DISTRIBUTED GENERATION CONTRIBUTION TO VOLTAGE CONTROL

Pierre BOUSSEAU, EDF R&D – France, pierre.bousseau@edf.fr
Etienne MONNOT, EDF R&D – France, etienne.monnot@edf.fr
Gilles MALARANGE, EDF R&D – France, gilles.malarange@edf.fr
Olivier Gonbeau, EDF ERD – France, olivier.gonbeau@edf.fr

ABSTRACT

Since the beginning of the 90's, many countries have experienced a substantial growth of distributed generation (DG) on their power systems. If currently in most countries, either a constant power factor regulation, or a constant reactive power regulation are specified by the Distribution System Operators (DSO) for a distribution network grid connection, in the future, the use of a more elaborated voltage regulation (for instance based on a voltage set point) is expected.

The choice of an elaborated set point based voltage regulation brings more flexibility by further optimising the network operation whereas there is no voltage constraint. Indeed, the choice and design of a DG voltage regulation should be the result of an optimisation maximizing the benefits to the whole network. It can for instance be performed in order to:

- *facilitate the grid connection of both power production units and consumers installations, and so to reduce the connection costs,*
- *limit active power losses on the network,*
- *limit the cost related to the reactive power exchanges between the distribution and the transmission systems,*
- *improve network stability.*

Indeed, for DG connected to distribution networks, the voltage regulation must at least respect the following requirements:

- *The contractual and regulatory constraints are respected: steady state voltage kept within the admissible values, limited voltage fluctuations, voltage quality maintained, etc.*

There will be no overvoltage leading to damages to grid components or consumers' installations.

The use of a voltage regulation affects different physical phenomena in steady state and in transients such as voltage profile, currents magnitudes, losses, short-circuits, flicker, etc. This paper analyses its impact on different phenomena in order to prepare an evolution of the grid connection study methods needed for the use of an elaborated voltage regulation.

Furthermore the use of a voltage regulation supposes the existence of a compatible regulatory and contractual framework (for instance not to charge the DG for reactive power consumption if it is regulating the voltage). An example of a simplified voltage regulation, with a partial compatibility with the French actual contractual and regulatory framework is presented, along with EDF R&D perspective and future works on more efficient voltage regulations that suppose a contractual and regulatory framework modification (for instance on the network tariff [9]), and a modification of the grid connection studies methods and tools.

INTRODUCTION

The connection of a DG on a distribution network affects the physical phenomena in steady state (currents, voltages), and in transients (flicker, short-circuit currents, etc). So the DSO has to perform a grid connection study for each new connection in order to determine the optimal solution that enables to fulfill the technical, regulatory and contractual constraints towards the network users.

When the grid connection study shows a voltage constraint in steady state (corresponding to an overvoltage for DG connection), different solutions are possible, among them:

- a modification of the point of common coupling (PCC),
- a modification of the voltage regulation for the DG with a decrease of reactive power production or an increase of the reactive power consumption to decrease the voltage,
- a network reinforcement.

Generally, the regulatory framework is adapted in the different countries with grid connection requirements concerning the production and absorption capabilities of reactive power by DG. These capabilities might be used with different control modes. For instance in France, the DSO (voltage level up to 20 kV) may ask for a constant power factor control mode, a constant reactive power control mode or a voltage regulation based on a voltage set point.

Nowadays, a common practice for the DG connection to radial distribution networks is to ask for a constant power factor regulation mode. To cope with voltage constraints, for instance an inductive power factor set point can be defined. If this control mode enables to decrease the voltage, it however does not take into account the actual value of the voltage at the PCC (that depends also on the load, on the on-load HV/MV transformer). Hence this control mode leads sometimes to reactive power consumption (and corresponding losses) whereas the maximum voltage is not reached. Furthermore, in case of a grid event (such as a short-circuit), this regulation does not support the voltage and in case of network reconfiguration, voltage constraints can appear with a power factor set point calculated only for normal operation.

The use of a voltage regulation based on a voltage set point brings more flexibility to the network with a possibility to improve the DG reactive power capability use. This paper focuses on the impact of the use of a voltage regulation on the network behavior and the grid connection studies. The following points are presented:

- DG grid connection requirements, with French case,
- DG static and dynamic capabilities regarding reactive power and voltage control,
- Physical phenomena affected by the choice of the

voltage regulation,
- An example of a first voltage regulation that considers the lack of communication means between the DG and the network,
- EDF R&D research perspectives.

GRID CONNECTION REQUIREMENTS AND NETWORK TARIFF

The French voltage limits are 230V +6%,-10% for the LV customers and contracted voltage level (generally around 20kV) ± 5% for the MV customers.
The grid connection requirements for DG regarding reactive power and voltage control capabilities are different depending on the country considered. They are generally more complex and detailed for a connection to the transmission grid than for a connection to the distribution networks. These requirements can concern:
- maximum reactive power consumed or produced, either independently from the active power production, or for instance with a maximum power factor specified.
- Different operating modes that a DG has to be able to implement.

As an illustration and to show possible limits of a voltage regulation, this section presents the connection requirements to the French distribution grid exploited by EDF [1-2], where most of French DG is connected.

Table 1: distribution grid DG connection requirements

PCC	DG installed power	Connection conditions regarding voltage control and reactive power
LV	P < 250 kVA	No reactive power must be consumed
MV	P ≤ 1 MW	Each generating unit shall be able to produce (at the machine terminals) reactive power up to 40% of its apparent nominal power Sn
	1 MW < P ≤ 10 MW	Each generator must be able to produce (at the machine terminals) at least 50% of Sn and consume at least 10% of Sn. The DG shall be able to adjust the voltage control at the DSO's request.
	10 MW <P ≤ 12 MW	Each generating unit must be able to produce (at the machine terminals) at least 60% of Sn and to consume at least 20% of Sn. The DG shall be equipped with a voltage control system.

A specific rule applies for classical induction generators: their reactive power needs and the possibly required additional reactive power generation are provided by capacitor banks connected either to the producer's installation or to the HV/MV[1] substation. The reactive power produced by the capacitor banks at the DSO's request shall not exceed 0.4 Sn.

The value of the reactive power produced and the control mode (voltage, power factor or reactive power control) are determined by the DSO in accordance with network operation requirements.

A voltage regulation can act within this regulatory reactive power range but can also act within a more extended range if possible with the DG considered and if agreed between the producer and the DSO. Indeed a higher reactive power consumption capability might facilitate the grid connection with the use of a voltage regulation. Note that the whole static and dynamic characteristics of a voltage regulation are not presented in the regulation.

Note that the definition of a voltage regulation, in addition to taking into account the regulatory requirements, should also be coherent with the network tariff (for instance with the rules for the invoicing of the reactive power consumed or not provided). Indeed, a DG should not be invoiced by the DSO for reactive power consumption if it results from the voltage regulation asked by the DSO. Depending on the country considered, the use of an elaborated voltage regulation might require or lead to a modification of the network tariff. It is the case in France for DG connection to distribution networks with a regulatory network tariff that leads to an invoicing process of reactive power based on:
- Constant power factor set points, instead for instance of a reactive power (or a power factor, etc) set point depending on voltage.

In addition, the use of a voltage regulation might have an impact on the contracts between the DSOs and the TSO for the invoicing of the reactive power at the connection point of the distribution to the transmission network.

DG TECHNOLOGIES REGARDING VOLTAGE CONTROL

The different DG generator technologies are: synchronous generators, doubly-fed generators, synchronous or induction generators connected by power electronics and classical induction generators. Only this last type of generator has no inherent reactive power and voltage control capability. Anyway, whatever the type considered, the reactive power and voltage control capabilities can be extended by the use of additional devices such as static var compensators, STATCOMs, etc. This is sometimes required to comply with the grid connection requirements.

The minimum time constants associated to reactive power and voltage control are in the range of:
- 20 ms for the generators with power electronics

[1] In France, HV levels are 400 kV, 225 kV, 150 kV, 90 kV and 63 kV voltage levels. The MV level is mostly 20 kV voltage level and sometimes 15 kV voltage level.

(doubly fed, synchronous and induction generators connected with power electronics),
- 0.5 to 15 seconds for synchronous generators depending on the generator and excitation electrical characteristics [3-5]. This corresponds to a minimum 5% response time between 1.5 and 45 seconds.

The static and dynamic voltage regulation characteristics have to take into account the DG technologies specificities.

PHYSICAL PHENOMENA AFFECTED BY THE CHOICE OF A DG VOLTAGE REGULATION MODE

Different physical phenomena are affected by the choice of the voltage regulation, among them:
- Average voltage (10 minutes): on which the DSO has contractual commitments,
- Average voltages (60seconds and 10 seconds): used for the operating of on-load tap changers at the HV/MV substations. Based on different hypotheses for the French case, it is assumed that a DG reactive power variation limited to 0.4*Sn / % of Un for the voltage regulation prevents in each case from false operating of the on-load tap changer of the HV/MV transformer (i.e. uninterrupted tap changes to minimum or maximum taps).
- Steady state current: the maximum increase of the steady state current delivered by the DG is 15% (considering the French limits of the regulation reactive power capabilities).
- Short-circuit currents (at 250 ms and 1-second equivalent): based on different assumptions, the choice of a time constant higher than 5 seconds prevents from an increase of more than 5% of these short-circuit currents with the use of a voltage regulation.
- MV network losses: the DG reactive power changes the power flows through the network and can lead either to an increase or a decrease of these losses. In a general way, when the voltage regulation decreases the voltage it leads to higher losses. However when there is no voltage constraint, an evolved voltage regulation might enable to decrease the losses by producing reactive power closer to the load.
- Protection plan: if the voltage regulation sustains the voltage during a fault, it can increase the risk of islanding operation (in French MV distribution networks, an islanded situation is considered when during at least 400 ms). A global time constant for the voltage regulation higher than 7 seconds prevents from significantly increasing the risk of islanding.
- Dynamic stability: the voltage regulation has an impact on the generator and on the network stability.
- Power quality (among which flicker): the voltage regulation might have a significant impact on flicker. Up to date, flicker coefficients for a DG unit are mostly measured with a unity power factor. Either new measurements and/or an adapted methodology have to be taken into account to integrate the use of a voltage regulation in the flicker grid connection studies.

The voltage regulation static and dynamic characteristics specifications have to take into account these impacts. And the grid connection studies have to be adapted for the use of a voltage regulation.

EXAMPLE OF A VOLTAGE REGULATION

The following characteristics have been chosen as an example for a first (and simplified) voltage regulation that supposes the lack of communication links between the DG and the distribution network devices:
- A – Global time constant of the voltage regulation, 7 seconds: to limit the impact of the regulation on the short-circuit current and the protection plan.
- B – Maximum reactive power variation: 0.4 Sn / %Un : to prevent from a false operating of the on-load tap changer of the HV/MV transformer.
- C – Static characteristic of the voltage regulation**:** to decrease losses and prevent from too high voltages.

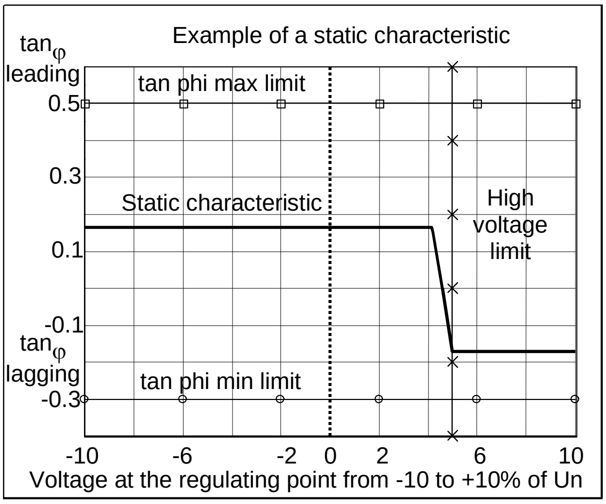

Figure 1: Example of a static characteristic

This simplified voltage regulation (see Figure 1) has been chosen considering the lack of communication means and keeping a characteristic based on a tan φ (=Q/P) versus PCC voltage curve in order to be as close as possible to actual French network tariff. Anyway, even for this simplified voltage regulation, and all the more for an evolved one, a modification of the network tariff might be required.

EDF R&D RESEARCH PERSPECTIVES CONCERNING DG VOLTAGE REGULATION

At the present time, three evolved methods have been studied for voltage control on distribution network, a centralised method that corresponds to the coordinated regulation on French transmission system and two local methods, the auto-adaptive voltage regulation developed by

IDEA and a regulation developed by EDF.

1. The coordinated regulation uses distributed generation to control voltage to its set-point value at the substation and at some other specific nodes called pilot busses. Simulations were carried out on reference networks.
2. The auto-adaptive voltage regulator is a local intelligent regulator that is able to coordinate in real time the control of several DGs, connected to the same HV/MV substation, without communication system. This Automatic Voltage Regulator (AVR) is described in paper [6].
3. EDF developed and studied a method for voltage control at DG connection point. This regulation has two loops. A reactive loop is used to produce or to absorb reactive power. An active loop controls active power to limit the voltage when reactive power limits are reached. Several regulation modes have been devised: two for reactive power regulation and three for active power regulation.

The two local methods have led to patents [7-8]. Experimentations of these methods are envisaged.

The coordinated voltage control, first designed for meshed transmission systems, is not well adapted for radial distribution networks. Moreover, this it requires many investments on DSO's communication system.

In return, local methods are well suited for distribution grids. However, they require coordination with DSO equipments (notably HV/MV transformer on-load tap changer), in particular when distributed generation allocation is not homogeneous on all the feeders. Indeed, in this case, over-voltages could occur on DG feeders when the load is high because the on-load tap changer tries to maintain the voltage on the other feeders with a high voltage set point at the HV/MV substation. This coordination will be greatly enhanced with communication systems between DG and DSO's equipments.

Today, EDF R&D research works consist in characterizing and optimising the different local regulations according to the various physical phenomena influenced by DG voltage control. Then, a method of coordination of local regulations with DSO's automation systems should be developed for radial distribution networks. This method will probably require an evolution of DSO's communication system. Additionally, EDF R&D works on the corresponding evolutions of grid connection studies methods and tools.

CONCLUSION

EDF R&D and EDF ERD (DSO) are working together on the definition of an efficient and evolved voltage regulation for DG. This regulation should be the better solution to increase DG grid connection and it should also enhance distribution grid operation. The implementation of this regulation requires main steps among which, ensuring the good coordination between DG voltage regulation and DSO's equipments, adapting grid connection methods and tools, modifying the contractual and regulatory framework.

REFERENCES

[1] Ministère de l'économie, des finances et de l'industrie, Arrêtés du 17/03 et 22/04/2003 relatifs "aux prescriptions techniques de conception et de fonctionnement pour le raccordement à un réseau public de distribution d'une installation de production d'énergie électrique", Ministerial Order, Journal Officiel de la République Française, IND0301276A, IND0301379A. http:// www.legifrance.gouv.fr

[2] R. Belhomme, C. Corenwinder, 2004, "Wind Power Integration in the French Distribution Grid - Regulations and Network Requirements ", *Proceedings Nordic Wind Power Conference.*

[3] P. Kundur, 1994, Power System Stability and Control, EPRI

[4] P.M. Anderson, A.A. Fouad, 2003, "Power System Control and Stability"

[5] "IEEE Recommended Practice For Excitation System Models for Power System Stability Studies", Standard IEEE Std 421.5_1992

[6] T.TRAN-QUOC, E.MONNOT, G.RAMI, A.ALMEIDA, C.KIENY, N.HADJSAID, CIRED 2007, paper 0727 « Intelligent voltage control in distribution network with distributed generation »

[7] T.TRAN-QUOC, G.RAMI, A.ALMEIDA, N.HADJSAID, JC.KIENY, JC.SABONNADIERE, Brevet 05 11946, « Méthode et dispositif de régulation pour un dispositif de production décentralisée d'énergie et installation comportant au moins deux dispositifs de production dotés dudit dispositif de régulation »

[8] P.LEMERLE, I.PASCAUD, X.LOMBARD, S.NGUEUFEU, Brevet 01 04640, « Procédé et installation de régulation de la tension d'un dispositif décentralisé de production d'énergie électrique raccordé à un réseau de distribution »

[9] Ministère de l'économie, des finances et de l'industrie, INDI0505749S « Décision du 23 septembre 2005 approuvant les tarifs d'utilisation des réseaux publics de transport et de distribution d'électricité »