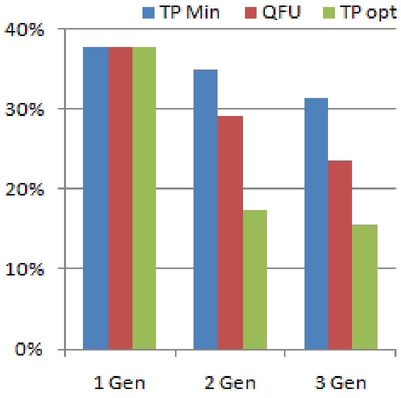

Figure 5: Rate of avoided reinforcements regarding number of DG connected (1MW each)

Concerning network losses, *QFU* induces generally less network losses than *TP Opt* because the regulation is activated only to solve a constraint while *TP Opt* generates a permanent reactive power flow. To conclude, reactive regulation brings a global gain of about 30%; a second-order factor is the average number of generators per feeder.

Ultimately, the relevant strategy for ERDF appears to be a combination of Q=f(U) and Optimized

***TanPhi*.** This allows the best technical and economical assessment for a single generator, and the reactive power solicitation self-adapts when new generators are connected to the same feeder. **This strategy leads to an extra gain of 1 to 5% compared to Optimized *TanPhi*.**

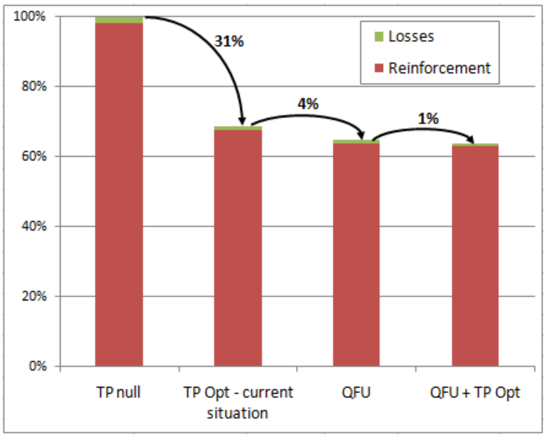

Figure 6: Full economic comparison
PV farm: mean 0.35MVA per feeder

FIELD EXPERIMENTATIONS

The first tests have been performed on a 20 kV distribution rural grid, as described in [3]:

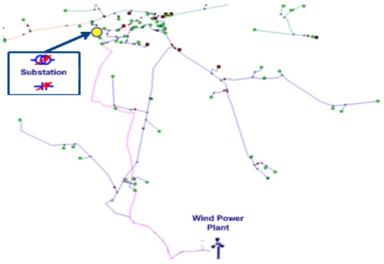

Figure 7: Wind farm connected to the rural MV grid.

The Power Plant consists of 3 wind turbines connected at the end of the feeder reported in Figure 7 that takes up the maximum admissible capacity at the point of connection. The grid is submitted to high voltage constraints during the periods of minimum load and maximum production.

One month period of measurements with constant *TanPhi*=0 and *TanPhi* at minimum value were performed at the beginning and two periods with different kind of voltage regulators (*QFU* laws with and without dead-band). Obviously, according to the existing requirements, the voltage level is not maintained within the acceptable limits with *TanPhi*=0 whereas a dynamic voltage management allows to avoid voltage constraints at the DG connection point.

Other tests with different parameters of the regulators (dead band width) have also been performed to ascertain the most appropriate strategy for the regulation.

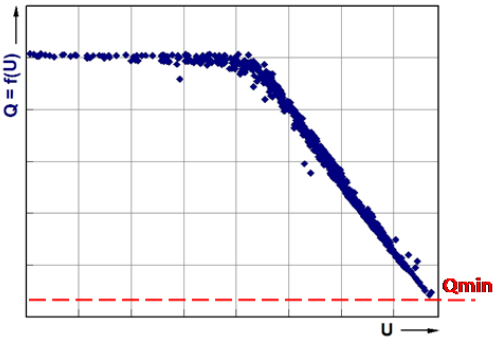

Figure 8: Q=f(U) law measured with 10 minutes averaged points

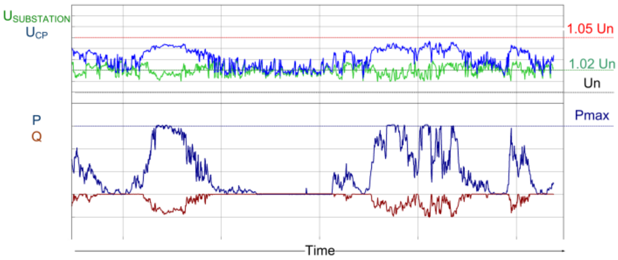

Figure 9: 2nd phase of experimentation: "dead band"
$U_{SUBSTATION}$: Substation voltage, U_{CP}: connection point voltage
P, Q: active and reactive power of the wind power plant

The "dead band" regulation (shown in Figure 8) enables the DG plant to adapt its reactive power demand only when high voltage constraints occur at the point of connection and therefore to optimize local voltage management together with the DG reactive power demand. As shown in Figure 9, low production doesn't increase the voltage over the dead band limit of the regulator and thus the local voltage regulation is not activated.

Another onsite experimentation is in progress with two rather big PV farms that are connected to the same MV feeder in a rural grid of the South of France (Figure 10). These farms together contribute to a substantial rise of the voltage locally. This configuration is very interesting for different reasons.

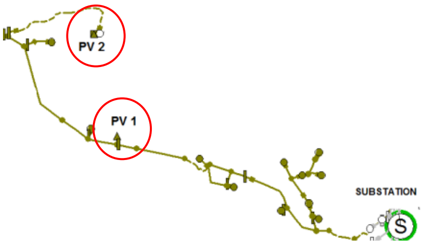

Figure 10: PV Farms connected to the same MV feeder

One of the ideas is to study the possible dynamic interactions between two Q=f(U) regulations that regulate the voltage on nearby connection points.

At the same time, it is very interesting to analyze the case where one of the two generation plants is already connected with a constant *TanPhi* (*TP Opt*) whereas the second producer could implement a Q=f(U) regulation scheme. It is therefore important to assess the impact of a similar case on the connection study.

To analyze all these phenomenon, different combinations of regulation modes are being tested on field.

SPECIFIC CONNECTION STUDIES

To permit the future implementation of the local voltage regulation, connection studies are being revised. The goal is to determine in which cases the two regulation modes (dynamic regulation and constant *TanPhi*) are compatible or not and to define applicability cases for the local voltage regulation.

Thanks to the results of the technical and economical analysis and the different field experimentations, a new flow chart for the connection studies is being considered:

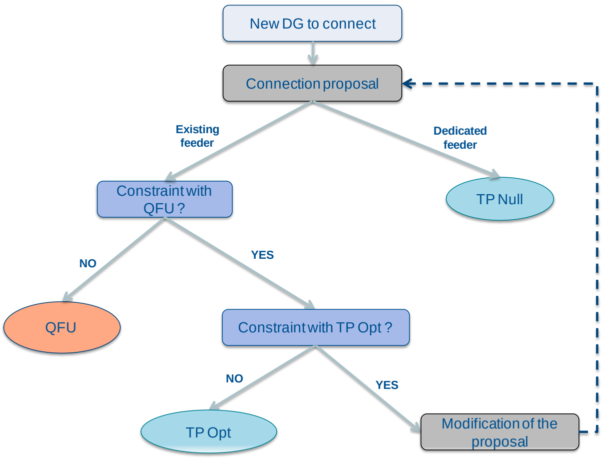

Figure 11: Decision chart for reactive power regulation in connection studies

On dedicated feeders, DG facilities are already connected with a *TanPhi* null. On existing feeders with consumers, the proposed method favors *QFU* solution over Optimized *TanPhi*.

However an Optimized *TanPhi* can sometimes solve a constraint where a local regulation is useless if the voltage rise at the producer is not enough to trigger the absorption of reactive power (the producer is still in its dead band but the voltage keeps rising further, as showed in the example below): Generator 1 connected at the end of a feeder is under voltage constraint, whereas Generator 2 connected at the middle of the same feeder operates in the dead band (see Figure 12).

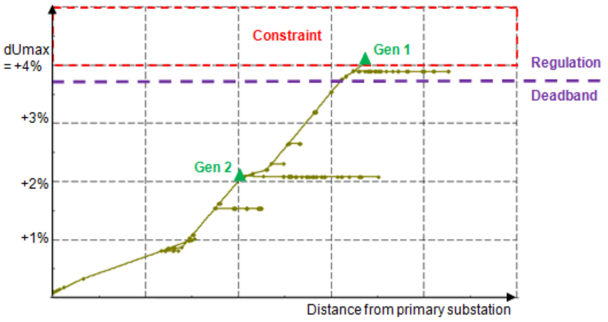

Figure 12: Situation of inappropriate QFU regulation for Generator 2

Besides, local regulation induces more complex studies. Current production connection studies consider only one scenario: maximum production and minimum consumption (about 20% of the maximum consumption). This method is adapted for fixed *TanPhi* solutions. But *QFU* law can induce constraints in other situation that have to be considered. For example voltage constraints can happen when the DG facility is just at the end of its dead band and vanish when it starts consuming reactive power.

The new studies currently developed at ERDF on the software Power Factory® [4] will take into account these new situations.

CONCLUSION

Both the technical experimentations and the theoretical studies confirm a positive view on the local voltage regulation.

The first results from the field experimentations confirm that using local voltage regulation at the MV DG facility's connection point allows the preservation of the network's voltage within the acceptable limits as well as the optimization of the DG reactive power demand. The DG facility can regulate the voltage locally (mainly absorbing reactive power), only when needed, without substituting itself to the DSO. Its contribution to voltage regulation is proportional to the constraint this producer and the others eventually connected to the same feeder, may give rise to.

In order to implement this new regulation system wisely, a specific connection study and an associated calculation module are currently under development at ERDF on the software Power Factory® [4]. They take into account the dynamic aspect of the Q=f(U) characteristic in order to test the different network situations that could cause a voltage constraint along the considered feeder.

Eventually, the use of local voltage regulation is a cost effective alternative to network reinforcement, above all in the case of rural networks. Moreover, as explained in [5], the use of a deadband zone into the Q=f(U) characteristic tends to make the risk of islanding stabilization phenomenon decrease.

Local voltage regulation is one process to implement before centralized voltage management which consists in state estimators calculating optimized voltage target values at the primary substation. The implementation of local voltage regulation in French Grid Code will be a first step towards a more global DG integration strategy.

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