International Journal of Research
Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue14
November 2017

A Smart Strategy For Voltage Controlancillary 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.*

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

I. INTRODUCTION

The reliability and security of electrical power systemsrequire usually ancillary services, such as reactive powersupport, power quality, spinning reserves, energybalancing and frequency regulation. In a deregulatedpower system market, the responsibility of maintainingthe correct operations of the system is basically attributedto the System Operator, that, hence, purchases theseservices directly from the generators [1]. Since the supportof the power system with an ancillary service implies areduction of the active power supplied to the grid, afinancial compensation should be given to the provider bythe System Operator. Moreover, the ancillary servicesupplied should be the most appropriate for the technicalcharacteristics of the generator. In the case of generationwith switching power converters, which is the case ofmost of the renewable energy generators, the moresuitable ancillary services are the voltage regulation andthe harmonic suppression [2]. In particular, thephotovoltaic (PV) generation system, being connected tothe grid by means of a voltage-source inverter (VSI), canprovide reactive power anytime the power available fromthe source is lower than the maximum one. Thiseventuality happens for many hours during the day. In thisway it can participate in voltage regulation withoutadditional costs. The amount of necessary reactive powershould be given by the system operator or, in alternative,can be derived from the PV system by measuring thevoltage at its node. In the last situation the reactive powerrequested by loads connected at the same node of the PVunit can be realized without any signal from the network.At the same manner, the PV generation unit can be used tocompensate current harmonics measured on the grid. Inthis way, all the harmonics due to loads connected at thesame node of the PV system can be suppressed withoutsignificant additional costs in the interface converter.

The possibility of using renewable energy sources also forproviding ancillary services appeared only recently in thetechnical literature, because switching power convertersare normally devoted to regulate the injection of powerinto the grid in order to maximize the energy delivered bythe renewable source. In case of wind turbines, theancillary services proposed have been the compensation ofreactive power [3] and the governor response [4].

In the past, reactive power regulation has been proposed forvoltage control at the connection bus by using decentralizedapproaches, often without any coordination of distributedgeneration (DG) units [3]–[9]. Lately, however, thanks to advances in information and communication technologies (ICTs),which address power systems toward Smart Grids, centralizedapproaches are spreading more, although both approachescan be applied to yield good performances. Nonetheless, it isreasonable to assume that centralized control will typicallygive more robust and overall better results [10].Many presented approaches allow DSO to take advantage ofancillary services without consideration of the potential benefits for IPPs. For this reason, we present a smart strategy thatoffers the mandatory voltage control ancillary service, based ona coordinated control method, able to obtain the maximum allowable active power production for each RES unit owned bythe same IPP. It allows avoiding, as much as possible, the DGunits disconnections due to the infringement of voltage regulatory limits. This control strategy operates controlling the DGs'reactive/active power exchange with the distribution networkand it is based on the cooperation of data transfer between DSOand IPPs. Specifically, DSO communicates power system stateto IPP that solves an optimization problem to provide referencesto RESs in order to avoid voltage constraint violations. The proposed control, thus, reaps the benefits of both approaches: thecontrol 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 optimumcontrol input is local.

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

1) the approach discussed in this paper takesinto account not only the power converter capability curves, butalso the limits imposed by national standards;

2) the optimizationtechniqueincreasestheactivepowerproductionofIPPscompared to other local controls [7], [8];

3) in the presence of severalDG-RESunitstheproposedalgorithmcalculatesthesetpoints foreach one in order to control the voltage profiles without the necessity of a complete sensitivity analysis;

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

5) the proposed method allowsobtaining more benefits in terms of active power maximizationcompared to other voltage controls reported in literature also inthe presence of high DG penetration.

II. VOLTAGE CONTROL AND PROBLEM FORMULATION

The proposed voltage control is based on a local regulationperformed by an IPP, owner of some DG units connected todifferent 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 bymeans 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 connectedto the DN by meansofelectronic power converters. Using power converters it is possible tocontrol the voltage at the BSP varying the P/Q ratio.

Fig. 1depicts the structure of the proposedvoltagecontrol through a generic diagram of inverter based RES-DG,where and are the active and reactive power set points,respectively, elaborated by the IPPCC by solving an optimizationproblem; and are the inverter outgoing current and voltage;is the reactance, which takes into account the DG transformerandthegridfiltersusedforDGconnectionto DN.Finally, isthevoltage connection bus value.

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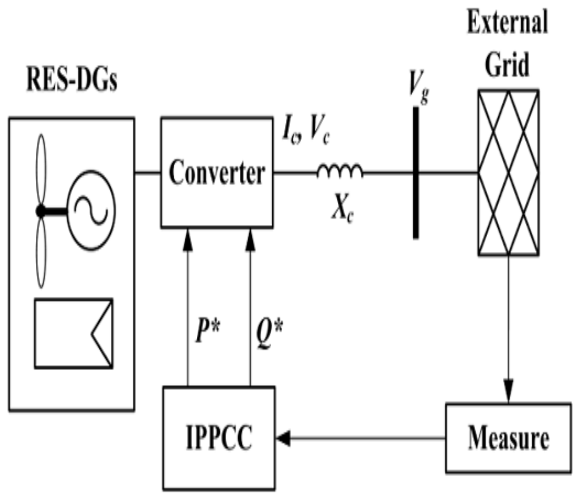


Fig. 1. Proposed control structure.

B. Problem Formulation

The coordinated voltage control action takes place only if thefirst 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 limitedby the capability curves of the grid-side inverter connection depicted in Fig. 1. Here, without loss of generality, RES unitsbased on distributed wind turbines (DWTs) with synchronousgenerators and photovoltaic (PV) systems are considered.

III. METHOD OF SOLUTION

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

It isdivided in three zones where the proposed control algorithmoperates 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 ($\varepsilon_u, \varepsilon_d$).

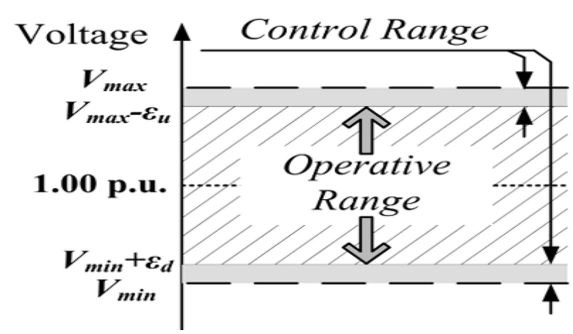
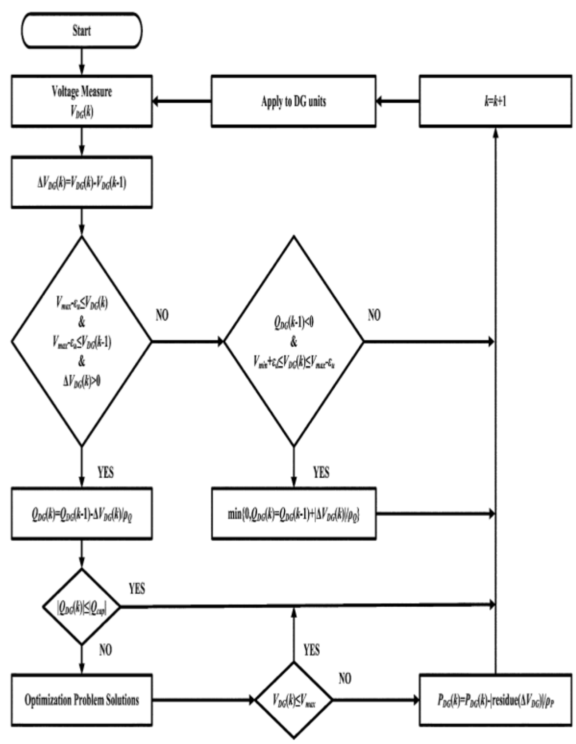


Fig. 2. Allowed, Operative and Control Ranges used in the proposed controlmethod.



e-ISSN: 2348-6848
p-ISSN: 2348-795X
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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 curvesthe cycle ends, otherwise the optimization problem, illustratedin the previous section, is solved. At the end, another voltagecheck on the controlled bus is carried out, and, if it fails, the active power is reduced proportionally to the uncompensatedresidue 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 allowsalso maximizing the overall active power production becausethe active power curtailment is only a backup solution that occurs when it is impossible to control the voltage profiles withinthe mandatory limits by means of coordination between DGunits.

IV. SIMULATION RESULTS

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

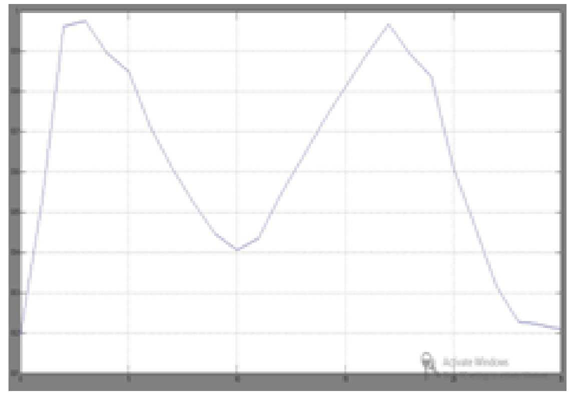

Fig. 4.

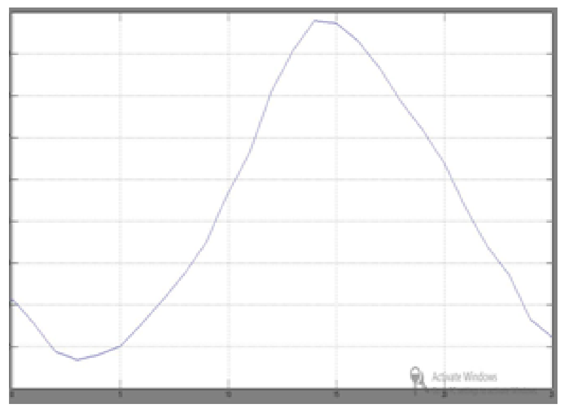

Fig. 5

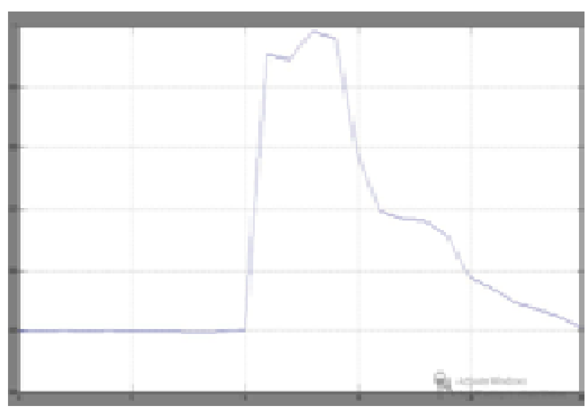

Fig. 6

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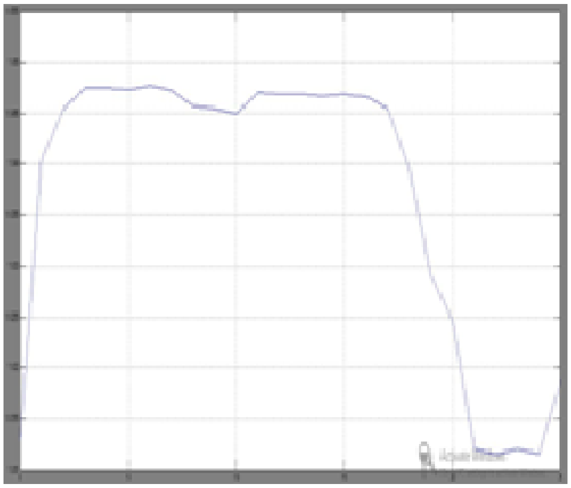
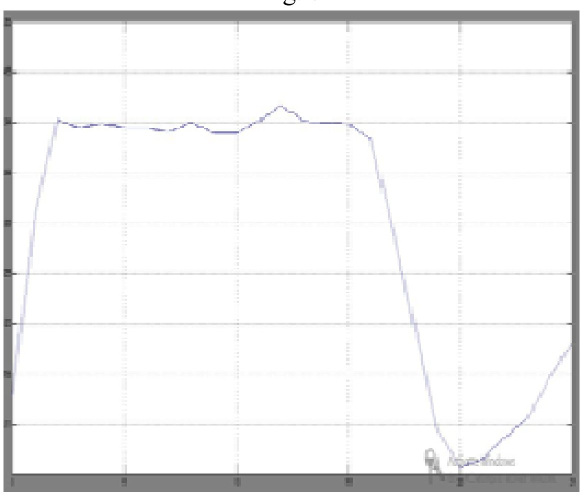


Fig. 7



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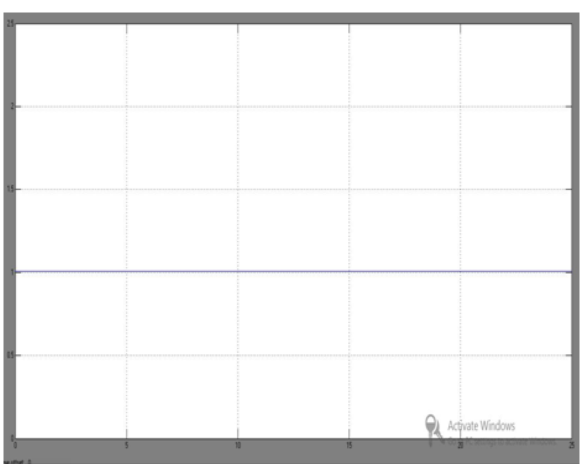

Fig. 9

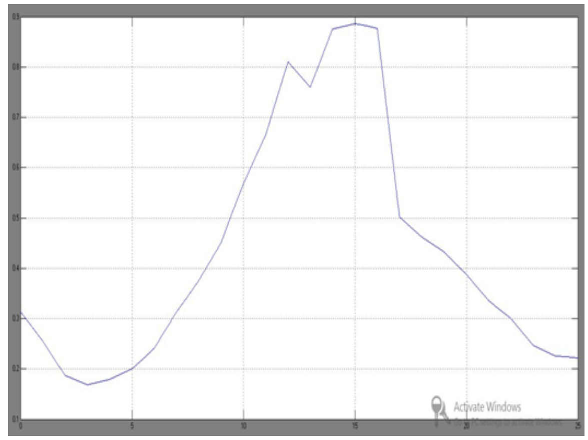

Fig. 10

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 optimizationproblem is solved in order to maximize the active power production within mandatory limits. In this second step, DSO isinvolved sharing the set points of the distribution network withIPP, which offers an ancillary service bringing benefits for both.

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e-ISSN: 2348-6848
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