Journal of Operation and Automation in Power Engineering

Vol. 8, No. 2, Aug. 2020, Pages: 164-171

http://joape.uma.ac.ir

Distributed Voltage Control in Distribution Networks with High Penetration of Photovoltaic Systems

H. Yousefi[1], S.A. Gholamian [1,], A. Zakariazadeh [2]*

[1]Department of Electrical and Computer Engineering, Babol Noshirvani University of Technology, Babol, Iran

[2] Department of Electrical Engineering, University of Science and Technology of Mazandaran, Behshahr, Iran

Abstract- *In this paper, a distributed method for reactive power management in a distribution system has been presented. The proposed method focuses on the voltage rise where the distribution systems are equipped with a considerable number of photovoltaic units. This paper proposes the alternating direction method of multipliers (ADMMs) approach for solving the optimal voltage control problem in a distributed manner in a distribution system with high penetration of PVs. Also, the proposed method uses a clustering approach to divide the network into partitions based on the coupling degrees among different nodes. The optimal reactive power control strategy is conducted in each partition and integrated using ADMM. The proposed method is tested on a 33 bus IEEE distribution test system and a modified IEEE 123-node system. The result evidence that the proposed method has used the lower reactive power if compared to the conventional method.*

Keyword: Reactive power, Distribution system, Photovoltaic system, Distributed algorithm.

1. INTRODUCTION

One of the important challenges in distribution systems has been voltage drop, especially during peak load. Due to the radial configuration and high length of the distribution system, the voltage drop in far distances may usually result in voltage go the allowable range out. To overcome this challenge, the distribution system is equipped with distributed generation units or capacitor banks [1]. However, in the advanced distribution system, the networks may face a new challenge due to the high penetration of distributed energy resources [2-3]. As the power injection of DGs leads to rising the voltage in connection points, the voltage may go upper limits while the generation level is high and the load demand is low [4]. For example, photovoltaic (PV) units deliver their maximum power during mid-day while the system load demand is not at peak level. So, voltage and reactive power control methods are expected to be upgraded in accordance with the photovoltaic penetration in distribution networks.

In Ref. [5], an upgrading voltage control method corresponding to photovoltaic penetration rate has been presented in which moving the on-load tap changer control method along with the additional installation of the static Var compensator or step voltage regulator have been considered. In Ref. [6], the effect of large scale photovoltaic units integration on power transmission systems has been investigated where one of objective functions was voltage deviation reduction. In Ref. [7], a voltage management method considering the power factor droop parameters of PV inverters has been presented in which serious voltage variations as well as excessive step voltage regulators tap operations have been successfully mitigated. In Ref. [8], a probabilistic voltage regulation method in distribution networks has been presented. The voltage management in multiple low and medium voltage networks has been carried out through the placement of on-load tap changers and distribution static compensators as well as considering the reactive capability of PV inverters.

Using a partitioning approach, large and complex distribution networks can be divided into smaller sub-networks. Then, the reactive power and voltage control of the whole network can be reached by the voltage control of each sub-network. As a result, the complexity of the problem reduces and it can be solved in a fast way [9-10]. Comparing with the non-partitioned network, the zonal reactive power and voltage control can be conducted in a parallel mode and, as a result, the number of variables as well as control dimensions can

Received: 09 Jul. 2019
Revised: 04 Nov. 2019
Accepted: 19 Jan. 2020
∗Corresponding author:
E-mail: gholamian@nit.ac.ir (S.A. Gholamian)
Digital object identifier: 10.22098/joape.2020.6259.1472
Research paper

be considerably reduced. In Ref. [11], an online voltage regulation method based on particle swarm optimization algorithm has been presented in which a distribution network has been divided into several separate control areas. In Ref. [12], a voltage control method by implementing the voltage regulation capability of PV inverters has been proposed. Also, a network partition method based on a community detection algorithm has been used to apply zonal voltage control. In Ref. [13], a voltage control method based on the spectral clustering algorithm has been presented for distribution networks with high penetration of PVs.

In a smart distribution system, distributed energy resources together with the distributed nature of data, significantly increase the complexity of distribution systems operation and motivate the needs for distributed optimization. Recently, several types of research have been carried out aiming at resolving power system operation problems in a distributed manner. Lagrangian Relaxation (LR) is known as this type of methods [14-15]. In the LR method, coupling constraints among various sub-networks are relaxed via Lagrangian multipliers where the derived problem converts into separable sub-problems. In Ref. [16], a decentralized method based on Dantzig-Wolfe decomposition and column generation to optimally coordinate distributed generation resources has been presented. In Ref. [17], a modified distributed gradient projection algorithm has been used to optimally coordinate loads to provide frequency control service to the grid. In Ref. [18], the consensus-based distributed energy management algorithm has been presented to help devices to estimate system global information. Lately, the alternating direction method of multipliers (ADMM) has taken more into considerations, which is well-matched for distributed convex optimization [19]–[24]. In Ref. [25], a distributed voltage control method based on the relationship of the active and reactive power outputs of PV units has been presented. The method considered the conventional voltage regulating devices along with the PV smart inverter's capability in providing reactive power service. In Ref. [26], a decentralized reactive power control method through a linear decision rule has been presented where the reactive power from PV inverter confirming standard characteristic curves in the German grid code has been taken into account. In Ref. [27], a rule-based approach for decentralized reactive power control of PV inverters has been presented. The method focused on reducing voltage violations which may occur due to the fluctuations of PV real power in the time interval between VVC set-point executions in the field. The rule-based method has been added to the traditional volt/var control due to the growing integration of PV capacity in distribution networks.

To sum up, the main objective of the voltage control problem is maintaining the quality of voltage magnitude in distribution networks when increasing hosting capacity of current distribution network for installing more PV units. So, the problem arises where the distribution network cannot still operate without violating its operational constraints due to high penetration of PV units [28]. The conventional centralized voltage control approaches can solve the problem but the complexity and computation time of the problem are introduced as a challenge. Now, reducing total computational effort during the voltage control optimization process can be taken into account as an objective.

In this paper, a distributed voltage control based on clustering distribution networks into partitions is proposed. The voltage regulation is carried out by reactive power management of PV inverters. To coordinate the voltage control in all partitions, the ADMM approach is adapted to the proposed method. In comparison to centralized methods, the advantage of the proposed method is to reduce the computational burden and eliminate the need for all network information. The contributions of this paper are highlighted as follows:

1) A partitioning approach base on voltage sensitivity matrix analysis has been presented to divide a large complex distribution network into multiple smaller subnetwork.

2) A distributed voltage control based on ADMM is presented.

The rest of this paper is organized as follows. In Section II, the formulation of the network partitioning approach and the proposed distributed voltage control approach has been presented. Results of numerical case studies are presented in Section III. Finally, Section IV summarizes conclusions.

2. VOLTAGE CONTROL FORMULATION

In this section, the optimal reactive power management method aiming at controlling network voltage has been described. The proposed method is divided into three parts listed as follows.

Firstly, the distribution network is divided into some partitions based on the voltage sensitivity analysis among nodes. So, the nodes, which have the most voltage impact on each other, have been clustered in the same partition. In the next step, optimal active and reactive power control is carried out in each partition where the voltage control strategy is coordinated by ADMM in a distributed manner.

To implement the proposed method in a real distribution network, the smart grid communication infrastructure is required. The future distribution network includes a cyber-physical system containing three layers [29]: a physical layer, a communication layer and a control layer. The communication data is processed within the control layer (such as running the distributed algorithm). Respect to distributed algorithms, a distributed controller can be set in each bus or a part of the whole network. A middleware exists between the physical network and communication network where it is able to process the collected data and conducts the distributed algorithm.

In this paper, the physical and communication layers shown in Fig. 1 are supposed. First of all, the distribution network is divided into some sections. Then, a distributed controller is assigned to each section. All distributed controllers are connected to a central controller via the communication layer. The central controller is located in a distribution management system under supervision of distribution system operators. The distributed controllers obtain measurements from and issue commands to the PV units inverters installed at their sections. It runs voltage control program by its data as well as estimating the value of bus voltage magnitude and angles corresponding to neighbouring sections. After that, all distributed controllers send their calculated values to the central controller. Then, a mean value is calculated using the voltage magnitude and phase values in each section and the corresponding ones estimated by adjacent sections. Finally, after some iteration, the optimal solution is found.

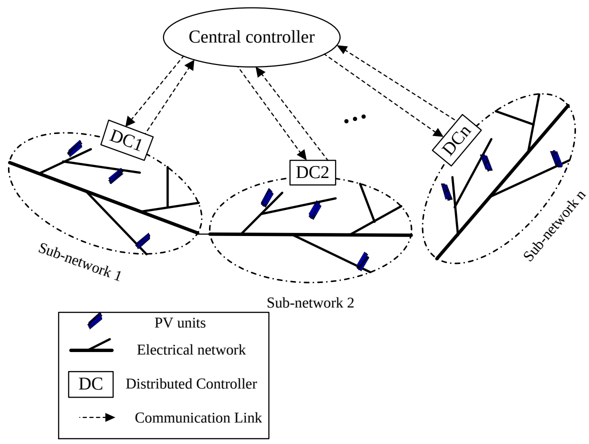

Fig. 1. Data flow of the proposed distributed voltage control

The details of the proposed voltage control strategy have been described as follows.

2.1 Network clustering

By increasing the penetration of PV units, a distribution system operation and control are faced by challenges. On the other hand, due to increasing the size of distribution operation problems, it is difficult to handle the problem in a centralized manner. On the basis that the voltage coupling degrees among different nodes are not the same, some problems such as voltage control can be individually applied to a part of the distribution system.

In the proposed method, the spectral clustering [30, 31] combining to K-means method [32] is used to divide a complex distribution network into partitions. Regarding graph theory, a distribution network can be defined by an undirected weighted graph $G(\mathrm{Z}, \mathrm{M})$, where $\mathrm{Z} = \{Z_1, Z_2, \dots, Z_N\}$ and M are, respectively, the set of nodes and the set of all nodes and branches in the distribution network. A symmetric weight matrix is defined by an average edge weight as a set of edge weights:

$$W_{ij} = \frac{w(i,j)+w(j,i)}{2} \qquad (1)$$

Next, a diagonal degree matrix D is made as:

$$d_i = \sum_{j=1}^{n} W_{ij}, \quad D = diag(d_1, d_2, \dots, d_N) \qquad (2)$$

Then, the normalized Laplacian matrix is constructed as:

$$L = D^{-1/2}\ (D - W)D^{1/2} \qquad (3)$$

After that, eigenvectors and eigenvalues of the normalized Laplacian matrix are computed. k_1 eigenvalues are selected, and their related eigenvectors are normalized to construct a $N \times k_1$ feature matrix Θ. Each row of Θ corresponds to a spectral data point and mapped to the related node in the power distribution network. The dimensionality of the problem is effectively reduced by implementing the Laplacian treatment. To yield network partitioning, then, the classical *K*-means method is implemented to manage the cluster spectral data points. The edge weight and clustering fitness are defined as follows.

In this paper, the active power-voltage (P-V) or reactive power-voltage (Q-V) sensitivity matrix is used to determine the edge weight w of a distribution system. The sensitivity matrix which shows the relationship between the voltages and the changes in the power injections are defined as follows:

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = \begin{bmatrix} \Gamma_{\delta P} & \Gamma_{\delta Q} \\ \Gamma_{VP} & \Gamma_{VQ} \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \qquad (4)$$

where, ΔP, ΔQ, ΔV and $\Delta\delta$ represent the incremental change in active power, reactive power, voltage magnitude and phase angle, respectively; $\Gamma_{\delta P}$, $\Gamma_{\delta Q}$, Γ_{VP} and Γ_{VQ} are the voltage angle and the voltage magnitude sensitivity relating to active and reactive power, respectively. An average edge weight (Ψ_{ij}^{VQ}) is defined as an index to show the coupling degree of two nodes; that is,

$$\Psi_{ij}^{VQ} = \frac{\Gamma_{VQ}^{ij}+\Gamma_{VQ}^{ji}}{2} \quad (5)$$

2.2 Reactive power control by PV

It is assumed the PV system is equipped with a controllable inverter which is able to provide sufficient reactive power. The objective function OF aims at minimizing the total reactive power injection provided by PV units.

$$OF = \min(\sum_{n=1}^{N} \Delta Q_n) \quad (6)$$

where, ΔQ_n is the reactive power absorbed by the n-th PV unit. The constraints of the problem are given as follows:

$$P_{Gi} - P_{Di} = V_i \sum_{j=1}^{N_{C_k}} V_j\left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) \quad (7)$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{j=1}^{N_{C_k}} V_j\left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right) \quad (8)$$

$$0.95\, p.u. \le V_{C_k}^{i} \le 1.05\, p.u. \quad (9)$$

$$0 \le \Delta Q_n \le Q_{absorb}^{n} \qquad n = 1,2,\dots,N \quad (10)$$

$$-\cos^{-1}(0.95) \le \varphi_{PV_n} \le \cos^{-1}(0.95) \quad (11)$$

where, N_{C_k} is cluster number C_k; P_{Gi}, Q_{Gi} represent the active power and reactive power generated by generators (conventional and PV units), respectively; P_{Di}, Q_{Di} represent the active and reactive power load demand, respectively; V_i and V_j represents the voltage magnitudes of the node i and node j, respectively; B_{ij} and G_{ij} are the susceptance and conductance of line between nodes i and j, respectively; δ_{ij} the angle difference of node i and node j; $V_{C_k}^{i}$ represents the voltage magnitude at node i in the cluster C_k; ΔQ_n is reactive power amount absorbed from the n-th PV system where its maximum value shown by Q_{absorb}^{n}; and φ_{PV_d} is the power factor angle of n-th inverter.

The optimal reactive power considering the voltage between allowable ranges is determined based on the objective function in Eq. (6).

To encourage private PV owners to participate in the voltage control program, there are two ways. The first is a mandatory law for participating in ancillary service program in a defined power factor range [33-35]. The second one is to provide an incentive by valuing or pricing reactive power services. In this way, the reactive power absorbed by PV units is paid [36-37]. The reactive power pricing can be carried out by two methodologies: a) pricing based on the active power loss opportunity cost, b) the equivalent cost of voltage control process if it is carried out by other equipment such as reactors, demand response program or FACTs devises. In this paper, it is assumed that each PV owners will be paid based on the reactive power price as an incentive program if they participate in voltage control program.

2.3 ADMM

ADMM is known as a distributed algorithm that uses both the decomposability of dual ascent as well as the superior convergence properties of the method of multipliers [38]. This method reforms problems formulation as given in (10):

$$\min_{x,\xi} L_\rho(x,\xi,\lambda) = \sum_{n=1}^{N}[C_n(x_n) + \lambda_n^T.(\tilde{x}_n - \xi_n) + (\rho/2).\|\tilde{x}_n - \xi_n\|_2^2] \quad (12)$$

where, $L_\rho(.)$ is the augmented Lagrangian function; $C_n(x_n)$ is the objective function of subsystem n; x_n are variables of subsystem n which comprise local variables $\bar{x}_n$ and coupling variables $\tilde{x}_n$; ξ_n are global variables corresponding to subsystem n; λ_n are Lagrangian multipliers; $\rho > 0$ is a predefined parameter; and $\|.\|_2^2$ represents the l_2-norm of a vector.

ADMM involves the iterative procedure among equations (13) - (16):

$$x_n^{i+1} = \arg\min_{x_n\in\chi_n}\left(C_n(x_n) + \lambda_n^{iT}.x_n + \left(\frac{\rho}{2}\right).\left\|\tilde{x}_n - \xi_n^i\right\|_2^2\right)\ \forall n \in N \quad (13)$$

$$\xi_g^{i+1} = \frac{\sum_{G(n,w)=g}\left(\tilde{x}_n^{i+1}\right)_w}{\sum_{G(n,w)=g} 1}, \forall g \in Z \quad (14)$$

$$\lambda_n^{i+1} = \lambda_n^i + \rho.(\tilde{x}_n^{i+1} - \xi_n^{i+1}), \forall n \in N \quad (15)$$

$$\xi_2 = (\theta_j^{S_1} + \theta_j + \theta_{nj}^{S_3})/3 \quad (16)$$

where i represents the index of ADMM iterations. Decision variables ξ and x are individually optimized in equations (13) and (14). For the distributed reactive power management problem, the objective of the entire system Eq. (6) can be represented as the summation of objectives for individual subsystems Eq. (12), x_n satisfies constraints (13) - (16) in subsystem n. The term $\left((\tilde{x}_n - \xi_n) = 0\right)$ warranties that the same variables stated in different subsystems are equal to each other. Eq. (14) means that ξ_g (the global variable) equals to the average of all $(\tilde{x}_n)_w$ which correspond to $z_g.(\tilde{x}_n)_w$ is the w^{th} variable of $\tilde{x}_n$. $g = G(n,w)$ represents the mapping from duplicated coupling variables $\tilde{x}_n$ onto ξ_n

as the global variable. That is, $(\tilde{x}_n)_w$ is related to the global variable ξ_g.

The convergence index of ADMM is determined based on the primal residual Eq. (17) and the dual residual Eq. (18), which ε_1 and ε_2 are predefined thresholds [38]. Also, the primal residual r is calculated by means of primal variables x and ξ. The stop criterion is achieved while primal and dual residuals are sufficiently small in each subsystem n.

$$\left\|r_n^{i+1}\right\|_2^2 = \left\|\lambda^{i+1} - \lambda^i\right\|_2^2 \le \varepsilon_1, \tag{17}$$

$$\left\|s_n^{i+1}\right\|_2^2 = \rho. \left\|\xi_n^{i+1} - \xi_n^i\right\|_2^2 \le \varepsilon_2 \tag{18}$$

3. CASE STUDY

In this section, we conduct some case studies in the IEEE 33-bus test feeder shown in Fig. 2, and the network parameters can be found in Ref. [39]. The PV model for the simulation studies is taken from [40]. Each inverter can be operated in a power factor range of (-0.95, 0.95). Also, the parameters of the GA algorithm are in Table 1. Regarding ADMM parameters, ρ is set as 20, and ε_1 and ε_2 are 0.0001 for all case studies.

According to the proposed method, the network should firstly be sectionalized in partitions. The optimal partition process has been carried out based on the coupling degrees among different nodes which was proposed in Section 2.1. As a result, the final partitions are illustrated in Fig. 3 where the partitions are indicated as {P1, P2, P3, P4, P5}. Two ways have been implemented to validate the generality and applicability of the presented clustering approach in the voltage control problem. To certify the clustering results, another clustering method has also been implemented to divide the same distribution test network into multiple smaller sub-networks [41]. The results showed the clusters are practically similar in both approaches. As the second validation approach, the voltage control problem has also run using the conventional centralized method without carrying out the partitioning process. The comparison evidenced that the proposed method provides better results. It shows that the proposed clustering approach has efficiently and properly divided the complex network in the case of voltage control problem.

To show the effect of integration of large scale photovoltaic units in the distribution network, three cases have been defined as follows. The first case, namely the base case, corresponds to the system before installing PV units. Cases 2 and 3 are related to the distribution network including future planned PV units with and without the proposed voltage control scheme. The node voltage profiles of the three cases are shown in Fig. 4. As shown, the proposed method is able to regulate the voltages within the acceptable range.

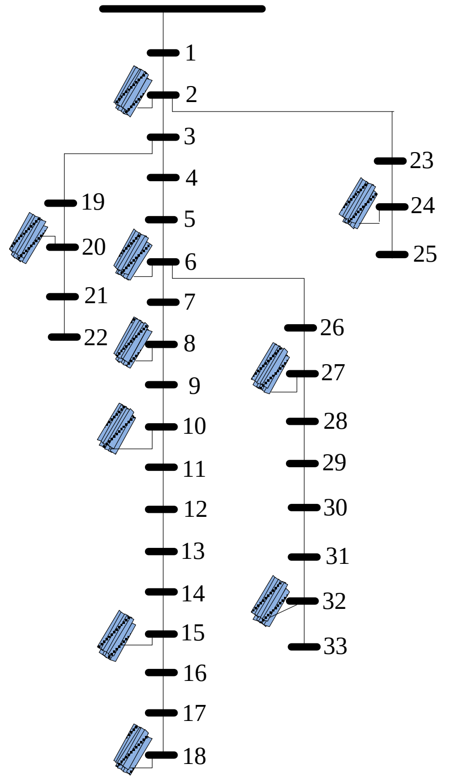

Fig. 2. The IEEE 33-bus system topology.

Table 1. GA Parameters

Parameter	Value
Number of Population	50
Population Type	Double vector
Selection Operators	Stochastic uniform
Mutation Operators	Gaussian
Percent of Mutation	20%

In order to prove the feasibility of the proposed voltage control method, the simulation results of a conventional centralized voltage control strategy [42-43] are given as a comparison where optimal reactive power management is optimized by the GA algorithm. Using the centralized scheme, the absorbed reactive power for each PV unit is given in Table 2. The total reactive power compensation in centralized method is 2005 kVar where the one in the proposed method is 1125 kVar. It can be found that the centralized method results in a higher amount of reactive power absorption if compared to the one in ADMM.

It should be noted that the centralized voltage control scheme requires a whole optimization procedure for all the PV inverters when the operation condition varies. So, without considering the regulation sensitivity of each inverter, the setpoints of active and reactive power for all inverters are the variants that should be optimized. Therefore, it shows a poor dynamic response to sudden transients like a transient weather condition caused by passing cloud shadows. The most important advantage of the distributed voltage regulation is that it only requires to regulate local inverters in order to control voltage for the partitions. Also, the inverters in other partitions can still conserve their operation strategies. In this manner, a complex problem is separated into several relatively simple sub-problems that can be solved fast and easily. Additionally, if only limited communication links are existing between PVs, the proposed method based on partitions can still achieve the voltage regulation aim.

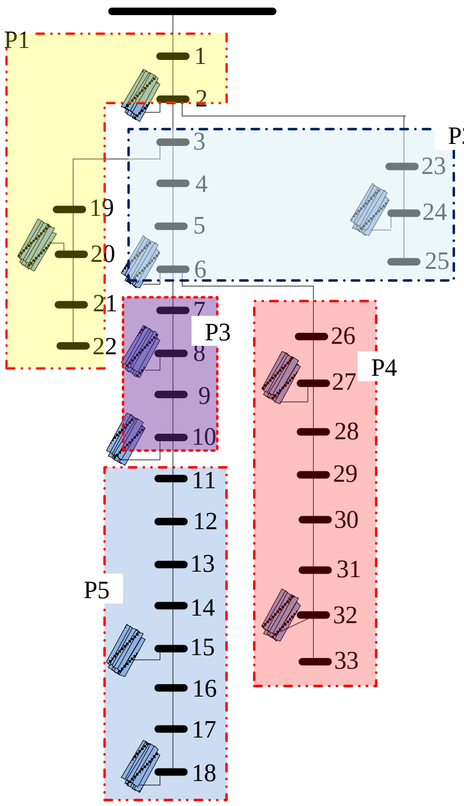

Fig. 3. The five partitions of the test system

Table 2. The absorbed reactive power in two methods

PV No	Bus No	Q of PV (kVar)	
		Centralized	The proposed
1	2	0	0
2	24	339	0
3	27	50	0
4	32	280	2
5	6	339	0
6	20	339	0
7	8	339	106
8	10	0	339
9	15	0	339
10	18	319	339
Total		2005	1125

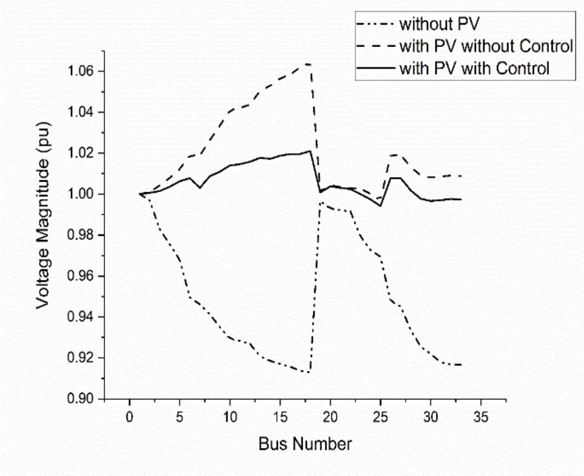

Fig. 4. Voltage profiles of the network in three cases

Fig. 5 shows the regulated voltage magnitude profiles for the two methods, namely the proposed distributed voltage control method, and the centralized management method.

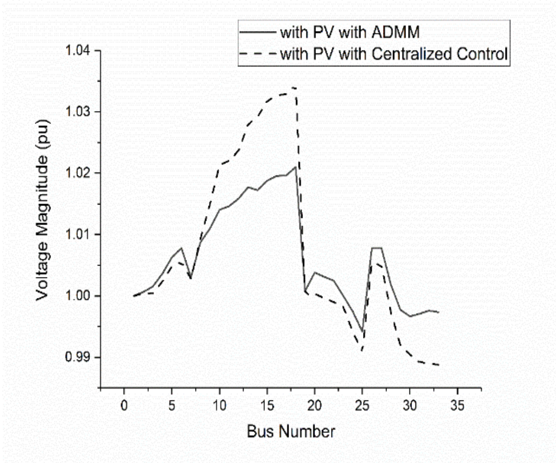

Fig.5. Voltage profiles of the network in two methods

Table 3. Comparison of computation time in two schemes

Voltage regulation scheme	Time (s)
The proposed method	11.25
Centralized method	182.12

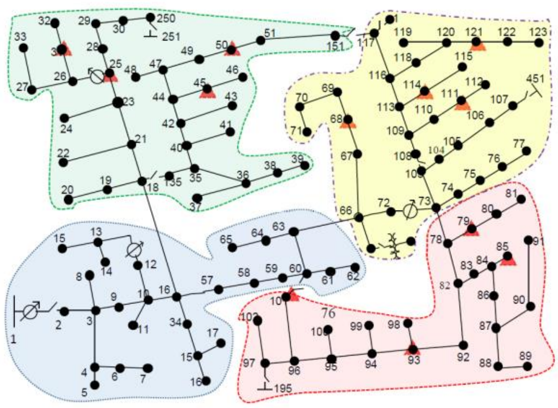

Fig. 6. The IEEE 123-bus test system diagram

Table 4. PV systems capacity and location on the 123-node system

Location	Capacity (kW)	Location	Capacity (kW)
25	400	85	400
31	200	93	400
45	200	101	400
50	400	111	400
68	400	114	400
79	400	121	200

Table 5. Comparison of computation time in two schemes

Voltage regulation scheme	Time (s)
The proposed method	13.65
The centralized method	229.37

The average computation time for each voltage regulation scheme is listed in Table 3. Regarding the fact that the proposed method divides the complex network into smaller sub-networks, a shorter time is required than the centralized control scheme.

To evaluate the generality and practicality of the proposed method, a large test system named IEEE 123-node distribution test feeder has been also selected [44]. The partitioning approach has been applied to this test system and the result has been illustrated in Fig. 6. It should be noted that the voltage control ability by PV units inverters has been only taken into account where the tap position of transformer has been kept constant during the regulation process. As shown by triangular-shaped in Fig. 6, 12 PV units have been installed in the test system and the capacity and location of PV units are given in Table 4.

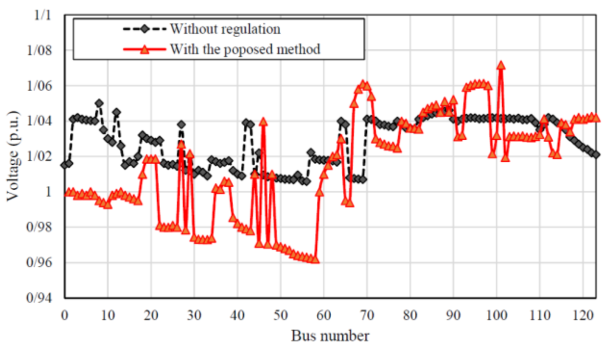

Fig. 7. The voltage profiles of IEEE 123-bus test system

The voltage profiles under the proposed method and without any regulation have been depicted in Fig. 7. As shown, the proposed method has effectively regulated the voltage within its acceptable range. To compare the response time of the proposed voltage control method, Table 5 provides the computation times for the proposed method and the conventional centralized voltage control method in the same simulation study condition. The results evidenced that the proposed method provides a much shorter computation time if compared to the one in non-partition centralized method where the results are nearly the same.

4. CONCLUSIONS

Due to the sudden change in PV unit output, the need for an online solution to manage and regulate the voltage of distribution networks is felt. In this paper, a distributed voltage control scheme base on ADMM approach has been presented to optimally regulate the voltage of distribution networks in the situation of high PV unit penetration. Also, a comparison between the conventional centralized voltage control method and the proposed distributed method has been carried out. The results evidenced that the proposed method takes advantage of less amount of reactive power compensation and lower computation time. Also, the proposed method resulted in a much less number of PV inverters which have been involved for voltage control than those of the centralized method. So, the proposed method introduces an applicable real-time voltage control in distribution networks which largely equipped with PV systems.

REFERENCES

[1] S. Golshannavaz, "Cooperation of electric vehicle and energy storage in reactive power compensation: An optimal home energy management system considering PV presence", *Sustainable cities soc.*, vol. 39, pp. 317-325, 2018.

[2] S. Moradian, O. Homaee, S. Jadid and P. Siano, "Optimal placement of switched capacitors equipped with standalone voltage control systems in radial distribution networks", *Int. Trans. Electri. Energy Syst.*, vol. 29, pp. 2753, 2019.

[3] M. Farhadi and F. Mohammadi, "Performance improvement of single-phase transformerless grid-connected PV inverters regarding common-mode voltage (CMV) and LVRT", *J. Oper. Autom. Power Eng.*, vol. 7, pp. 1-15, 2019.

[4] S. Jashfar and S. Esmaeili, "Volt/var/THD control in distribution networks considering reactive power capability of solar energy conversion", *Int. J. Electr. Power Energy Syst.*, vol. 60, pp. 221-233, 2014.

[5] H. Shayeghi and Y. Hashemi, "Hierarchy style application in line extension with responsive loads evaluating the dynamic nature of solar units", *J. Oper. Autom. Power Eng.*, vol. 6, pp. 268-284, 2018.

[6] S. Akagi et al., "Upgrading voltage control method based on photovoltaic penetration rate", *IEEE Trans. Smart Grid*, vol. 9, pp. 3994-4003, 2018.

[7] L. Wang, R. Yan and T. Kumar Saha, "Voltage management for large scale PV integration into weak distribution systems", *IEEE Trans. Smart Grid*, vol. 9, pp. 4128-39, 2018.

[8] H. Pezeshki, A. Arefi, G. Ledwich and P. Wolfs, "Probabilistic voltage management using OLTC and DSTATCOM in distribution networks", *IEEE Trans. Power Delivery*, vol. 33, pp. 570-580, 2018.

[9] P. Li et al., "Combined decentralized and local voltage control strategy of soft open points in active distribution networks", *Appl. Energy*, vol. 241, pp. 613-624, 2019.

[10] M. Monadi et al., "Measurement-based network clustering for active distribution systems", *IEEE Trans. Smart* Grid, vol. 10, pp. 6714-23, 2019.

[11] M. Nayeripour, H. Fallahzadeh, E. Waffenschmidt and S. Hasanvand, "Coordinated online voltage management of distributed generation using network partitioning", *Electr. Power Syst. Res.*, vol. 141, pp. 202-209, 2016.

[12] B. Zhao, Z. Xu, C. Xu, C. Wang and F. Lin, "Network partition-based zonal voltage control for distribution networks with distributed PV systems", *IEEE Trans. Smart Grid,* vol. 9, pp. 4087-4098, 2018.

[13] J. Ding, Q. Zhang, S. Hu, Q. Wang and Q. Ye, "Clusters partition and zonal voltage regulation for distribution networks with high penetration of PVs", *IET Gener. Transm. Distrib.*, vol. 12, pp. 6041-6051, 2018.

[14] P. Biskas, A. Bakirtzis, N. Macheras and N. Pasialis, "A decentralized implementation of DC optimal power flow on a network of computers", *IEEE Trans. Power Syst.*, vol. 20, pp. 25-33, 2005.

[15] A. Bakirtzis and P. Biskas, "A decentralized solution to the DC-OPF of interconnected power systems", *IEEE Trans. Power Syst.*, vol. 18, pp. 1007-13, 2003.

[16] M. Anjos, A. Lodi and M. Tanneau, "A decentralized framework for the optimal coordination of distributed energy resources", *IEEE Trans. Power Syst.*, vol. 34, pp. 349-359, 2018.

[17] J. Brooks, R. Trevizan, P. Barooah and A. Bretas, "Analysis and evaluation of a distributed optimal load coordination algorithm for frequency control", *Electr. Power Syst. Res.*, vol. 167, pp.86-93, 2019.

[18] J. Duan and M. Chow, "A novel data integrity attack on consensus-based distributed energy management algorithm using local information", *IEEE Trans. Ind. Inf.*, vol. 15, pp. 1544-1553, 2018.

[19] S. Rokni, M. Radmehr and A. Zakariazadeh, "Optimum energy resource scheduling in a microgrid using a distributed algorithm framework", *Sustainable cities soc.*, vol. 37, pp. 222-231, 2018.

[20] K. Lai and M. Illindala, "A distributed energy management strategy for resilient shipboard power system", *Appl. Energy,* vol. 228, pp. 821-832, 2018.

[21] P. Sulc, S. Backhaus and M. Chertkov, "Optimal distributed control of reactive power via the alternating direction method of multipliers", *IEEE Trans. Energy Convers*., vol. 29, pp. 968-977, 2014.

[22] H. Nguyen, A. Khodaei and Z. Han, "Incentive mechanism design for integrated microgrids in peak ramp minimization problem", *IEEE Trans. Smart Grid.*, vol. 9, pp. 5774-5785, 2017.

[23] T. Erseghe, "Distributed optimal power flow using ADMM", *IEEE Trans. Power Syst.*, vol. 29, pp. 2370-2380, 2014.

[24] V. Bhattacharjee and I. Khan, "A non-linear convex cost model for economic dispatch in microgrids", *Appl. Energy,* vol. 222, pp. 637-648, 2018.

[25] M. Chamana, B. Chowdhury and F. Jahanbakhsh, "Distributed control of voltage regulating devices in the presence of high PV penetration to mitigate ramp-rate issues", *IEEE Trans. Smart Grid,* vol. 9, pp.1086-1095, 2018.

[26] R. Jabr, "Linear decision rules for control of reactive power by distributed photovoltaic generators", *IEEE Trans. Power Syst.,* vol. 33, pp. 2165-2174, 2018.

[27] R. Jabr, "Robust Volt/VAr control with photovoltaics", *IEEE Trans. Power Syst.*, vol. 34, pp.2401-2408, 2019.

[28] F. Ding and B. Mather, "On distributed PV hosting capacity estimation, sensitivity study and improvement", *IEEE Trans. Sustainable Energy,* vol. 8, pp. 1010-1020, 2016.

[29] G. Gharehpetian, M. Naderi, H. Modaghegh and A. Zakariazadeh, "Iranian smart grid road map and Iranian national advanced metering infrastructure plan (FAHAM)", in L. Lamont and A. Sayigh, "Application of Smart Grid Technologies, Case Studies in Saving Electricity in Different Parts of the World", Academic Press, Elsevier, 2018.

[30] S. Cotilla et al., "Multi-attribute partitioning of power networks based on electrical distance", *IEEE Trans. Power Syst.*, vol. 28, pp. 4979-4987, 2013.

[31] S. Arefifar, A. Mohamed and T. ElFouly, "Optimized multiple microgrid based clustering of active distribution systems considering communication and control requirements", *IEEE Trans. Ind. Electr.*, vol. 62, pp. 711-723, 2015.

[32] K. Christakou et al, "Efficient computation of sensitivity coefficients of node voltages and line currents in unbalanced radial electrical distribution networks", *IEEE Trans. Smart Grid*, vol. 4, pp. 741-750, 2012.

[33] T. Ehara, "Overcoming PV grid issues in the urban areas", 2009.

[34] National Renewable Energy Laboratory (NREL), "Advanced inverter functions to support high levels of distributed solar policy and regulatory the need for advanced", 2014.

[35] T. Preda, K. Uhlen and D. Eirik, "An overview of the present grid codes for integration of distributed generation", *CIRED 2012 Workshop: Integr. Renewables Distrib. Grid*, 2012.

[36] S. Hao and A. Papalexopoulos, "Reactive power pricing and management", *IEEE trans. Power Syst.,* vol. 12, pp. 95-104, 2017.

[37] X. Nan, C. Yu and F. Wen, "Valuation of reactive power support services based on sensitivity and risk analysis", *Electr. Power Syst. Res.*, vol. 77, pp. 646-651, 2007.

[38] S. Boyd et al., "Distributed optimization and statistical learning via the alternating direction method of multipliers," *Found. Trends Mach. Learn.*, vol. 3, pp. 1-122, 2011.

[39] J. Zhu, "Optimal reconfiguration of electrical distribution network using the refined genetic algorithm", *Electr. Power Syst. Res.*, vol. 62, pp. 37-42, 2002.

[40] J. Smith, R. Dugan and W. Sunderman, "Distribution modeling and analysis of high penetration PV", 2011 *IEEE Power Energy Soc. Gen. Meeting*, United states, 2011.

[41] M. Newman, M. Girvan, "Finding and evaluating community structure in networks", *Phys. Rev. E,* vol. 69, pp. 026113, 2004.

[42] P. Vovos, A. Kiprakis, A. Wallace and P. Harrison, "Centralized and distributed voltage control: Impact on distributed generation penetration", *IEEE Trans. power syst.*, vol. 22, pp. 476-483, 2007.

[43] A. Cagnano and E. Tuglie, "Centralized voltage control for distribution networks with embedded PV systems", *Renewable Energy,* vol. 76, pp. 173-185, 2015.

[44] B. Robbins, C. Hadjicostis and A. Dominguez-Garcia, "A two-stage distributed architecture for voltage control in power distribution systems", *IEEE Trans. Power Syst*., vol. 28, pp. 1470-1482, 2013.