CENTRALIZED VOLTAGE CONTROL IN MEDIUM VOLTAGE DISTRIBUTION NETWORKS WITH DISTRIBUTED GENERATION

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ABSTRACT

The growing shares of distributed generation represent new challenges to distribution grids operation regarding estimation and control of voltage profile along medium and low voltage feeders. This fact leads distribution networks to become active distribution systems in order to increase monitoring and control in medium and low voltage networks. In addition, Distributed Generation (DG) may be a new resource to provide a voltage control ancillary service to Distribution System Operators (DSOs). This issue is one of the main objectives of PRICE-GDI project[1]*. This paper presents analyses carried out within this project in order to determine the benefits of voltage control provided by DG.*

The new regulatory framework which is being stated in European Network Codes includes some requirements for DSOs regarding voltage control. This paper analyses the impact of these requirements on voltage control provided by DG.

INTRODUCTION

The growing share of distributed generation (DG) represents new challenges to distribution grids operation. Present distribution grids have low automation and monitoring levels in lower voltage levels which hamper voltage profiles estimation along medium voltage (MV) feeders with DG, as well as voltage control. This leads distribution networks to become active distribution systems, increasing monitoring and automation levels and dealing with new reactive power resources which can be involved in voltage control. Although higher automation and monitoring levels are actually being implemented at MV networks following the smart grids trend, voltage control with distributed generation is a field which should still be further explored in order to state suitable procedures.

At the aforementioned frame, the PRICE-GDI project aims exploring solutions for DG integration in MV grids. The main objective of PRICE-GDI project is to develop a demo of a centralized voltage control running within an advanced distribution management system (ADMS). This paper presents some of the analyses which have been carried out in PRICE-GDI, previously to the voltage control development and implementation [1].

Some European projects have studied as well the provision of voltage control services by generators connected to distribution networks. Among others, PVGrid project analyses the barriers for the integration of photovoltaic generation (PV) into European distribution grids, facing the ancillary services provided by PV from a regulatory perspective [2]. REserviceS project explore the possibilities of renewable generators (PV and wind) for ancillary services provision, as well as the distribution system needs from a technical and an economical point of view [3]. PRICE-GDI is one of the demonstrations projects considered in the European project IGreenGrid, which aims comparing and scaling solutions adopted in different demonstration projects for distributed generation integration in Europe [4].

Many solutions for voltage control with distributed energy resources, including DG, have been proposed in the literature in the last decade. The main objective of voltage control has been the mitigation of voltage rise due to the injection of active power from DG [5]. For this aim, mainly local control solutions, as the one presented in [6], have been proposed due to its simplicity. The discussion about centralized and distributed voltage control presented in [7] suggests that centralized control provides better results when hosting capacity increase is aimed. From a technical point of view, a centralized voltage control considering the coordination of different reactive power resources is an overcome barrier [8]. From a regulatory framework point of view, a better coordination between DSOs and DG will be required for an optimum voltage control approach in distribution networks [9].

This paper analyses the effect of a centralized voltage control with distributed resources in voltage limits fulfillment (under and over-voltages) and active power losses minimization, as an alternative solution to the *Business As Usual* (BAU) which always involves network reinforcements to deal with voltage problems.

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The reactive power needs from the distributed resources are also analyzed.

The paradigm change in distribution systems is accompanied in the European Union by a new regulatory framework stated in new Network Codes. Network Code on Demand Connection (DCC) draft [10] requires DSOs to have the capability of fixing a power factor at the connection point to the transmission network. Moreover, DSOs must assure no export of reactive power to transmission system if active power flow does not exceed 25% of maximum demand capacity at the connection point. This paper aims to evaluate the impact of reactive power flow requirements on the performance of voltage control provided by DG. Power factor setpoints at the connection points to the transmission network are supposed to result from the transmission level voltage optimization. Due to the lack of setpoints for the considered scenarios, only the second requirement (not injecting reactive power to transmission level) is taken into account for this analysis.

The paper is structured as follows. First, the definition of the scenarios of the study is presented. Second, the considered methodology is explained. Next, results of voltage control for every scenario are detailed and analyzed. Finally, the main conclusions of the analysis are presented.

SCENARIOS

A 15 kV semi-urban feeder located at the *Unión Fenosa Distribución* network in Madrid has been modeled for this study. The feeder is presented in Figure 1. 2831 service points are fed by means of 65 secondary substations connected along the 28 km length of the feeder. The impedance of the feeder has an average R/X ratio 1.54, which is a typical value for MV feeders and is much higher than typical R/X ratio for HV networks due to a higher resistive component.

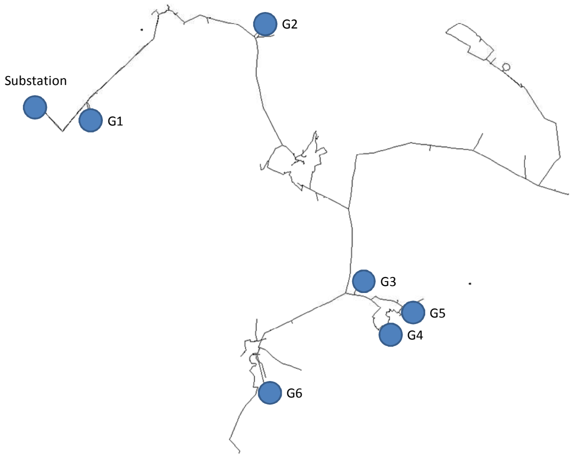

Figure 1. MV feeder

The locations of generators connected to MV have been represented in Figure 1. The main characteristics of DG connected to MV are presented in Table I. Two different technologies of DG have been considered connected to MV: PV and CHP. The main difference between PV and CHP models is the minimum power factor (PF) they can work when they provide Q/V control. Only PV has been considered connected to LV. Generation connected to LV is discarded to take part in the centralized Q/V control. LV generation is supposed to carry out a local voltage control with unitary power factor setpoint.

Table I. DG connected to MV network

DG	Technology	Pmax [MW]	Min PF
G1	CHP	3.0	0.80
G2	PV	0.4	0.85
G3	PV	0.4	0.85
G4	PV	0.4	0.85
G5	CHP	1.0	0.80
G6	CHP	5.0	0.80

Taking into account the considerations above, five different DG scenarios have been defined. Table II shows the generators connected in MV and their respective active power generation for scenarios from DG1 to DG5. In addition, Table II includes the number and the total active power generation from generators connected to LV, dispersed along the MV feeder. DG penetration has been calculated as the ratio of installed DG capacity to the demand of the scenario.

Table II. DG scenarios

Scenario	Voltage level	Generators	Pgen [MW]	Penetration DG (%)
DG1	**MV**	-	-	
	LV	-	-	
DG2	**MV**	G2 G3 G4	0.4 0.4 0.4	28.0 %
	LV	-	-	
DG3	**MV**	-	-	23.4 %
	LV	37 PV	1.0	
DG4	**MV**	G2 G3 G4 G1	0.4 0.4 0.4 2.0	98.1 %
	LV	37 PV	1.0	
DG5	**MV**	G2 G3 G4 G1 G5 G6	0.4 0.4 0.4 3.0 1.0 5.0	261.7 %
	LV	37 PV	1.0	

A demand of 4.28 MW and a load power factor of 0.95 (leading) have been considered for all the scenarios.

METHODOLOGY

The benefits of a centralized voltage control are estimated by comparison of results of the voltage control assuming three different approaches: BAU, SMART and DCC. These approaches are defined below:

- BAU (Business as usual) – Voltage control by means of tap changing and capacitor placement at primary substation.
- SMART – Centralized voltage control with DG.
- DCC – Centralized voltage control with DG observing reactive power flow constraint at TSO/DSO connection point (not injection of reactive power from DSO to TSO). This approach is considered in order to evaluate the impact of fixing reactive power flow constraints as the ones stated at DCC.

Results for BAU approach are obtained by means of a power flow adjusting the MV bar of the substation to nominal voltage as the slack bus. The centralized voltage control is simulated by means of an Optimal Power Flow (OPF) with an objective of power losses minimization and keeping the security standards (thermal ratings and voltage limits).

In order to determine if the participation of DG in voltage control is useful for solving voltage problems, the maximum and the minimum voltages are measured in each scenario for the BAU and the SMART approaches. In addition, the effect of the DG and the SMART approach on active power losses has been analyzed. Finally, the reactive power required from DG (injected or withdrawn) and the maximum voltage rise in the whole network have been measured in order to analyze the amount of reactive power needed for voltage control in MV networks.

RESULTS

This section presents the results of the simulations and analyses them in order to determine the performance of DG in a centralized voltage control. In addition, the impact of fixing reactive power requirements at TSO/DSO connection points on voltage control with DG is analyzed.

Voltage control for active power losses minimization and voltage limits fulfillment

Figure 2 shows the maximum and the minimum bus voltage in the network obtained from voltage control simulations with BAU and SMART approaches. Maximum and minimum voltage limits are also represented with dashed lines.

Figure 2 shows how the minimum bus voltage in the network rises when the generated active power increases in the BAU approach simulations, where DGs do not take part on voltage control. Furthermore, in DG5, overvoltages appear in the BAU approach. This fact proves that active power injection causes a voltage rise in MV networks. This effect can be useful in case of undervoltages but a problem may appear in case of overvoltages.

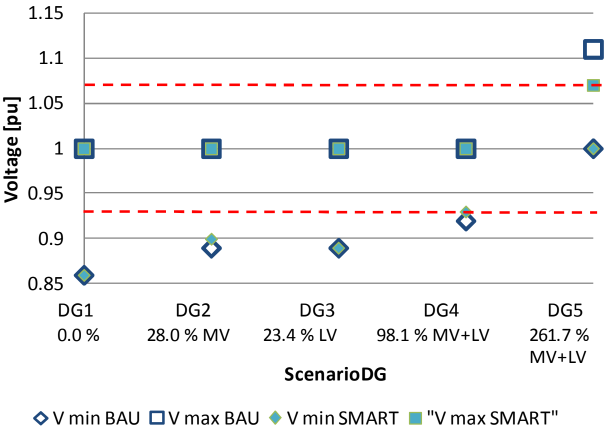

Figure 2. Voltage limits fulfillment using voltage control

When a SMART approach is applied, DGs manage their reactive power injection or withdrawal in order to make bus voltages tend to fulfill the voltage limits. While in scenarios DG1, DG2 and DG3 reactive power capacity of DG is not sufficient to keep bus voltages within limits, voltage limits violations are solved in scenarios DG4 and DG5, as it is shown in Figure 2.

Figure 3 presents the increment of active power losses obtained in scenarios DG2 to DG5 addressed with a BAU and a SMART approach respect to active power losses obtained in scenario DG1 (BAU and SMART approaches produce the same results in DG1 scenario since no DG is able to provide voltage control).

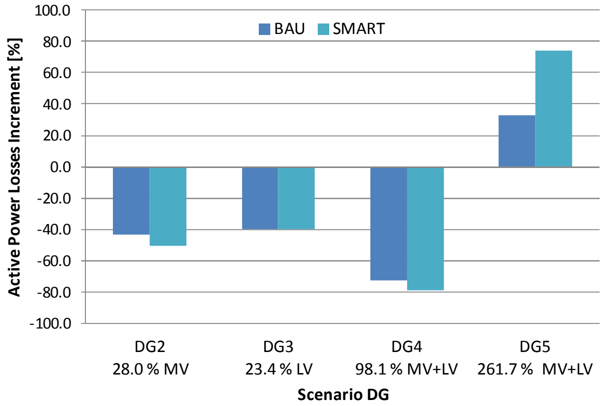

Figure 3. Increment of power losses respect to DG1 scenario with BAU approach

Figure 3 shows that, considering a BAU approach, active power losses are reduced with the increase of DG active power injection up to a penetration level which presents an increase of power losses. This effect is caused by the reversion of the power flow in part of the feeder, what is coherent with the rise of the maximum bus voltage shown in Figure 2.

When a SMART approach is applied, active power losses are even more reduced in scenario DG2, despite DGs are not able to cope with the minimum voltage required. In scenario DG3, DGs are connected at LV network and they do not participate in the centralized voltage control, so active power losses for SMART approach are the same as for BAU. In DG4, when SMART approach is applied, DGs are able to keep voltage security standards and they have enough reactive power margin to reduce active power losses respect to BAU results. However, in scenario DG5, despite the objective of active power losses minimization, the voltage limits constraint cause a power losses increase. As a conclusion, the centralized voltage control can reduce active power losses unless solving voltage violations avoid it.

Figure 4 presents the maximum voltage variation obtained with the SMART approach (measured from bus voltages in BAU approach) for scenarios DG2 to DG5. Besides, the amount of reactive power required from all the DGs (injected or withdrawn) is represented for the same scenarios. Therefore, Figure 4 denotes the amount of reactive power which is needed to change bus voltages in this case example.

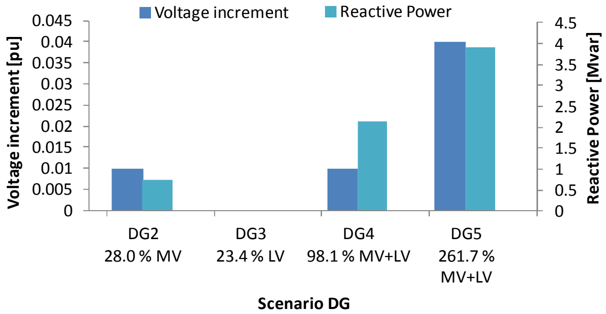

Figure 4. Reactive power need from generators and maximum voltage increment

In DG1 and DG3 scenarios, no DGs are able to participate in a centralized voltage control, thus bus voltages remain the same values and no reactive power capacity is used. For this reason, voltage problems also remain and no active power losses minimization is possible. In DG2 and DG4, the maximum bus voltage variation is 1% for both cases. To obtain this variation, less than 1 Mvar is used in DG2 while more than 2 Mvar are used in DG4. The reason is that in DG4 the voltage control is more useful since voltage problems are solved and active power losses improve more than they do in DG2. In DG5, a maximum bus voltage increment of 4% is obtained using close to 4 Mvar. As a result, a high reactive power capability is needed to get generators involved in steady state voltage control. The cause is the low sensitivity of bus voltages respect to reactive power injection/withdrawal, consequence of the characteristic impedance of MV power lines, with a high resistive component.

In order to determine DG capability to provide voltage control (Q/V) to DSOs, the amount of reactive power needed must be analyzed. In this case example, none of the CHP generators work with a power factor less than 0.8 regarding their nominal capacity and PV generators also observe their minimum power factor of 0.85. Thus, in this case, DG would have enough reactive power capacity to get involved in voltage control.

Impact of the reactive power requirement on voltage control with DG

For the following analysis, only scenario DG1 is considered. In this scenario, two new unlimited resources of reactive power (e.g. two big generators or two SVCs or STATCOMs) are connected to the MV power line. Unlimited reactive power sources have been considered in order to determine the amount of reactive power which is needed to fulfill security standards and the reactive power requirement at the same time. For this analysis, BAU and SMART approaches are also applied, added to DCC approach. DCC approach simulates a centralized voltage control with a power losses minimization objective subject to security constraints and the requirement of not injecting reactive power to HV level.

Figure 5 represents the maximum and the minimum bus voltage in the network for the three approaches. Maximum and minimum voltage limits are also represented with dashed lines.

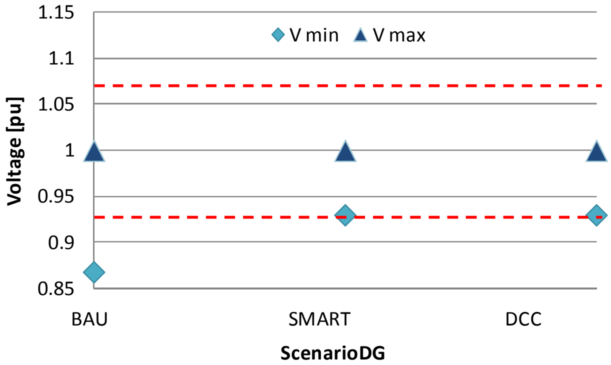

Figure 5. Voltage limits fulfillment using voltage control

As Figure 5 shows, while in BAU scenario voltage problems appear, in both SMART and DCC scenarios voltage limits fulfillment is achieved by means of the DG (or SVCs or STATCOMs) reactive power management.

Figure 6 presents the active power losses and the reactive power used for scenarios BAU, SMART and DCC. Figure 6 shows that, although active power losses minimization is intended in scenario SMART, they increase because of reactive power flows needed to fulfill bus voltage constraints.

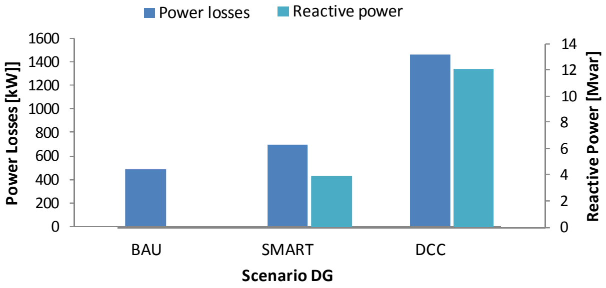

Figure 6. Impact of reactive power requirement at HV/MV connection point on power losses and reactive power needs

Figure 6 also shows that fixing the reactive power flow constraint at the DSO/TSO connection point (DCC approach) increases active power losses in comparison to the SMART approach results. Moreover, this requirement increases the reactive power needs up to levels which can be unaffordable for DGs. Furthermore, high reactive power flows may increase circuits current up to values close to security limits or even higher, which could make this solution unfeasible. In this case, if reactive power requirement is observed, only new investments would solve voltage problems, avoiding the benefits of DG voltage control.

CONCLUSIONS

In this paper, the performance of DG participation in a centralized voltage control has been studied. A centralized voltage control with DG involved could be useful to solve voltage problems in MV networks. As a consequence, the hosting capacity may increase if this solution is applied.

Big amounts of reactive power from DG are needed if they participate in the voltage control. As a consequence, a cost/benefit analysis is required for every single case in order to determine if this is an efficient solution. In the case study presented in this paper, in DG scenarios with a high penetration, DGs have enough reactive power capacity to achieve the objectives of voltage control. Similar analysis should be carried out in order to determine DG capability to provide voltage control services in other cases.

In addition to the first study, this paper analyzes the impact of the reactive power requirements at the TSO/DSO connection point specified in the DCC on the performance of DG participation in a centralized voltage control. The main conclusion is that fixing reactive power flow requirements at the connection point of MV to HV grids cause inefficiencies in system operation, increasing power losses and reactive power needs for the voltage control. Moreover, fixing this constraint can make DG participation in voltage control infeasible because of high necessities of reactive power capacity or because of the violation of MV thermal ratings.

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