LOCAL VOLTAGE REGULATION INFLUENCE ON DG AND DISTRIBUTION NETWORK

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INTRODUCTION

Distribution grids were initially not designed to house significant amount of distributed generation (DG). However, DSO experienced during the last few years a huge increase in penetration rate of renewables. Since DG has a major impact on the voltage level, its connection can result in voltage constraints that limit its integration or lead to grid investments. In such situations, using voltage control may relieve some constraints with no or limited investments. Higher penetration rate of DG will make generation facilities' contribution to voltage control a necessity in a near future, in addition to existing control devices (on-load tap changers ...).

DG development in France

Due to current energy related framework conditions and technical developments the penetration of distributed energy resources and especially DG in distribution networks increases continuously and it can be expected that this increase will continue in the future.

The chart hereafter shows the development of DG connected to ERDF's network (about 95% of the French distribution network): the installed capacity has grown by 250% within 10 years, mainly PV and wind farms: from nearly 5 GW in 2001 to more than 12.8 GW at the end of 2011.

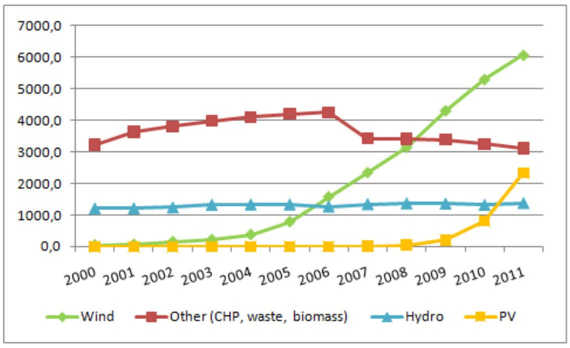

Figure 1: Evolution of DG installed capacity connected to ERDF's network since 2000

The integration of DG is therefore a major issue, leading ERDF to consider alternatives for local voltage regulation.

DG Connection rules

According to the French distribution grid code, the DG connection solution shall be determined with respect to voltage, thermal, short circuit and equipment rating constraints, without disturbing the power quality or the quality of supply of the electrical network. These studies shall be carried out at the DG maximal power, i.e. based on the worst case scenario, in particular, as regard to network planning studies. It shall be ensured that the permissible voltage variation range is not exceeded at these conditions, combined with a minimum load on the feeder.

If not, DG reactive power capabilities can be used and as a result, DG would be required to operate with a negative constant power factor in summer season to mitigate the maximal voltage constraints. Currently the reactive power demand from DG is constant and doesn't take into consideration the real network conditions.

Towards a local voltage regulation

ERDF investigates DG supplying or absorbing reactive power following a local active regulation law to be defined by the DNO as this has been enabled by the French distribution grid code (order of the 23rd of April 2008) and pricing policy.

As mentioned in [2], a working group has been launched in July 2010 between ERDF, DG producers and manufacturers to set the dynamic law and its mode of enforcement into ERDF technical guidelines.

TECHNICAL APPROACH

Local voltage regulation strategies

Based on a benchmark, several courses of action have been considered regarding local voltage regulation strategies.

Business as usual

This solution consists in requiring a constant power factor only if a voltage constraint can be removed by drawing reactive power from the DG.

Improving the current voltage regulation

The current regulation can be improved by introducing a regulation law consisting in a target value set by a reactive power/voltage characteristics Q(P): the reactive power demand depends on the active power generated by the plant, which has a major impact on the voltage rise on the MV feeder. Two Q(P) characteristics have been looked at: constant regulation and "dead band" approach, as shown in Figure 2.

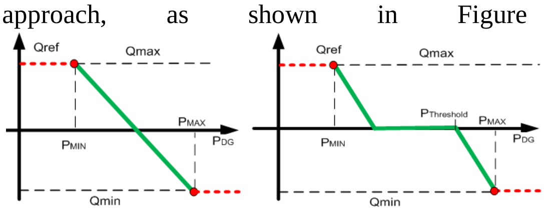

Figure 2: Q(P) characteristics: constant regulation (left) or dead band (right) where P_{DG} is the active power supplied by the DG at the connection point.

The first one is very close to the existing regulation and therefore presents little benefits. The second one would enable reducing significantly the reactive power demand and losses. However, even if the voltage at the point of connection stay within acceptable limits at the maximum active power, it might exceed the contractual limits in some configurations, depending on the R/X ratio (R and X being the network line impedance), when the voltage rise at $P_{Threshold}$ is greater than the one at Pmax, i.e. when:

$$\frac{Pmax - Pthreshold}{Pmax} < \frac{X}{R} \tan \varphi min$$

Consequently, these strategies have been rolled out.

Implementing a new voltage regulation

The last option consists in a target value set by a reactive power/voltage characteristic Q(U) (see Figure 3). The main advantage of this regulation is to enable to take into consideration the real network conditions as the reactive power demand from the DG depends on actual voltage constraints, leading us to focus on this strategy.

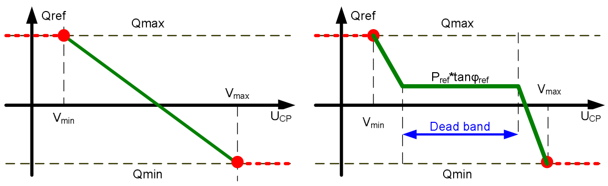

Figure 3: Reactive power management strategies: voltage droop (left) or dead band (right). where: Q_{ref} – reactive power reference; U_{DP} – connection point voltage; Q_{max} and Q_{min} – reactive power limits defined in the Franch distribution code; V_{max} and V_{min} – voltage limits at the connection point; P_{ref} - active power reference; $Tan\varphi_{ref}$ - constant power factor reference

Objectives of the simulations

Once the voltage regulation strategies have been selected, several dynamic simulations are performed in order to assess the potential benefits and drawbacks, and to measure the impact of the local voltage regulation:

- on HV/MV substation equipments,
- on the studied DG, in terms of reactive power demand,
- on other DG connected to the MV distribution network.

The simulations are detailed in the following sections.

SIMULATION HYPOTHESES

Description of the voltage regulation feature

The regulation developed by EDF and ERDF, and presented in [1] was adapted to the French distributed grid code rules. It is based on reactive power management and maintains voltage at grid connection point within admissible limits. Two U/Q characteristics have been employed, as reported in Figure 3.

Considered distribution grid for study

The study is based on dynamic simulations of a realistic 20 kV distribution network, which have been performed with the Eurostag software. The test case is a rural grid submitted to voltage constraints when connecting DG on existing feeders.

The DG was integrated into the chosen feeder reported in Figure 4 so as to reach the maximum admissible capacity at the connection points. In order to consider realistic cases, DG was implemented so as not to create thermal constraints (no grid upgrade is required).

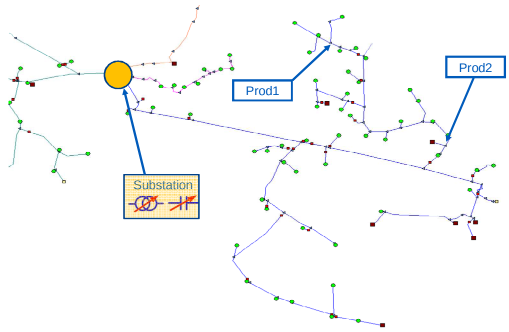

Figure 4: Chosen feeder.

Two locations are considered for grid connection of DG, figuring different possible configurations:

Table 1: DG configurations.

	Prod1	Prod2
Distance from Substation	12.35 km (6.79 Ω)	8.00 km (3.79 Ω)
Configuration 1	3MW with tgφ = - 0.25	Off
Configuration 2	1.8MW with tgφ = 0	1.1MW with tgφ = -0.25

Dynamic behavior of grid devices, like on-load tap changers and substation capacitor banks, is included.

Dynamic scenarios

First, the dynamic simulations of a 10 hours period performed with significant load or production variations are going to be presented. Wind and solar power plants real production variations are considered. The studied cases reflect examples of high voltage constraints that occur while connecting the production in sensitive zones, as at the end of the rural feeders.

Furthermore the regulator behavior during the period of "normal" voltage constraints and its ability to decrease the reactive power demand is to be analyzed. This reflection leads to study a scenario which takes into account 72 hours period with real load and production variations and three different day profiles: day D1 - minimum load and maximum available production, day D2 - maximum load and maximum available production and finally day D3 with maximum load and reduced production level as reported in the Figure 5:

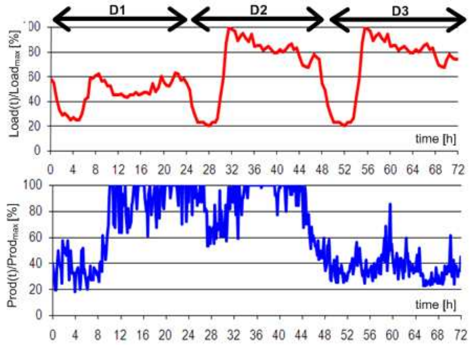

Figure 5: Load and wind production profile.

IMPACT OF LOCAL VOLTAGE REGULATION ON DG AND THE DISTRIBUTION NETWORK

First simulations were completed with respect to the existing French grid code requirements: no voltage regulation and a constant power factor. Then the voltage regulation was then implemented on simulated DG in order to assess the impact on DG and network.

Voltage regulation

Using new local voltage regulation at the MV producer's level allows the preservation of the voltage level in the network within the acceptable limits with both U/Q characteristics employed. Obviously, it is also a case with presently required constant power factor. As a matter of fact, local voltage regulation brings in an active contribution of the producer according to the real time voltage constraints. Besides many generators with voltage regulation can be connected to the same feeder and act together to maintain voltage within admissible limits without disturbing their reactive power request. In this case, the participation rate of each producer depends on voltage constraints at its connecting point.

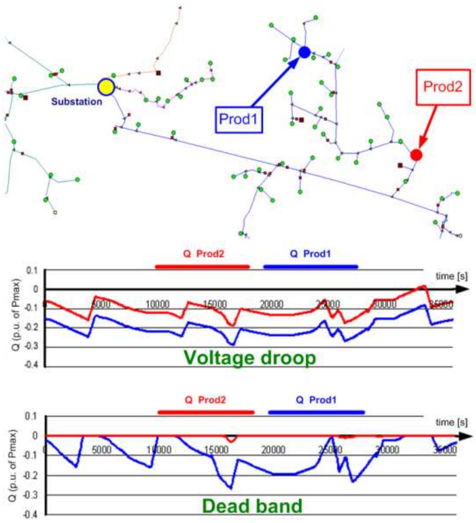

Figure 6: Reactive power requested from two producers connected to the same feeder.

The simulations have also shown that, while the DG connected further from the substation (Prod1 in Figure 6) is not equipped with local regulation, the reactive power absorbed by another DG plant connected in the middle of the feeder (Prod2 in Figure 6) might not be sufficient to preserve the voltage within the acceptable limits all along the feeder. Therefore an adaptation of the regulation in Prod2's plant is necessary to give enough margins to ensure that the voltage rise which could occur downstream from the connection point stays within acceptable limits. Otherwise the connection of Prod2,'s plant with constant power factor (as made at present but with an optimized value) could resolve this situation.

Impact on grid assets

The impact resulting from reactive power modulation on existing grid components was studied in every configuration described in Table 1.

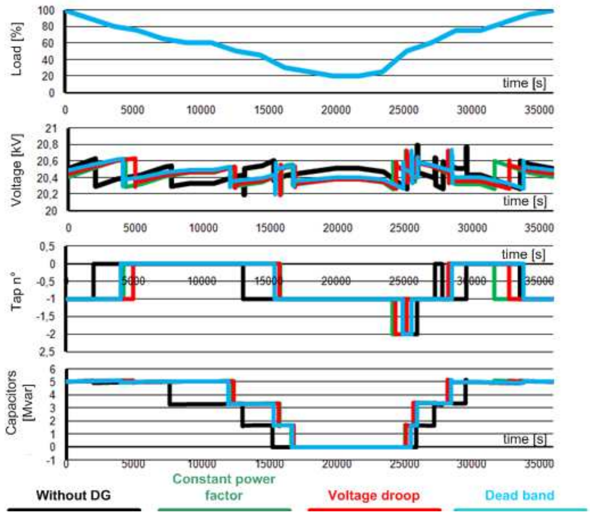

Figure 7: Impact on grid assets (example of substation behavior while one producer connected)

Local voltage regulation may indeed affect devices like on-load tap changers and capacitor banks at HV/MV substations: there's no additional stress but their operation will be time-shifted. It is important to note that the producer which regulates the voltage near the point of connection can't replace the DSO for voltage control in the network. Substation equipment behaves in order to answer to the voltage constraints in presence or not of the local regulation at the producer connecting point. As a matter of fact, local voltage regulation brings in an active contribution of every participant to the voltage management and reveals voltage constraints in the neighborhood of equipped producer.

Impact on reactive power demand

The mean values of reactive power demand from the producer according to the simulated day have been calculated and are reported in Figure 8:

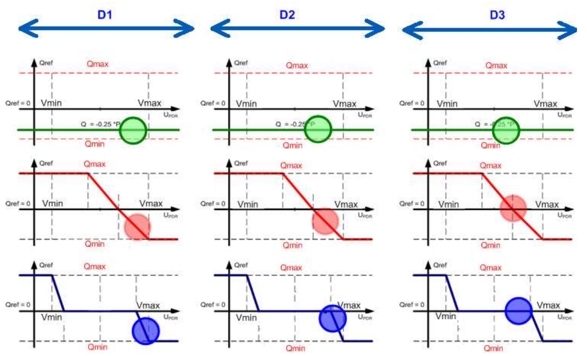

Figure 8: Impact of reactive power demand

The strategy with "dead band" enables a significant decrease of reactive power demand in comparison with a classical approach (tgφ = - 0.25 in summer season). This is mainly due to the occasional voltage constraints that occur while minimum load coincides with maximum available generation. Probability of high voltage at connecting point can be associated with the probability of high production. An illustration of the reactive power demand optimization is given below, based on the distribution of the active power generated by wind and PV farms during one year.

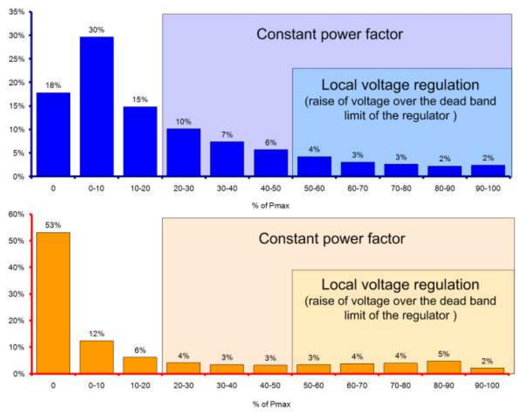

Figure 9: Distribution of available production of the real wind (East France region – top chart) and PV (South France region – bottom chart) power plants.

We consider that the generator equipped with constant power factor works when the production exceeds 20% P_{MAX}. That gives 38% of the year for the studied wind farm and 28% for the PV one. On the other hand reactive power demand of the generator equipped with "dead band" regulation will be requested when the production is between 50 % and 100 % of P_{MAX}. Thus the "dead band" regulation would only demand an active contribution of the producer during 15 % (wind) or 18 % (solar) of the year.

However, while the reactive power demand is very similar for the cases of the "constant power factor" and "voltage droop" an effective decrease of reactive power demand without dead band is not possible because of the continuous reactive power demand.

Above estimation is given as an example. As a matter of fact, taking into account load impact would fairly decrease obtained result.

CONCLUSION AND PERSPECTIVES

This comprehensive study has shown that the Q(U) characteristic with "dead band" has the greater advantage among the considered local voltage regulations, as it enables the DG plant to adapt its reactive power demand in function of actual voltage constraints at the point of connection and therefore to optimize local voltage management together with the DG reactive power demand. Moreover, this regulation is resilient as regard to the network structure and possible evolutions, and the seasonality of the actual approach.

Besides, no negative impacts have been identified, in terms of primary substation equipment operation or instability between the local voltage regulation of a plant and the one of another plant connected to same feeder.

However the implementation of such a regulation requires changing the present connection rules. Whereas the present guidelines require reactive power management only in case of voltage constraints, this local voltage regulation only makes sense when the full reactive power capabilities of DG, as defined in the French distribution code, are installed from the connection of the plant to the distribution network. The fitting of the full reactive power capabilities might have an impact on the cost of the DG plant, but it would also maximize the network capacities.

In order to better assess the benefits and drawbacks of local voltage regulation, **onsite experimentations will be launched in spring 2012**. Two sites are considered: a wind farm in the East of France and a PV farm in the South of France. The objectives are to complete a full technical-economical analysis of the implementation of local voltage regulation, supported by onsite measurements at the primary substation and at the point of connection and by associated dynamic simulations.

Furthermore, local voltage regulation is **one of the possible strategies that could evolve towards centralized voltage management**: research projects have been launched to develop and experiment advanced methods based on network sensors measurements and state estimators to calculate optimized voltage target values set to active network components such as the primary substations. An experimentation will be carried out jointly with centralized and local voltage regulation.

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