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# Coordinated local reactive power control in smart distribution grids for voltage regulation using sensitivity method to maximize active power

*Distributed generation (DG) integrated into Smart grid is the future of distribution systems. The expected impact is wide in terms of control, management, supply and use. In particular, in order to integrate DG based on renewable sources in distribution networks without compromising the integrity of the grid, it needs to develop proper control techniques to allow power delivery to customers in compliance with power quality and reliability standards. This paper proposes a coordinate local control approach based on a mixed distribution network (DN) sensitivity analysis to maintain voltage levels within regulatory limits. The proposed control is based on a reactive/active power regulation able to offer voltage regulation as ancillary services to the DN, and to maximize the produced active power of the DGs. The validation of the proposed control technique has been conducted through a several number of simulations on a real MV Italian distribution system.*

Keywords: Smart Grid, Distributed Generation, Power Distribution, Reactive Power Control, Voltage Control.

## 1. Introduction

Smart Grids could play a key role in supporting the integration of Distributed Generation (DG) in distribution systems. In fact, advances in research on Smart Grids could lead power systems toward active, flexible, scalable web-energy networks able to support large-scale penetration of DG, to facilitate the integration of Renewable Energy Sources (RES), and to reduce Green House Gas Emissions [1]. However, are DG sources desirable everywhere and always?

In order to avoid any problem, DG must be integrated in distribution networks without compromising the integrity of the grid, existing level of availability and reliability of supply, ensuring benefits for customers in energy purchasing [2]. With these aims, a sustainable penetration of DG can be achieved only if benefits for both the DG owners and electric utilities are guaranteed: for the first, in presence of a high penetration of DG, the network must be able to ensure the dispatching of the maximum power produced; from the perspective of electric utilities DG could be included to offer ancillary services for better resources utilization of distribution systems. Among these ancillary services, reactive power support for voltage regulation appears as one of the most important [3].

Here, the ancillary service of voltage support is addressed through the proposal of a coordinated local reactive power control for DG-RESs based owners with the aim to: i) regulate the voltage at the DG connection bus and ii) maximize active power production.

Reactive power support has been adequately proposed in several research activities by considering two different approaches. In [4]-[7] centralized control approach has been used, but the two major drawbacks are the requirement of: i) substantial investments in

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communications and control systems, ii) a greater amount of information to be telemetered to a control center and processed, and sent to local controller devices [8]-[9]. In contrast, decentralized control strategies act locally and can be implemented by reducing the burden information. This approach has been proposed by Kerber *et al.* in [10] where an adaptive decentralized voltage control for PV systems, designed, modeled and tested on different Low Voltage (LV) grids prone to voltage problems was presented, while in [11] a voltage control of decentralized PV in LV network has been presented with the aim of distribution loss reduction and voltage regulation into statutory range without any telecommunications. In [12] a decentralized reactive power management technique addressing the problem of sensitivity analysis, based on voltage regulation in microgrids with a single doubly fed wind energy induction generator, was presented. Robbins *et al.* proposed a local controller on each bus of the network that monitors the bus voltage and, whenever there is a voltage violation, it uses locally available information to estimate the amount of reactive power that needs to be injected into the bus in order to correct the violation [13].

This paper is focused on the benefits that better use of the reactive power capabilities of DG can deliver to distribution systems by using a hybrid approach, coordinated/decentralized. Moving beyond the local controller designs for voltage regulation, covered in [14]-[17], this work proposes a local control method for DG-RESs that a single Independent Power Producer (IPP) coordinates on its distributed plant. The method is based on the sensitivity analysis that gives information concerning as the variation in the output of a model (voltage) can be apportioned, qualitatively and quantitatively, to different sources of variation (active or reactive power). The main contribution of the paper is to introduce the concept of *Mixed Sensitivity Analysis* that allows regulating the voltage at RES connection bus by means of a reactive/active power variation produced by another DG connection bus. The proposed methodology assures low computational effort in order to guarantee effective on-line solution to the voltage regulation problem.

The paper is laid out as follows: Section II briefly presents the concept of capability curve and the European current grid code of DG-RESs connection in terms of reactive control. In Section III, the control problem formulation and the solution method is presented. In Section IV, the methodology is applied to a typical Italian distribution network with the results and Section V presents discussion with conclusions..

## 2. Voltage regulation

Usually, RESs are connected to the Distribution Network (DN) through electronic power converters and are responsible for the modification of the voltage profiles at customer's end. The voltage at the customer depends on the voltage drop along the lines, which in turn is a function of the active and reactive power exported from RES connection bus toward the bulk supply point (BSP).

Typically, Distribution Network Operators (DNOs) require to DG to operate in Power Factor Control (PFC) mode, so that the ratio P/Q is kept almost constant and the reactive power follows the variation of the active power. This requirement allows voltage profiles to be kept within statutory limits, but with a high penetration of DG this operation mode could tend to increase the voltage variation, especially in rural areas, and voltage rise becomes a significant constraint for both the DNOs and the DG owners in terms of grid security and reliability, and power output maximization, respectively. Thus, new voltage control strategies are expected in order to meet reactive compensation standards that are becoming a reality for DG in Europe, Asia, and USA. The following are the grid codes used in European countries where RES penetration is high.

## 2.1. European grid codes

Typically, the power factor at the grid connection bus is limited by the capability curves reported in the Grid Code that depends on the country rules. In the paper we have compared the power factor limits (leading and lagging) relating to the DN of four European countries at MV level, and the values are shown in the Table 1.

Table 1: PF limits (leading and lagging) in Denmark, Germany, Italy and United Kingdom Grid Code at MV level

| | **Denmark** | **Germany** | **Italy** | **United Kingdom** |
|---|---|---|---|---|
| $PF_{min}$ | 0.975 for 1.5 - 25MW power plant<br>0.950 for > 25MW power plant | 0.950 | 0.950 | 0.950 |

$PF_{min}$ is the minimum allowable value of power factor (leading or lagging) at the grid connection bus. It is worth to note that in Germany, Italy and UK $PF_{min}$ is independent from the power to inject, while in Denmark increases with decreasing the produced active power. Therefore, being fixed $P_{DG}$, the Grid Code limits the reactive power absorbed or injected by the DWTs.

## 2.2. Capability curves for DG inverter based and control system

Fig. 1 depicts the structure of the proposed control system that includes a generic electronic interface based DG, where $V_{act}$, $P_{DG}$ and $Q_{DG}$ are the voltage, the active power and the reactive power measured at grid connection point, respectively. They are used in order to calculate the reference signals $P^*$ and $Q^*$ that drive the converter. $I_c$ and $V_c$ are the current output and the voltage output of inverter, respectively; $X_c$ represents the total reactance of the DG transformer that adapts the DG's output voltage to the grid voltage ($V_g$) and the one of the grid filters.

The power converter output is limited by the generator capability curve because current and voltage output define the boundary levels to vary the DG reactive and active power. Here, we consider Distributed Wind Turbines (DWTs) based on a synchronous generator, so that the capability curve of reactive power, fixed the maximum active power available from the primary source, can be calculated as seen in [18].

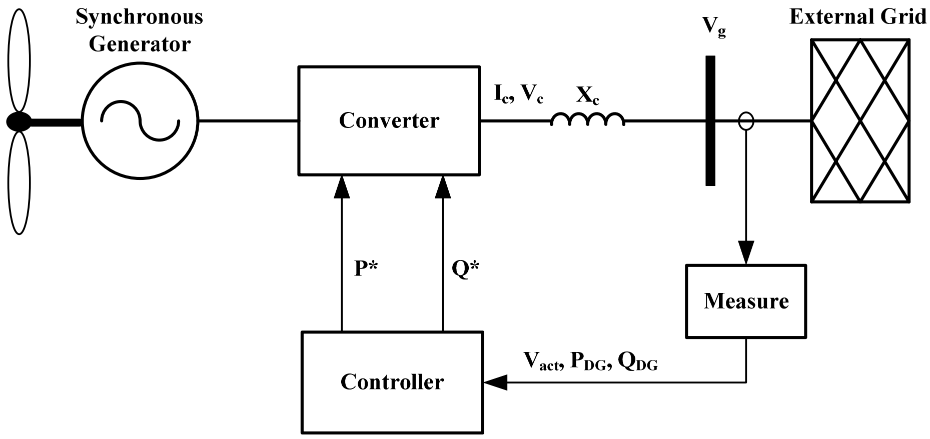


Fig. 1: Control system scheme

It is possible to demonstrate [15] that the reactive power capability corresponds to:

$$Q_{cap} = min\{ Q_{DG}^{c}, Q_{DG}^{v} \} \tag{1}$$

where $Q_{DG}^{c}$ and $Q_{DG}^{v}$ are the maximum amounts of reactive power limited by the current and voltage constraints:

$$\begin{cases} Q_{DG}^{c} = \sqrt{(V_g I_{c_{max}})^2 - P_{DG}^2} \\ Q_{DG}^{v} = \sqrt{\left(\dfrac{V_g V_{c_{max}}}{X_c}\right)^2 - P_{DG}^2} - \dfrac{V_g^2}{X_c} \end{cases} \tag{2}$$

In (2) $I_{c_{\max}}$ and $V_{c_{max}}$ are respectively the maximum current output and the maximum voltage output of inverter, which depends by the dc-link voltage ($V_{dc}$) and by the adopted modulation technique. The values of $I_{c_{max}}$ and $V_{c_{max}}$ depend on the rated active and reactive power of the DWTs by the following relations [18]:

$$\begin{cases} I_{c_{max}} = \dfrac{\sqrt{P_R^2 + Q_R^2}}{V_{g_{max}}} \\ V_{c_{max}} = \dfrac{f_{max} X_c}{V_{g_{max}}} \sqrt{1 + \left( tan\,\theta_R + \dfrac{V_{g_{max}}^2}{f_{max} X_c} \right)^2} \end{cases} \tag{3}$$

where $\theta_R$ is the rated power factor angle and $f_{max}$ is the maximum grid frequency [15]. Generally, the values obtained by (3) are less restrictively than the values shown in Table 1, however in the proposed control method are both considered.

## 3. Mixed Sensitivity Analysis based on coordinated local control

In order to give the reference values to the electronic converter, a mixed sensitivity method is introduced to regulate and coordinate active and reactive power injections at RES connection bus. In fact, the sensitivity analysis allows evaluating the relationship among power injections and voltage changes: in particular, sensitivity coefficients give information concerning the effect, qualitative and quantitative, produced by a variation of reactive power injection/absorption at RES connection bus.

The sensitivity analysis consists to calculate the sensitivity coefficients ( $\rho_Q^{xy}$ and $\rho_P^{xy}$ ) by varying $P_{DG}$ and $Q_{DG}$ injections at a generic bus $x$ at each time step and evaluating the voltage variations at generic bus $y$. Analytically, $\rho_Q^{xy}$ and $\rho_P^{xy}$ can be calculated by:

$$\begin{cases} \rho_Q^{xy} = \dfrac{\Delta V_{DG_Q}^{x}(k)}{\Delta Q_{DG}^{y}(k)} \\ \rho_P^{xy} = \dfrac{\Delta V_{DG_P}^{x}(k)}{\Delta P_{DG}^{y}(k)} \end{cases} \tag{4}$$

where $\Delta V_{DG_Q}^{x}(k)$ and $\Delta V_{DG_P}^{x}(k)$ represent the voltage variations at bus $x$ due to reactive power ( $\Delta Q_{DG}^{y}(k)$ ) and active power ( $\Delta P_{DG}^{y}(k)$ ) variations at bus $y$. In that case the sensitivity matrix $\underline{\underline{\Lambda}}_Q$ ( $\underline{\underline{\Lambda}}_P$ ) can be calculated as following: as the sensitivity coefficients are evaluated off-line, $\rho_Q^{xy}$ can be estimated by fixing all network parameters, including load and the active power generation profiles and only by varying the reactive power of each bus:

$$\underline{\Delta V}_{DG_Q} = \begin{pmatrix} \rho_Q^{11} & \rho_Q^{12} & \cdots & \rho_Q^{1n} \\ \rho_Q^{21} & \rho_Q^{22} & \cdots & \rho_Q^{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \rho_Q^{n1} & \rho_Q^{n2} & \cdots & \rho_Q^{nn} \end{pmatrix} \underline{\Delta Q}_{DG_Q} = \underline{\underline{\Lambda}}_Q \underline{\Delta Q}_{DG_Q} \tag{5}$$

where $n$ is the number of RES units, the elements out of diagonal are the mixed sensitivity coefficients and the diagonal elements are the sensitivity of the bus used in decentralized approach [14]. Analogously, the matrix $\underline{\underline{\Lambda}}_P$ is defined.

## 4. Control method and proposed algorithm

The control method proposed in this paper realizes the regulation of voltage profile by means of injection or absorption of reactive power and, only if necessary, active power.

In order to explain the method, it is necessary to introduce a voltage plane in which four threshold levels are defined around the rate value ( $V_{opt}$ = 1 p.u.). Considering the allowable voltage range $[V_{min}, V_{max}]$ a *operative voltage range* and a *control voltage range* can be determined through two threshold levels $(\varepsilon_u, \varepsilon_d)$, like depicted in Fig. 2.

If the measured voltage at the connection RES bus is within the *operative voltage range* no control actions are carried out; otherwise, if the value is within the *control voltage range* and the voltage variation is greater than zero, a certain amount of reactive or active power is injected or absorbed proportionally to the voltage variation. The amount of reactive (active) power is calculated by using sensitivity coefficients and depends on the voltage variation. A better explanation of sensitivity coordinated control method is shown in Fig. 3, where the flow chart algorithm in the case of the voltage goes on the upper limit is depicted.

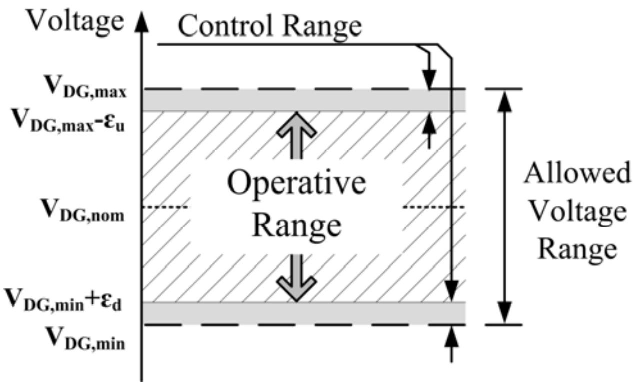



Fig. 2: Allowed, Operative and Control Ranges for the proposed control method

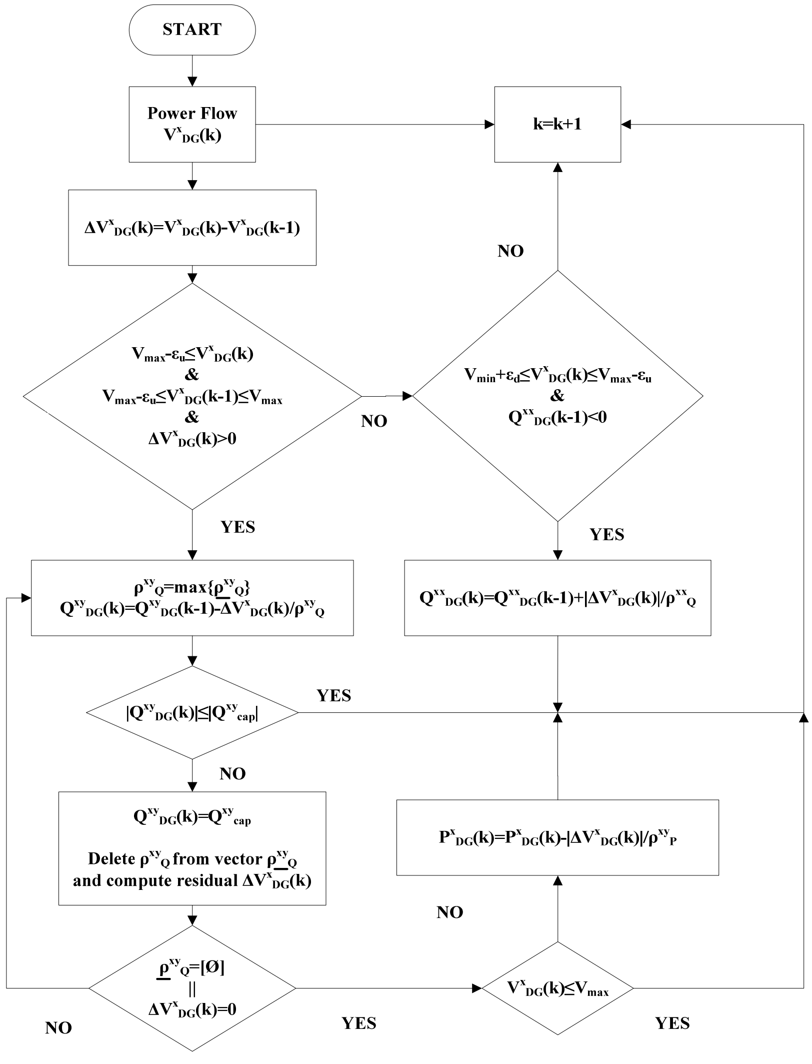



Fig. 3: Flow-chart of the proposed sensitivity coordinated voltage method

The procedure begins evaluating the difference at RES connection bus of generator *x* ($V_{DG}^{x}$) between the voltage measured at the generic instant $k$ and the previous one $(k-1)$:

$$\Delta V_{DG}^{x}(k) = V_{DG}^{x}(k) - V_{DG}^{x}(k-1) \tag{6}$$

If (6) is positive and the voltage is greater than $(V_{max} - \varepsilon_u)$, the control computes the maximum value of the sensitivity vector:

$$\underline{\rho}_{Q}^{xy} = \left[\rho_Q^{x1}, \rho_Q^{x2}, \ldots\ldots, \rho_Q^{xn}\right] \tag{7}$$

where $n$ is the number of DG generator that have a sensitivity different by zero relative to bus $x$, and after the value of reactive absorption according to:

$$Q_{DG}^{xy}(k) = Q_{DG}^{xy}(k-1) - \frac{\Delta V_{DG}^{x}(k)}{\rho_Q^{xy}} \tag{8}$$

If the amount of reactive power is within the capability region of the DG converter the algorithm ends, otherwise $Q_{DG}^{xy}(k)$ is set at capability value $Q_{cap}^{xy}$, the maximum sensitivity value found ( $\rho_Q^{xy}$ ) is eliminated by vector $\underline{\rho}_{Q}^{xy}$ and the residual of $\Delta V_{DG}^{x}(k)$ is calculated.

The cycle goes on trying to compensate the variation of voltage on the bus $x$ by absorption of reactive power of DG generators, respecting the limits imposed by capability curve until either the residual of $\Delta V_{DG}^{x}(k)$ is zero or the vector $\underline{\rho}_{Q}^{xy}$ is empty. At the end of this cycle the algorithm checks if the value of $V_{DG}^{x}(k)$ is smallest than the maximum allowed voltage ( $V_{max}$ ); otherwise, it reduces the amount of the active power at bus $x$ according to:

$$P_{DG}^{xy}(k) = P_{DG_{av}}^{xy}(k) - \frac{\Delta V_{DG}^{x}(k)}{\rho_P^{xy}} \tag{9}$$

where $P_{DG_{av}}^{xy}(k)$ is the power available at bus $x$ at instant $k$ .

## 5. Case study: simulations and results

In order to illustrate the sensitivity coordinated control method, a real Distribution Network, located in the south of Italy, has been considered. The network diagram is shown in Fig. 4. It consists of a 132 kV (50 Hz) sub-transmission connected to 4 MV feeders (20 kV) through a 150/20 kV $\Delta/Y_g$ transformer with rated power equal to $S_T$ = 25 MVA, $V_{cc}$ = 15.5% and $X/R$ = 0.1. The transformer's tap is fixed to 1.006 p.u. according to one of the two classical control strategies used for the Italian distribution systems [16]. The DWTs are connected at the bus 31, 46, 53 and 54 with a rated power of $S_T$ = 5 MVA. The four lines are characterized by the presence of feeders with different load concentration levels (high concentration in *feeder A*, medium in *feeder B* and low in *feeder C*). *Feeder D* represents an equivalent load tapped at the MV busbars. Data of interest referred to the MV distribution network are reported in Table 2 [19].

Table 2: Network geometrical characteristics

| Feeder | Total Length (km) | Cable Lines (km) | Uninsulated Overhead Lines (km) | Feeder Section Variation (mm$^2$) |
|---|---|---|---|---|
| A | 17.23 | 7.63 | 9.60 | 3x(1x50) ÷ 3x(1x120) |
| B | 4.30 | 4.30 | --- | 3x(1x95) ÷ 3x(1x185) |
| C | 20.37 | --- | 20.37 | 3x(1x35) ÷ 3x(1x150) |

The sensitivity matrix is calculated by using the procedure described in the Section III. The sensitivity coefficients relating to the generator connected at the bus 54 are represented by the average of the angular coefficients of the curves shown in Fig. 5.

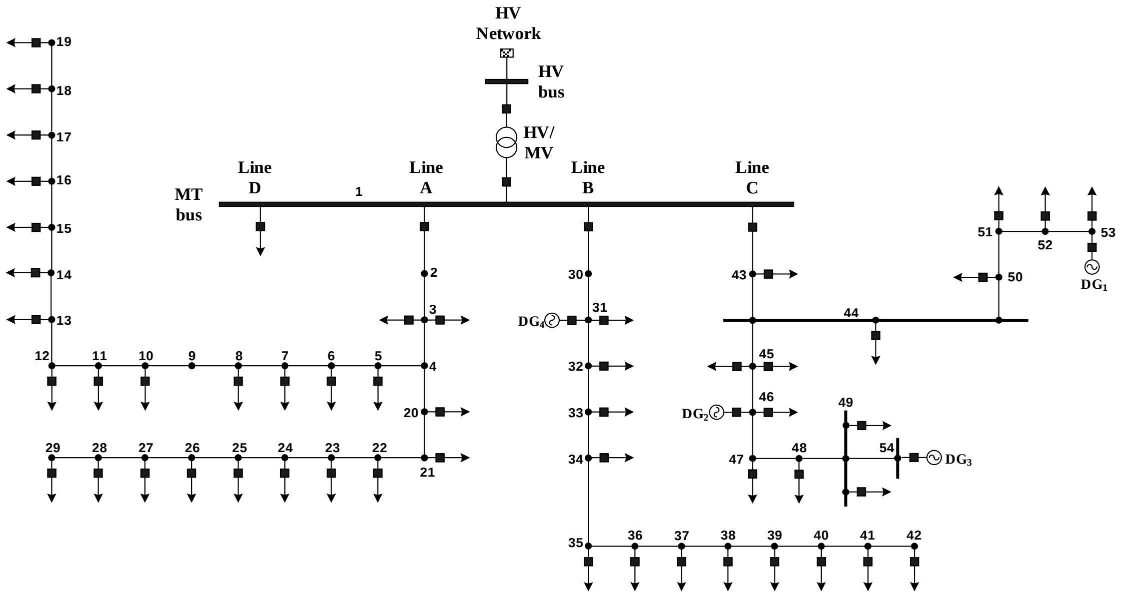



Fig. 4: Single diagram of the distribution network under test

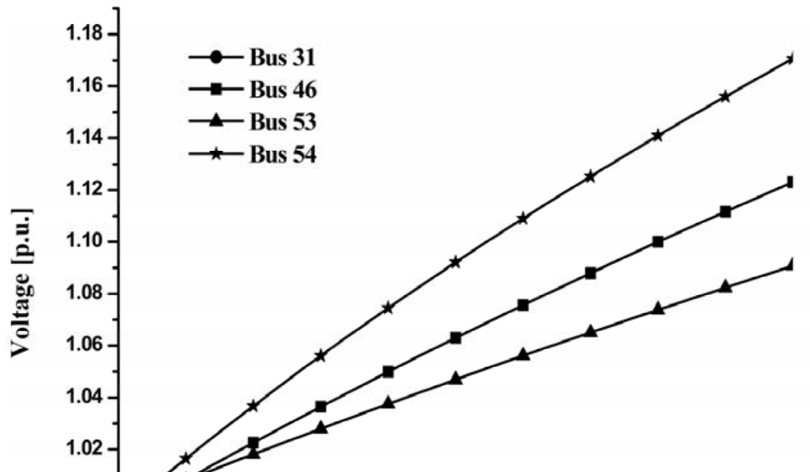
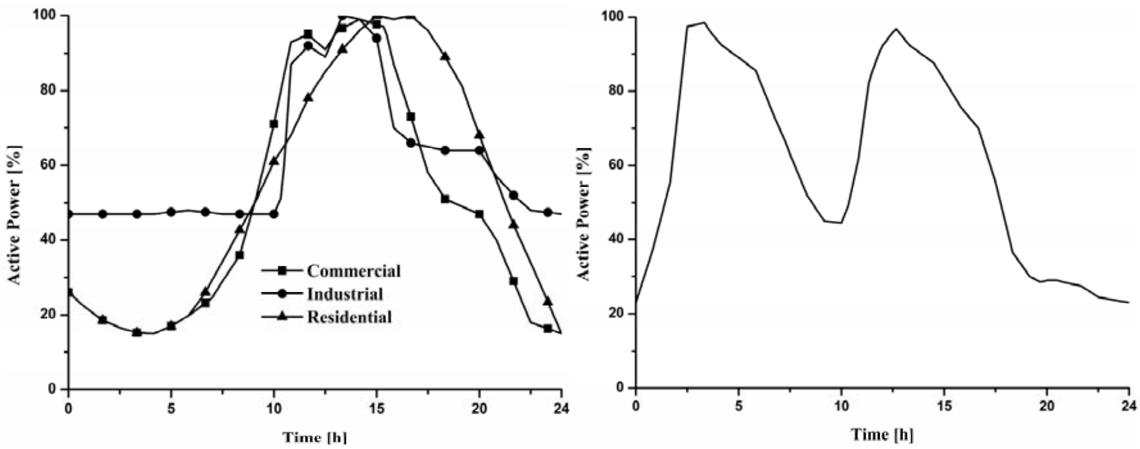



Fig. 5: Sensitivity reactive power curves of bus 54

Initially, the power factors of the DG are set to 1 and the voltage limits are fixed to ±5% of the rated voltage, according to the constraints imposed by [20]; moreover, the power factor is limited between 0.95 leading and 0.95 lagging. The *operative voltage range* is completely defined setting $\varepsilon_u = \varepsilon_d = 0.015$.

A time series simulation based on a one-day-ahead load forecast with computed state of 10 minute is carried out in order to show the effectiveness of the proposed control method. In Fig.6, the load and generation normalized profiles, employed for the customers and the 4 DWTs, are depicted.




a)Load demands b)Generation profiles

Fig. 6: Active power normalized profiles

The resulted voltage values at DWT connection buses are recorded at each step. In Fig. 7 it is possible to see how, without control system, the voltages on the bus 46, 53 and 54 exceed the limits. In order to compare the goodness of the proposed coordinated control three different types of regulation are implemented. The first one consists in a simple curtailment of the active power when the voltage goes over the limits imposed by the standards. The active power reduction needed to avoid voltage problem is calculated using the sensitivity active power coefficients. The second method is a decentralized control as described in [15]. In this case there is an active power reduction only if the reactive power reaches the limits imposed by the capability curve of the generator or the limits imposed by the power factor. The last one is the coordinated control illustrated in the Section 4. It is possible to achieve a voltage control within the limits with each of the three method illustrated, as shown in Fig. 8.

The difference is the active power curtailment that each method needed in order to obtain the voltage control on the distribution network within the limits imposed by the standard. Indeed, as depicted in Fig. 9, the coordinated method does not need active power reduction to comply with the voltage constraints. When the reactive power reaches the limits of the capability curves, in contrast to the other method, the coordinated control takes advantage of the availability of reactive power of other DWTs in order to achieve the voltage control.

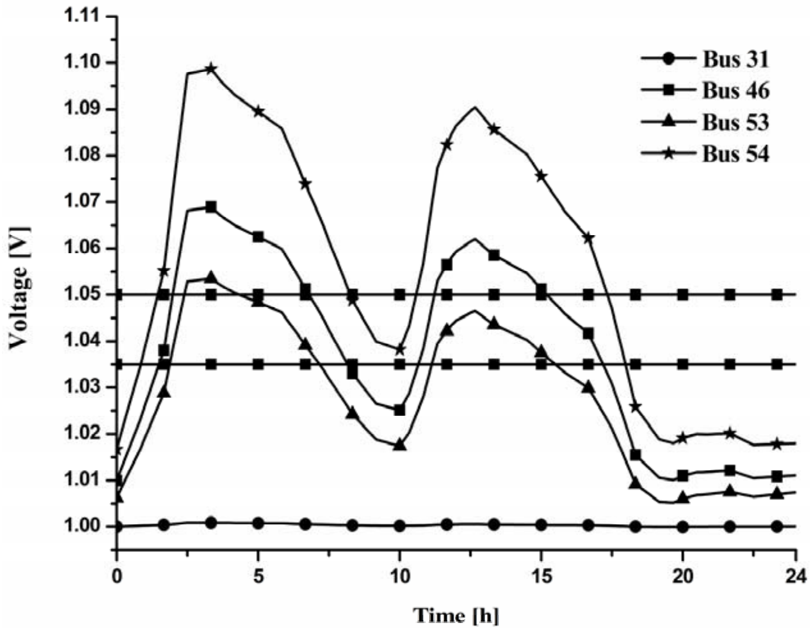



Fig. 7: Voltage profiles at the DWT connection buses without control

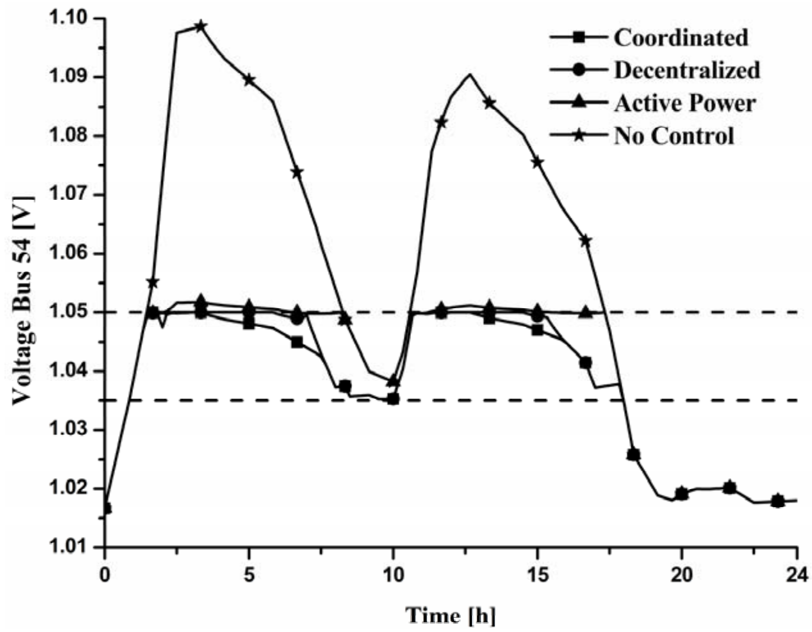



Fig. 8: Voltage profiles at the bus 54 with different voltage control methods

Fig. 10 shows the reactive power absorbed by the DWT connected at the bus 46 even though the voltage is within the limits (Fig. 11). Indeed, as it shown in Fig. 5, the bus 46 is the second with the higher sensitivity coefficient at the bus 54. It is worthy to note that, as shown in Fig.12, the proposed coordinate control model never exceeds the capability curve limits and the power factor limits of the DG.

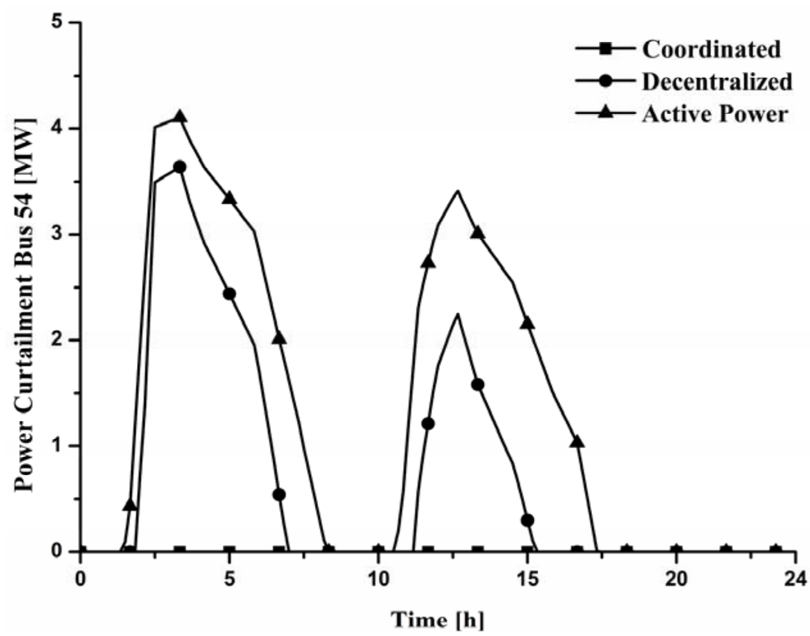



Fig. 9: Active power curtailment at bus 54 using different voltage control methods

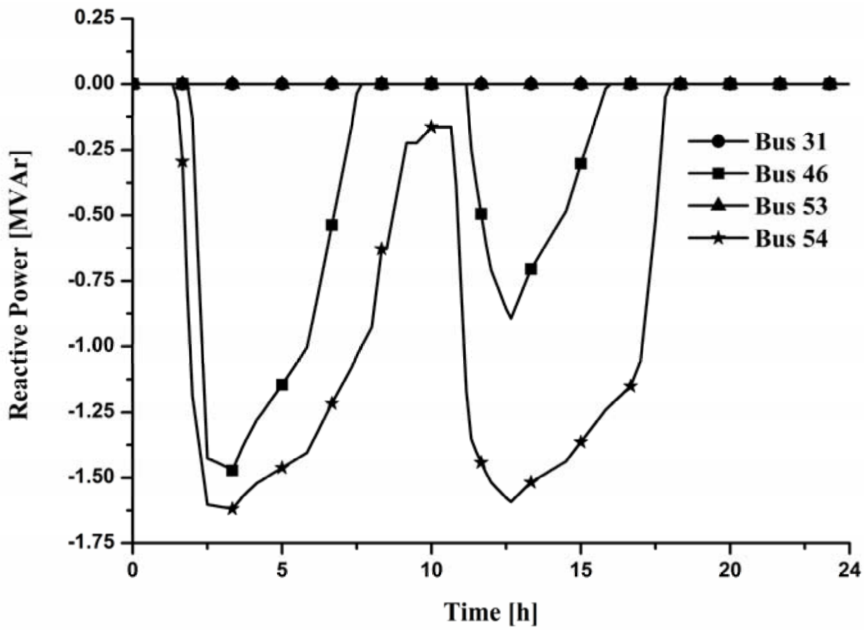



Fig. 10: Reactive power at DWT connections using coordinated voltage control

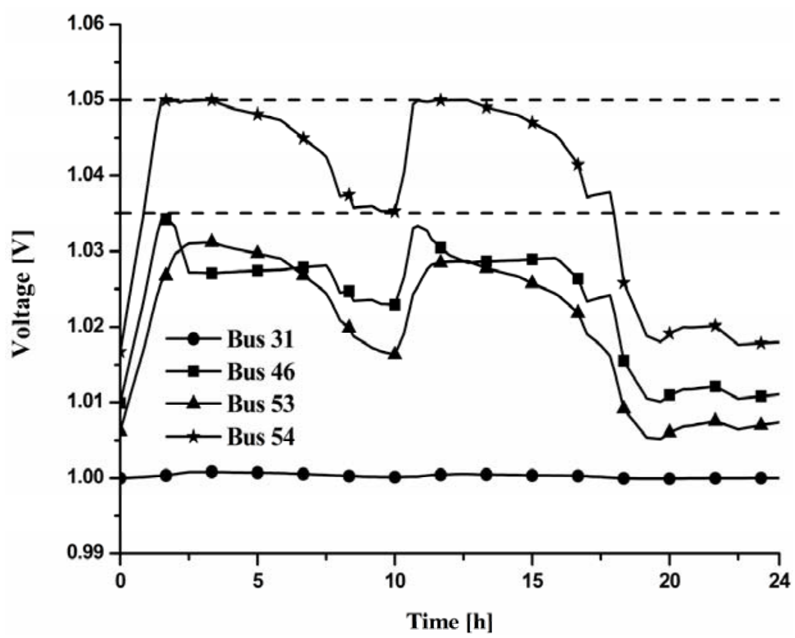



Fig. 11: Voltage profiles at DWT connection using coordinated voltage control

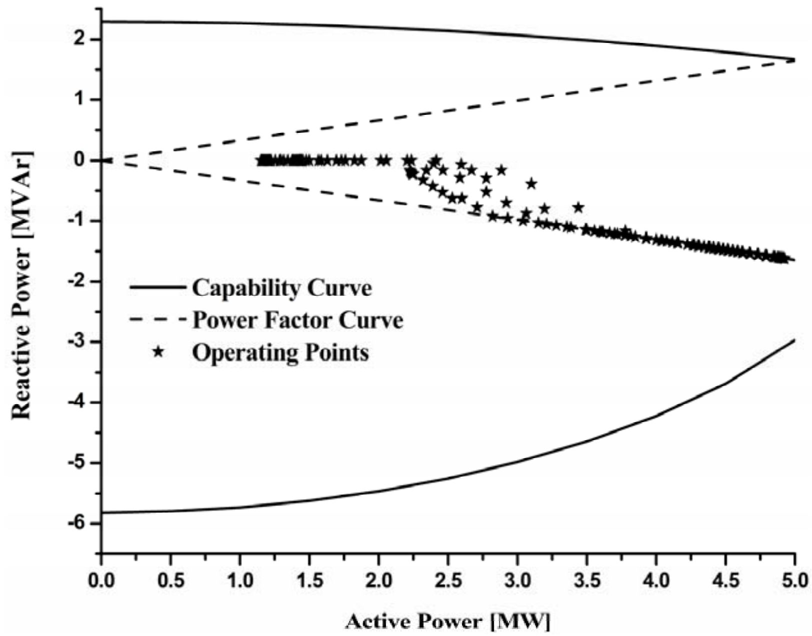


Fig. 12: Capability curves of the DWT connected at bus 54

## 6. Conclusions

This paper has demonstrated the validity of the proposed local coordinate regulation method based on a mixed sensitivity analysis applied to a real distribution network with four Distributed Wind Turbines.

The carried out time series simulations have highlighted the better performance of the coordinated method compared to other strategies present in literature (e.g.: methods based on decentralized controls). In fact in the study case, the proposed control avoids voltage problems without active power curtailments compared to other methods. Furthermore, the control takes into account also the physical limits imposed by the capability curves of the generators and the limitation of the power factor present in the national standards.

## References

[1] V. Loia, A. Vaccaro, A decentralized architecture for voltage regulation in Smart Grids, Industrial Electronics (ISIE), in Proc. IEEE International Symposium, pp.1679-1684, 2011.

[2] M. Cavlovic, Challenges of optimizing the integration of distributed generation into the distribution network, Energy Market (EEM), in Proc. 8th International Conference on the European, pp.419-426, 2011.

[3] A. C. Rueda-Medina, A. Padilha-Feltrin, Distributed Generators as Providers of Reactive Power Support—A Market Approach, IEEE Trans. Power Syst, vol.28, no.1, pp.490-502, Feb. 2013.

[4] M. Pucci, M. Cirrincione, Neural MPPT Control of Wind Generators With Induction Machines Without Speed Sensors, IEEE Trans. Ind. Electron., vol.58, no. 1, pp.37-47, Jan. 2011.

[5] J. A. P. Lopes, Â. Mendonça, N. Fonseca and L. Seca, Voltage and reactive power control provided by DG units, in Proc. of CIGRE Symp.: Power Systems With Dispersed Generation, 2005.

[6] A. Casavola, G. Franzè, D. Menniti, N. Sorrentino, Voltage regulation in distribution networks in the presence of distributed generation: A voltage set-point reconfiguration approach, Elec. Power Syst. Res., vol. 81, pp. 25-34, 2011.

[7] A. Keane, L. F. Ochoa, E. Vittal, C. J. Dent, G. P. Harrison, Enhanced Utilization of Voltage Control Resources With Distributed Generation, IEEE Trans. Power Syst., vol. 26, no. 1, pp. 252-260, 2011.

[8] M. S. P. Carvalho, P. F. Correia, Luís A. F. M. Ferreira, Distributed Reactive Power Generation Control for Voltage Rise Mitigation in Distribution Networks, IEEE Trans. Power Syst., vol. 23, no. 2, pp. 766-772, 2008.

[9] A. Cagnano, E. De Tuglie, M. Liserre, R. A. Mastromauro, Online Optimal Reactive Power Control Strategy of PV Inverters, IEEE Trans. Ind. Electron., vol.58, no.10, pp.4549-4558, Oct. 2011.

[10] G. Kerber, R. Witzmann, H. Sappl, Voltage limitation by autonomous reactive power control of grid connected photovoltaic inverters, in Proc. of Compatibility and Power Electronics, pp. 129-133, 2009.

[11] K. Tanaka, M. Oshiro, S. Toma, A. Yona, T. Senjyu, T. Funabashi, C.H. Kim, Decentralised control of voltage in distribution systems by distributed generators, IET Gener. Transm. Distrib., vol. 4, no. 11, pp. 1251–1260, 2010.
[12] R. Aghatehrani, R. Kavasseri, Reactive power management of a DFIG wind system in microgrids based on voltage sensitivity analysis, IEEE Trans. Sustain. Ener., vol. 2, no. 4, pp. 451-458, 2011.
[13] B. A. Robbins, C. N. Hadjicostis, A. D. Domínguez-García, A two-stage distributed architecture for voltage control in power distribution systems, IEEE Trans. Power Syst., accepted for inclusion in a future issue of the journal, pp. 1-13, 2012.
[14] V. Calderaro, V. Galdi, G. Massa, A. Piccolo, Distributed generation management: an optimal sensitivity approach for decentralized power control, in Proc. of 3rd Conf. and Exhib. on Innovative Smart Grid Technologies (ISGT Europe), pp. 1-8, 2012.
[15] V. Calderaro, V. Galdi, G. Massa, A. Piccolo, Distributed Generation and local voltage regulation: an approach based on sensitivity analysis, in Proc. of 2nd Conf. and Exhib. on Innovative Smart Grid Technologies (ISGT Europe), pp- 1-8, 2011.
[16] V. Calderaro, G. Conio, V. Galdi, A. Piccolo, Reactive power control for improving voltage profiles: a comparison between two decentralized approaches, Elec. Power Syst. Res., vol. 83, no. 1, pp. 247-254, 2012.
[17] V. Calderaro, V. Galdi, G. Massa, A. Piccolo, Optimal fuzzy controller for voltage control in distribution systems, in Proc. of 11th International Conference on Intelligent Systems Design and Applications (ISDA), pp.1282-1287, 2011.
[18] N.R. Ullah, K. Bhattacharya, T. Thiringer, Wind Farms as Reactive Power Ancillary Service Providers-Technical and Economic Issues, IEEE Trans. Energy Convers., vol.24, no.3, pp. 661-672, 2009.
[19] S. Conti, A. M. Greco, Innovative voltage regulation method for distribution networks with distributed generation, in Proc. 2007 International Conf. on Electricity Distrib. (CIRED), pp 1-4, 2007.
[20] IEEE Application Guide for IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE Std 1547.2-2008, pp.1-207, April 15 2009.