Proceedings of the 54th Hawaii International Conference on System Sciences | 2021

Resilient Distributed Control Approach for Online Voltage Regulation in Distribution Networks under Adversaries

Tianqiao Zhao* and Jianhui Wang*

*Department of Electrical and Computer Engineering
Southern Methodist University, Dallas, TX 75275 USA
Email: tianqiaoz@smu.edu; jianhui@smu.edu

***Abstract*—This paper proposes a resilient distributed control approach for the voltage regulation problem in distribution networks with high penetration of photovoltaic systems. Aiming to reduce the network power loss and curtailment of photovoltaic active power generation, an objective function is formulated while subjecting to physical operation constraints. With feedback-based information, the proposed solution to optimal voltage regulation can be implemented in an online and distributed manner that ensures a real-time regulation response to fast voltage fluctuations. The proposed approach provides a cyber-secure solution that mitigates attack impacts on voltage control based on a weighted mean subsequence reduced technique. The proposed approach further addresses potential cyber-threats to the information and communication-based control of distributed PV inverters. Numerical studies on the IEEE 37-bus distribution system verify that the proposed approach achieves the optimal voltage regulation performance while ensuring the resilience.**

***Index Terms*—Resilient control, distributed algorithm, voltage regulation, mean subsequence reduced algorithm, distribution systems**

I. INTRODUCTION

The operation of power systems will be beneficial from the development of photovoltaic (PV) generation units, especially for distribution networks (DNs) [1]. However, installing PV units substantially with significant variability could pose unexpected challenges, i.e., voltage violations in the low-voltage DNs [2].

Traditional voltage regulation approaches by on-load tap changers, step-voltage regulators and shunt capacitors are in a slow time-scale. These approaches would be insufficient for a DN with high PV penetration since the fast fluctuation of solar energy [3]. Results in recent works have shown the capacity of controlling PV inverters to provide the voltage regulation service to the DNs [4], [5].

Conventionally, voltage control approaches are implemented in a centralised structure that shares information with a control centre [5], [6]. The centralised approach has several bottleneck, e.g., the single point failure and scalability. Recently, different control approaches have been proposed for voltage regulation in DNs from different perspectives according to their communication structure and communication requirement: such as the centralised [5]–[7], decentralised [8], [9] and distributed approaches [10], [11]. However, as shown in [12], the decentralised approaches using only local information would result in a sub-optimal and even unstable solution. In contrast, the distributed control structure is a promising solution to address this issue, which utilises effectively information exchanging among distributed generators (DGs) by a communication network [13]. Studies in [11], [14] have successfully shown the benefits of applying distributed structures to voltage regulation through controlling the curtailment of PV active power generation and the reactive power output from PV inverters.

The aforementioned distributed approaches to voltage regulation highly rely on the information and communication between PV inverters, leveraging advanced communication networks, and in turn it exposes them to future cyber attacks. Authors in [15] investigated the cyber-security of future microgrids and the importance of resilience in network-based control of power systems. For a communication-based control structure, both communication and control layers can be potential targets for cyber-attacks, e.g., denial-of-service (DoS) attack targeting the communication layer [16] and False data injection (FDI) attack targeting the sensor and control layers [17]. Many cyber-secure and resilient approaches for control layers have been reported to distributed microgrid control design [17], [18]. However, none of them investigated the voltage regulation problem in DNs.

This paper focuses on the FDI attacks on the control layer targeting the sensor and controller of PV inverters. From this perspective, this paper proposes a resilient distributed control approach aiming to mitigate secure intrusion during the voltage regulation process. An optimisation problem is first introduced to reduce network power losses and PV curtailment costs with voltage limits as operation constraints. The sparsity of distribution network matrices enables a distributed implementation of our solution. Recently, a weighted mean subsequence reduced (wMSR) framework has been reported in the research of multi-agent systems under adversaries [19]. The wMSR-based framework is a systematic technique to discard the extremely information shared by units in a communication network, which has been successfully applied in different application areas [20], [21]. Taking advantages of the wMSR-based framework, the proposed solution is resilient to FDI attacks aiming to destabilise voltage profiles in DNs. Unlike the existing solutions, the proposed wMSR-based framework

URI: https://hdl.handle.net/10125/70997
978-0-9981331-4-0
(CC BY-NC-ND 4.0)

features local computation and verification. Hence, introducing this framework does not affect the distributed implementation of the original voltage control approach. It further provides a cyber-secure solution to the voltage regulation problem. The effectiveness of the proposed strategy is verified by numerical studies in a modified IEEE 37-bus system, where the fully AC power flow is adopted to assess its performance.

The remainder of this paper is organized as follows. Section II introduces the system model and problem formulation. In Section III, a resilient distributed control algorithm is developed. Section IV illustrates the case study. Finally, Section V provides the conclusion and future works.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. Branch flow model for a distribution network

Let $\mathcal{N} \cup \{0\}$ be the set of buses in a radial DN, where $|\mathcal{N}| = N$ represents all branch buses and $\{0\}$ is the feeder bus. Define a set of the neighbouring buses of jth bus as $\mathcal{N}_j$ that includes jth bus but excluding the feeder bus. The branch power flow of a DN is generally non-convex [22]. In this work, a widely adopted linearised branch flow (LinDistFlow) model is used to facilitate a distributed design, which neglects line losses and assumes the flat voltage. Assuming the voltage magnitude of a reference bus v_0 is constant, and the voltage magnitude at ith bus is v_i with $\mathbf{v} := [v_1, \ldots, v_N]^T$ collecting all measured voltage magnitudes, the following model is introduced, $\forall (i,j) \in \mathcal{E}$,

$$P_{ij} = \sum_{k \in \mathcal{N}_i \setminus \{i,j\}} P_{jk} - p_j \tag{1a}$$

$$Q_{ij} = \sum_{k \in \mathcal{N}_i \setminus \{i,j\}} Q_{jk} - q_j \tag{1b}$$

$$v_i - v_j = r_{ij} P_{ij} + x_{ij} P_{ij}, \tag{1c}$$

where P_{ij}/Q_{ij} is the active/reactive power flow from ith bus to jth bus; p_j/q_j is the active/reactive power injection at jth bus; r_{ij} and x_{ij} are the resistance and reactance of each line $(i,j) \in \mathcal{E}$, respectively, where $\mathcal{E} := \{(i,j), \forall i,j \in \mathcal{N}\}$ is the set of line branches. Denoting $\mathbf{p} = [p_1, \ldots, p_N]^T$ and $\mathbf{q} = [q_1, \ldots, q_N]^T$, (1) can be written compactly as

$$\mathbf{v} = R\mathbf{p} + X\mathbf{q} + v_0 \mathbf{1} \tag{2}$$

where $\mathbf{1}$ is an N-dimensional vector with all entries being 1. $R := D^{-T} M_r D^{-1}$ where D is the line-bus incidence matrix and $M_r \in \mathbb{R}^{N \times N}$ is a diagonal matrix with r_{ij} being the diagonal entry; and similarly for $X := D^{-T} M_x D^{-1}$. Following [11], D is a positive definite matrix and D^{-1} is a weighted Laplacian matrix with sparsity.

It should be noted that the accuracy of the LinDistFlow model has been numerically corroborated by several recent works on voltage regulation [11], [23]. Note that although this study adopts the LinDistFlow model, the numerical studies utilise voltage magnitudes calculated by a fully AC power flow model in the algorithm update.

B. Problem Formulation of Voltage Regulation

In this subsection, the voltage regulation problem is formulated. Write the power and reactive power injections p_j and q_j as $p_j = p_j^m - p_j^v - p_j^l$ and $q_j = q_j^v - q_j^l$, where p_j^v and q_j^v are respectively the active curtailment power and reactive power injected by an inverter of a PV unit at jth bus; p_j^m denotes the maximum available active power from jth PV unit; p_j^l/q_j^l is the active/reactive power demand at jth bus. In this study, PVs are considered as controllable units that provide voltage regulation through optimal inverter dispatch [5].

The objective of a voltage controller is to regulate voltage to an acceptable range by optimally adjusting active and reactive power injections while ensuring the physical relationship (2). Specifically, the following objective of voltage regulation is formulated,

*1) **Objective function**:* The following cost functions are introduced to ensure optimal voltage regulation

- Network loss: as in [11], the network loss is approximated by

$$l(P_{ij}, Q_{ij}) \approx \sum_{(i,j) \in \mathcal{E}} \frac{P_{ij}^2 + Q_{ij}^2}{v_0} \tag{3}$$

  where v_0 is the voltage magnitude at the substation bus and assuming $v_0 = 1$ p.u., the above function can be further rewritten as following

$$\begin{aligned} l(P_{ij}, Q_{ij}) = l(\mathbf{p}, \mathbf{q}) &= \left\| D_r^{1/2} \mathbf{P} \right\|_2^2 + \left\| D_x^{1/2} \mathbf{Q} \right\|_2^2 \\ &= \mathbf{p}^T R \mathbf{p} + \mathbf{q}^T R \mathbf{q} \end{aligned} \tag{4}$$

  where the facts $-M^T \mathbf{P} = \mathbf{p}$ and $-M^T \mathbf{Q} = \mathbf{q}$ from (1a) and (1b) are used to derive the last equality.
- PV operation cost: In addition to the network loss, PV units in voltage regulation service should be operated considering their operation costs. This study assumes their costs are evaluated by convex quadratic functions while considering the network topology, i.e.,

$$c(\mathbf{p}^v) = [\mathbf{p}^v]^T R \mathbf{p}^v, \tag{5}$$

  where $\mathbf{p}^v$ is the vector collecting p_i^v, $\forall i \in \mathcal{N}$; R collects information about the network topology, and thus the formulated cost functions can be interpreted as penalties for the power output from PV units at different locations.

*2) **Operational constraints**:*

- Voltage constraint: system voltage profiles should be within the acceptable range $[\underline{v}_i,\ \bar{v}_i]$

$$\underline{v}_i \leq v_i \leq \bar{v}_i, \ \forall i \in \mathcal{N}, \tag{6}$$

  where $\underline{v}_i$ and $\bar{v}_i$ are the lower and upper voltage limits.
- Power constraint: the active and reactive power output from the inverters of each PV unit should not exceed the power capacity. The operation regions of active and reactive power of PV inverters can be respectively written by,

$$0 \leq p_i^v \leq p_i^m, \tag{7}$$

$$|q|_i^v \leq \sqrt{(S_i^v)^2 - (p_i^v)^2}, \ \forall i \in \mathcal{N}, \tag{8}$$

where S_i^v is the rated apparent power of the PV inverter. The following linearisation are introduced to decouple the P-Q correlation in (8),

$$\underline{q}_i^v \leq q_i^v \leq \bar{q}_i^v, \ \forall i \in \mathcal{N}, \tag{9}$$

where $\bar{q}_i^v = \sqrt{(S_i^v)^2 - (p_i^m)^2}$ and $\underline{q}_i^v = -\bar{q}_i^v$ are the upper and lower limits of the reactive power from the PV inverter, respectively.

*3) **Optimisation problem**:* Overall, the optimisation problem for voltage regulation is formulated by

$$\min_{\mathbf{p}^v, \mathbf{q}^v} \quad \frac{1}{2}\big(w_l l(\mathbf{p}, \mathbf{q}) + w_v c(\mathbf{p}^v)\big) \tag{10a}$$

$$\text{s.t} \quad \underline{\mathbf{v}} \leq \mathbf{v}^o - R\mathbf{p}^v + X\mathbf{q}^v \leq \bar{\mathbf{v}} \tag{10b}$$

$$\text{(7) and (9),} \tag{10c}$$

where $\mathbf{v}^o := v_0 \mathbf{1} + R(\mathbf{p}^m - \mathbf{p}^l) - X\mathbf{q}^l$; w_l and w_v are the weighting factors for network loss minimisation and cost reduction, respectively. In (10a) the first term can be rewritten as $l(\mathbf{p}, \mathbf{q}) = (\mathbf{p}^m - \mathbf{p}^v - \mathbf{p}^l)^T R(\mathbf{p}^m - \mathbf{p}^v - \mathbf{p}^l) + (\mathbf{q}^v - \mathbf{q}^l)^T R(\mathbf{q}^v - \mathbf{q}^l)$. For convenience, the following sections use f to represent (10a). Note that the formulation of f will turn out that the voltage controller only depends on the local information and neighbouring information as in Section III, which makes the designed solution compatible with a feedback design using a fully ac power flow.

The voltage regulation problem can be solved by centralised or decentralised methods. However, as illustrated in [12], using only local information, these methods could not guarantee the success of voltage regulation. Although results on distributed voltage control have been recently introduced [11], [23], they fail to converge or even result in an unstable system if there exist adversaries in the communication network. To address this issue, the following section will introduce a resilient voltage control approach.

III. RESILIENT DISTRIBUTED CONTROL FOR REAL-TIME VOLTAGE REGULATION

With the development of communication and control technologies in modern power systems, cyber-threats can easily gain access to PMUs and control units. As a result, distributed voltage controllers in DNs are vulnerable to cyber-threats. The focus of this paper is on FDI attacks targeting decision-making units of voltage controllers. Before presenting the proposed resilient solution, the following definition is introduced.

Definition 3.1 (Malicious voltage controller): An adversarial voltage controller is said to be malicious if it updates active/reactive power injections by taking arbitrary values as its control input due to FDI attacks and sends the updates to neighbouring controllers.

An adversarial voltage controller can transmit different values to different neighbouring units through WSNs, aiming to: i) slow down voltage control; ii) endanger voltage stability in DNs; iii) overload the line thermal limits. Note that enabling resilience of distributed voltage controllers requires the certain connectivity of the communication network. As in [19], a subset $\mathcal{S}$ is $r-reachable$ if it contains a voltage controller that at least r communication links from outside $\mathcal{S}$. Then, a graph is called $r - robust$ if for any pairs of two disjoint subsets $\mathcal{S}_1$ and $\mathcal{S}_1$, at least one of $\mathcal{S}_1$ or $\mathcal{S}_1$ is $r - reachable$. The set of all agents is partitioned into a set of adversarial controllers $\mathcal{A}$ and a set of normal controllers $\mathcal{N}/\mathcal{A}$. Based on the above preparation, the following wMSR-VC algorithm is introduced.

A. wMSR-VC algorithm

Let $(\underline{\lambda}_i, \bar{\lambda}_i)$, $(\underline{\nu}_i, \bar{\nu}_i)$ and $(\underline{\mu}_i, \bar{\mu}_i)$, are the Lagrangian multipliers associated with respectively (6), (7) and (9). Initialising these multipliers by zeros, the wMSR-VC algorithm comprises the following steps:

1) Dual update: Using a standard dual-ascent method [24], the updates of $\lambda_i = (\underline{\lambda}_i, \bar{\lambda}_i)$ and $\zeta_i(k) = (\underline{\nu}_i, \bar{\nu}_i, \underline{\mu}_i, \bar{\mu}_i)$ are given by, $\forall i \in \mathcal{N}$

$$\lambda_i(k+1) = \left[\lambda_i(k) + \alpha \begin{bmatrix} v_i(k) - \bar{v}_i \\ \underline{v}_i - v_i(k) \end{bmatrix}\right]^+ \tag{11a}$$

$$\zeta_i(k+1) = \left[\zeta_i(k) + \gamma \begin{bmatrix} p_i^v(k) - p_i^m \\ 0 - p_i^v(k) \\ q_i^v(k) - \bar{q}_i^v \\ \underline{q}_i^v - q_i^v(k) \end{bmatrix}\right]^+ \tag{11b}$$

where α and γ are step sizes. The operator $[\cdot]^+$ projects $[\cdot]$ onto the positive range. Note that the updates of dual variables only use local information and thus, the wMSR-based algorithm is adopted in primal updates as follows.

2) the wMSR-based update: At each time step k, a list of λ_j and ζ_j, $j \in \mathcal{N}_i$ is created at ith voltage controller.

- Information sorting: the values of λ_j and ζ_j, $j \in \mathcal{N}_i$ including its own values of λ_i and ζ_i will be further sorted in the list from the largest to the smallest.
- Suspicious information deleting: Comparing the values of λ_j and ζ_j, $j \in \mathcal{N}_i$ with λ_i and ζ_i, ith voltage controller removes the F largest and F smallest values from the list where $F = |A|$. If the number of larger and smaller values is less than F, then all of them are discarded.

3) Primal update: For the primal update, a closed-form solution can be proposed due to the quadratic Lagrangian function. Using the remaining values, the following power injection updates are performed:

- p_i^v update:

$$p_i^v(k) = \Big(p_i^m - p_i^l(k) + \underline{\lambda}_i(k) - \bar{\lambda}_i(k) + \sum_{j \in \mathcal{R}_i(k)} [H_r]_{ij}(\underline{\nu}_j(k) - \bar{\nu}_j(k))\Big)/(w_v + 1), \tag{12}$$

- q_i^v update:

$$q_i^v(k) = q_i^l(k) + \sum_{j \in \mathcal{R}_i(k)} [H_{x/r}]_{ij}(\underline{\lambda}_j(k) - \bar{\lambda}_j(k)) + \sum_{j \in \mathcal{R}_i(k)} [H_r]_{ij}(\underline{\mu}_j(k) - \bar{\mu}_j(k)) \tag{13}$$

- Projection operation: in case of infeasible solutions, the above power injections will be projected onto their corresponding feasible sets.

where $[H_r]_{ij}$ and $[H_{x/r}]_{ij}$ are ijth entry of H_r and $H_{x/r}$ respectively; $\mathcal{R}_i(k) \in \mathcal{N}_i$ denotes the set of remaining values after the wMSR-based update at time step k. As illustrated in [11], H_r and $H_{x/r}$ are the inverse of R and X/R that are weighted Laplacian matrices. The sparsity of H_r and $H_{x/r}$ ensures the proposed wMSR-VC that is suitable for a distributed implementation. Algorithm 1 specifies the details of the proposed wMSR-VC.

Algorithm 1 wMSR-VC: resilient distributed voltage control

```
Initialize: Initialise $\lambda_i(0) = [0, 0]$ and $\zeta_i(0) = (0, 0, 0, 0)$;
    choose step sizes $\alpha$ and $\gamma$
wMSR-VC:
1: Collects local measurements of voltage magnitudes
2: Dual update:
     a) Update $\lambda_i(k)$ using (11a)
     b) Update $\zeta_i(k)$ using (11b)
3: Transmits and receives the corresponding dual variables
   with neighbouring PV units
4: Locally perform the wMSR-based operation: i) sorting
   collected values ii) deleting $F$ largest and $F$ smallest
   values
5: Update PV power injections according to (12) - (13)
6: Project the injections onto the feasible sets
7: return $p_i^v(k)$, $q_i^v(k)$;
   $k \to k + 1$ goes to Step 1
```

The proposed voltage regulation solution is a standard dual-ascent method [24] with the wMSR-based operations. As proved by [19], if the communication graph is $(2F + 1) - robust$, the proposed wMSR-VC algorithm ensures a reliable voltage regulation even under adversary controllers. The main challenge of the wMSR-based algorithm is the design of a $(2F+1)-robust$ communication graph. A virtual communication graph is introduced, where the graph weights are initialised following H_r and $H_{x/r}$. However, it may not have $(2F+1)-robust$. To address this issue, following [21], it can update a communication network to ensure its algebraic connectivity with the level of $r-robust$ being lower-bounded by $\lambda_2/2$. The communication network design is beyond the scope of this study. Interesting readers can refer to [21].

Note that the introduced wMSR-based framework is a local computation that is to process the received neighbouring information. After this process, the updates in (12) - (13) only use the information from the filtered set $\mathcal{R}_i(k)$ that is sill a subset only containing neighbouring information. The introduced framework will not change the distributed nature of the solution, and (12) - (13) are still only updated by the local interactions due to the sparsity of H_r and $H_{x/r}$. Therefore, the scalability and flexibility of the solution are not affected.

IV. NUMERICAL STUDY

In this section, PV units are located at buses in a distributed manner except for the substation bus on a modified IEEE 37-bus system, where the system information can be found in [25]. An illustrative case is studied to demonstrate the performance of the proposed wMSR-VC algorithm. The proposed algorithm is compared with an existing solution without resilience consideration. A 2.4 GHz Intel Core I5 PC was used to perform this case study based on the Matlab/Matpower [26].

The per unit is used in the following case based on a 4.8 kV nominal voltage value. The range of voltage operation is [0.95, 1.05] p.u. The PV system has the120 kW peak capacity and 1.05× 120 kVA rated apparent power. The step-sizes α and γ are chosen as 0.5 and 0.06 respectively. Although the designed solution is based on the linear power flow model of Section II-A, the real voltage magnitudes are used to update dual variables, where the actual bus voltage magnitudes are obtained by solving the fully AC power flow in Matpower. A control diagram is shown in Fig. 1 that illustrates the procedures of the wMSR-VC algorithm.

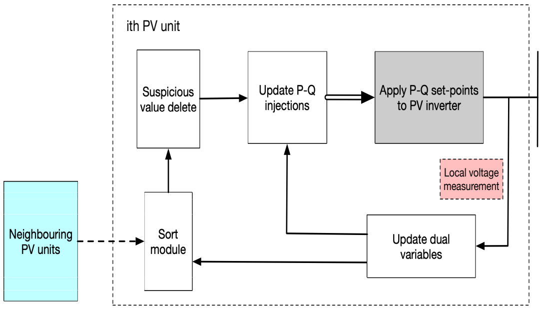

Fig. 1. Control diagram of the proposed wMSR-VC algorithm

A. Static loading and PV generation

In this case, PV units are installed in the modified 37-bus test feeder. The distribution system operating condition (loading condition) is assumed to be static during the simulation process. Suppose that the controllers at Node 3 and Node 16 are respectively compromised two kinds of FDI attacks where one is a periodic function $\lambda_i = \sin(0.2 * k)$ and another is a linear increasing function $\nu_i = 0.2 * k$, where k is the time step. Note that the types of these attacks cover various attack problems introduced by [27], particularly for consensus-based distributed control in microgrids. It includes continuous attacks with bounded and unbounded magnitudes.

The proposed wMSR-VC algorithm is applied to regulate voltage profiles into the voltage limit. Figs. 2 - 3 illustrate the updates of dual variables under adversaries. It is shown that the FDI attacks at Node 3 and Node 16 will not affect the rest of the updates of dual variables. The corresponding regulated voltage magnitudes are given in Fig. 4. As shown in the results, although there are FDI attacks in the network system, the proposed algorithm is immune to these attacks and can still converge to a reliable and stable solution, where the voltage magnitude of each node is quickly regulated to its limits, i.e., [0.95 1.05] p.u..

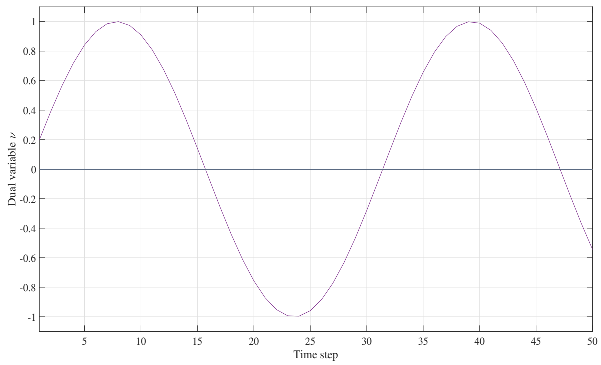

Fig. 2. Convergence of dual variables λ using the proposed wMSR-VC algorithm

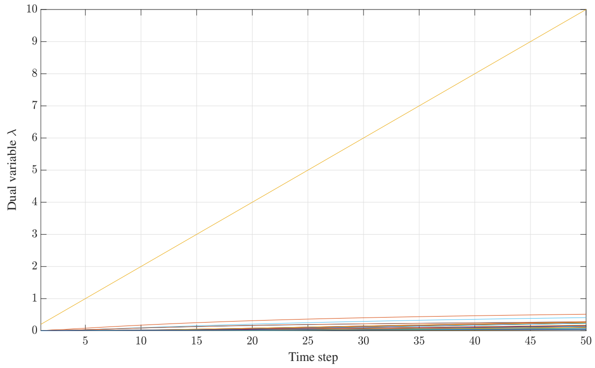

Fig. 3. Convergence of dual variables ν using the proposed wMSR-VC algorithm

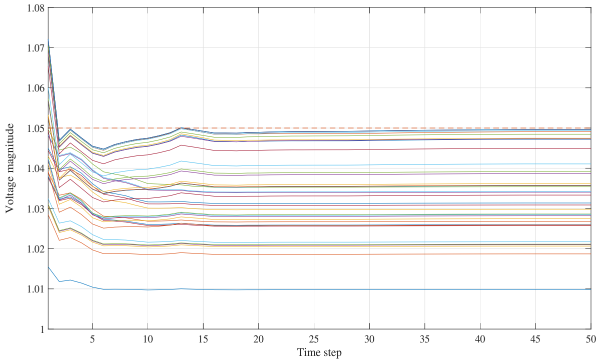

Fig. 4. Convergence of voltage magnitudes using the proposed wMSR-VC algorithm

To further highlight the importance of resilience, the proposed wMSR-VC algorithm is compared with a recently distributed voltage control approach [11] without the resilience consideration. Fig. 5 illustrates the evaluations of the network loss, where both approaches are compared with an ideal result without attacks using Yalmip [28]. It is clearly shown that

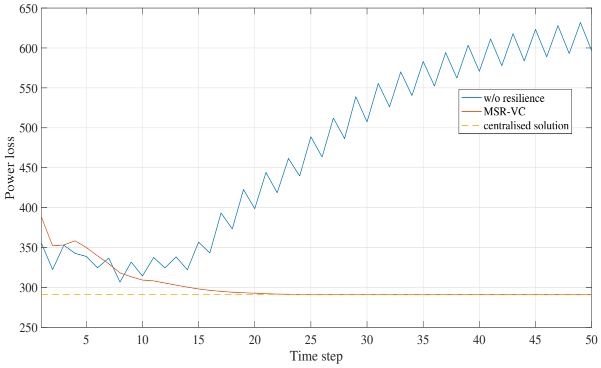

Fig. 5. Convergence of the network loss, using using the proposed wMSR-VC algorithm and the approach in [11]

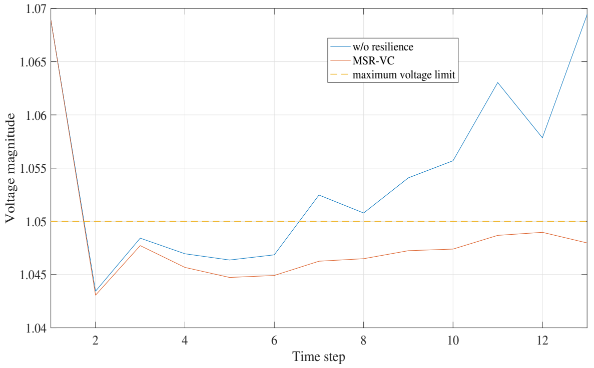

Fig. 6. Convergence of voltage magnitudes, using the proposed wMSR-VC algorithm and the approach in [11]

the proposed algorithm ensures the solution that converges to the correct result. However, the approach without the resilience consideration will be divergent due to the attacks. The corresponding updates of voltage magnitudes are illustrated in Fig. 6. The result in Fig. 6 shows that without resilience consideration, the voltage magnitude will beyond the upper limit at time step 5 if the voltage controllers are attacked. Therefore, the FDI attacks result in divergent and unstable voltage control. But the proposed solution ensures a stable and reliable voltage regulation.

V. CONCLUSION

A resilient distributed control approach is proposed to online voltage regulation by coordinating PV systems in distribution networks while providing a reliable solution to the voltage regulation problem in the control design. The focus of the optimisation problem is on minimising network costs including the network loss and PV curtailment cost for the cost-effective service delivery. The optimisation problem is solved distributively utilising only neighbouring information. Finally, a wMSR-based algorithm is introduced to deal with FDI attacks when there are malicious voltage controllers in the networked system. The effectiveness of the proposed approach is verified through numerical studies. The results show that our solution can achieve a remarkable performance under adversaries, and therefore it is a cyber-secure solution.

Although this work verifies the performance of the wMSR-VC algorithm, two aspects still need to be further investigated: 1) more detailed attack types and their corresponding models should be considered in the proposed solution; 2) its effectiveness should be analyzed by implementing the solution in a real large-scale power system.

REFERENCES

[1] N. Mahmud and A. Zahedi, "Review of control strategies for voltage regulation of the smart distribution network with high penetration of renewable distributed generation," *Renewable and Sustainable Energy Reviews*, vol. 64, pp. 582–595, 2016.

[2] F. Olivier, P. Aristidou, D. Ernst, and T. Van Cutsem, "Active management of low-voltage networks for mitigating overvoltages due to photovoltaic units," *IEEE Trans. Smart Grid*, vol. 7, no. 2, pp. 926–936, 2015.

[3] S. Alyami, Y. Wang, C. Wang, J. Zhao, and B. Zhao, "Adaptive real power capping method for fair overvoltage regulation of distribution networks with high penetration of pv systems," *IEEE Trans. Smart Grid*, vol. 5, no. 6, pp. 2729–2738, 2014.

[4] S. Deshmukh, B. Natarajan, and A. Pahwa, "Voltage/var control in distribution networks via reactive power injection through distributed generators," *IEEE Trans. smart grid*, vol. 3, no. 3, pp. 1226–1234, 2012.

[5] E. Dall'Anese, S. V. Dhople, and G. B. Giannakis, "Optimal dispatch of photovoltaic inverters in residential distribution systems," *IEEE Trans. Sustain. Energy*, vol. 5, no. 2, pp. 487–497, 2014.

[6] X. Liu, A. Aichhorn, L. Liu, and H. Li, "Coordinated control of distributed energy storage system with tap changer transformers for voltage rise mitigation under high photovoltaic penetration," *IEEE Trans. Smart Grid*, vol. 3, no. 2, pp. 897–906, 2012.

[7] L. Wang, D. H. Liang, A. F. Crossland, P. C. Taylor, D. Jones, and N. S. Wade, "Coordination of multiple energy storage units in a low-voltage distribution network," *IEEE Trans. Smart grid*, vol. 6, no. 6, pp. 2906–2918, 2015.

[8] J. Von Appen, T. Stetz, M. Braun, and A. Schmiegel, "Local voltage control strategies for pv storage systems in distribution grids," *IEEE Trans. Smart Grid*, vol. 5, no. 2, pp. 1002–1009, 2014.

[9] P. Jahangiri and D. C. Aliprantis, "Distributed volt/var control by pv inverters," *IEEE Trans. Power Syst.*, vol. 28, no. 3, pp. 3429–3439, 2013.

[10] Y. Wang, K. Tan, X. Y. Peng, and P. L. So, "Coordinated control of distributed energy-storage systems for voltage regulation in distribution networks," *IEEE Trans. Power Del.*, vol. 31, no. 3, pp. 1132–1141, 2015.

[11] J. Li, Z. Xu, J. Zhao, and C. Zhang, "Distributed online voltage control in active distribution networks considering pv curtailment," *IEEE Trans. Ind. Informat.*, vol. 15, no. 10, pp. 5519–5530, Oct 2019.

[12] S. Bolognani, R. Carli, G. Cavraro, and S. Zampieri, "On the need for communication for voltage regulation of power distribution grids," *IEEE Control Netw. Syst.*, 2019.

[13] H. J. Liu, W. Shi, and H. Zhu, "Distributed voltage control in distribution networks: Online and robust implementations," *IEEE Trans. Smart Grid*, vol. 9, no. 6, pp. 6106–6117, 2017.

[14] W. Zheng, W. Wu, B. Zhang, H. Sun, and Y. Liu, "A fully distributed reactive power optimization and control method for active distribution networks," *IEEE Trans. Smart Grid*, vol. 7, no. 2, pp. 1021–1033, 2015.

[15] Z. Li, M. Shahidehpour, F. Aminifar, A. Alabdulwahab, and Y. Al-Turki, "Networked microgrids for enhancing the power system resilience," *Proceedings of the IEEE*, vol. 105, no. 7, pp. 1289–1310, 2017.

[16] M. Chlela, D. Mascarella, G. Joós, and M. Kassouf, "Fallback control for isochronous energy storage systems in autonomous microgrids under denial-of-service cyber-attacks," *IEEE Transactions on Smart Grid*, vol. 9, no. 5, pp. 4702–4711, 2017.

[17] X. Liu and Z. Li, "False data attacks against ac state estimation with incomplete network information," *IEEE Transactions on smart grid*, vol. 8, no. 5, pp. 2239–2248, 2016.

[18] L. Liu, M. Esmalifalak, Q. Ding, V. A. Emesih, and Z. Han, "Detecting false data injection attacks on power grid by sparse optimization," *IEEE Transactions on Smart Grid*, vol. 5, no. 2, pp. 612–621, 2014.

[19] H. J. LeBlanc, H. Zhang, X. Koutsoukos, and S. Sundaram, "Resilient asymptotic consensus in robust networks," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 4, pp. 766–781, 2013.

[20] Y. Wang and H. Ishii, "Resilient consensus through event-based communication," *IEEE Transactions on Control of Network Systems*, 2019.

[21] K. Saulnier, D. Saldana, A. Prorok, G. J. Pappas, and V. Kumar, "Resilient flocking for mobile robot teams," *IEEE Robotics and Automation letters*, vol. 2, no. 2, pp. 1039–1046, 2017.

[22] M. Farivar and S. H. Low, "Branch flow model: Relaxations and convexification—part i," *IEEE Trans. Power Syst.*, vol. 28, no. 3, pp. 2554–2564, 2013.

[23] H. Zhu and H. J. Liu, "Fast local voltage control under limited reactive power: Optimality and stability analysis," *IEEE Trans. Power Syst.*, vol. 31, no. 5, pp. 3794–3803, 2015.

[24] S. Boyd, N. Parikh, E. Chu, B. Peleato, J. Eckstein *et al.*, "Distributed optimization and statistical learning via the alternating direction method of multipliers," *Foundations and Trends® in Machine learning*, vol. 3, no. 1, pp. 1–122, 2011.

[25] D. T. F. W. Group. (2010) Distribution test feeders. [Online]. Available: https://site.ieee.org/pes-testfeeders/resources/

[26] R. D. Zimmerman, C. E. Murillo-Sanchez, and R. J. Thomas, "Matpower: Steady-state operations, planning, and analysis tools for power systems research and education," *IEEE Trans. Power Syst.*, vol. 26, no. 1, pp. 12–19, Feb 2011.

[27] J. Duan and M.-Y. Chow, "A resilient consensus-based distributed energy management algorithm against data integrity attacks," *IEEE Transactions on Smart Grid*, vol. 10, no. 5, pp. 4729–4740, 2018.

[28] J. Löfberg, "Yalmip : A toolbox for modeling and optimization in matlab," in *In Proceedings of the CACSD Conference*, Taipei, Taiwan, 2004.