energies

Article

Voltage Control Strategy for Energy Storage System in Sustainable Distribution System Operation

Yue Zhang [1,†] and Anurag Srivastava [2,*,†]

[1] General Electric, Bothell, WA 98011, USA; zzyt1998@gmail.com
[2] The School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA 99164, USA
* Correspondence: anurag.k.srivastava@wsu.edu
† Current address: School of Electrical and Computer Engineering, Washington State University, Pullman, WA 99164, USA.

Abstract: Due to the increasing penetration of distributed energy resources (DERs) required for the sustainable distribution system, new voltage control strategy is needed by utilities. Traditional voltage control strategy can not support the increasing number of DERs in a coordinated and scalable manner to meet the operational voltage regulation requirement. Supported by the power electronics converter, the energy storage system can provide fast, smooth, and flexible voltage control services. In this paper, an effective and easy to implement sensitivity-based voltage control strategy is developed for the energy storage system. The developed control strategy is validated using an industrial feeder data in Northwest Washington. The proposed strategy can mitigate the voltage unbalance issue, improve the voltage profile, and correct power factors while supporting sustainable distribution system operation.

Keywords: voltage control; smart distribution system; energy storage system; DERs; storage management

Citation: Zhang, Y.; Srivastava, A. Voltage Control Strategy for Energy Storage System in Sustainable Distribution System Operation. *Energies* **2021**, *14*, 832. https://doi.org/10.3390/en14040832

Academic Editors: João Soares, Bruno Canizes and Zita Vale

Received: 27 December 2020
Accepted: 28 January 2021
Published: 5 February 2021

1. Introduction

Many conventional generators are approaching their lifespan and are planned to be replaced by renewable energy given the push for sustainable power systems. Around 2000 MW of conventional generators will be retired in the Washington and Oregon states [1] by end of 2020 and are being replaced by renewable and distributed energy resources (DERs) like photo-voltaic (PV) and wind turbines [2]. Enhanced integration of DERs could significantly impact the system voltage profile and the operations of the voltage regulation devices [3]. Variation in energy output may also increase the voltage unbalance rate of the system [4]. The voltage unbalance rate in the distribution system is usually larger than that in the transmission system due to the unbalanced network configuration. Imbalance voltages may damage equipment like induction motors [5], lead to an even higher unbalanced phase current [6] and introduce more losses and heating effects [7]. Therefore, maintaining a low voltage unbalance rate could help to improve the power quality and increase the reliability of the distribution system.

Traditionally, devices like regulators or capacitors are utilized to do Volt/Var control in the distribution system. Authors in [8] propose a multi-objective Volt/Var control method to optimize the operation of capacitor banks and tap changing transformers in the distribution network. In [9], an integrated voltage control method is introduced to minimize energy losses with capacitors and regulators. Using data from measurement and communication infrastructure, the control scheme shows good coordination among voltage regulators and capacitor banks and thus provides an effective Volt/Var control. Another strategy that aims to control capacitors through communication among remote terminal units is presented in [10]. An online Volt/Var optimization application that runs at the utility control center is described in [11]. Authors in [12] develop a voltage control method to minimize the line losses by adjusting the transformer tap position. An intelligent voltage control algorithm to maximize total energy savings in the distribution system is discussed in [13]. In [14], wireless distributed processing units are utilized to control the voltage control devices through performing power flow analysis. Authors in [15] propose a hybrid genetic-fuzzy algorithm to control the voltage profile, reactive power flow, and total harmonic distortion.

Since frequently switching these traditional voltage control devices will shorten their lifespan [16], there is a need for fast response and flexible operation devices. Supported by the power electronics-based four-quadrant operation, the energy storage system (ESS) becomes a promising option and could provide active and reactive support to the grid [17,18]. ESS is usually used to provide active power support like load shedding and peak shaving. An ESS-based active power management scheme is proposed for PV capacity firming and energy time shift in [19]. The authors in [20] utilize a multi-agent ESS frequency schedule to regulate the active power. Another fuzzy active power control method is introduced for ESS to reduce the operating cost and power exchange. Due to the relatively high installation cost of ESS, utility companies show growing interest in investigating the potential benefits of ESS in addition to the active power support. For example, ESS is mainly used to manage the adjacent PV station in Marshall Steam Station Energy Storage Project. However, Duke Energy uses ESS to provide both active and reactive power support, such as peak shaving, energy time-shift, capacity firming, and voltage control [21]. In the research field, researchers are also investigating how to design a control strategy that can utilize ESS' reactive power capacity on top of real power capacity. For example, Kashem and Ledwich design a P-I controller for ESS for real and reactive power support [22]. Under the Q mode, ESS can inject reactive power from the converter for low voltage correction. Similar to other P-I controllers, it may suffer from high starting overshoot and sensitive to controller gains [23]. In [24], an optimization-based ESS control strategy is proposed to ensure the voltage quality requirements in an low voltage grid with high PV penetration. This strategy requires frequently power flow solutions to get the voltage value from critical nodes. Similarly, authors in [25] propose an ESS control strategy in middle voltage level distribution systems to provide peak load shaving and voltage support. This method takes into account power flow, bus voltage, and associated ESS control parameters. Notice that the above optimization-based ESS control strategy usually need a continuous power flow solution to control the reactive power output. For a relatively large industrial distribution system, an accurate and high-frequency power flow solution is not always available. Besides, the voltage unbalance issue is not fully investigated with ESS control.

In the eastern Washington area, Avista deployed an ESS to provide a continuous power supply to a local manufacturer customer for enhanced reliability. Avista is also interested to use ESS to provide frequency regulation and voltage control services [26]. The modeling of the feeder with this ESS is done in [27], and the ESS real power control strategy for frequency support is provided in [26]. The local ESS reactive power control strategy is developed in [28]. In addition to our previous work in [28], a sensitivity-based coordinated voltage control strategy is developed for ESS to mitigate the voltage regulation issues along the feeder and help to reduce voltage unbalance rate under varying load conditions and varying installed PV capacity. The contributions of this paper are summarized as follows: (1) Comparing to our previous work in [28], the proposed strategy can further reduce voltage unbalance rate under varying conditions. (2) Comparing to optimization-based control strategies, the proposed strategy does not require regular distribution power flow solutions results to control the reactive power output. (3) The simulation results are tested and validated with a real industrial feeder model and actual field data. The local utility company can easily validate the performance of the proposed strategy with its own energy management systems.

2. Voltage Sensitivity-Based ESS Control Scheme

2.1. Voltage Control Scheme in Distribution System

Voltage control is an important distribution energy management application, which can provide voltage support based on the measured data [29]. A typical voltage control scheme in the distribution system is explained in Figure 1. The overall goal is to improve voltage profile and reduce the total network losses [30,31]. The voltage control scheme can be implemented by centralized or decentralized approaches with load tap changers, voltage regulators, capacitor banks, and etc. Each approach includes a specific problem algorithm to achieve the required network targets. The centralized control scheme can achieve a theoretical global optimal object through a series of control actions. However, this approach requires an accurate distribution model and reliable power flow and state estimation results. The network changes will also impact the results. On the other hand, a decentralized control scheme uses real-time local measurements to control a certain one or a group of voltage control devices to achieve a specific objective. Although it may not produce the "optimal" control steps like the centralized scheme, this approach is not limited by the power flow results and can produce fast voltage support.

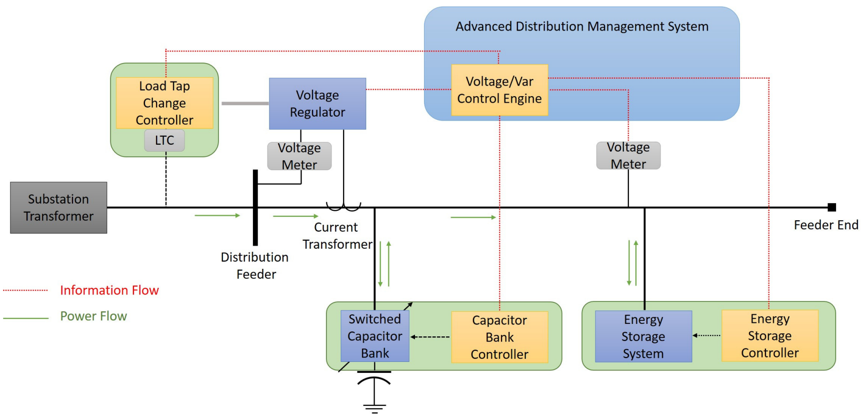


Figure 1. The voltage control scheme in the distribution system.

In order to enable ESS to provide support in presence of the above existing control scheme, a new voltage control strategy for ESS is needed. Usually, utilities hesitate to do large scale control scheme change due to large scale field testing requirement and safety concerns, so a control strategy that can help to improve distribution system operation with minimal coordination problem with other control devices is preferred.

To meet the need of utilities, a sensitivity based control strategy is proposed. The control scheme is presented in Figure 2. Based on the voltage sensitivity analysis method [32], the sensitivity factor estimator will utilize the system model and smart meter data to generate the sensitivity factor for this system. In real-time operation, the ESS controller can control the reactive power output based on the measured voltages and the sensitivity factor.

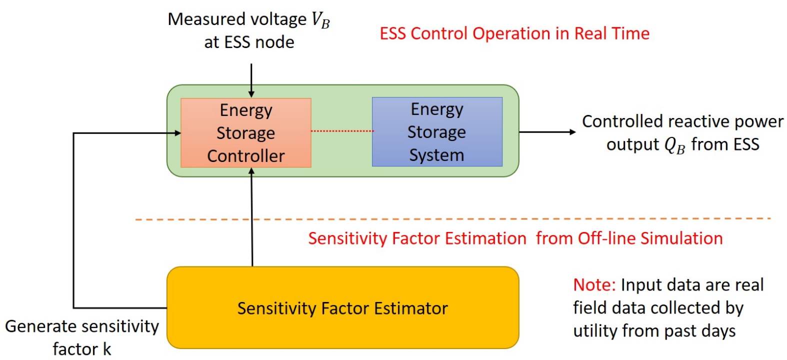


Figure 2. The scheme of the proposed energy storage system (ESS) control strategy.

2.2. Sensitivity Factor Estimator

The sensitive factor estimator will generate the sensitivity factor through off-line simulation. To get the sensitivity factor of the studied system, the general power flow equations are introduced first:

$$P_k = \sum_{n=1}^{N} |V_k||V_n||Y_{kn}|\cos(\vartheta_{kn} + \delta_n - \delta_k) \tag{1}$$

$$Q_k = \sum_{n=1}^{N} |V_k||V_n||Y_{kn}|\sin(\vartheta_{kn} + \delta_n - \delta_k) \tag{2}$$

where P_k and Q_k represent the injected active and reactive powers at node k; V_k and V_n represent the voltage magnitude for node k and n. δ_k, δ_n represent the voltage angle at nodes k and n. $Y_{kn}\angle\vartheta_{kn}$ is the admittance between nodes k and n. For a given nominal operation point, the above equations can be linearized as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial V} \end{bmatrix} \cdot \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \tag{3}$$

The inverse of the Jacobian matrix is the sensitivity matrix. $S_{\delta p}, S_{\delta q}, S_{vp}, S_{vq}$ describe the relationship between the voltage angle, magnitude and the active, reactive power.

$$\begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} = \begin{bmatrix} S_{\delta p} & S_{\delta q} \\ S_{vp} & S_{vq} \end{bmatrix} \cdot \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{4}$$

For a given operational point, the voltage change for each node can be calculated with changed reactive power. Assuming the ESS is installed at node k. If the reactive power output of ESS is changed by ΔQ_B, the voltage changes (ΔV_i) at node i can be calculated as:

$$\Delta V_i = S_{vq}(i,k) \cdot \Delta Q_B \tag{5}$$

Since the focus of this study is Volt/Var control strategy, the real power control is not included here. The ESS real power output ΔP_B is zero and $S_{vp}(i,k)$ is neglected. The sensitivity factor is defined as the inverse of $S_{vq}(i,k)$.

$$k = \frac{1}{S_{vq}(i,k)} \tag{6}$$

Noticing that for any $i \neq k$, $S_{vq}(i,k) \leq S_{vq}(k,k)$, so the reactive output of the ESS has the highest effectiveness on the installed node [33].

The sensitivity factor can be calculated through two off-line simulations using the feeder model and collected field data. In each case, ESS will provide a constant reactive power output during the entire period, namely Q_{B1} and Q_{B2}. The output difference should be small and meet the linear approximation criteria. The sensitivity factor for each snapshot k_t can be calculated.

$$k_t = \frac{\Delta Q_B}{\Delta V_B} = \frac{Q_{B2} - Q_{B1}}{V_{B2} - V_{B1}} \tag{7}$$

where V_{B1} and V_{B2} is the average voltage measured at the ESS terminal from the above two scenarios. Depending on the simulation time interval (ΔT) and total simulation time T, there will be $N = T/\Delta T$ sensitivity factors generated from the simulation. Finally, we get the average sensitivity factor K from averaging them using Equation (8).

$$K = \frac{1}{N}\sum_{t=1}^{N} k_t \tag{8}$$

2.3. ESS Controller

The ESS controller will control the reactive power output for each phase based on the calculated sensitivity factor from the sensitive factor estimator and the measured voltage value at the ESS terminal. In order to change the voltage to the desired target voltage (V_T) from the current measured voltage (V_B), the total required reactive power Q_B is determined by Equation (9), whereas, Q_B should vary within the reactive power output limits (Q_{min} and Q_{max}).

$$Q_B = K \cdot (V_T - V_B) \tag{9}$$

$$Q_{min} \leq Q_B \leq Q_{max} \tag{10}$$

Once the total required reactive power is determined, it will be allocated to each phase properly to mitigate the voltage unbalance issue. The reactive power for each phase is calculated using Equation (11).

$$Q_B^p = \frac{(V_T - V_B^p)}{\sum_p (V_T - V_B^p)} \times Q_B \tag{11}$$

where Q_B^p is reactive compensation needed for each phase p from ESS and V_B^p is the measured phase voltage at the ESS node. The voltage sensitivity analysis method is initially derived for the transmission system. To validate the proposed method for the distribution system which normally has an unbalanced charter and has a relatively lower X/R ratio [34,35], a detailed feeder model is needed. For our feeder model, each phase is explicitly modeled. The electromagnetic coupling between phases is also included. The resistance and reactance of each component are considered as well. Applying the sensitivity analysis method on this detailed distribution model, we demonstrate that the measured average voltage at ESS bus with the proposed strategy is very close to the pre-set target voltage, which proves the feasibility of this method.

3. Simulation Results and Analysis

In this section, several simulation cases have been conducted to present the benefits of the proposed control strategy.

3.1. Simulation Environment and Evaluation Metrics

The simulation system is developed based on an actual feeder in Pullman with gridlab-D. The configuration of the feeder is presented in Figure 3. This system has over 300 nodes and the load data is collected from smart meters. The studied 1.31 MVA/ 3.2 MWh ESS has 65–70% AC round trip efficiency. The ESS inverter has 5s charge/discharge lock time and 97.5% efficiency. The model detail and model validation process is present in our previous work in [27,28].

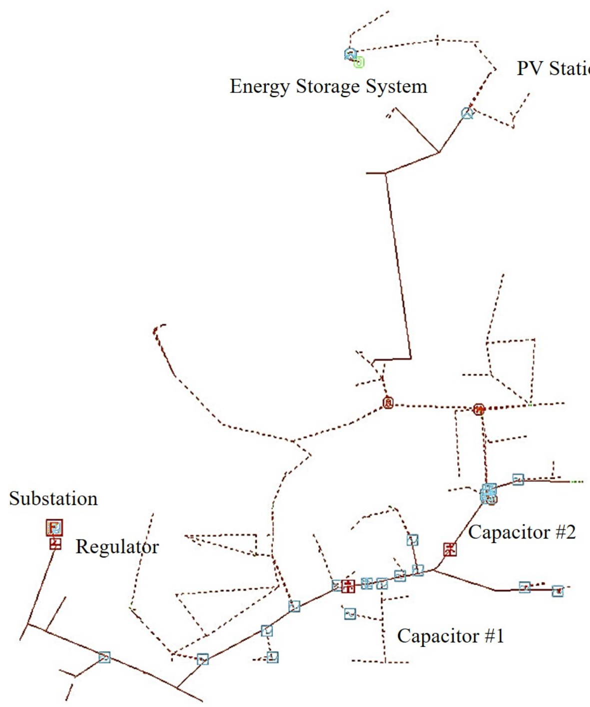


Figure 3. The configuration of the modeled industrial feeder.

In this paper, two metrics are utilized to quantify the impact of ESS on voltage unbalance mitigation and voltage profile improvement. The phase voltage unbalance rate (PVUR) defined by the Institute of Electrical and Electronics Engineers (IEEE) [4] is used to evaluate the voltage unbalance rate. The PVUR is defined as [36]:

$$\mathrm{PVUR} = \frac{V_D}{V_A} \times 100\% \tag{12}$$

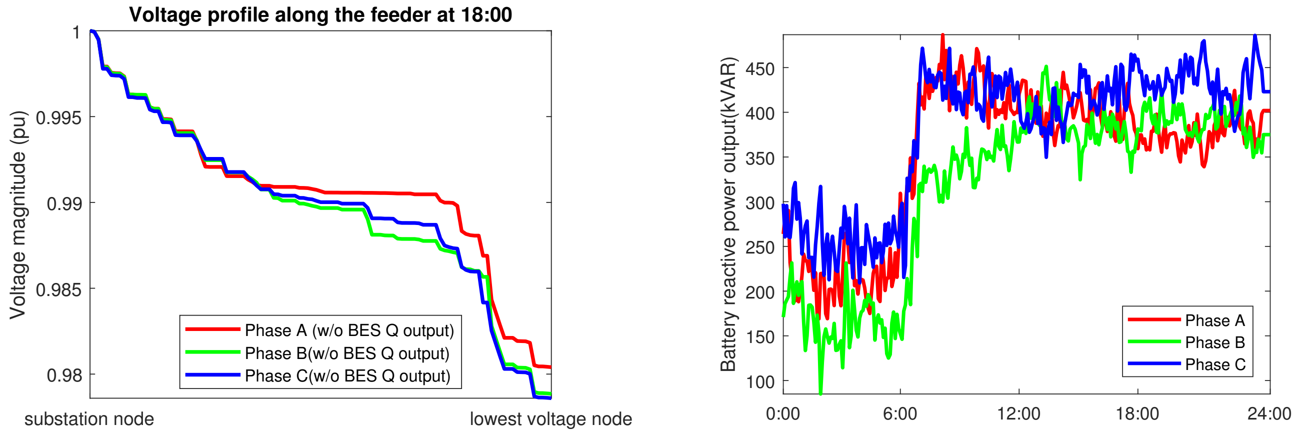
where V_D represent the max voltage deviation from the average phase voltage and V_A is the average phase voltage. For the voltage drop improvement, we evaluate the mean voltage magnitude changes at the feeder end using Equation (13).

$$\mathrm{IMP} = \frac{V_{wo} - V_w}{V_{wo}} \times 100\% \tag{13}$$

where V_w and V_{wo} is the mean voltage with/without the proposed method.

3.2. Simulation Results for One Specific Day

The performance of the three-phase Volt/Var control strategy is tested on a typical winter day on 16 January 2017. The voltage profile along the feeder without ESS at 18:00 is shown in Figure 4a. Since Feeder I is a relatively short feeder, the voltage drop along the feeder is relatively small. However, due to the nature unbalanced characteristics of the distribution system, the voltage unbalance rate is noticeable and gets worse at the feeder end. Based on the measured voltage at the ESS node, ESS will inject reactive power to the feeder as shown in Figure 4b. According to the control algorithm, the lower the measured phase voltage, the higher the injected reactive power. ESS will inject more reactive power to phase B and C at 18:00. As a result, the average voltage drop improvement is 30.9%, and the maximum voltage unbalance rate in terms of PVUR can decrease from 0.2415% to 0.1225%.

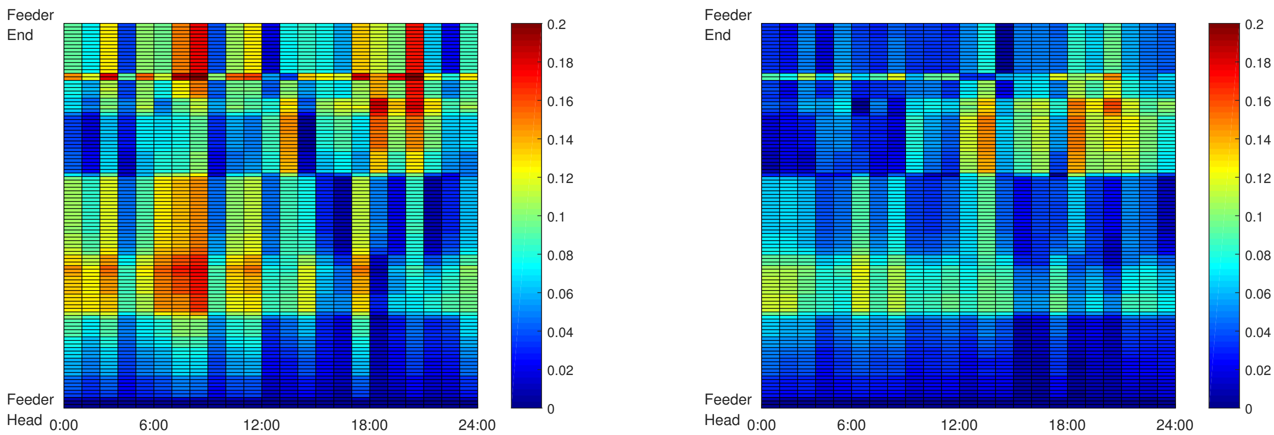


(**a**) Voltage profile without ESS (**b**) Reactive power output from ESS

Figure 4. Simulation results on 16 January 2017.

3.3. PVUR Mitigation

The proposed ESS control strategy can help to mitigate high voltage unbalance rate along the feeder and quantified in terms of PVUR improvement. The original PVUR for each three-phase node without ESS on 16 January is plotted in Figure 5a. Due to the physical structure of the feeder, the node at the feeder end tends to have a higher PVUR. However, the highest PVUR rate is not always at the feeder end. PVUR is also varying with time, usually higher PVUR is during morning and night peak time. Typically, less than 1% PVUR is recommended [37] and the feeder is operated within the range. With the help of ESS, the PVUR can be future reduced to improve the power quality. The PVUR for each three-phase node with ESS on the same day is plotted in Figure 5b. Compared with feeder without ESS, the PVUR is decreased significantly, especially during peak hours. The average PVUR decreases from 0.074% to 0.053% and the maximum PVUR decrease from 0.241% to 0.160%. The PVUR for all testing days are listed in Table 1. For all testing days, the PVUR improvement ranges from 9.65% to 43.84%.



(**a**) PVUR profilo without ESS control (**b**) PVUR profilo with ESS control

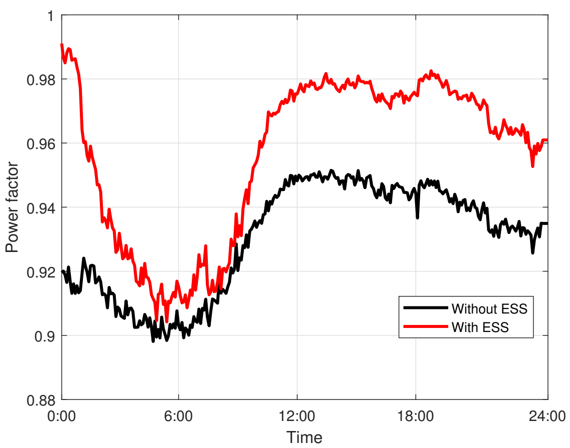
Figure 5. Phase voltage unbalance rate (PVUR) for each three-phase node on 16 January 2017.

Table 1. Maximum PVUR improvement from ESS controller.

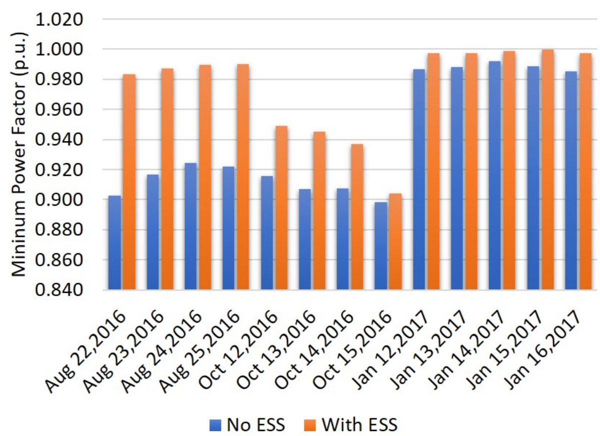
Season	Data	No ESS	With ESS	Improvement
Summer	22 August 2016	0.22%	0.19%	13.07%
	23 August 2016	0.20%	0.18%	12.82%
	24 August 2016	0.20%	0.18%	9.93%
	25 August 2016	0.20%	0.18%	9.65%
Autumn	12 October 2016	0.23%	0.19%	19.18%
	13 October 2016	0.28%	0.21%	24.72%
	14 October 2016	0.21%	0.17%	18.59%
	15 October 2016	0.27%	0.21%	21.90%
Winter	12 January 2017	0.25%	0.18%	30.47%
	13 January 2017	0.24%	0.14%	43.84%
	14 January 2017	0.23%	0.15%	34.21%
	15 January 2017	0.22%	0.14%	35.80%
	16 January 2017	0.24%	0.16%	33.70%

3.4. Power Factor Correction and Voltage Profile Improvement

Power factor correction is another benefit of the ESS controller. The improvement for one simulation case on 15 October is plotted in Figure 6a. The improvement is relatively low in the morning and high during the rest of the time. For days with higher reactive power demand like this testing day, ESS can help to improve the power factor from 0.93 to 0.956. Mininum power factor correction for all testing days is presented in Figure 6b. For different loading conditions, all testing days show power factor improvement from ESS.



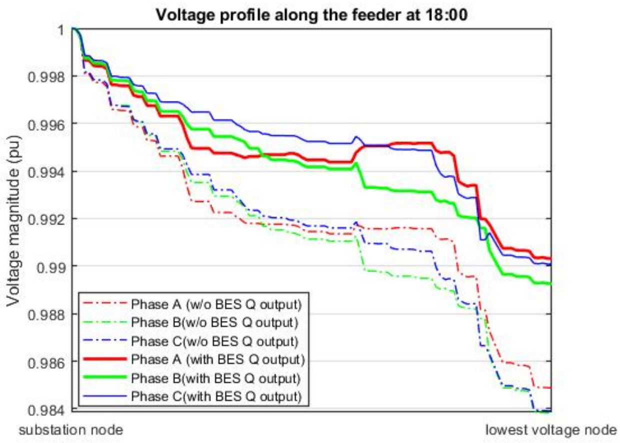
(**a**) Power factor improvement on 15 October



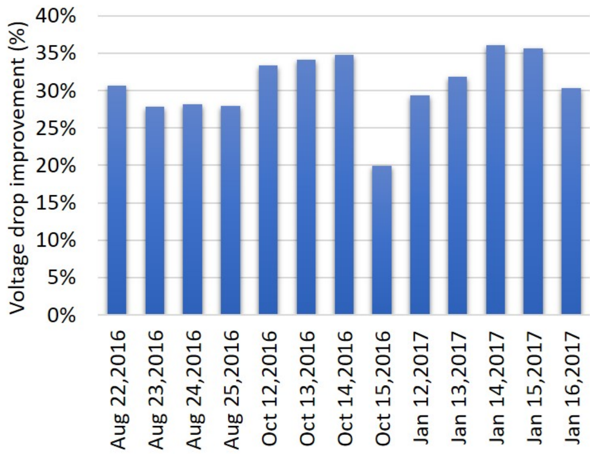
(**b**) Mininum power factor correction for all testing days

Figure 6. Power factor correction results.

ESS could also help to improve voltage profile through increasing the voltage magnitude along the feeder for all three phases. The power loss and transferring capacity can benefit from such improvement. The voltage profile with and without the proposed control strategy on 14 January is presented in Figure 7a. Under different load conditions, the improvement varies from 2.2% to 38.1%, but the average improvement is about 30% as shown in Figure 7b.



(**a**) Voltage profile improvement on 14 January



(**b**) Voltage profile improvement for all testing days

Figure 7. Voltage profile improvement results.

3.5. Control Strategy Comparison

Compared to the original ESS control strategy proposed in [28], named as Strategy I, the new strategy, named as Strategy II, can provide a better voltage unbalance rate mitigation and a similar level of voltage profile improvement at the same time. The maximum PVUR for all nodes on 16 January 2017 is plotted in Figure 8. Visually, Strategy II is more efficient in voltage unbalance rate mitigation during the entire testing day. Strategy I is not designed for PVUR mitigation and ESS will inject reactive power equally to each phase, so the PVUR rate is only slightly better than the benchmark case without ESS. In comparison, the new control strategy II will provide a different level of reactive power compensation at each phase based on the measured voltage. As a result, PVUR can be further reduced. Especially, during the morning and night peak period, strategy II can help to reduce the PVUR much higher than strategy I.

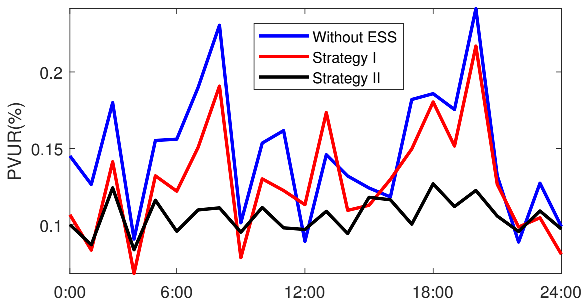
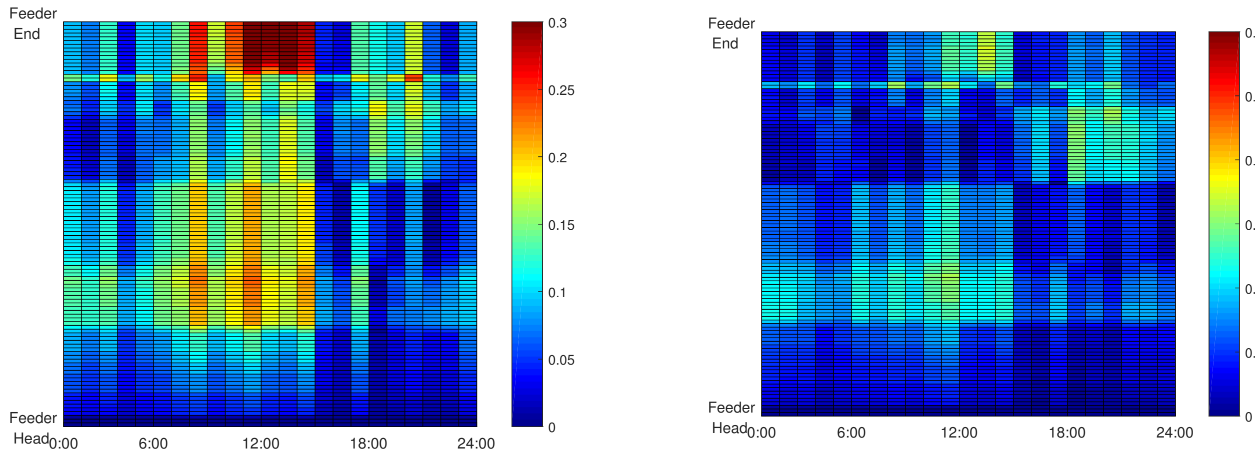


Figure 8. Maximum PVUR comparison between control strategies I and II.

3.6. Impact of PV on PVUR

Deeper PV penetration could cause the voltage unbalance issues. For example, when the PV size increases to 750 kVA, the PVUR increases significantly during noontime as shown in Figure 9a. Originally, the maximum PVUR is 0.241% and happened at 20:00. Due to the effect of PV, the maximum PVUR is 0.359% and happened at 13:00. PV generators not only increase the overall PVUR along the feeder but also creates new peak PVUR hours during the noontime. For the current penetration level, a 75 kVA PV has a limited impact on PVUR. However, when the penetration level reaches 750 kVA, the impact will become quite obvious. To test the influence of high-level PV penetration on the voltage control strategy, one test case is conducted on 16 January with a 750 kVA PV system. The new PVUR profile for this feeder is plotted in Figure 9b. Compared with the system without

ESS control, the maximum PVUR decreases from 0.359% to 0.175%. The noon PVUR peak caused by PV is almost fully mitigated.



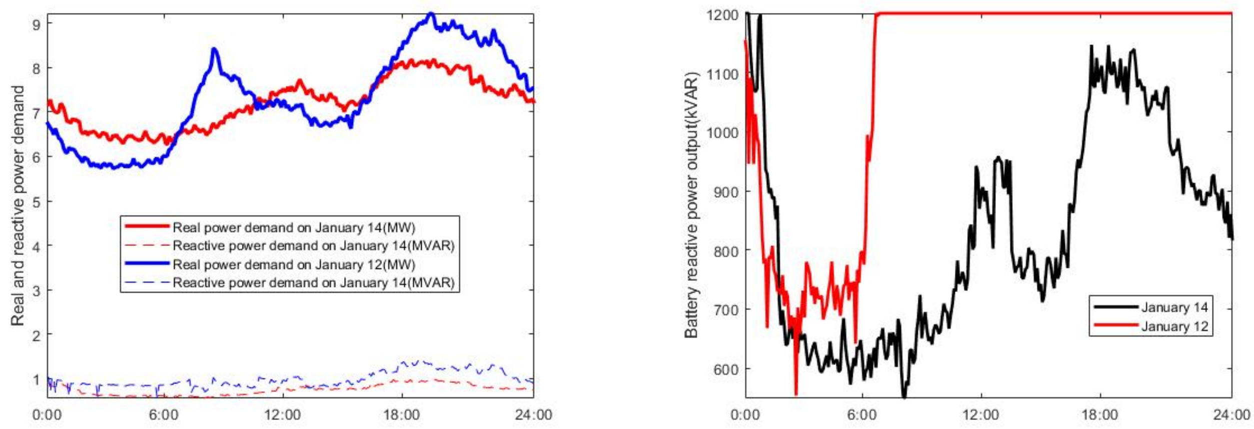
(**a**) PVUR profile without ESS control

(**b**) PVUR profile with ESS control

Figure 9. PVUR mitigation under high photo-voltaic (PV) penetration scenario.

3.7. The Impact of Load Level on Voltage Control Performance

Since there is a certain reactive power output limit for the ESS, it may not increase the voltage as desired under heavy load conditions. As shown in Figure 10a, the demand on 12 January is significantly higher than that on 14 January. During the test, the reactive output from ESS on 12 January capped at 1.2 MVar after 6:00 am as shown in Figure 10b. Therefore, it is beneficial to find a suitable size of ESS for a certain feeder through simulation.



(**a**) Real and reactive power demand

(**b**) The reactive power output of ESS

Figure 10. The impact of load level on voltage control performance.

4. Conclusions

This paper proposes a sensitivity-based voltage control strategy for the real-time operation of sustainable distribution systems with a high DER penetration rate. The proposed method utilizes only measured voltage at the ESS terminal to determine the reactive power output for each phase, which can reduce voltage unbalance rate under varying conditions on top of voltage profile improvement and power factor correction. Under a high DERs penetration case, the maximum PVUR is reduced significantly. The new PVUR peak during noon-time caused by PVs is properly mitigated. The developed technique has been validated using a detailed feeder model based on real field data. The utility company can easily validate the proposed strategy with its energy management systems. Future work includes extending the proposed algorithm for the four-quadrant operation of converters and coordination with distributed energy resources such as PV and wind.

Author Contributions: Conceptualization, Y.Z. and A.S.; methodology, Y.Z. and A.S.; software, Y.Z. and A.S.; validation, Y.Z. and A.S.; formal analysis, Y.Z. and A.S.; investigation, Y.Z. and A.S.; resources, Y.Z. and A.S.; data curation, Y.Z. and A.S.; writing—original draft preparation, Y.Z.; writing—review and editing, Y.Z. and A.S.; visualization, Y.Z. and A.S.; supervision, A.S.; project administration, A.S.; funding acquisition, A.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable .

Informed Consent Statement: Not applicable .

Data Availability Statement: 3rd Party Data Restrictions apply to the availability of these data. Data was obtained from [Avista Utilities] and are available [from the authors] with the permission of [Avista].

Acknowledgments: The authors would like to thank the Avista Utilities, the Pacific Northwest National Lab (PNNL) and US Department of Energy for the financial support and providing industrial data to conduct this work. We would like to acknowledge support from Chen-Ching Liu, Yin Xu, and Venkatesh Venkataramanan for supporting part of this work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Balducci, P.J.; Jin, C.; Wu, D.; Kintner-Meyer, M.; Leslie, P.; Daitch, C. *Assessment of Energy Storage Alternatives in the Puget Sound Energy System*; Technical Report; Pacific Northwest National Laboratory: Richland, WA, USA, 2013.
2. Mahmud, N.; Zahedi, A. Review of control strategies for voltage regulation of the smart distribution network with high penetration of renewable distributed generation. *Renew. Sustain. Energy Rev.* **2016**, *64*, 582–595. [CrossRef]
3. Eghtedarpour, N.; Farjah, E. Distributed charge/discharge control of energy storages in a renewable-energy-based DC micro-grid. *IET Renew. Power Gener.* **2014**, *8*, 45–57. [CrossRef]
4. Tangsunantham, N.; Pirak, C. Voltage unbalance measurement in three-phase smart meter applied to AMI systems. In Proceedings of the 2013 10th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, Krabi, Thailand, 15–17 May 2013; pp. 1–5. [CrossRef]
5. Pillay, P.; Hofmann, P.; Manyage, M. Derating of induction motors operating with a combination of unbalanced voltages and over or undervoltages. *IEEE Trans. Energy Convers.* **2002**, *17*, 485–491. [CrossRef]
6. Lee, C.Y. Effects of unbalanced voltage on the operation performance of a three-phase induction motor. *IEEE Trans. Energy Convers.* **1999**, *14*, 202–208. [CrossRef]
7. Von Jouanne, A.; Banerjee, B. Assessment of voltage unbalance. *IEEE Trans. Power Deliv.* **2001**, *16*, 782–790. [CrossRef]
8. Niknam, T.; Zare, M.; Aghaei, J. Scenario-Based Multiobjective Volt/Var Control in Distribution Networks Including Renewable Energy Sources. *IEEE Trans. Power Deliv.* **2012**, *27*, 2004–2019. [CrossRef]
9. Borozan, V.; Baran, M.E.; Novosel, D. Integrated Volt/Var control in distribution systems. In Proceedings of the 2001 IEEE Power Engineering Society Winter Meeting, Columbus, OH, USA, 28 January–1 February 2001; Volume 3, pp. 1485–1490.
10. Homaee, O.; Zakariazadeh, A.; Jadid, S. Real-time voltage control algorithm with switched capacitors in smart distribution system in presence of renewable generations. *Int. J. Electr. Power Energy Syst.* **2014**, *54*, 187–197. [CrossRef]
11. Feng, X.; Peterson, W.; Yang, F.; Wickramasekara, G.M.; Finney, J. Implementation of control center based voltage and var optimization in distribution management system. In Proceedings of the IEEE PES Transmission and Distribution Conference Exposition, New Orleans, LA, USA, 19–22 April 2010; pp. 1–6.
12. Qiu, J.; Shahidehpour, S.M. A new approach for minimizing power losses and improving voltage profile. *IEEE Trans. Power Syst.* **1987**, *2*, 287–295. [CrossRef]
13. Anilkumar, R.; Devriese, G.; Srivastava, A.K. Voltage and Reactive Power Control to Maximize the Energy Savings in Power Distribution System With Wind Energy. *IEEE Trans. Ind. Appl.* **2018**, *54*, 656–664. [CrossRef]
14. Ibrahim, M.; Salama, M.M.A. Smart distribution system volt/VAR control using distributed intelligence and wireless communication. *IET Gener. Transm. Distrib.* **2015**, *9*, 307–318. [CrossRef]

15. Ulinuha, A.; Masoum, M.A.S.; Islam, S. Hybrid genetic-fuzzy algorithm for volt/var/total harmonic distortion control of distribution systems with high penetration of non-linear loads. *IET Gener. Transm. Distrib.* **2011**, *5*, 425–439. [CrossRef]
16. Elkhatib, M.E.; Shatshat, R.E.; Salama, M.M.A. Optimal Control of Voltage Regulators for Multiple Feeders. *IEEE Trans. Power Deliv.* **2010**, *25*, 2670–2675. [CrossRef]
17. Zhang, Y.; Li, J.; Meng, K.; Dong, Z.Y.; Yu, Z.; Wong, K.P. Voltage regulation in distribution network using battery storage units via distributed optimization. In Proceedings of the 2016 IEEE International Conference on Power System Technology, Wollongong, Australia, 28 September–1 October 2016; pp. 1–6. [CrossRef]
18. Quoc Hung, D.; Mishra, Y. Voltage fluctuation mitigation: fast allocation and daily local control of DSTATCOMs to increase solar energy harvest. *IET Renew. Power Gener.* **2019**, *13*, 2558–2568. [CrossRef]
19. Abdelrazek, S.A.; Kamalasadan, S. Integrated PV Capacity Firming and Energy Time Shift Battery Energy Storage Management Using Energy-Oriented Optimization. *IEEE Trans. Ind. Appl.* **2016**, *52*, 2607–2617. [CrossRef]
20. Li, C.; Coelho, E.A.A.; Dragicevic, T.; Guerrero, J.M.; Vasquez, J.C. Multiagent-Based Distributed State of Charge Balancing Control for Distributed Energy Storage Units in AC Microgrids. *IEEE Trans. Ind. Appl.* **2017**, *53*, 2369–2381. [CrossRef]
21. Infante, L.; Chistyakova, O. *Leading the Way: U.S. Electric Company Investment and Innovation in Energy Storage*; Technical Report; Edison Electric Institute: Washington, DC, USA, 2018.
22. Kashem, M.; Ledwich, G. Energy requirement for distributed energy resources with battery energy storage for voltage support in three-phase distribution lines. *Electr. Power Syst. Res.* **2007**, *77*, 10 – 23. [CrossRef]
23. Sreekumar, T.; Jiji, K.S. Comparison of Proportional-Integral (P-I) and Integral-Proportional (I-P) controllers for speed control in vector controlled induction Motor drive. In Proceedings of the 2012 2nd International Conference on Power, Control and Embedded Systems, Allahabad, Uttar Pradesh, India, 17–19 December 2012; pp. 1–6. [CrossRef]
24. Marra, F.; Fawzy, Y.T.; Bülo, T.; Blažic, B. Energy storage options for voltage support in low-voltage grids with high penetration of photovoltaic. In Proceedings of the 2012 3rd IEEE PES Innovative Smart Grid Technologies Europe, Berlin, Germany, 14–17 October 2012; pp. 1–7. [CrossRef]
25. Wang, J.; Hashemi, S.; You, S.; Trœholt, C. Active and reactive power support of MV distribution systems using battery energy storage. In Proceedings of the 2017 IEEE International Conference on Industrial Technology, Toronto, ON, Canada, 22–25 March 2017; pp. 382–387. [CrossRef]
26. Alam, M.J.E.; Balducci, P.J.; Hardy, T.D.; Bose, A.; Liu, C.C.; Srivastava, A.K.; Xu, Y.; Morrell, T.J.; Venkatramanan, V.; Zhang, Y.; et al. *Development and Analysis of Control Strategies for a 1 MW/3.2 MWh Energy Storage System at Avista Utilities*; Technical Report; Pacific Northwest National Lab (PNNL): Richland, WA, USA, 2020.
27. Morrell, T.J.; Venkataramanan, V.; Srivastava, A.; Bose, A.; Liu, C. Modeling of Electric Distribution Feeder Using Smart Meter Data. In Proceedings of the 2018 IEEE/PES Transmission and Distribution Conference and Exposition (T&D), Denver, CO, USA, 16–19 April 2018; pp. 1–9. [CrossRef]
28. Zhang, Y.; Xu, Y.; Srivastava, A.K.; Liu, C.C. Voltage control strategy in distribution system with energy storage and distributed generations. In Proceedings of the 2017 IEEE Industry Applications Society Annual Meeting, Cincinnati, OH, USA, 1–5 October 2017; pp. 1–8. [CrossRef]
29. Chanda, S.; Shariatzadeh, F.; Srivastava, A.; Lee, E.; Stone, W.; Ham, J. Implementation of non-intrusive energy saving estimation for Volt/VAr control of smart distribution system. *Electr. Power Syst. Res.* **2015**, *120*, 39–46. [CrossRef]
30. Saiz-Marin, E.; Lobato, E.; Egido, I. Optimal voltage control by wind farms using data mining techniques. *IET Renew. Power Gener.* **2014**, *8*, 141–150. [CrossRef]
31. Guo, Y.; Gao, H.; Wu, Q.; Zhao, H.; Østergaard, J. Coordinated voltage control scheme for VSC-HVDC connected wind power plants. *IET Renew. Power Gener.* **2018**, *12*, 198–206. [CrossRef]
32. Aghatehrani, R.; Kavasseri, R. Sensitivity-analysis-based sliding mode control for voltage regulation in microgrids. *IEEE Trans. Sustain. Energy* **2013**, *4*, 50–57. [CrossRef]
33. Liu, C.C.; Tomsovic, K. An expert system assisting decision-making of reactive power/voltage control. *IEEE Trans. Power Syst.* **1986**, *1*, 195–201. [CrossRef]
34. Corsi, S. *Voltage Control and Protection in Electrical Power Systems: From System Components to Wide-Area Control*; Springer: London, UK, 2015.
35. Eremia, M.; Shahidehpour, M. *Handbook of Electrical Power System Dynamics: Modeling, Stability, and Control*; John Wiley & Sons: Hoboken, NJ, USA, 2013; Volume 92.
36. IEEE. *IEEE Standard Test Procedure for Polyphase Induction Motors and Generators*; IEEE: New York, NY, USA, 2004.
37. Advanced Manufacturing Office. *Energy Tips: Motor Systems*; Technical Report; U.S. Department of Energy: Washington, DC, USA, 2012.