Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources

Preprint

Harsha Padullaparti,[1] Annabelle Pratt,[1] Ismael Mendoza,[1] Soumya Tiwari,[1] Murali Baggu,[1] Chris Bilby,[2] and Young Ngo[3]

[1] National Renewable Energy Laboratory
[2] Holy Cross Energy
[3] Survalent

Presented at the 2021 IEEE Green Technologies Conference
April 7–9, 2021

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

Conference Paper
NREL/CP-5D00-78798
April 2021

Contract No. DE-AC36-08GO28308

Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources

Preprint

Harsha Padullaparti,[1] Annabelle Pratt,[1] Ismael Mendoza,[1]
Soumya Tiwari,[1] Murali Baggu,[1] Chris Bilby,[2] and
Young Ngo[3]

[1] *National Renewable Energy Laboratory*
[2] *Holy Cross Energy*
[3] *Survalent*

Suggested Citation
Padullaparti, Harsha, Annabelle Pratt, Ismael Mendoza, Soumya Tiwari, Murali Baggu, Chris Bilby, and Young Ngo. 2021. *Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources: Preprint*. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5D00-78798. https://www.nrel.gov/docs/fy21osti/78798.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-5D00-78798
April 2021

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Electricity, Advanced Grid Research and Development Program through the Advanced Distribution Management System Test Bed Project at the National Renewable Energy Laboratory.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources

Harsha Padullaparti, Annabelle Pratt, Ismael Mendoza,
Soumya Tiwari, Murali Baggu
National Renewable Energy Laboratory (NREL)
Golden, Colorado, USA
harsha.p@nrel.gov, annabelle.pratt@nrel.gov

Chris Bilby
Holy Cross Energy
Glenwood Springs, Colorado, USA

Young Ngo
Survalent
Brampton, Ontario, Canada

***Abstract*—The ability to perform peak load management in distribution systems has several benefits for utilities, including reduced demand charges and improved reliability, efficiency, and utilization of the network infrastructure. This paper demonstrates the coordinated operation of an advanced distribution management system (ADMS) and a distributed energy resource management system (DERMS) to achieve peak load management using a realistic laboratory test bed. A commercial ADMS reduces the peak demand by reducing system voltages using a dynamic voltage regulation (DVR) application. A prototype DERMS—based on real-time optimal power flow—controls distributed battery energy storage systems to further reduce the feeder power. Results from the experiments conducted using a model of a real distribution feeder show that the coordinated operation of the ADMS and DERMS is effective in accomplishing peak load management.**

***Index Terms*—ADMS, DERMS, energy storage, optimal power flow, peak load management.**

I. INTRODUCTION

Distribution networks are designed to deliver customers' load demand in real time. The network infrastructure is generally rated to ensure reliable power supply at all times, including the peak load periods. Some distribution utilities are experiencing growth in peak demand, which leads to several operational challenges such as power quality and reliability issues, the need for network upgrades, and poor energy efficiency [1]. In other areas, there is little to no load growth and/or significant growth in distributed energy resources (DERs), and here utilities face the challenge of continuing to deliver reliable and affordable power with flat or reduced energy sales. In either case, peak demand charges are often a significant part of a utility's overall expenses [2], and peak load management (PLM) helps to address these challenges. The major strategies for PLM include the integration of DERs, such as battery energy storage systems (BESS) and electric vehicles; demand-side management; and conservation voltage reduction [1], [3], [4].

Distribution utilities are increasingly deploying advanced distribution management systems (ADMS) to optimize grid operations. An ADMS is an integrated platform that uses network data and measurements to perform various monitoring and control functions, such as volt-VAR optimization, network reconfiguration, and outage management [5]; however, the ADMS typically does not have access to behind-the-meter assets, such as rooftop photovoltaic (PV) systems and residential BESS [6]. A distributed energy resource management system (DERMS), on the other hand, is a software platform focused on controlling DERs to provide grid services such as PLM and voltage profile improvement. We propose that the coordinated operation of ADMS and DERMS can provide improved benefits than using each system alone. In this paper, the coordinated operation of an ADMS and a DERMS in achieving PLM is demonstrated in a laboratory environment. A commercial ADMS is employed to reduce the peak demand using a dynamic voltage regulation (DVR) application [4]. The DVR application controls legacy assets, such as load tap changers (LTCs) and voltage regulators (VRs), to reduce the system voltages. As a result, the load demand is reduced through conservation voltage reduction (CVR). A prototype DERMS [7]–[9] is used to control residential PV and BESS to perform PLM while keeping the voltages within ANSI limits. The ADMS test bed at the National Renewable Energy Laboratory's (NREL's) Energy Systems Integration Facility (ESIF) [10] was used to demonstrate the PLM strategy using an ADMS and a DERMS.

In the remainder of this paper, Section II describes the distribution utility feeder used in this study. Section III presents an overview of the ADMS test bed experimental setup. Section IV discusses the experiment scenarios and results, and Section V concludes.

II. DISTRIBUTION FEEDER DETAILS

The topology of the utility distribution feeder used in this work, plotted using the GridPV tool [11], is shown in

---

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. Funding provided by the U.S. Department of Energy Office of Electricity, Advanced Grid Research and Development Program through Advanced Distribution Management System Test Bed Project at National Renewable Energy Laboratory.

Fig. 1. This is a 14.4-kV feeder with a peak load demand of approximately 11 MW. The substation transformer is equipped with a three-phase gang-operated LTC. Additionally, three single-phase line VRs are available for voltage regulation at the three-phase bus marked in Fig. 1. There are 163 homes in this feeder that have all-electric loads. For this study, we assumed that all the homes have PV and BESS on their premises that can be controlled by a DERMS to perform PLM. The DVR application in the ADMS requires voltage measurement feedback from selected locations in the feeder. The locations of the DVR measurement feedback and the all-electric homes with PV and BESS are highlighted in Fig. 1. The total residential PV and BESS ratings are shown in Table I for different phases.

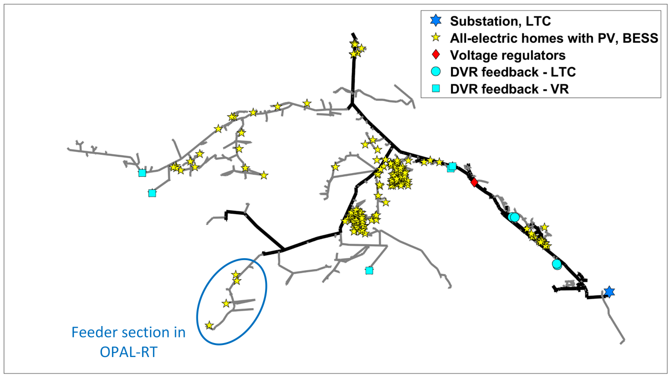


Fig. 1. Topology of the utility distribution feeder.

TABLE I
TOTAL RESIDENTIAL PV AND BESS RATINGS

DER	Phase A	Phase B	Phase C
PV	495 kW	588 kW	552 kW
BESS	295 kW, 796 kWh	360 kW, 972 kWh	335 kW, 904 kWh

III. ADMS TEST BED EXPERIMENTAL SETUP

The coordinated PLM was demonstrated on a national, vendor-neutral ADMS test bed funded by the U.S. Department of Energy Office of Electricity Advanced Grid Research Program to accelerate industry development and the adoption of ADMS capabilities [10]. The test bed enables utilities, vendors, and researchers to evaluate existing and future ADMS, DERMS, and other utility management system applications, such as volt/VAR optimization [12], as well as grid control architectures [13] in a realistic laboratory environment.

The experimental setup is shown in Fig. 2. This setup consists of a SurvalentONE ADMS and a prototype DERMS interfaced with the ADMS test bed through industry-standard communications interfaces. The ADMS and DERMS coordinate through a MultiSpeak interface. The ADMS test bed runs a real-time, multi-timescale simulation of the distribution feeder, including any DERs, in OpenDSS and OPAL-RT's electromechanical transient (EMT) simulation tool. An LTC and VR controllers are interfaced to the simulation through controller-hardware-in-the-loop (CHIL) techniques. The local DER controllers for the PV and BESS are also included in the test bed and interfaced with the respective simulated DERs through the test bed coordinator. The test bed coordinator is a co-simulation manager for synchronous data exchange among the ADMS test bed subsystems.

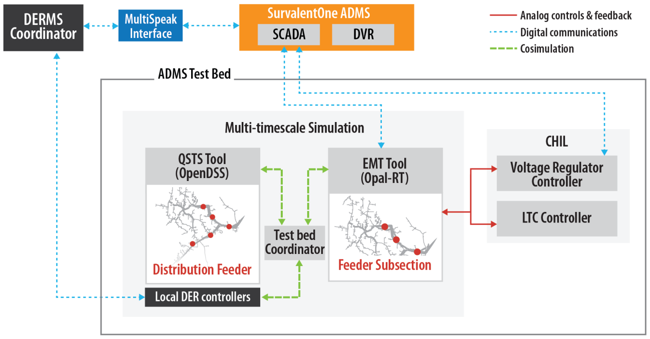


Fig. 2. ADMS test bed experimental setup.

A. Feeder Network Simulation

We simulate a distribution feeder model developed based on the data from Holy Cross Energy on the ADMS test bed. The majority of the utility feeder is simulated in OpenDSS, a quasi-static- time-series (QSTS) simulator, with a time step of 2 s, and a small part of the feeder containing 65 nodes is modeled on an OPAL-RT digital real-time simulator, as highlighted in Fig. 1. That specific section of the feeder was selected for simulation on the OPAL-RT platform to facilitate power-hardware-in-the-loop (PHIL) simulation with a PV inverter in the future. We use OPAL-RT's EMT simulation tool, eMEGASIM, at a simulation time step of 100 μs. The subtree feeder head in Opal-RT is modeled as a Thevenin circuit where the magnitude and angle of the voltage is received from OpenDSS and the impedance is calculated based on the short-circuit impedance at the point of common coupling (PCC). The active and reactive power at the subtree feeder head are fed back from eMEGASIM to OpenDSS to close the power flow loop [9]. The test bed coordinator, described in Section III-F, is used as the broker for the data exchange during the co-simulation.

In addition to the EMT simulation capability, the OPAL-RT platform has capabilities to communicate using industrial communications protocols, such as Distributed Network Protocol 3 (DNP3) and MODBUS, which facilitate communications with the ADMS system. In this setup, OPAL-RT's DNP3 communications interface is used to provide voltage feedback from both eMEGASIM and OpenDSS to the ADMS. The OPAL-RT platform also provides analog interfaces that are used to include the LTC and VR controllers as CHIL.

B. SurvalentONE ADMS

We use the DVR application of the SurvalentONE ADMS to reduce system voltages by controlling the LTC and VR set points to assist in reducing feeder demand. The DVR application is configured to achieve a specific objective while keeping system voltages within an acceptable range. We set the objective to operate at the lowest voltages possible without exceeding the user-defined voltage limits. Once activated, the DVR application relies on field data from the supervisory control and data acquisition (SCADA) system as feedback for its algorithm. The field information allows the program to prevent any voltage excursions that could affect any portion of the feeder. In the ADMS, each device controlled by the DVR application can be configured to monitor up to six downstream voltages. Three points are selected to be near the device, and the other three are selected to represent voltages far from each controller, as shown in Fig. 1. The DVR application compares measurements at these points to the configured limits and issues set points to the regulators to adjust the voltages to be as low as possible without exceeding the limits. The initial DVR voltage set points for the regulators are set to be the same as the set points when the regulators operate in local control mode to allow for a smooth transition. These initial set points and the limits for the monitored points are shown in Table II.

A second global parameter that needs to be configured is how often the application operates once activated. The system has the flexibility to be configured to any time interval with a minute resolution. The evaluation interval is dependent on the field data polling interval. For our configuration, we opted for the most aggressive interval of 1 minute to allow us to reduce the voltages promptly because our SCADA reading interval is set to 30 seconds. The regulator set point adjustment is calculated based on a voltage change of approximately 0.75 volts for each tap change.

TABLE II
LTC AND VR SET POINT LIMITS

Regulator	**Initial Set Point**	**Near High Limit**	**Near Low Limit**	**Far High Limit**	**Far Low Limit**
LTC	121 V	124 V	115 V	124 V	114 V
VR	123 V	124 V	115 V	124 V	114 V

The DVR application continues to adjust the regulator set points until it reaches the desired voltage objective or the regulators reach their tap limits. The DVR application can be programmed to run automatically on a set schedule or on demand. For this paper, we manually switched on and off the DVR application. Once the DVR application is deactivated, the regulator set point voltage is returned to the initial set point.

C. Prototype DERMS

The DERMS controls the PV and BESS to perform PLM as well as voltage regulation. For the PLM, the DERMS objective is to track a power target for each phase that is set by the ADMS through the MultiSpeak interface, described next. For voltage regulation, the DERMS objective is to keep all the system voltages within user-defined bounds.

The RTOPF DERMS distributed control algorithm reported in [7]–[9] is used in this study. The DERMS has two control layers: a coordinator and local DER controllers. For this study, both layers are implemented in Python on the same computer that runs OpenDSS, but it has been demonstrated with implementation on commercial distributed controllers [9]. The coordinator receives the voltage and feeder head power measurement feedback from the feeder model. In our current experimental setup, this feedback is implemented locally on the computer that runs both OpenDSS and the DERMS, but in the future, the feedback will be provided through the SCADA application on the ADMS. Based on the target power references and voltage limits, it computes the optimization parameters (gradient signals) for each local controller. Each local controller uses the optimization parameters received from the coordinator and the local voltage and power measurements to compute the optimal real and reactive power set points for PV and the active power set point for the BESS located at that control node. The collective response of all the local controllers ensures that the DERMS control objectives related to PLM and voltage regulation are achieved.

D. MultiSpeak Interface

The DERMS is interfaced with the ADMS using the MultiSpeak communications standard to enable coordinated operation. We worked with the National Rural Electric Cooperative Association (NRECA), the developer of the MultiSpeak standard, to develop a business process based on the existing load management process to support the messages required for coordination. The ADMS sends enable/disable commands to the DERMS as MultiSpeak messages for both PLM and voltage regulation. In the case of PLM, the ADMS also sends the target feeder head power references for the DERMS to track, as well as the start time and end time or duration of the event. NRECA provided a limited release of this new business process for our use, and Survalent updated their MultiSpeak interface to support this new process. We also partnered with the Electric Power Research Institute (EPRI) to provide a MultiSpeak interface for NREL's prototype DERMS.

E. Controller-Hardware-in-the-loop

OPAL-RT's eMEGASIM platform is used to interface with the hardware controllers to facilitate CHIL operation. We use a Beckwith Electric LTC controller and three Schweitzer Engineering Laboratories VR controllers coupled with the simulation using analog-to-digital and digital-to-analog converters in the OPAL-RT. The controllers receive the operating set point from the ADMS using the DNP3 communication protocol. The LTC and VRs are modeled in OpenDSS. If the simulated voltages at the secondary signal of the regulators are outside the controllers' voltage band, the controllers will issue a tap-up/-down pulse to OPAL-RT that then gets translated into a digital signal for the simulated regulators in OpenDSS. This continues until the simulated voltages are around the set point within the deadband. The voltages are also sent to the ADMS using DNP3 communications so that ADMS has an understanding about the voltages across the feeder and for use by the DVR application in performing CVR.

F. Test Bed Coordinator

A co-simulation platform developed in the Python programming language is used to enable synchronous data exchange among the multiple subsystems of the ADMS test bed, as shown in Fig. 2. This platform is referred to as the test bed coordinator, and it uses the Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS) [14], an open-source cyber-physical-energy co-simulation framework for electric power systems developed through the U.S. Department of Energy Grid Modernization Initiative as the core co-simulation engine. The specific actions of the test bed coordinator include streaming the required data from the OpenDSS power flow to Opal-RT, receiving the LTC and VR tap-up/-down commands from the CHIL via OPAL-RT, receiving the PV and BESS power set points from the DERMS local controllers, and implementing the set points in the feeder model.

IV. EXPERIMENT SCENARIOS AND RESULTS

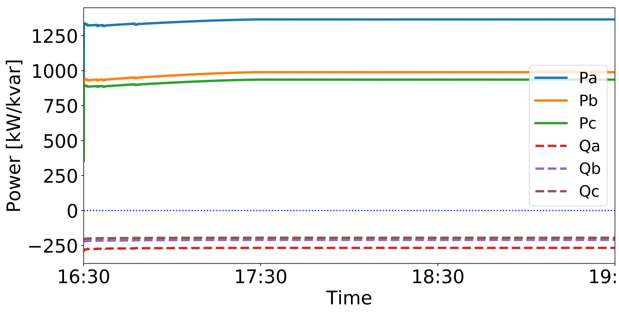
Experiments are carried out to demonstrate the PLM through coordinated operation of the ADMS DVR and DERMS. The scenarios considered are summarized in Table III. In the baseline scenario (S0), the LTC and VR are configured to operate in local control mode with their control settings as in the field. Specifically, the LTC and voltage regulators are set to operate with the default voltage regulation set points of; 121 V for the LTC, 123 V for the VRs, voltage deadband of 2 V, and inter-tap time delays of 45 seconds. All other controls are disabled in the baseline scenario (S0). The DVR application is enabled in the DVR-Only (S1) and the DVR + DERMS (S3) scenarios, and the DERMS control is enabled in the DERMS-Only (S2) and DVR + DERMS (S3) scenarios. Whenever the DVR is disabled (S0 and S2), the LTC and VR are assumed to be in local control mode with the specified settings. The simulation period is selected as 4:30–7:30 p.m. on December 30, 2019, because this period illustrates the characteristics of high load demand and low PV generation, making it an ideal period to perform PLM.

TABLE III
SCENARIOS FOR THE EXPERIMENTS

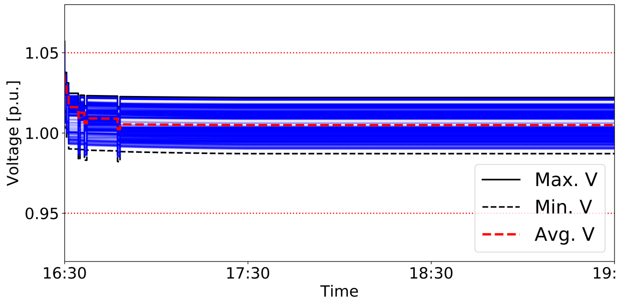
Scenario	ADMS DVR	DERMS
S0: Baseline	Disabled	PLM − disabled Voltage regulation − disabled
S1: DVR-Only	Enabled	PLM − disabled Voltage regulation − disabled
S2: DERM-Only	Disabled	PLM − enabled Voltage regulation − enabled
S3: DVR + DERMS	Enabled	PLM − enabled Voltage regulation − enabled

A. Baseline Results

The feeder head powers in each phase from the baseline experiment are shown in Fig. 3(a). The active power consumptions are nearly 1,350 kW, 980 kW, and 930 kW in phases A, B, and C, respectively. The LTC and VR taps are adjusted by their local controllers during the initial period of the experiment, and the corresponding changes in the bus voltages can be observed in Fig. 3(b). All the bus voltages are well within the ANSI limits.



(a)



(b)

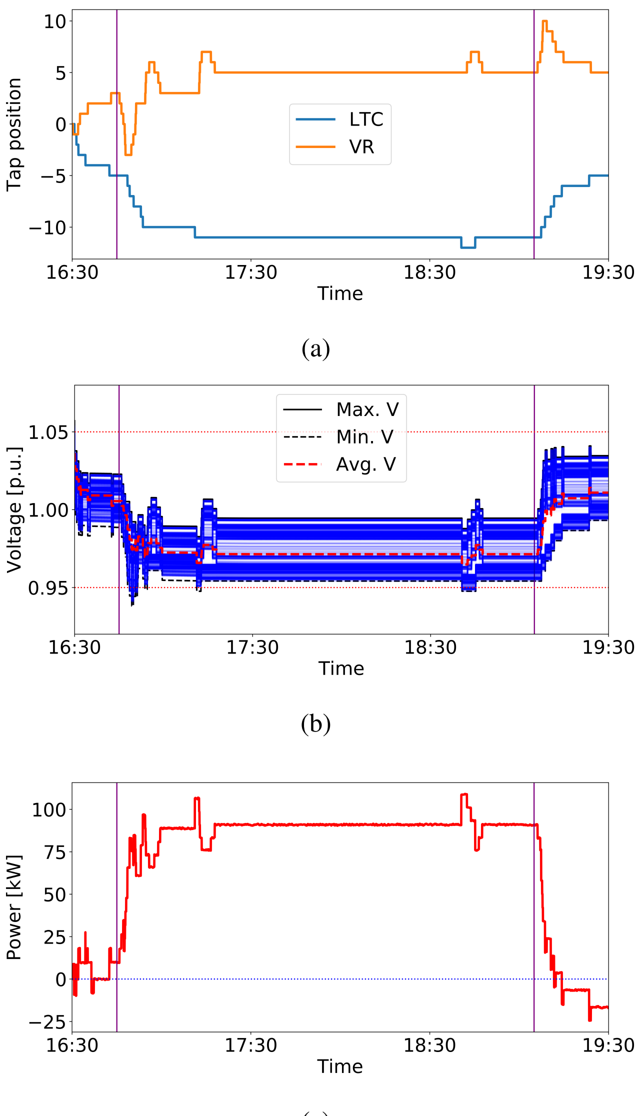
Fig. 3. Baseline scenario: (a) Feeder head powers and (b) bus voltages.

B. DVR-Only Scenario Results

The DVR application is enabled at 16:45 hours and disabled at 19:05 hours in the DVR-Only (S1) experiment using the set point limits defined in Table II, as marked by the purple vertical lines in Fig. 4(a). The LTC and VR tap statuses resulting from the DVR operation are shown Fig. 4(a). It can be observed that the VR tap position complements the LTC tap position to keep the voltages uniform in the feeder. Consequently, the bus voltages are restricted within the lower ANSI band until the DVR is disabled, as shown in Fig. 4(b), to achieve the load reduction demand through CVR. The resulting reduction in the substation demand compared to the baseline is shown in Fig. 4(c). An average demand reduction of approximately 90 kW is achieved through DVR only while regulating the voltages to be within the ANSI limits.

C. DERMS-Only Scenario Results

In this scenario, the LTC and VR are set in local control mode, and the DERMS voltage regulation is enabled at 16:40 hours, with upper and lower voltage limits of 1.04 p.u. and 0.96 p.u., respectively. The bus voltages settle during the initial period of the experiment, as observed in Fig. 5(a). Then the PLM is enabled at 17:00 hours, with the target powers as



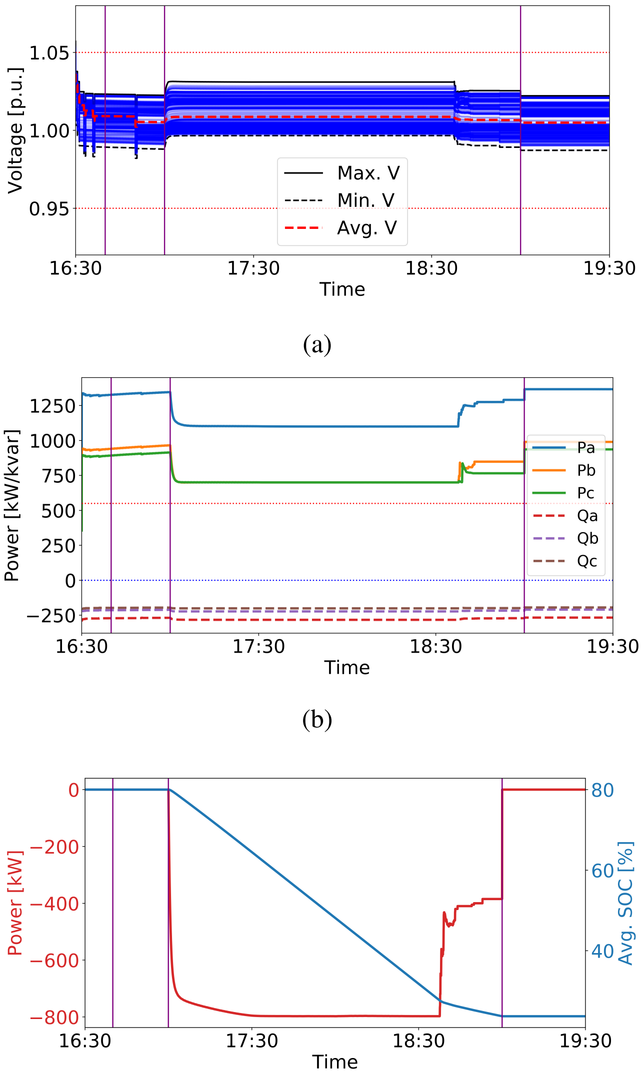
(a)

(b)

(c)

Fig. 4. DVR-Only scenario (S1): (a) LTC and VR statuses, (b) bus voltages, and (c) substation demand deviation compared to baseline.

1100 kW, 700 kW, and 700 kW for phases A, B, and C, respectively, and a duration of 120 minutes. System voltages increase when the DERMS is enabled due to the active power injection from the BESS. The enable/disable event times of the DERMS voltage regulation and PLM are marked by the purple vertical lines. As shown in Fig. 5(b), the feeder head power in each phase changed from the baseline value to the target power reference at 17:00 hours and stayed consistent until 18:40 hours. The total BESS output, where a negative value denotes the battery discharging, and the average state of charge (SOC) of all the BESS in the system are shown in Fig. 5(c). The DERMS commanded the distributed BESS to discharge power to supply the balance power to regulate the feeder head powers to the PLM target values. A peak power output of approximately 800 kW is observed from the BESS. The BESS are configured to have a 20% reserve SOC limit.When the average SOC began reaching this limit near 18:40 hours (see Fig. 5(c)), some of the distributed BESS started to shut off; therefore, the BESS could not track the target PLM power references after 18:40 hours because of the lack of BESS capacity (SOC) in the feeder.



(a)

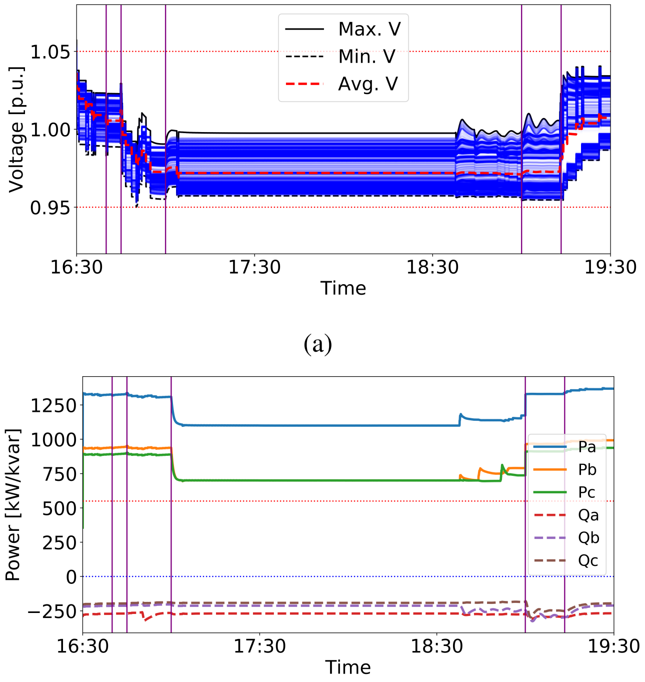
(b)

(c)

Fig. 5. DERMS-Only scenario (S2): (a) bus voltages (b) feeder head powers, and (c) total BESS output power and average SOC.

D. *DVR + DERMS Scenario Results*

In this experiment, the coordinated operation of the ADMS DVR and DERMS is studied. The experiment is started in baseline mode at 16:30 hours. Then the DERMS voltage regulation, ADMS DVR, and DERMS PLM are enabled at 16:40, 16:45, and 17:00 hours, respectively, as indicated by the vertical purple lines. Additionally, the DERMS PLM is disabled at 19:00 hours, and the DVR is disabled near 19:15 hours. The bus voltages settle within the lower ANSI band by 17:00 because of the combined voltage regulation by the DVR and DERMS, as shown in Fig. 6(a). In Fig. 6(b), the feeder head powers are regulated at the target power reference values shortly after enabling the DERMS PLM at 17:00 hours.



(a)

(b)

Fig. 6. DVR + DERMS scenario (S3): (a) bus voltages and (b) feeder head powers.

Fig. 7 compares the substation demand in all four scenarios. The demand with DVR-Only (S1) is lower than that in the baseline (S0) because the ADMS DVR application performed CVR. With DERMS-Only (S2), the substation demand is nearly the same as in the baseline (S0) before enabling the PLM at 17:00 hours. After enabling the PLM, the demand was reduced by approximately 800 kW beause of the active power injection by the distributed BESS until some of the BESS hit the lower SOC near 18:40 hours. Similar power tracking performance is observed with the DVR + DERMS (S3) after enabling the PLM at 17:00 hours; however, the power tracking continued slightly longer than with the DERMS-Only (S2). This is because the distributed BESS needed to inject less power with the DVR + DERMS (S3) than with the DERMS-Only (S2) because the DVR reduce the demand before enabling the PLM in S3.

V. CONCLUSION

Some distribution utilities, specifically municipally-owned and electric cooperatives, are experiencing peak demand growth, which leads to operational challenges, such as power quality and reliability issues. And in other areas with little to no load growth and/or significant growth in DERs, utilities need to deliver reliable and affordable power with flat or reduced energy sales. In either case, peak demand charges are often a significant part of a utility's overall expenses, and PLM helps to address these challenges.

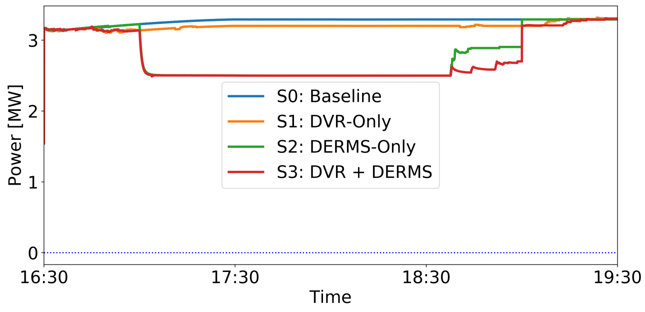


Fig. 7. Comparison of substation demand among all scenarios.

This paper demonstrated the coordinated operation of an ADMS controlling legacy equipment and a prototype DERMS in achieving PLM. The ADMS DVR application controls the LTC and VRs to reduce the system voltages to reduce the substation demand through CVR. The DERMS controls the distributed BESS to inject the required amount of active power to maintain the substation demand at power reference levels set by the ADMS. The PLM is achieved while maintaining voltages within ANSI limits. The results show that the PLM can be performed longer for a given BESS capacity if the DVR application is used to perform demand reduction using CVR. In future work, we plan to more closely study the interaction of the DERMS voltage regulation and the ADMS DVR operation. Future work is also warranted on developing ADMS algorithms to automatically set the target power values for the DERMS.

ACKNOWLEDGMENTS

We gratefully acknowledge the support and vision of Eric Lightner with the U.S. Department of Energy in establishing the ADMS test bed capability. We appreciate the support of Jeremy Westbrook, with Increase Technologies, who developed the new MultiSpeak business process in partnership with NRECA. This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. Funding provided by the U.S. DOE Office of Electricity, Advanced Grid Research program. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

REFERENCES

[1] M. Uddin, M. F. Romlie, M. F. Abdullah, S. Abd Halim, T. C. Kwang, *et al.*, "A review on peak load shaving strategies," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 3323–3332, 2018.

[2] M. R. Narimani, J.-Y. Joo, and M. L. Crow, "The effect of demand response on distribution system operation," in *2015 IEEE Power and Energy Conference at Illinois (PECI)*, pp. 1–6, IEEE, 2015.

[3] Z. Wang and J. Wang, "Review on implementation and assessment of conservation voltage reduction," *IEEE Transactions on Power Systems*, vol. 29, no. 3, pp. 1306–1315, 2014.

[4] *Dynamic Voltage Regulation (DVR)*, [accessed Dec. 16, 2020]. https://www.survalent.com/wp-content/uploads/resource/Survalent_Dynamic-Voltage-Regulation-DVR-Brochure.pdf.

[5] D. Mcnair, D. Phelan, and L. Coleman, "Voices of Experience: Insights into advanced distribution management systems," *US Department of Energy, Office of Electricity*, 2015.

[6] *A vision for the ADMS-DERMS relationship*, [accessed Dec. 16, 2020]. https://cdn2.hubspot.net/hubfs/415845/White%20papers/ADMS-DERMS%20white%20paper/ADMS-DERMS%20whitepaper.pdf.

[7] E. Dall'Anese and A. Simonetto, "Optimal power flow pursuit," *IEEE Transactions on Smart Grid*, vol. 9, pp. 942–952, March 2018.

[8] F. Ding, "Distributed energy resource management solution using real-time optimization," in *NREL Software Record, SWR-20-46*, 2019.

[9] J. Wang, M. Blonsky, F. Ding, S. Drew, H. Padullaparti, S. Ghosh, *et al.*, "Performance evaluation of distributed energy resource management via advanced hardware-in-the-loop simulation," in *IEEE Innovative Smart Grid Technologies (ISGT)*, pp. 1–5, 2020.

[10] A. Pratt, M. Baggu, F. Ding, S. Veda, I. Mendoza, and E. Lightner, "A test bed to evaluate advanced distribution management systems for modern power systems," in *IEEE EUROCON 2019 -18th International Conference on Smart Technologies*, pp. 1–6, July 2019.

[11] M. J. Reno and K. Coogan, "Grid integrated distributed PV (GridPV)," *Sandia National Laboratories SAND2013-6733*, 2013.

[12] A. Pratt, I. Mendoza, M. Usman, S. Tiwari, H. Padullaparti, M. Baggu, and E. Lightner, "Using an advanced distribution management system test bed to evaluate the impact of model quality on volt/var optimization," in *IEEE T&D Conference & Exposition*, Oct 2020.

[13] J. Wang, H. Padullaparti, S. Veda, I. Mendoza, S. Tiwari, and M. Baggu, "Performance evaluation of data-enhanced hierarchical control for grid operations," in *IEEE Power Energy Society General Meeting*, Aug 2020.

[14] B. Palmintier, D. Krishnamurthy, P. Top, S. Smith, J. Daily, and J. Fuller, "Design of the HELICS high-performance transmission-distribution-communication-market co-simulation framework," in *Workshop on Modeling and Simulation of Cyber-Physical Energy Systems*, pp. 1–6, 2017.