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A Smooth Strategy for Voltage Control Ancillary Service for Smart Distribution Networks

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ABSTRACT:*With large-scale plans to assimilate renewable generation driven mainly by state-level renewableselection requirements, more resources will be needed to recompense for the uncertainty and variabilityassociated with intermittent generation resources.The proposed control allows reducing the whole reactivepower injection/absorption, maximizing, at the same time, theactive power production.Thispaper proposes a coordinated local control approach that allowsdistribution system operator (DSO) and independent powerproducers (IPPs) to obtain benefits offering the voltage regulation ancillary service to DSO and maximizing allowable activepower production for each RES unit belonging to the same IPP.The control is based on a cooperation of data transfer betweenDSO and IPPs. In order to realize such cooperation, a nonlinearconstrained optimization problem is formulated and solved bysequential quadratic programming (SQP) method.*

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

I. INTRODUCTION

The blackouts around the world raised fundamental ques- tions about the appropriateness of the rules, regulations and system operating practices governing electrical system security. Management of system security needs to keepimproving to maintain reliable electricity services in moredynamic operating environment. System operating practicesneed to give greater emphasis to system- wide preparationto support flexible, integrated real-time system management[1]. Real-time coordination, communication and informationexchange, particularly within integrated transmission and distribution systems spanning multiple control areas, can andmust be improved [2]. Recently, similar major power systemdisturbances have occurred in USA, Italy, Germany and UKinterconnections that in terms of intensity, extent and duration,have caused multi-billion USD damages to the utilities andtheir customers.

In 1995, Federal Energy Regulatory Commission (FERC) ofUSA defined ancillary services as “those services necessary tosupport the transmission of electric power from seller to purchaser given the obligations of control areas and transmittingutilities within those areas to maintain reliable operations ofthe interconnection system.” [3]. At the present, ancillary services typically include: AGC/Regulation, Spinning/OperatingReserve, Voltage/Reactive Power support and Black-start [3].Currently, these services are offered by large plants centrallydispatched generation, without possibility of being offered byDistributed Energy Resources (DER) [4]. Island OperationCapability (IOC) is not a new service from the conceptualpoint of view, since in the last decade, several authors andbusinesses around the world have advanced on recognize theneed for Island Operation capabilities but might not be able todetermine its availability or current performance [5]. However,it is in the currently where consolidation is projected by thenew paradigm of operation of active distribution systems onsmart grid [6].

The service IOC payment can be paid by availability,operation or both [7]. The restoration process normally accountwith plans that include the general premises and additionallymind some of the possible scenarios of restoration, but inmost cases have no strict applicability in practice by the samedynamic systems and random failures and events that mayoccur in a power system [8].Photovoltaic arrays generate power in DC. In order tosupply energy to the grid, an intermediate switchingpower converter is needed. In this study, a double-stageconverter is used, made of a boost DC-DC converter incascade to a space vector modulated (SVM) inverter. Theinverter is connected to the AC power by means of atransformer, that guarantees electrical insulation betweenPVs and mains, and a LCL filter, that reduces harmoniccontent given by the space vector modulation of theinverter. Some papers published in the technical literatureproved that LCL filter achieve better performances thanthose of traditional L filters. The detailed procedure forthe selection of filter elements is presented in [10].

Following this procedure, the inductance L1 can beselected on the basis of the current ripple desired oninverter side. If the transformer is specifically built for PVgeneration, this inductance is not actually present in thefilter because it is the leakage inductance of thetransformer itself. The capacitance C is usually sized as apercentage of the equivalent impedance seen at full load.The inductance L2 is evaluated on the basis of the resonantfrequency of the LCL filter. This is usually placed in arange between ten time the grid frequency and one-half ofthe inverter switching frequency. This choice is a goodcompromise between the necessity to have the cutofffrequency above grid frequency and below the switchingfrequency. The damping resistance is finally selected onthe basis of the desired filter efficiency, usually greaterthan 99%.

A load absorbing distorted currents at low power factor isconnected to the same node of the PV system. This load istypically constituted by some different loads connected inparallel. The low power factor is due to ohmic-inductiveloads whereas the harmonic distortion is mainly caused bypower electronics. In particular, diode rectifiers representa diffused class of loads that introduces a very highharmonic content in the source current.

So, in order toshow that the system is capable of compensating thereactive power and reducing the harmonic distortion, aload constituted by a RL load in parallel to a dioderectifier has been simulated. A schematic of the PV plantsimulated in this paper is shown in Fig. 1

The main goal of the system is the generation of themaximum allowable power given by the PV source.Moreover, as above mentioned, also the ancillary servicesof local voltage regulation and current harmoniccompensation should be obtained. Therefore, the controlsystem has to achieve the following tasks:

- PLL function to lock the grid voltage;
- MPPT algorithm to follow the maximum power pointof the PV source;
- stabilization of the voltage on the inverter DC-bus;
- regulation of the AC rms voltage by means of thereactive power generated;
- compensation of the current harmonics injected by thelocal load.

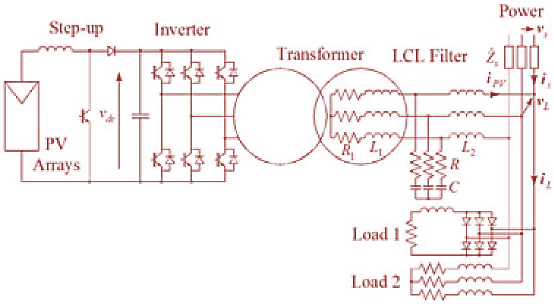

Fig. 1. Circuit configuration of grid-connected photovoltaicpower plant

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.2depicts 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.

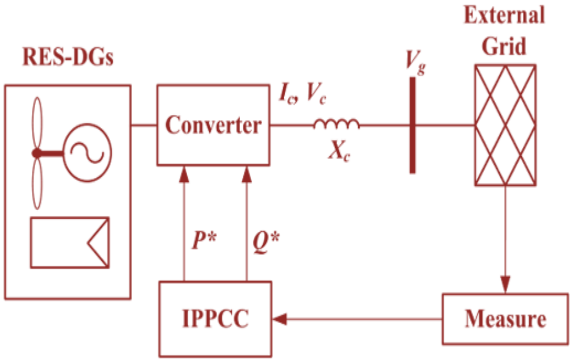

Fig. 2. Proposed control structure.

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. 2. 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. 3.

It isdivided in three zones where the proposed control algorithmoperates applying the following rules:

a) no control actions arecarried out within the Operative Range;

b) an amount of reactive(active) power is absorbed/injected into the grid to satisfy thevoltage constraints if the voltage variation is positive/negativewithin the Control Ranges, delimited by two threshold levels ($\varepsilon_u, \varepsilon_d$).

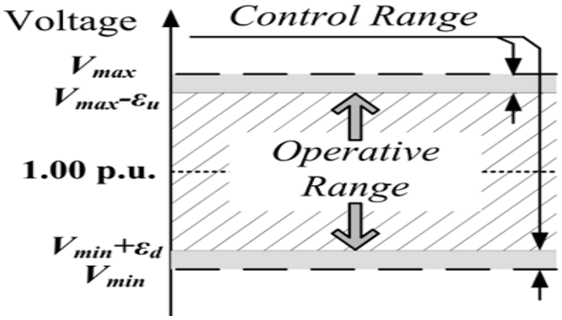

Fig. 3 Allowed, Operative and Control Ranges used in the proposed controlmethod.

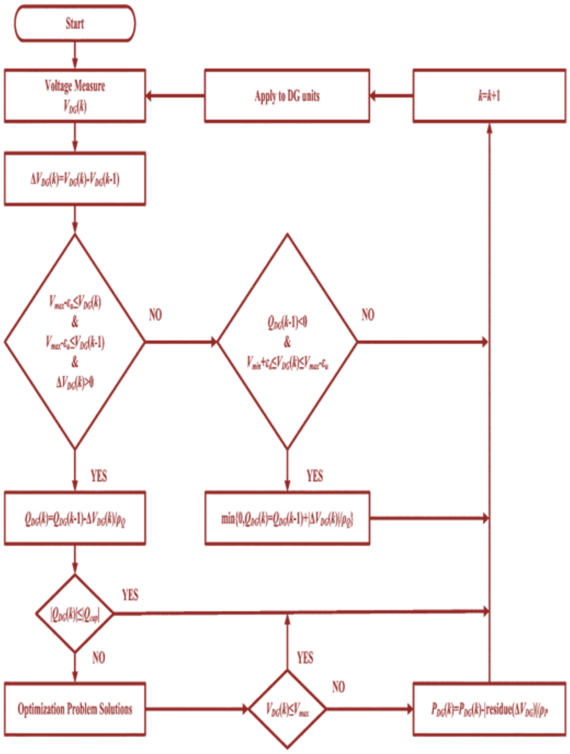

Fig. 4. Flow chart of the control algorithm.

In Fig. 4 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 *OperativeRange*and the reactive power is different from zero, the algorithm reduces the reactive power absorption proportionally tothe 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 controlmethod a real Italian MV distribution network has been considered.

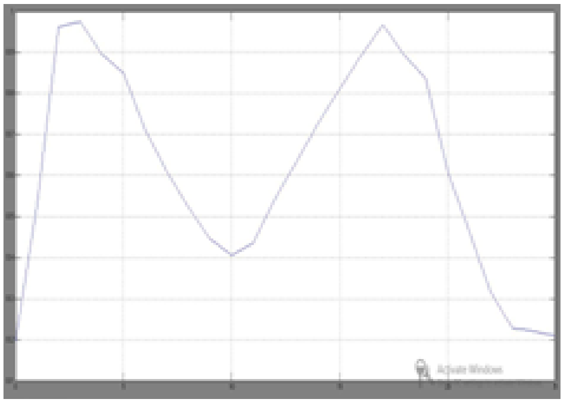

Fig. 5

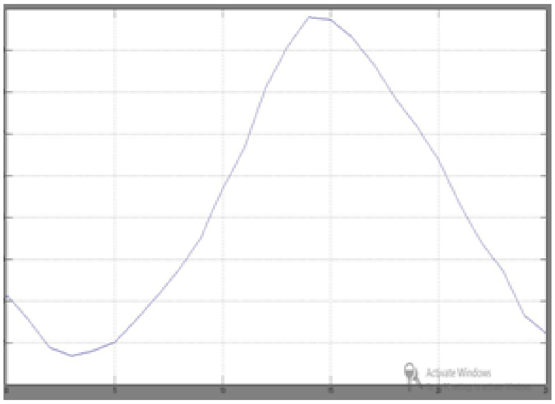

Fig. 6

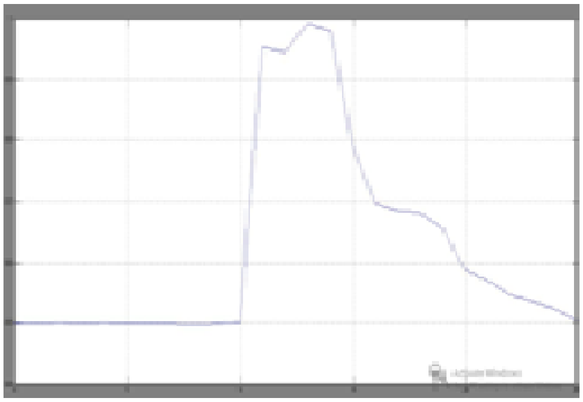

Fig. 7

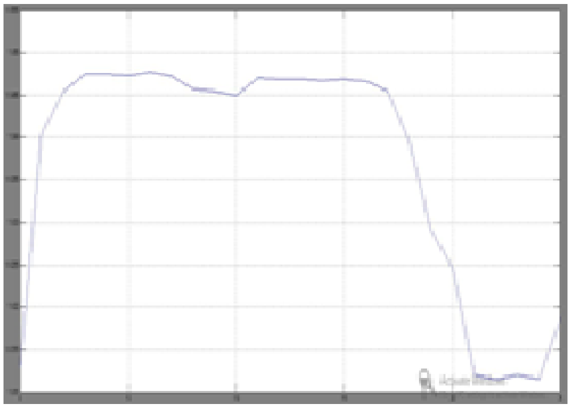

Fig. 8

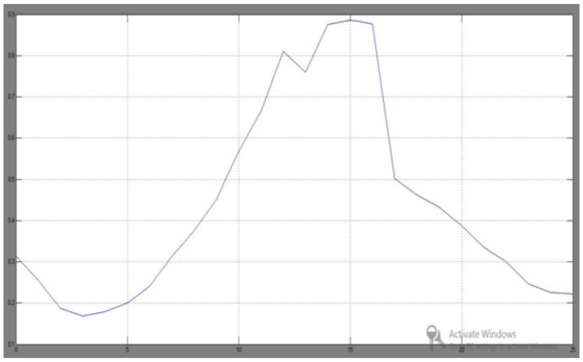

Fig. 9

V. CONCLUSION

A methodicaltactic was proposed for a demand-side primary frequency strategy to regulate thefrequency of the system to its nominal value and restore power balance for a multi-machine power systemmodel.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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