ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

A New Method for Voltage Control in Distribution Networks Using MATLAB

P.Keerthi,
M.Tech Student
Department of EEE,
Sreenivasa Institute of Technology and Management, Chittoor, A.P, India.

J. Sreeranganayakulu,
Assistant Professor,
Department of EEE,
Sreenivasa Institute of Technology and Management, Chittoor, A.P, India.

Dr.Shaik Rafi Kiran,
Associate Professor and HoD,
Department of EEE,
Sreenivasa Institute of Technology and Management, Chittoor, A.P, India.

ABSTRACT

Recent research has shown that installation of Distributed Generation (DG) units in the utilities distribution system of a power network would lead to attainment of numerous potential benefits. To maximize these benefits, it is crucial to find the optimal number or size of DG units and their appropriate locations in power distribution systems, since sitting DG units in improper locations could jeopardizes the system operation. The aim of the optimal DG placement (OPDG) is to provide the best locations and sizes of DGs to optimize electrical distribution network operation and planning taking into account DG capacity constraints. Several models and methods have been suggested for the solution of the OPDG problem. This paper presents an overview of the state of the art models and methods applied to the OPDG problem, analyzing and classifying current and future research trends in this field.

Keywords

Decentralized Generation, Disperse-D Generation, Distributed Energy Resources, Distributed Generation (DG), Distribution Systems Optimization, and Embedded Generation, Optimal Placement of Distributed Generation (OPDG).

I. INTRODUCTION

In the last years the penetration of renewable energy sources (RESs) is growing worldwide encouraged by national and international policies, which aim to increase the share of sustainable sources and highly efficient power units to reduce greenhouse gas emissions and alleviate global warming [1]. However, power quality in existing power systems could worsen because of the high penetration of RESs, which could cause unexpected voltage rises on the distribution lines. In the context of SmartGrid, based on active/autonomous distribution networks and/or multiple microgrids, many technologies and control strategies, such as smart inverters and intelligent distribution transformers, can be implemented on distribution systems providing ancillary services for voltage control [2]. 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 Nonetheless, it is reasonable to assume that centralized control will typically give more robust and overall better results have dealt with the voltage control problem considering a centralized approach.

In particular, in an optimal control voltage method with coordination of distributed installations, such as on load tap changer (OLTC), step voltage regulator (SVR), shunt capacitor (SC), shunt reactor (ShR), and static var compensator (SVC), was proposed. presented a control strategy based on a predictive control idea for online reconfiguration of OLTC voltage set-point in medium voltage (MV) power grids with DG. In a centralized approach to reduce voltage rises in distribution grid in the presence of high DG penetration was discussed.

The same approach was used in to provide ancillary services in distribution systems: a centralized control system in real time produces the reference signals to all converters of the DG units in order to control the reactive power injections. Furthermore, it allows partial compensation or elimination of waveform distortions and voltage unbalances either at all system buses or in particularareas with more sensitive loads. Other interesting works focused on ancillary services are described . In particular, Authors deal with new proceduresfor reactive/voltage ancillary services market: the first proposes a minimization of the reactive power payments by distribution system operator (DSO) to independent power producers (IPPs), power losses, and voltage profile index; the second one addresses voltage control in multi-microgrid systems.

The minimization of the losses is also the goal , where an optimal management of the reactive power, supplied by photovoltaic unit inverters, was proposed. A good discussion on the use of operating charts for describing resources availability in ancillary services is reported . 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. Thus, the IPPs, often constrained to offer the ancillary service of voltage regulation to DSO , can maximize, at the same time, the active power production. Its main contributions compared to the literature can be summarized as follows:

1)the approach discussed in this paper takes into 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 .

3) in the presence of several DG-RES units the proposed algorithm calculates the 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 generation.

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 0network (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. In the second one IPP performs a coordinated regulation of the reactive powers among the DG units. In particular, the previous cited references present control methods based on an a-priori sensitivity analysis of the DN buses in order to calculate the sensitivity coefficients of the DG units that allow changing voltage values on the BSP by means of reactive (or active) power. This result is achieved by applying a decentralized voltage control up to capability curves limits by means of the reactive power provided by power inverters or through a reduction of the active power (backup solution). On the contrary, in

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

the proposed control, if the local reactive power compensation based on the sensitivity analysis fails (the reactive power reaches the vailability limits) then IPP performs a coordinated regulation of the reactive powers among the RES units. The aim is to avoid their disconnections due to voltage

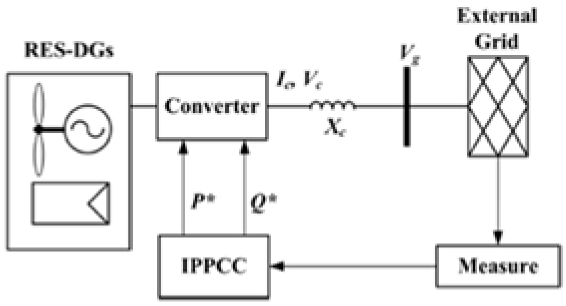

Fig 1: proposed control structure.

limit violation increasing the total power fed into the grid. It is worthy to highlight that only in this second case the proposed coordinated approach involves also the DSO during the control, which provides the power system state in order to develop the coordinated control. In detail, from an operational point of view, the coordinated regulation of the reactive power can be divided in three steps:

1) DSO sends data of DN state to IPP;

2) IPP Control Centre (IPPCC) processes data estimating the power set points (active and reactive power) of each RES unit in order to control the voltage profiles within the limits taken into account;

3) each generator changes the actual power set point with the new one received by IPPCC. Therefore, the core of the control described so far is carried out by IPPCC that has to solve a constrained optimization problem to have the regulation set point.

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. 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 . Fig.1depicts 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.

B. 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 profiles. The objective function to minimize through the control variable is the sum of the DG-RESs reactive powers owned by IPP:

$$\min_{\mathbf{Q_{DG}}} \{f(\mathbf{Q_{DG}})\} = \min_{\mathbf{Q_{DG}}} \left\{ \sum_{i=1}^{N_{DG}} Q_{DG_i} \right\}$$

CALDERARO *et al.*: A SMART STRATEGY FOR VOLTAGE CONTROL ANCILLARY SERVICE IN DISTRIBUTION NETWORKS

subject to the following constraints:

$$\begin{cases} V_{\min} \leq V_{DG_i} \leq V_{\max} \\ PF_{\min} \leq PF_{DG_i} \leq PF_{\max} \\ Q_{\min} \leq Q_{DG_i} \leq Q_{\max} \end{cases} \tag{2}$$

where is the number of DG units, is the vector of the reactive powers injected/absorbed by DG units, and are, respectively, the minimum and maximum values of the voltage imposed by the standard [21], and are the power factor constraints, and are the limits imposed by the physical capability of the converter, as described in the next subsection. , , 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 in (2) and the control variable for the bus are

$$\begin{cases} Q_{DG_i} = V_i \sum\limits_{h \in Ni} V_h [G_{ih} \sin(\vartheta_i - \vartheta_h) - B_{ih} \cos(\vartheta_i - \vartheta_h)] \\ PF_i = \cos\left(\tan^{-1}\left(\frac{Q_{DG_i}}{P_{DG_i}}\right)\right) \\ Q_{cap_i} = \min\left(Q^c_{DG_i}, Q^v_{DG_i}\right) \end{cases} \quad (3)$$

where and are the voltage values at bus and are the real and the imaginary part, respectively, of the element in the bus admittance matrix corresponding to the th row and the th column; and are the voltage angles at the th and th bus; is the number of bus directly connected to the th bus and is the active power of the DG unit connected to the 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 (1) needed to control voltage allows reducing conductor losses, inverter losses, transformer losses and opportunity costs.

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. Set the maximum available active power, the capability curves can be calculated as described in [8] and [20]. The maximum available reactive power of a generator is

$$Q_{cap} = \min\{Q^c_{DG}, Q^v_{DG}\}$$

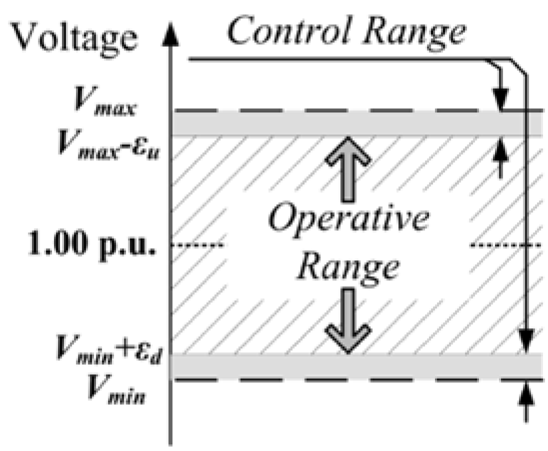

Fig. 2. Allowed, Operative and Control Ranges used in the proposed control method.

where Q^c_{DG} and Q^v_{DG} are

$$\begin{cases} Q^c_{DG} = \sqrt{(V_g I_{c_{\max}})^2 - P^2_{DG}} \\ Q^v_{DG} = \sqrt{\left(\frac{V_g V_{c_{\max}}}{X_c}\right)^2 - P^2_{DG}} - \frac{V_g^2}{X_c} \end{cases} \quad (5)$$

with maximum current output and maximum voltage output of inverter. The latter constraints can be formulated as follows:

$$\begin{cases} I_{c_{\max}} = \frac{\sqrt{P_R^2 + Q_R^2}}{V_{g\max}} \\ V_{c_{\max}} = \frac{f_{\max} X_c}{V_{g\max}} \sqrt{1 + \left(\tan\theta_R + \frac{V^2_{g\max}}{f_{\max} X_c}\right)^2} \end{cases} \quad (6)$$

where and are the rated active and reactive power and is the rated power factor angle. Besides, and are the maximum frequency and voltage of the electrical grid. Furthermore, the constraints, imposed by Grid Code on the power factor, are taken into account in this study to better simulate reality conditions. The values shown in Table I are referred to four European countries with a high penetration of RES plants onthe DN. indicates the minimum value of power factor (leading and lagging) at the BSP.

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 is defined as *Allowed*

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Voltage Range, as depicted in Fig. 2. It is divided in three zones where the proposed control algorithm operates applying the following rules: no control actions are carried out within the *Operative Range*; 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.

$$Q_{DG}(k) = Q_{DG}(k-1) - \frac{\Delta V_{DG}(k)}{\rho_Q} \qquad (7)$$

where is the reactive power sensitivity coefficient calculated as described in [13]. If the amount of reactive power is within the capability curves 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. In this case, it is possible to calculate the active power necessary to satisfy the voltage constraints by means of the RES unit sensitivity coefficient, .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. It is important to remark that the 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. The optimization problem is solved by means of an SQP method considering a quadratic approximation of the Large gain function as follows:

$$L(x,\lambda,\mu) = f(x) + \sum_{j=1}^{n} \mu_j h_j(x) + \sum_{i=1}^{m} \lambda_i g_i(x) \qquad (8)$$

where is the objective function described in (1), are the equality constraints of the power flow equations and are the inequality constraints as in (2); and are the number of equality and inequality constraints included in the optimization problem, respectively. Finally, and are the Large gain multipliers. Starting from the solution defined in the previous iteration , at each new step the SQP algorithm provides an appropriate search direction towards the solution of the following quadratic programming sub problem:

$$\begin{cases} \min_d f(x_r) + \nabla f(x_r)^T d + \frac{1}{2} d^T \nabla^2_{rr} L(x_r, \lambda_r, \mu_r) d \\ \nabla h_j(x_r)^T d + h_j(x_r) = 0 \qquad j = 1, \ldots, n \\ \nabla g_i(x_r)^T d + g_i(x_r) = 0 \qquad i = 1, \ldots, m. \end{cases} \qquad (9)$$

The contribute is used to create a starting solution for the next iteration as follows:

$$x_{r+1} = x_r + \alpha_r d_r \qquad (10)$$

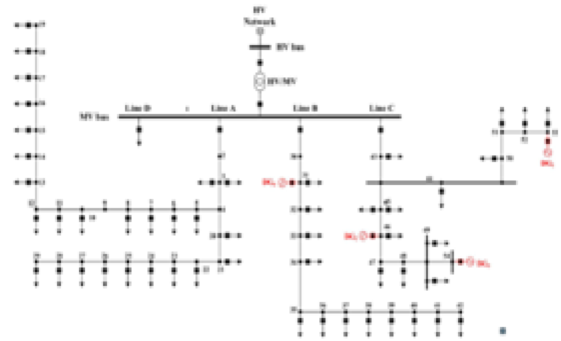

Fig. 4. [illegible]

Where is the step length parameter determined by using an appropriated line search procedure, so that a sufficient decrease in a merit function is obtained . The notable point of SQP is that it is a classical robust solution method in optimization theory that can deal with inequality constraints effectively. It has good performances in solving nonlinear constrained problems, which makes it a quite effective approach among the normal line search methods and widely considered as one of the most prominent algorithms in nonlinear programming. Furthermore, SQP allows obtaining a global optimization if a merit function is properly chosen extending the part convergence to global convergence.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

IV. SIMULATIONS AND RESULTS

In order to show the effectiveness of the proposed control method a real Italian MV distribution network has been considered. The network, depicted in Fig. 4, is a 54-bus 20-kV distribution system with 4 feeders fed by a 132-kV, 50-Hz sub transmission system with short circuit level of 750 MVA through a 150/20 kV transformer with rated power of 25 MVA and. The tap was set to 1.006 p.u., according to one of two classical Italian control strategies for distribution systems. Two DWTs, each with a rated power of 5 MVA, are connected to the buses 46 and 54 and two PV units with the same rated power are connected to the buses 31 and 53. Fig. 5 depicts the normalized profiles used for the different load categories (residential, commercial and industrial) and for the PV units and DWTs. These profiles are multiplied for the rated power of each load or generator in order to have the power daily profile of each bus. The rated powers of the loads are reported in the Appendix together with network data. The capability curves, imposed by Italian national standards, limit the power factor between 0.95

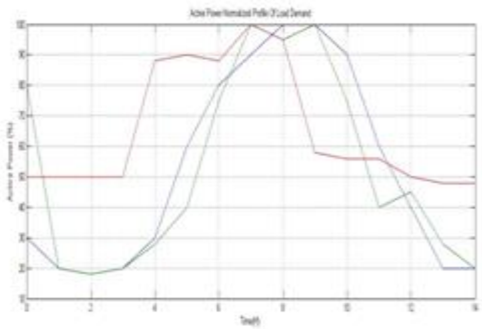

Fig 3: Active power and normalized load demand

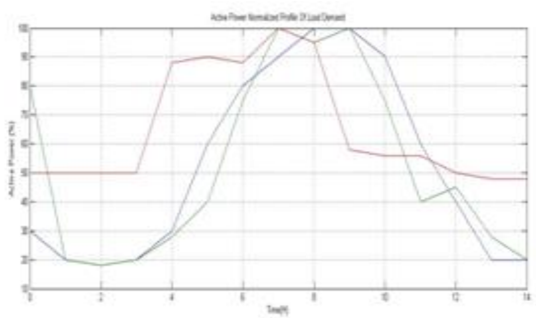

Fig 4: Active power normalized profile of load demand.

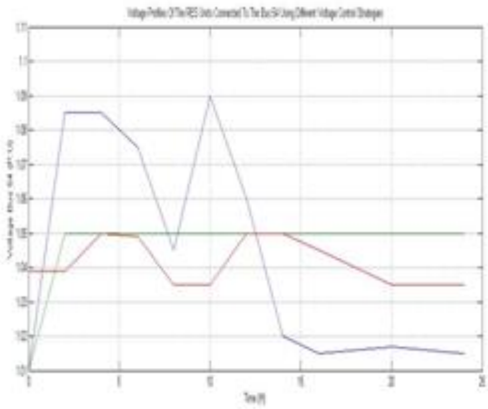

Fig 5: Voltage profile of the RES units connected to the BUS 54 using different Voltage control strategies.

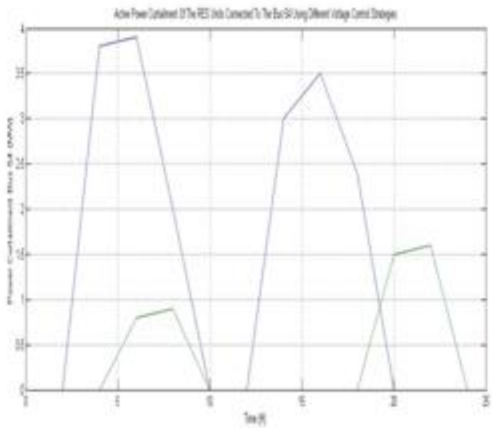

Fig 6: Active power curtailment of the RES units connected to the BUS 54 using different voltage control strategies.

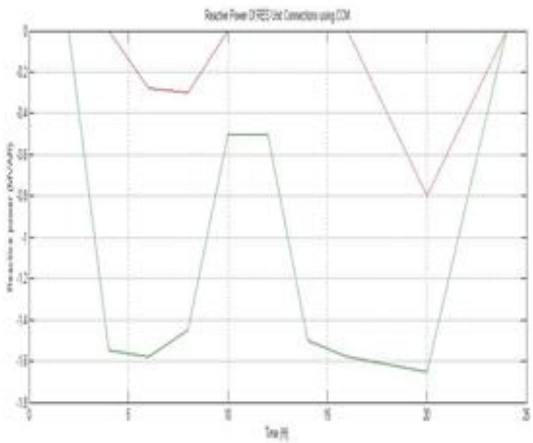

Fig 7: Reactive power of RES unit connection using CCM.

Lagging and 0.95 leading [19]. Furthermore, the threshold values are set to . Time series simulations have been carried out with computed state of 10 minutes in order to illustrate the potential benefits introduced by the proposed Coordinated Control Method (CCM) compared to two types of regulation common in literature. The first one, named Active Power Control Method (APCM), consists in a simple active power curtailment proportional to the voltage violation. The second one is a decentralized Control Method (DCM) that uses the sensitivity coefficients proposed and 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 work station with an Intel Xeon E3-1230 V2 (3.30 GHz, 64 bit) processor, 16 GB of RAM and MATLAB™ R2013a. In any case, it is worth to note that the simulation times for all steps have been less than a minute, which are compatibles with the considered control step time of 10 minutes. 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 a geniture of any constraint function. In Fig. 3, it is possible to seethe voltage profiles when no control actions have been applied. 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 46 and 54 exceed the maximum value limit of 1.05 p.u. On the contrary, by using one of the three described control methods it is possible to achieve a correct voltage regulation. Indeed, as illustrated in Fig. 4 for the bus 54, 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 indistinctly the *APCM*, *DCM*, and *CCM*. Nevertheless, these strategies are characterized by significant differences in terms of active and reactive power usage. In Figs. 5 and 6 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 highlighted 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. 8, the *CCM* allows injecting all the available active power increasing the active power production of 18.5% compared to the *DCM*. has been obtained increasing the reactive power absorption at the bus 46, which has not already reached the capability curves limits. Nonetheless, the *CCM* requires a daily reactive power absorption of 19.38 Mvarh that is slightly greater than 17.73 Furthermore, comparing Figs. 5 and 6, it is possible to understand that the solution given by the optimization process is correct because the bus 46 absorbs reactive power, supporting the bus 54 in voltage regulation, even though the voltage at BSP is within the mandatory limits (Fig. 6). Finally, a further check has been carried out on the capability curves. Indeed, Fig.7 shows the set points elaborated by the IPPCC solving the constrained optimization problem. Also in this case the control works properly, in fact, all the set points are within the standard imposed by national code (dashed lines) and physical limits (continuous lines).

V. CONCLUSIONS

This paper presents a review on the work that has been done with regards to voltage control methods implemented in the distribution systems connected with DGs. Various coordinated and distributed voltage regulation methods are overviewed and classified based on their control actions. Centralized or coordinated control methods are classified into three main categories, distribution management system, coordination of distribution system components and intelligent techniques. All these voltage control methods require high level of communication between

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

the components of the system,. However, the outputs of these type of voltage management proves to be more systematic and robust hence improving system operation significantly.

On the other hand, the decentralized voltage control methods consider power factor control, reactive power compensation, OLTC, generation curtailment and also intelligent techniques that are based on local information with limited number of communication level between the network components. These methods do not provide solutions for the whole system, but still remains reliable depending on the control actions taken. Power-factor control methods proved to be reliable to a certain extent of DG inputs to the system, where increased DG level would result in voltage deviating from its permissible limit.

Reactive power compensation is based on the idea that the generator is able to absorb the amount of excessive power to limit the voltage rise, but the main drawback of this reactive power absorption is loss increment. The amount of output power to be absorbed also depends on the generator's capability. The OLTC scheme is limited by its tapping capability while the generation curtailment scheme is the last option to be implemented. The intelligent technique utilizes different optimization methods to maximize the control actions of the system's components in managing power quality issues. All these methods which have been discussed and presented, provides voltage control support in distribution systems with DGs in their own unique way, depending on the situation and demand.

REFERENCES

[1] P. S. Georgilakis and N. D. Hatziargyriou, "Optimal distributed generation placement in power distribution networks: Models, methods, and future research," IEEE Trans. Power Syst., vol. 28, no. 3, pp. 3420–3428, Aug. 2013.

[2] C.-H. Lo and N. Ansari, "Decentralized controls and communications for autonomous distribution networks in smart grid," IEEE Trans. Smart Grid, vol. 4, no. 1, pp. 66–77, Mar. 2013.

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

[4] K. Tanaka,M. Oshiro, S. Toma, A. Yona, T. Senjyu, T. Funabashi, an d C. H. Kim, "Decentralised control of voltage in distribution systems by distributed generators," IET Gener. Transm. Distrib., vol. 4, no. 11 pp. 1251–1260, Nov. 2010.

[5] R. Aghatehrani and R. Kavasseri, "Reactive power management of a DFIGwind systeminmicrogrids based on voltage sensitivity analysis," IEEE Trans. Sustain. Energy, vol. 2, no. 4, pp. 451–458, Oct. 2011.

[6] V. Calderaro, V. Galdi, G. Massa, and A. Piccolo, "Distributed generation and local voltage regulation: An approach based on sensitivity analysis," Proc. 2011 Int. Innovative Smart Grid Technologies, pp. 1–8.

[7] V. Calderaro, G. Conio, V. Galdi, and A. Piccolo, "Reactive power control for improving voltage profiles: A comparison between two decentralized approaches," Elect. Power Syst. Res., vol. 83, no. 1, pp. 247–254, Feb. 2012.

[8] V. Calderaro, G. Conio, V. Galdi, G. Massa, and A. Piccolo, "Optimal decentralized voltage control for distribution systems with inverter - based distributed generators," IEEE Trans. Power Syst., vol. 29, no. 1, pp. 230–241, Jan. 2014.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Author Details

Name: P.Keerthi
Branch (specialization):- electrical power engineering (EPE)
College:-Sreenivasa Institute of Technology and Management Studies(SITAMS)
MailId:- keerthipalagala@gmail.com

Name: J. Sreeranganayakulu

Working as Assistant professor' in Dept. Of EEE in Sreenivasa Institute of Technology and Management Studies, Chittoor A.P. Pursuing Ph.D from Jawaharlal Nehru Technological University, Anantapur, A.P. from September 2012. Passed Pre-PhD examinations conducted JNTUA, Anantapuramu, A.P in November 2013.Passed M.Tech in Power system operation and control from Sri Venkateswara University, Tirupati, A.P. in 2008 with an aggregate of 71.27%.Passed B.Tech in Electrical and Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, A.P. in 2005 with an aggregate of 72.63%.

Name: Dr.Shaik Rafi Kiran

Obtained his Masters degree(Control Systems) from JNTU, Anantapur. And Ph.D from JNTU, Anantapur. His Area of interest includes System Identification and Control Systems. He has over 15 years of teaching experience and published more than 10 papers in International and National Journals .Currently, he is a Professor and head of EEE Department, Sreenivasa institute of Technology and Management studies