

A SMART STRATEGY FOR VOLTAGE CONTROL ANCILLARY SERVICE

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Abstract- The proposed control allows reducing the whole reactive power injection/absorption, maximizing, at the same time, the active power production. This paper proposes a coordinated local control approach that allows distribution system operator (DSO) and independent power producers (IPPs) to obtain benefits offering the voltage regulation ancillary service to DSO and maximizing allowable active power production for each RES unit belonging to the same IPP. The control is based on a cooperation of data transfer between DSO and IPPs. In order to realize such cooperation, a nonlinear constrained optimization problem is formulated and solved by sequential quadratic programming (SQP) method.

Index Terms- Ancillary services, distribution networks, reactive power control, renewable distributed resources, smart grid, voltage control.

I. INTRODUCTION

The reliability and security of electrical power systems require usually ancillary services, such as reactive power support, power quality, spinning reserves, energy balancing and frequency regulation. In a deregulated power system market, the responsibility of maintaining the correct operations of the system is basically attributed to the System Operator, that, hence, purchases these services directly from the generators [1]. Since the support of the power system with an ancillary service implies a reduction of the active power supplied to the grid, a financial compensation should be given to the provider by the System Operator. Moreover, the ancillary services supplied should be the most appropriate for the technical characteristics of the generator. In the case of generation with switching power converters, which is the case of most of the renewable energy generators, the more suitable

ancillary services are the voltage regulation and the harmonic suppression [2]. In particular, the photovoltaic (PV) generation system, being connected to the grid by means of a voltage-source inverter (VSI), can provide reactive power anytime the power available from the source is lower than the maximum one. This eventuality happens for many hours during the day. In this way it can participate in voltage regulation without additional costs. The amount of necessary reactive power should be given by the system operator or, in alternative, can be derived from the PV system by measuring the voltage at its node. In the last situation the reactive power requested by loads connected at the same node of the PV unit can be realized without any signal from the network. At the same manner, the PV generation unit can be used to compensate current harmonics measured on the grid. In this way, all the harmonics due to loads connected at the same node of the PV system can be suppressed without significant additional costs in the interface converter.

The possibility of using renewable energy sources also for providing ancillary services appeared only recently in the technical literature, because switching power converters are normally devoted to regulate the injection of power into the grid in order to maximize the energy delivered by the renewable source. In case of wind turbines, the ancillary services proposed have been the compensation of reactive power [3] and the governor response [4].

In the past, reactive power regulation has been proposed for voltage control at the connection bus by using decentralized approaches, often without any coordination of distributed generation (DG) units [3]–

[9]. Lately, however, thanks to advances in information and communication technologies (ICTs), which address power systems toward Smart Grids, centralized approaches are spreading more, although both approaches can be applied to yield good performances. Nonetheless, it is reasonable to assume that centralized control will typically give more robust and overall better results [10]. Many presented approaches allow DSO to take advantage of ancillary services without consideration of the potential benefits for IPPs. For this reason, we present a smart strategy that offers the mandatory voltage control ancillary service, based on a coordinated control method, able to obtain the maximum allowable active power production for each RES unit owned by the same IPP. It allows avoiding, as much as possible, the DG units disconnections due to the infringement of voltage regulatory limits. This control strategy operates controlling the DGs' reactive/active power exchange with the distribution network and it is based on the cooperation of data transfer between DSO and IPPs. Specifically, DSO communicates power system state to IPP that solves an optimization problem to provide references to RESs in order to avoid voltage constraint violations. The proposed control, thus, reaps the benefits of both approaches: the control strategy is global because involves DSO and IPPs, therefore intrinsically more reliable and comprehensive, but the resolution of the regulation problem to achieve the overall optimum control input is local.

Its main contributions compared to the literature can be summarized as follows:

- 1) The approach discussed in this paper takes in to account not only the power converter capability curves, but also the limits imposed by national standards;
- 2) The optimization technique increases the active power production of IPPs compared to other local controls [7], [8];
- 3) In the presence of several DG-RES units the proposed algorithm calculates these set points for each one in order to control the voltage profiles without the necessity of a complete sensitivity analysis;

4) The control proposes a smart strategy that tries to enhance the classical ancillary service related to voltage regulation;

5) The proposed method allows obtaining more benefits in terms of active power maximization compared to other voltage controls reported in literature also in the presence of high DG penetration.

II. VOLTAGE CONTROL AND PROBLEM FORMULATION

The proposed voltage control is based on a local regulation performed by an IPP, owner of some DG units connected to different bulk supply points (BSPs) of the distribution network (DN). In particular, the control is implemented through two different steps: in the first one IPP regulates the voltage profiles by means of reactive power using the sensitivity coefficients evaluated for each RES unit connected to BSP as shown in [6]–[8].

A. Voltage Control

Typically, DG-RESs are connected to the DN by means of electronic power converters. Using power converters it is possible to control the voltage at the BSP varying the P/Q ratio.

Fig. 1 depicts the structure of the proposed voltage control through a generic diagram of inverter based RES-DG, where P_{ref} and Q_{ref} are the active and reactive power set points, respectively, elaborated by the IPPCC by solving an optimization problem; and i_{inv} is the inverter outgoing current and voltage; X is the reactance, which takes into account the DG transformer and the grid filters used for DG connection to DN. Finally, V_{bus} is the voltage connection bus value.

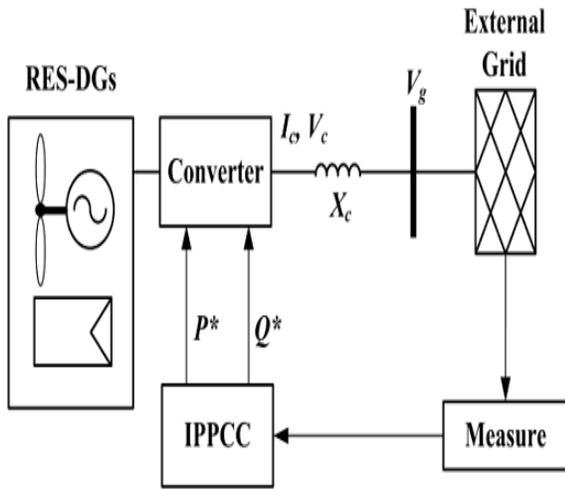


Fig. 1. Proposed control structure.

B. Problem Formulation

The coordinated voltage control action takes place only if the first regulation strategy, based on the sensitivity analysis analytically described in [6]–[8], fails. The solution of an optimization problem with nonlinear constraints allows obtaining the setpoints that IPP must use to regulate voltage profiles.

C. Power Converter Capability Curves

The converter output power (active and reactive) is limited by the capability curves of the grid-side inverter connection depicted in Fig. 1. Here, without loss of generality, RES units based on distributed wind turbines (DWTs) with synchronous generators and photovoltaic (PV) systems are considered.

III. METHOD OF SOLUTION

The proposed control method realizes a voltage regulation absorbing/injecting reactive power and, only if necessary, cutting active power taking into account the capability curves limits. The range delimited by standard limits $[V_{min}, V_{max}]$ is defined as Allowed Voltage Range, as depicted in Fig. 2.

It is divided in three zones where the proposed control algorithm operates applying the following rules:

- a) no control actions are carried out within the Operative Range;
- b) an amount of reactive (active) power is absorbed/injected into the grid to satisfy the

voltage constraints if the voltage variation is positive/negative within the Control Ranges, delimited by two threshold levels (ϵ_u, ϵ_d) .

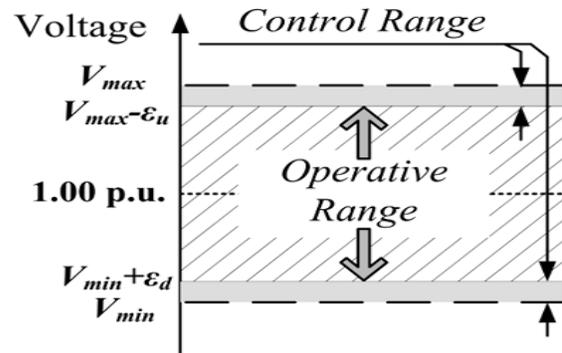


Fig. 2. Allowed, Operative and Control Ranges used in the proposed control method.

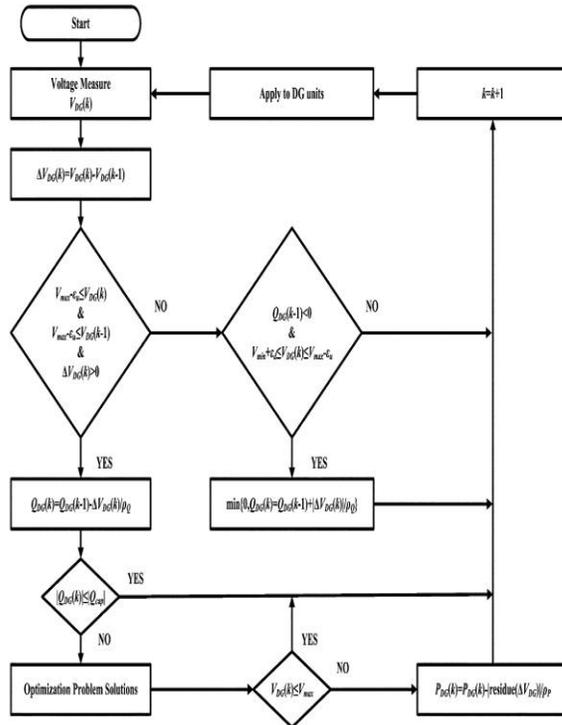


Fig. 3. Flow chart of the control algorithm.

In Fig. 3 the control algorithm flow chart related to a single RES unit is shown considering the above case violation (voltage rise). The IPPCC, after a power flow simulation, calculates the existing difference between the actual (at step k) and the previous (at step -1) voltage value at BSP.

If the amount of reactive power is within the capability curve the cycle ends, otherwise the optimization problem, illustrated in the previous section, is solved. At the end, another voltage check on the controlled bus is carried out, and, if it fails, the active power is reduced proportionally to the uncompensated residue voltage variation by using the reactive power control.

On the other hand, if the voltage is within the *Operative Range* and the reactive power is different from zero, the algorithm reduces the reactive power absorption proportionally to the voltage variation. proposed procedure allows also maximizing the overall active power production because the active power curtailment is only a backup solution that occurs when it is impossible to control the voltage profiles within the mandatory limits by means of coordination between DG units.

IV. SIMULATION RESULTS

In order to show the effectiveness of the proposed control method a real Italian MV distribution network has been considered.

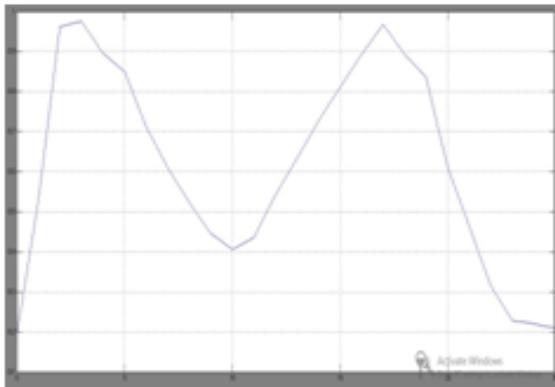


Fig. 4.

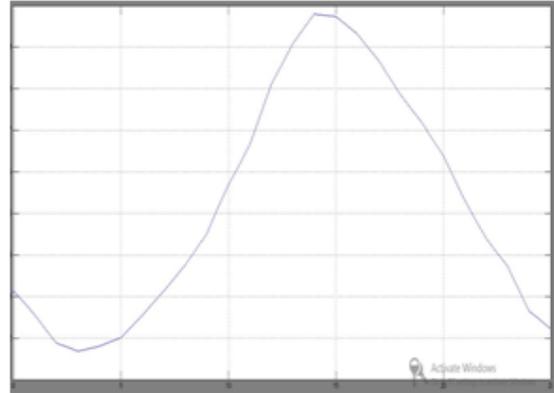


Fig. 5

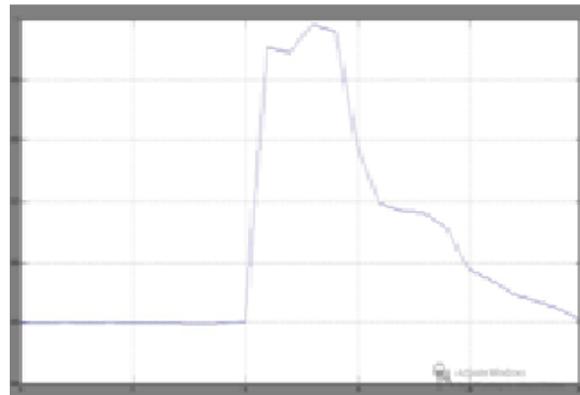


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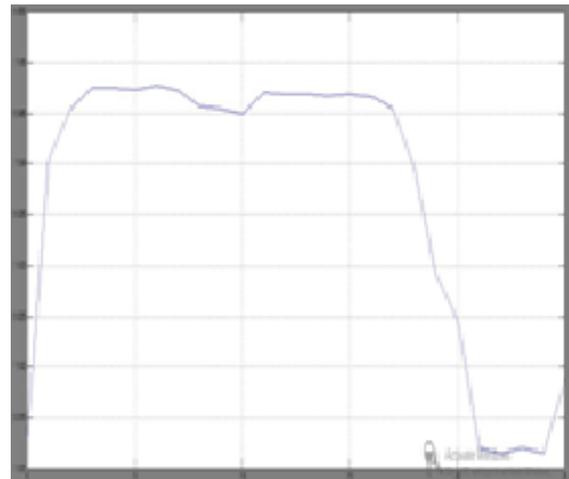


Fig. 7

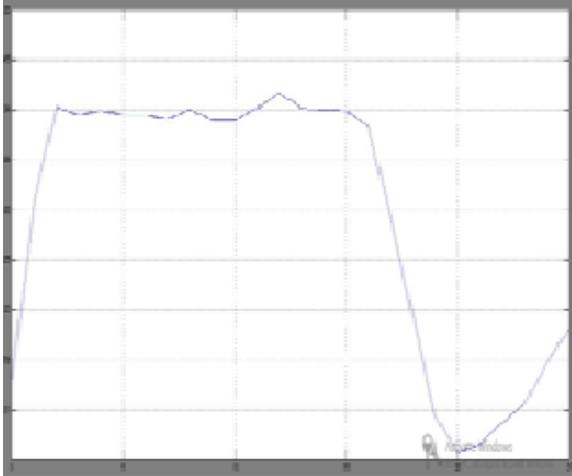


Fig. 8

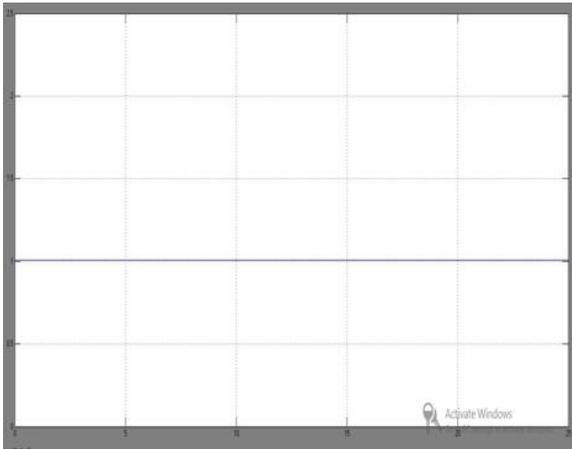


Fig. 9

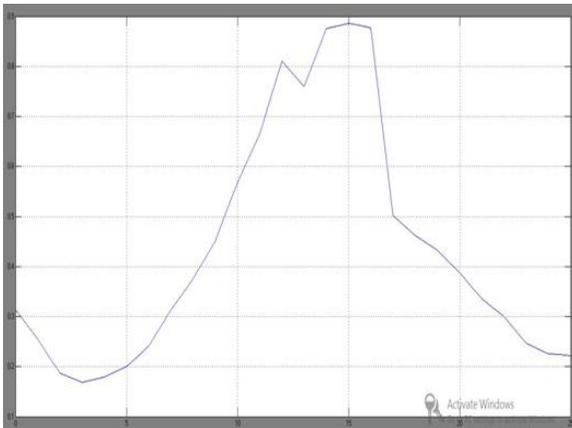


Fig. 10

V. CONCLUSION

It is based on a coordinated approach able to obtain the maximum allowable active power production for

each RES unit owned by an IPP. This strategy can be divided in two subsequent steps. Initially, a decentralized voltage control is carried out through a sensitivity analysis. If it fails, a nonlinear constrained optimization problem is solved in order to maximize the active power production within mandatory limits. In this second step, DSO is involved sharing the set points of the distribution network with IPP, which offers an ancillary service bringing benefits for both.

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