A FLEXIBLE CONTROL STRATEGY FOR ACTIVE DISTRIBUTION NETWORKS IN A FAST-CHANGING SCENARIO

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ABSTRACT

The quick growth of Distributed Generation (DG) is posing some challenges to the distribution networks and to the power system on the whole since the total installed power is now comparable to the conventional generation park. To face those possible criticalities, the connection rules are undergoing a revision process in order to guarantee a more flexible operation of the networks and outlining an advanced role for both the Distribution System Operator (DSO) and the DG itself. Among the innovative operation procedures, the voltage control may gain further flexibility from DG power modulation and storage units operated by the DSO.

This paper describes an algorithm for the voltage regulation developed by RSE ("DISCoVER") that guarantees achievement of technical goals minimizing the overall dispatching cost. It is able to manage different regulation resources, with respect to their technical and economic features. In order to evaluate possible contribution of storage units, different load and generation scenario could be considered. First results achieved from simulation activity on the test network (based on a real MV grid) are given.

INTRODUCTION

In Italy, as in several EU Countries, the huge growth of diffuse generation (DG) connected to distribution networks, from not-programmable Renewable Energy Resources (RES) especially, is leading towards potential criticalities given the dramatically different paces of DG expansion and network reinforcement.

A possible countermeasure comprises the transition towards 'active distribution network' where a stronger cooperation between DSO, generator owners and customers will enable a more reliable system even with an higher DG penetration. Given the additional constraints deriving from possible contingencies at the transmission level, a control approach where the DSO have the possibility (and the responsibility) of coordinating both directly owned and third-party resources to reach an overall target. Moreover, the probable introduction of storage devices will enlarge the control possibilities, and on the other hand the boundaries of the problem to be solved. In any case, DSO role will evolve towards a pivotal position between transmission network, generators and customers, balancing local generation and load and providing services to the higher level.

In that framework, a key variable is represented by the regulation advancement: to face the above mentioned criticalities, in Italy (and other countries) the grid code and the connection rules for DG units at MV level are undergoing a profound revision process that will enable more advanced control possibilities – not yet defined in their details.

ADVANCED SERVICES AND THE REVISION OF THE CONNECTION RULES

Up to these days, DG plants were connected according to the so called principle of 'fit & forget', where no functional contribution from generators was expected towards the system. Since the diffusion of DG rose very quickly to significant levels, a paradigm change is necessary to face possible criticalities not only on the distribution networks but also for the entire power system. For example, in Italy, thanks to a favourable framework, the RES-based plants led to a steep increase in the GD diffusion (Figure 1): the energy from PV plants alone passed in 2011 from 1.9 to 10.7 TWh (+463%). A slowing pace for the new connection rate was recently observed, because of the incentive fees lowering, but in any case a sustained flux of requests is expected even in the next years (nearly 3 GW/yr).

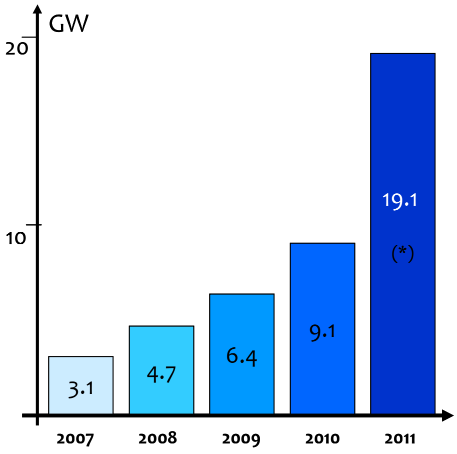

Fig. 1 – Cumulated GD connected to the distribution network; (*) 4.5 GW directly connected to the HV level (Source: Enel Distribuzione).

From the national power system's point of view, having a significant portion of the generation side composed by diffuse, not programmable RES-based plants entails potential inconvenience threatening the reliable and stable operation of the overall system: lack of observability, poor reserve margins, and possible massive disconnection of generation after system disturbances, for mentioning the most critical issues [1]. For these reasons, TSOs are requiring a proper update of grid codes and in Italy this need of a shared change was particularly felt by all the involved actors (TSO, DSOs, manufacturers, installers).
The recent edition of the Italian MV connection rules [2] includes several innovations, devoted to:

- distinguish between local problems (where the generator has to disconnect) and transmission level disturbances (where it has to remain connected). This smarter behaviour is reached by means of advanced protection settings for voltage and frequency, depending on local and even remote information;
- detect undesired islanding operation;
- enable automatic power curtailment in case of over-frequency;
- implement simple local regulations of the reactive power to counteract voltage rises deriving from the power injection itself [1];
- permit advanced network operation strategies by means of the modulation of reactive and active power, supported by proper exchange of information and commands between the generators and the network operator. This may include the participation to the defence plans, for example an active power curtailment required by the TSO.

Apart from the impact of these new rules on the plant design, outside the scope of the present paper, the above listed requests foresee the provision of 'ancillary services' by distributed energy resources (DERs) and the definition of proper remuneration schemes by the national Authority.
In fact, these services will have to support the implementation of new operation procedures, focused on the distribution network itself or allowing the lower grid provide support towards the transmission level. Since, as shortly depicted before, some criticalities are not related to the distribution network alone but to the whole system, it's worth underlining that DGs cannot always base their behavior to local information. For example, it could be possible for the DSOs require an active power reduction to the DG connected to their networks in absence of local overvoltages but following a TSO request to prevent critical system condition.

As a matter of fact, the advanced voltage regulation will represent a key function that will be implemented soon in the 'active' networks. The possible overvoltages, in particular, could be faced with a *local* or a *centralized* approach: the first one could be applied at the single generator without any communication infrastructure while the latter needs proper channels to exchange the necessary information but allows more complex options. The standard [1] established specific capability areas for the various generation technologies, in order to allow the provision of reactive power for both local control and centralized voltage regulation, as Fig. 2 depicts.

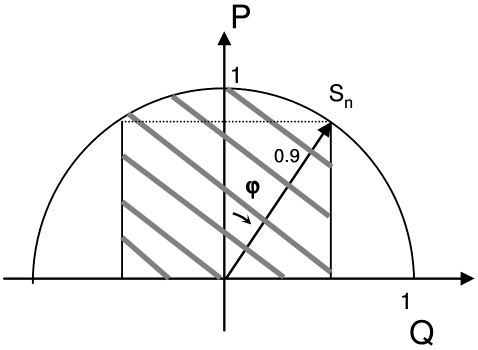

Fig. 2 – Requested capability (shaded area) for the reactive power modulation of inverter based generators in plants up to 400 kW. Generators belonging to plant >400kW should make available the entire semi-circle. S_n: rated apparent power at the rated voltage (source: [1])

In the following, a flexible framework for the advanced voltage control in active MV distribution networks is described. This scheme outlines the future evolution of DSO's role, permitting to evaluate the possible operating conditions taking into account different dispatching costs for the available regulation resources. The algorithm could be use for off-line analysis and it may be integrated in a centralized on-line controller, as described in the last section.

THE REGULATION RESOURCES AND THE 'BUSINESS MODEL'

The goal of the optimization algorithm, core of the proposed control procedure, is to minimize the overall cost of the dispatching actions needed to satisfy the technical constraints (voltage at nodes, current in branches, power exchange at the primary substation).
Together with 'internal' resources, that is devices directly operated by the DSO (OLTC and possibly storage units), as mentioned before other regulation resources are becoming available to the network operation:

- reactive power injection/absorption from DERs (all or a sub-set of DGs connected to the network);
- active power modulation from controllable resources (sub-set of DERs).

Therefore, having available different resource to solve, or prevent, some critical conditions, a DSO should identify in each case the 'best' solution depending not only on the technical side but even on the economic aspects.
As mentioned before, the reactive power modulation within

certain ranges will be likely a compulsory service that DGs will have to provide for free. On the other hand, larger Q modulation and especially the active power curtailment could represent a rewarded service.

Additionally, by means of financed demonstrative projects, DSOs are exploring the electrochemical storage application for supporting the operation of active networks with a large surplus of energy by RES. The choice between the distributed approach, that is the storage directly combined to the DG to smooth the power profile, or the centralized option, when the storage is operated by the DSO, is still under discussion in most countries.

Possible roles for storage units

The utilization of electricity storage based on electrochemical technologies is recently proposed in combination with RES based generators or connected directly to distribution and transmission networks to face congestion issues. It’s worth underlining that the storage units could provide not only a support to the voltage regulation; depending on the specific technology, these devices are able to provide diverse services to the DSO, and the entire systems, as summarized in the following Table I.

Table I – qualitative comparison between electric storage technologies [3].

	Time shift	*Power balance*	*Ancillary services*
Li-ion	+++	+++	+++
Li(LFP) *Lithium Iron posphate*	+++	+++	+++
VRB *Vanadium Redox battery*	++	++	++
VRLA *Valve regulated Lead acid battery*	++	++	–
Na/NiCl	+++	++	++
Na/S	+++	+++	++
NiCd	++	++	++
NiMH	++	++	++

Legend: +++ high attitude,++ medium attitude, – poor attitude.

Thanks to its flexibility, a storage unit could provide voltage regulation for the feeder when it is connected to, and it could support in limiting the net power exchange at the HV/LV boundary when requested (time shift). Because this technology is still expensive, it could be possible to use a single device to perform different services, both towards the distribution network and to the higher level (for example frequency regulation). In that case the control algorithm has to be able to manage the available energy with respect to the other changing boundary conditions. It's worth stressing that operation of storage units involves a integral constraint in the problem to be solved, since it is not possible to optimize the single period alone but the whole time horizon because of the recharge constraint. The proposed approach includes the storage unit into the mathematical problem by means of completely configurable parameters that could be updated in real time according to the changed boundaries, taking into account the desired energy level to the reached at the end of the horizon.

The remuneration of the services and the 'business model'

The remuneration of the ancillary services will play a significant role in addressing the control architecture, maybe privileging some solutions at the expenses of other options. In the opinion of the Authors, it is quite unlikely that a full market scheme will be adopted for setting the reward, given the limited size and number of the involved generators at the MV level. A plausible scheme could include prices set by the national Authority, depending on the DG technology and size.

Currently it is not possible to identify for certain which solution will be put into force, then a flexible framework could support in evaluating the available solutions depending on the different choices.

THE CASE STUDY: A REAL MV URBAN NETWORK

The framework was tested firstly on limited test networks to fine tuning the mathematical algorithm before passing to more complex test cases. The figure shows the main characteristics of a real MV network covering the border area of a large Italian city. It is characterized by:

- three different voltage levels (HV 150 kV, and two MV levels: V_1 =20kV and V_2=8.4 kV),
- the presence of different generators, both fossil and RES fueled, connected along feeders or directly to the MV busbar
- a complete passive feeder (from Primary Substation PS1).

In the present paper, a summary of the simulation activity [5] is reported: that activity focuses not only on the cases definition and their results but also on the aspects allowing the integration of the algorithm into a real time control. For example, the calculation time for such a large system (more than MV 150 nodes) was evaluated as adequate to permit the optimization process to be interfaced with the SCADA and carry out a complete acquisition-calculation cycle in 5-10 minute or less.

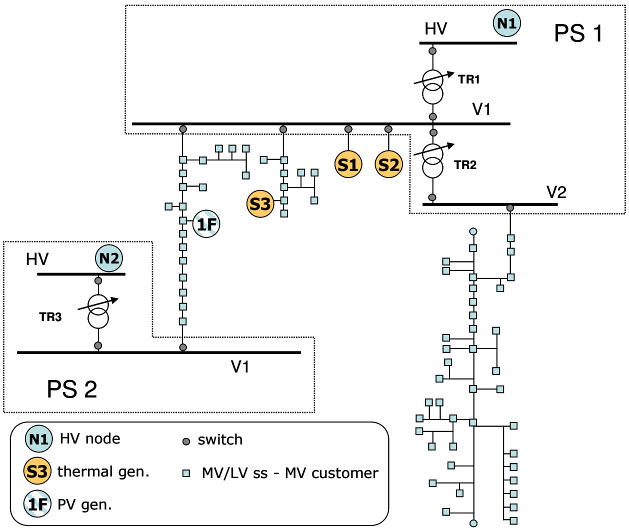

Fig. 3 – Test network (real MV feeders)

The simulation activity was based on different test cases, and succeeding evaluations with different rewards for the ancillary services were established. In any case a sound ranking order was followed, where reactive power modulation from DG has a lower cost in comparison with the active power curtailment. The active power modulation, then, was differentiated depending on the generator type, given that controlling RES based GD have to include a proper counterbalance to the incentive loss. Finally, various storage technologies may be evaluated by means of different *cost per cycle*, given the different investment cost and expected lifetime [3].

A simpler condition without any storage devices was evaluated. The first simulation deals with an undervoltage in the passive feeder: the algorithm identifies a solution where the participation of OLTCs of transformers TR2 and TR2 together with a reallocation of reactive power between the generators is able to reach a valid operation point and a reduction of the losses. This case could be considered as an example of the re-dispatching approach, where a local balance between loads and generators is found.

FINAL CONSIDERATION AND FUTURE ENHANCEMENTS

The paper proposed a technical-economic optimization technique that could help to improve hosting capacity of Medium Voltage network, maintaining technical parameters in desired range minimizing the operational cost.

The procedure here proposed is able to include storage units in a complete optimization problem with a simple and efficient management. Their application for improving network operation is not yet deployed in real networks but it is linked to a future view where storage technology will be economically competitive.

The framework here proposed allows exploring different scenarios in terms of load and generation patterns and as for cost for controllable resources (both internal and external). The procedure permits to evaluate the effect of several parameters on optimization results, in terms of ancillary services (costs and capabilities) and as regard to storage units' usage.

As it becomes clear, together with obligatory services, i.e. functionalities that DG will have to perform without any rewards, several 'ancillary services' are to be included as perspective functions to be offered by generators to the power system. Currently, it is not possible to identify for certain all the services that will be requested to generators and their consequent remuneration, therefore it is quite difficult to define operation tools that DSOs could adopt in their new role of 'dispatcher'. The proposed framework represent a basis for further evolution.

Acknowledgments

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