Adaptive Voltage Control Ancillary Service for Renewable Energy in Distribution Network

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***Abstract*: In this project highly concentrated about Distributed Generation (DG) into Smart Grid represents a great challenge of the future for power systems. The integration of DG based on Renewable Energy Sources (RESs) in distribution networks without compromising the integrity of the grid. It requires the development of proper control techniques to allow power delivery to customers in compliance with power quality and reliability standards. The transmission systems in the present time are becoming increasingly complex & stressed because of growing demand and because of restrictions on installation of new lines. For transmission network security and failure point of view it is quite important to calculate the most sensitive node in the network. The major issue in these problem is the collapse of transmission system which is most suffered by the frequent variations load. A coordinated local control approach that allows, Distribution System Operator (DSO) and Independent Power Producers (IPPs). That 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. It's to realize cooperation of a nonlinear constrained optimization problem is formulated and solved by Synchronous Reference Frame (SRF). The validation of the control technique has been conducted through several time series simulations on a distribution system.**

Keywords: Renewable energy, STATCOM, Synchronous Reference Frame, Distribution network, Independent Power producer.

I INTRODCTION

Renewable generation from wind and solar has increased substantially during. Past few years and forms significance proportion of the total generation in the grid. This renewable generation is concentrated in a few states, to the extent that it cannot be called marginal generation and serious thought needs to be given to balance the variability of such generation. There is an ambitious for increase of such renewable generation and therefore, it is imperative to work out a way forward for facilitating large scale integration of such variable Renewable Energy Sources (RES), keeping in view the security of the grid. It becomes even more challenging to balance this variable RES.

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. With these aims, a sustainable penetration of distributed generation 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.

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.

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 significant constraint for both the DNOs and the DG owners in terms of grid security and reliability, and power output maximization, respectively.

II EXISTING METHOD & PROBLEM FORMULATION

A. Ancillary Service

The ancillary services are necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system. And it identifies six different kinds of ancillary services:

1. scheduling and dispatch
2. Reactive Power And Voltage Control
3. loss compensation
4. load following
5. system protection
6. energy imbalance

B.Static Var Compensator

A static VAR compensator (VAR is defined as volt ampere reactive) is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, which is regulating voltage, power factor, harmonics and stabilizing the system Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks.

The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

1. SVCs are connected to the power system, to regulate the transmission voltage namely “Transmission SVC".
2. SVCs are connected near large industrial loads, to improve power quality, so it is called as "Industrial SVC".

In transmission applications, the SVC is used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use thyristor controlled reactors to consume VARs from the system, lower than rated system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher than system rated voltage. By connecting the thyristor-controlled reactor, inductive power are continuously changes along with a capacitor bank step which is, the net result is continuously-variable leading or lagging power obtained progressively. SVCs are typically placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage.

C.Problem Formulation

The coordinated voltage control action takes place only if the first regulation strategy, based on the sensitivity analysis analytically described, fails. The solution of an optimization problem with nonlinear constraints allows obtaining the set points that IPP must use to regulate voltage profile. The objective function f (Q_{dg}) to minimize through the control variable is the sum of the DG-RESs reactive powers owned by IPP:

$$min_{Q_{DG}}\{f\{Q_{DG}V\}\} = min_{Q_{DG}}\sum_{i=1}^{n} Q_{DG} \qquad (1)$$

Subject to the following constraints:

$$\begin{cases} V_{min} \le V_{DGi} \le V_{max} \\ PF_{min} \le PF_{DGi} \le PF_{max} \\ Q_{min} \le Q_{DGi} \le Q_{max} \end{cases} \qquad (2)$$

Where in equation (1) N is the number of DG units, is the vector of the reactive powers injected/absorbed by DG units, equation (2) represent V_{min} and V_{max} are, respectively, the minimum and maximum values of the voltage imposed by the standard, PF_{min} and are the power factor constraints, Q_{min} and are the limits imposed by the physical capability of the converter, as described in the next subsection. V_{DGi}, and are the voltage, power factor, and reactive power values of DG-RES, respectively. Furthermore, we need to consider the power flow equations as equality constraints of the optimization problem. The nonlinear relationships between the constraints and the control variable Q_{DGi} for the bus are

$$\begin{cases} Q_{DG} = V_I \sum_{h\in N_I} V_h[Gi]\sin(V_i - V_h) - Bih\cos(V_i - V_h) \\ PF_i = \cos\left(\tan^{-1}\left(\frac{Q_{DGi}}{P_{DGi}}\right)\right. \\ Q_{expi} = \min\left(Q_{DG}^{C} Q_{DGI}^{V}\right) \end{cases} \qquad (3)$$

Equation (3) is the voltage values at bus are the real imaginary part, respectively. The element in the bus admittance matrix corresponding to the G^{th} row and the H^{th} column; and are the voltage angles at the I^{th} and J^{th} bus; is the number of bus directly connected to the I^{th} bus and is the active power of the DG unit connected to the H^{th} bus. And are the boundaries of the converter capability curves limited by current and voltage constraints, respectively. It is worth to note that the minimization of the global reactive power needed to control voltage allows reducing conductor losses, inverter losses, transformer losses and opportunity costs.

D.Problem Overview

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. In order to implement a proper voltage control strategy, it is necessary to include in the control algorithm the capability curves of the power converter.

Depicts the structure of the proposed voltage control 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 optimization problem and are the inverter outgoing current and voltage is the reactance, which takes into account the DG transformer and the grid filters used for DG connection to DN. Finally, is the voltage connection bus value.

III SOLUTION FOR PROPOSED METHOD

A wind farm is a group of wind turbines in the same location used for production of electricity. A large wind farm may consist of several hundred individual wind turbines distributed over an extended area, but the land between the turbines may be used for agricultural or other purposes. A wind farm may also be located offshore.

Almost all large wind turbines have the same design a horizontal axis wind turbine having an upwind rotor with three blades, attached to a nacelle on top of a tall tubular tower. In a wind farm, individual turbines are interconnected with a medium voltage (often 34.5 kV), power collection system and communications network. At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.

A. Static Synchronous Compensator (Statcom)

A static synchronous compensator (STATCOM), is called as “static synchronous condenser" ("STATCON"), is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices.In the case of two AC sources, which have the same frequency and are connected through a series reactance, the power flows will be:

1. Active or Real Power flows from the leading source to the lagging source.
2. Reactive Power flows from the higher to the lower voltage magnitude source.

Consequently, the phase angle difference between the sources decides the active power flow, while the voltage magnitude difference between the sources determines the reactive power flow. STATCOMs are typically applied in long distance transmission systems, for power substations and industries level voltage stability control. In addition, static synchronous compensators are installed in select points of the power system: they are

1. Voltage support and control
2. Voltage fluctuation and flicker mitigation
3. Unsymmetrical load balancing
4. Power factor correction
5. Active harmonics cancellation
6. Improve transient stability of the power system

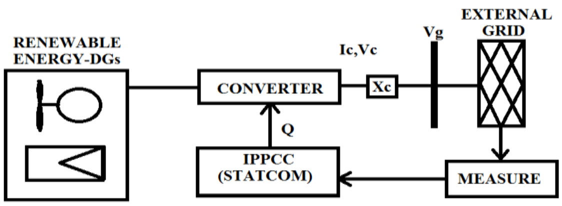

Fig 1. Block Diagram for Proposed System

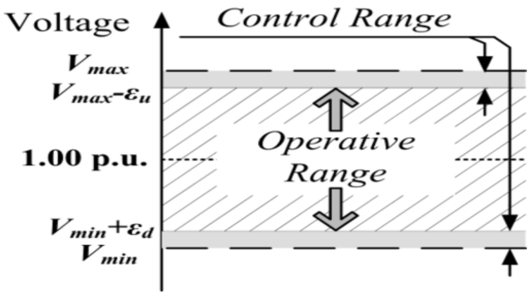

Fig 2. Allowed, Operative and Control Ranges used in the proposed control method.

B. Synchronous Reference Frame Algorithm

This discussion has been clearly defined. Consider a three-phase four-wire system. The instantaneous vectors, *v* and *i* are defined as follows;

$$V = \begin{Bmatrix} V_a \\ V_b \\ V_c \end{Bmatrix} \quad \& \quad i = \begin{Bmatrix} i_a \\ i_b \\ i_c \end{Bmatrix} \qquad (4)$$

In equation (4) the subscripts ‘a’, ‘b’ and ‘c’ denote the respective phases. The instantaneous active and reactive powers are defined as the dot and cross product of vectors *v* and *I* respectively.

$$P = v_i = v_a i_a + v_b i_b + v_c i_c \qquad (5)$$

$$q = v * i = \begin{cases} q_a \\ q_b \\ q_c \end{cases} \qquad (6)$$

$$q_a = \begin{bmatrix} v_b & v_c \\ i_b & i_c \end{bmatrix}, q_b = \begin{bmatrix} v_c & v_a \\ i_c & i_a \end{bmatrix}, q_c = \begin{bmatrix} v_a & v_b \\ i_a & i_b \end{bmatrix} \qquad (7)$$

The equation 7 gives total current vector is the sum of active and reactive current vectors

$$i = i_p + i_q \qquad (8)$$

C.Compensation Unbalanced Voltage

By simulation, we can show that the application of filter currents to an unbalance system result in distorted source currents so we must modify the Algorithm to obtain correct compensation as given below. Consider unbalance in magnitudes and in phase angles of main voltage

$$v_m = v_{ma} \sin(\omega t) \quad (9)$$

$$v_{sb} = v_{mb} \sin\left(\omega t - \frac{2\pi}{3} + a_b\right) \quad (10)$$

$$v_{sc} = v_{mc} \sin\left(\omega t + \frac{2\pi}{3} + a_c\right) \quad (11)$$

In the above equations (9), V_{ma} ,V_{mb} and V_{mc} are not equal to one another. The phase angles b_α and c_α are showing unbalance in phase angles. We consider a balanced set of main voltage which yields equal average real power with unbalanced source voltages. This balance set will satisfy Eqs. Consider the balanced set defined as follows

$$v_{sam} = v_m \sin(\omega t) \quad (12)$$

$$v_{sb1} = v_m \sin\left(\omega t - \frac{2\pi}{3}\right) \quad (13)$$

$$v_{sc} = v_{mc} \sin\left(\omega t + \frac{2\pi}{3}\right) \quad (14)$$

Two sets equation (12),(13),(14) of main voltage must have equal average real power, so from this requirement and zero phase angle between v_{sa} and i_{sa}, we obtain the magnitude v_m. Based of above considerations, the modified algorithm for active filter reference currents in unbalanced conditions is as follows,

$$i^*_{fa} = i_{sa} - \frac{1}{\sum_{j=a,b,c} v^2_{sj1}} \left(p_s v_{sa1} + q_{sb} v_{sc1} - q_{sc} v_{sb1}\right) \quad (15)$$

$$i^*_{fb} = i_{sb} - \frac{1}{\sum_{j=a,b,c} v^2_{sj1}} \left(p_s v_{sb1} + q_{sb} v_{sb1} - q_{sc} v_{sa1}\right) \quad (16)$$

$$i^*_{fc} = i_{sc} - \frac{1}{\sum_{j=a,b,c} v^2_{sj1}} \left(p_s v_{sc1} + q_{sb} v_{sa1} - q_{sc} v_{sb1}\right) \quad (17)$$

In the case of unbalance in magnitude only V_m is the average of the unequal magnitudes V_{ma} ,V_{mb} and V_{mc}. Equation (17) gives an under balanced conditions V_{ma} = V_{mb} = V_{mc} =0 and $b_\alpha = c_\alpha = 0$. Converge to that given in Eqs. It is to be noted that if we consider, V_{sa1}, V_{sb1} and V_{sc1} as balanced supply voltages, then the main source voltage set should supply average load power and zero mean oscillating active and reactive powers.

The dashed lines specify the band of the control range, where the greater one also indicates the maximum limit allowable for the voltage (1.05 p.u.). In these conditions the voltages at the buses 2 and 4 exceed the maximum value limit of 1.05 p.u. On the contrary, by using one of the three described control method possible to achieve a correct voltage regulation. Indeed, as illustrated for the bus 14, the voltage rise, due to the DG connected at the bus, is correctly regulated within the standard limits. Furthermore, it is possible to note how these results could be achieved using in distinctly the Power Control Method (APCM), Decentralized Control Method (DCM), and Coordinated Control Method (CCM). Nevertheless, these strategies are characterized by significant differences in terms of active and reactive power usage. In the active and reactive power injections/absorptions for these three methods are illustrated. In detail, the DCM compared with the APCM allows reducing active power curtailments absorbing reactive power up to the limits imposed by the capability curves. As matter of fact, the simulation results high-lighted an increment of 81.5% in the active power production on a whole day using the DCM instead of the APCM. However, as depicted in Fig 4, the CCM allows injecting all the available active power increasing the active power production of 18.5% compared to the DCM.

Time series simulations have been carried out with computed state of 10 minutes in order to illustrate the potential benefits introduced by the proposed CCM compared to two types of regulation common in literature. The first one, named Active APCM, consists in a simple active power curtailment proportional to the voltage violation. The second one is a DCM that uses the sensitivity co efficient proposed for absorbing/injecting reactive power in order to control voltage profiles. The average simulation time to perform the CCM has been estimated around 21 s by using a workstation with an Intel Xeon E3-1230 V2 (3.30 GHz, 64 bit) processor, 16 GB of RAM and MATLAB R2013a. However, the convergence times depend on the case study taken into account. The SQP has been implemented in MATLAB setting the maximum number of iterations to 1000, considering a tolerance of $1e^{-3}$ for the step size, $1e^{-6}$ for the objective function and $1e^{-20}$ for the magnitude of any constraint function. It is possible to see the voltage profiles when no control actions have been applied. In order to implement a proper voltage control strategy, it is necessary to include in the control algorithm the capability curves of the power converter by CCM method.

Table 1. 14-Buses per Unit Values

Line No	Bus No	Line Impedance		Half Line Charging Susceptance Per Unit
		R Per Unit	X Per Unit	
1	1-2	0.01938	0.05917	0.02640
2	2-3	0.04699	0.19797	0.02190
3	2-4	0.05811	0.17632	0.01870
4	1-5	0.05403	0.22304	0.02460
5	2-5	0.05695	0.17388	0.01700
6	3-4	0.00701	0.17103	0.01730
7	4-5	0.01335	0.04211	0.0064
8	5-6	0.0	0.25202	0.0
9	4-7	0.0	0.20912	0.0
10	7-7	0.0	0.17615	0.0
11	4-9	0.0	0.55618	0.0
12	7-9	0.0	0.11001	0.0
13	9-10	0.03181	0.08450	0.0
14	6-11	0.09498	0.19890	0.0
15	6-12	0.12291	0.25581	0.0
16	6-13	0.06615	0.13027	0.0
17	9-14	0.12711	0.27038	0.0
18	10-11	0.08205	0.19207	0.0
19	12-11	0.22092	0.19988	0.0
20	13-14	0.01709	0.34802	0.0

Sensitivity relates to the test's ability to identify positive results. The sensitivity of a test is the proportion of people that are known to have the disease who test positive for it. This can also be written as:

Sensitivity = Probability of a positive test, given that the patient is ill. In load flow, sensitivity terms are used to find which nodes to generate minimum voltage as compared to other nodes. Sensitive node is the one which is mostly suffered by the changes in load demands. The task of the transmission network in the Power System is to deliver the power generated in the power plants to the load centers in the network and the interconnected power systems. The transmission of electric power has to take place in the most resourceful way without the transmission network failure. The transmission systems in the present time Are becoming increasingly complex & stressed because of growing demand and because of restrictions on installation of new lines. For transmission network security & failure point of view it is quite important to calculate the most sensitive Node in the network. In this paper, we are looking or finding the sensitive node in IEEE-14 bus system by increasing the test system data by 5%, 10%, 15%, 20%, 25%, 30%, 35%, 45% and so on then we have compared all the result with the original power flow results of IEEE-14 bus system for finding a most sensitive node.

Transmission connected generators are generally required to support reactive power flow. For example on the United Kingdom transmission system generators are required by the Grid Code Requirements to supply their rated power between the limits of 0.85 power factor lagging and 0.90 power factor leading at the designated terminals. The system operator will perform switching actions to maintain a secure and economical voltage profile while maintaining a reactive power.

The ‘System gain’ is an important source of reactive power in the above power balance equation, which is generated by the capacitive nature of the transmission network. By making decisive switching actions in the early morning before the demand increases, the system gain can be maximized early on, helping to secure the system for the whole day. Other sources of reactive power that will also be used to shunt capacitors shunt reactors, Static VAR Compensators and voltage control circuits.

IV SIMULATION & RESULT

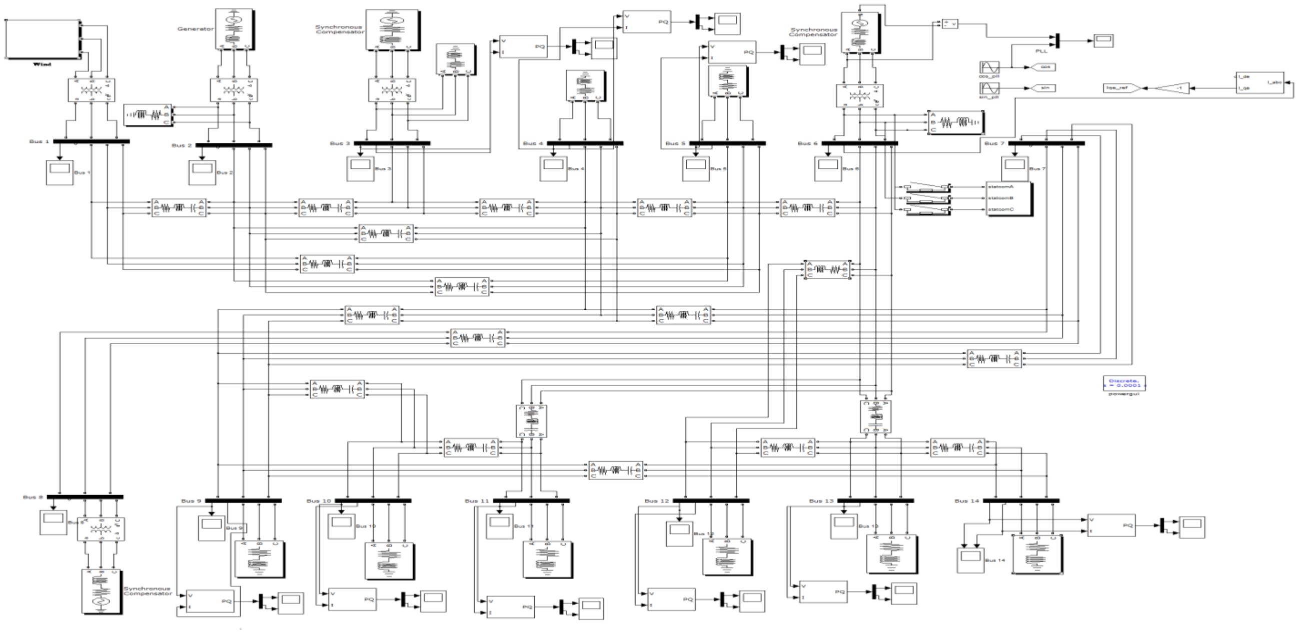

Fig 3. Simulation Diagram for Proposed Method

The effectiveness of the proposed control method a distribution network has been considered. The network is a 14-bus 20-KV distribution system with 4 feeders fed by a 1.0 p.u, 50-Hz sub transmission system with short circuit level of 1.05 p.u. The tap was set to 1.006 p.u.

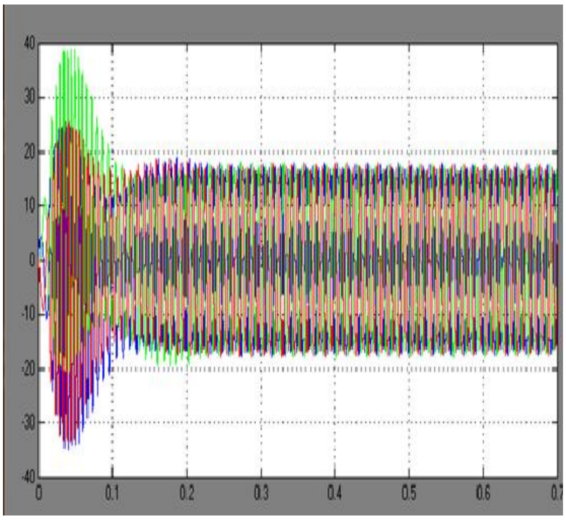

Fig 4. Output Waveform for Bus 1

In the above figure 4 shows the output waveform of bus 1.which gives the three phases output voltage waveform of renewable energy sores wind.

In the above figure 5 shows the output waveform of bus 14.which gives the three phase output voltage waveform of renewable energy wind source.

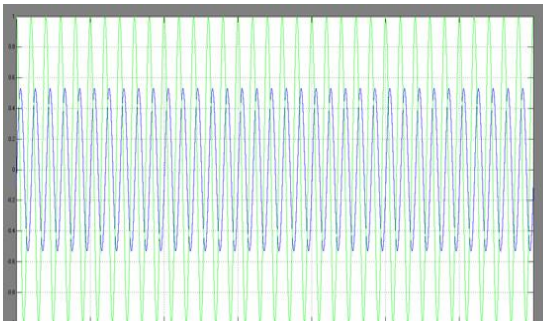

Fig 5. Output Waveform for STATCOM connected Bus

In the above figure 6 shows the output waveform of 6th bus .which gives the active and reactive power which controlled with the STATCOM connection at 6th bus.

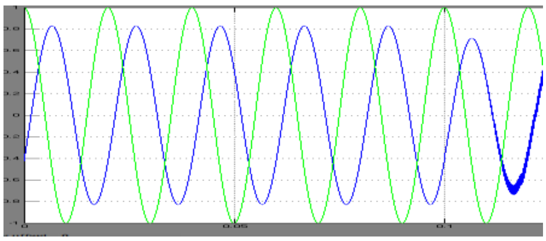

Fig 6. Final Output Waveform

V CONCLUSION

In this project a smart strategy to offer the mandatory voltage control ancillary service is developed. 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. The optimization problem is solved using an SQP method taking into account the limits imposed by physical (i.e., power converter capability curves) and Grid Code constraints. In order to prove that the validity of the proposed method several time simulated to an analyzed, it's run on a real Italian distribution network test grid with distributed wind turbines and photovoltaic units. The new method, named Coordinated Control Method is compared with other two voltage control methods presented in literature highlighting the advantages in terms of active power curtailments needed to avoid voltage problems. The simulation results point out an increase of 18.5% in the active power production during daily time series simulations, compared to a traditional decentralized voltage control. It is interesting to note that, in the presence of several DG units owned by an IPP and connected to the same distribution network,

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