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Field Demonstration of Distributed Energy Resource Management System (DERMS) with ADMS

F. STADTMUELLER
Pacific Gas and Electric Company
USA

SUMMARY

As a result of increasing penetration of distributed energy resources (DERs), utilities continue to explore new mitigation solutions to ensure that there are no adverse impacts to the reliability of power delivery. One potential solution is a Distributed Energy Resource Management System (DERMS) for bridging the gap between individual devices and grid operations[1]. DERMS capabilities include: visibility and monitoring of DERs, forecasting DER flexibility and operational impacts, and control of DERs to optimize the grid.

Through California's Electric Program Investment Charge (EPIC) program, Pacific Gas and Electric (PG&E) executed a field demonstration to evaluate the technical ability of a DERMS to coordinate DERs, namely photovoltaic (PV) generation and energy storage, to provide capacity and voltage support for distribution grid operations. Behind-the-meter (BTM) and utility-owned DERs across three distribution feeders were made available for the project. The DERMS was combined with a limited functionality Advanced Distribution Management System (ADMS) for determining grid needs.

Several use cases (UC) successfully demonstrated the DERMS capabilities via actual implementation:
UC1 Situational awareness of DER impacts on the distribution grid (visualize hidden load)
UC2 Manage capacity constraints and reverse power flow
UC3 Mitigate voltage issues with real power
UC4 Mitigate voltage issues with reactive power
UC5 Economic optimization – least-cost economic dispatch of DERs
UC6 Operational flexibility – optimization under abnormal switching conditions

KEYWORDS

DERMS, ADMS, distribution system, smart grid

franz.stadtmueller@pge.com

1. Introduction

Through California's Electric Program Investment Charge (EPIC) program, Pacific Gas and Electric (PG&E) executed a field demonstration to evaluate the technical ability of a DERMS to coordinate DERs to provide capacity and voltage support for distribution grid operations.

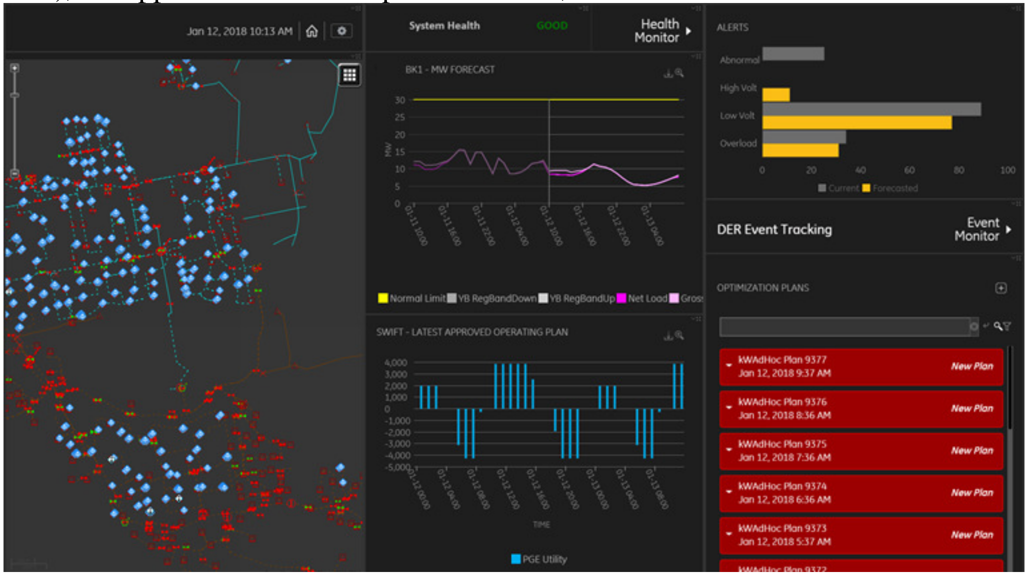
The project involved three 21 kV distribution feeders, a 4 MW distribution-connected, utility-owned Yerba Buena battery energy storage system (YB BESS), three BTM commercial and industrial scale battery energy storage systems (BESS) totaling 0.36 MW, and multiple mixed smart inverter-based, residential scale PV+BESS totaling 0.190 MW. The ratings of each participating DER asset were specified in the DERMS and ADMS.

For communication with third party DERs, an aggregator interface was established based on IEEE 2030.5 standard with custom extensions. Two third party aggregators provided forecasted DER flexibility and bids via the aggregator interface.

The ADMS calculated real-time and forecasted power flows for identifying simulated grid issues based on manually set limits. The DERMS used the total costs associated with the violations and energy prices to calculate the least cost optimization of dispatching DERs.

The DERMS created two types of optimization plans on an ongoing basis: day-ahead ask-bid-commit and real-time ad-hoc. For day-ahead plans, the DERMS requested flexibility from the aggregators who responded with their bids. From the bids, the DERMS optimization plan created a dispatch schedule starting at 12:00 AM the next day for every hour of a 24-hour timeframe and committed the DER assets to the schedule once the plan was manually approved. Ad-hoc plans were created hourly using flexibility forecasts instead of an ask-bid-commit process.

A web interface displayed the status of the grid and optimization plan details, as shown in Figure 1. The web interface featured the circuit layout with detailed layers of various device types and weather conditions. Also shown is the 24-hour load forecast (both net and hidden load), the approved 24-hour dispatch schedule, and real-time and forecast alerts.



kWAdHoc Plan 9377 Jan 12, 2018 9:37 AM New Plan
kWAdHoc Plan 9376 Jan 12, 2018 8:36 AM New Plan
kWAdHoc Plan 9375 Jan 12, 2018 7:36 AM New Plan
kWAdHoc Plan 9374 Jan 12, 2018 6:36 AM New Plan
kWAdHoc Plan 9373 Jan 12, 2018 5:37 AM New Plan
kWAdHoc Plan 9372

Figure 1 The DERMS web interface home screen

This project demonstrated that DERMS technology possesses the technical capabilities to coordinate DERs for distribution grid services to mitigate capacity and voltage violations. While the technical ability exists at test scale for a DERMS to orchestrate distribution grid services, the project indicates that the industry is still in the early stages. Scalable systems and processes continue to evolve and will need to leverage ongoing and planned utility investments in foundational grid modernization in order for a DERMS to be implemented at scale. In the policy realm, rules will need to be established to govern both operation and compensation of DERs across wholesale and distribution uses. The results of the demonstrations are provided in the following pages.

Optimization plans were reviewed to assess the DERMS capability. Each subsequent table shows an actual use case demonstration and optimization plan details with the following parameters: time, impacted device, default limit, imposed limit for the demonstration, DERMS alert time, DERMS optimization plan creation time, DER flexibility available for mitigation the violation, whether or not the issue was mitigated to the extent possible, the capacity dispatched in the plan, and the resulting measurement at the device taking into account the DERMS dispatch.

2. Results

2.1 UC1: Situational Awareness

The DERMS visualized real-time and forecasted grid conditions through its web interface. DER generation and feeder net load were calculated and displayed. The load forecast in the DERMS had increased error for feeders where high capacity DERs operated differently in real time than their day ahead schedule. For example, the YB BESS participated in frequency regulation, and real-time awards contributed to error in the load forecast.

Non-telemetered PV generation was estimated using the PVWatts[2] model to calculate the generation and the corresponding gross load for each hour of the load forecast. This was done for a rolling 24-hour horizon, shown in Figure 2.

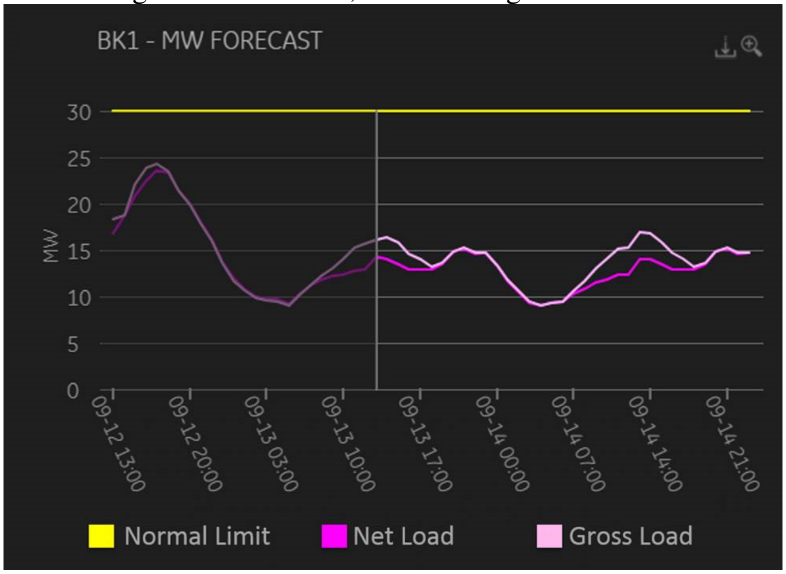


Figure 2 Load forecast showing net load (observed) and gross load (hidden by behind-the-meter DER)

The PVWATTS forecast total generation was compared with the actual total generation from daily measurements every five minutes, shown in Figure 3.

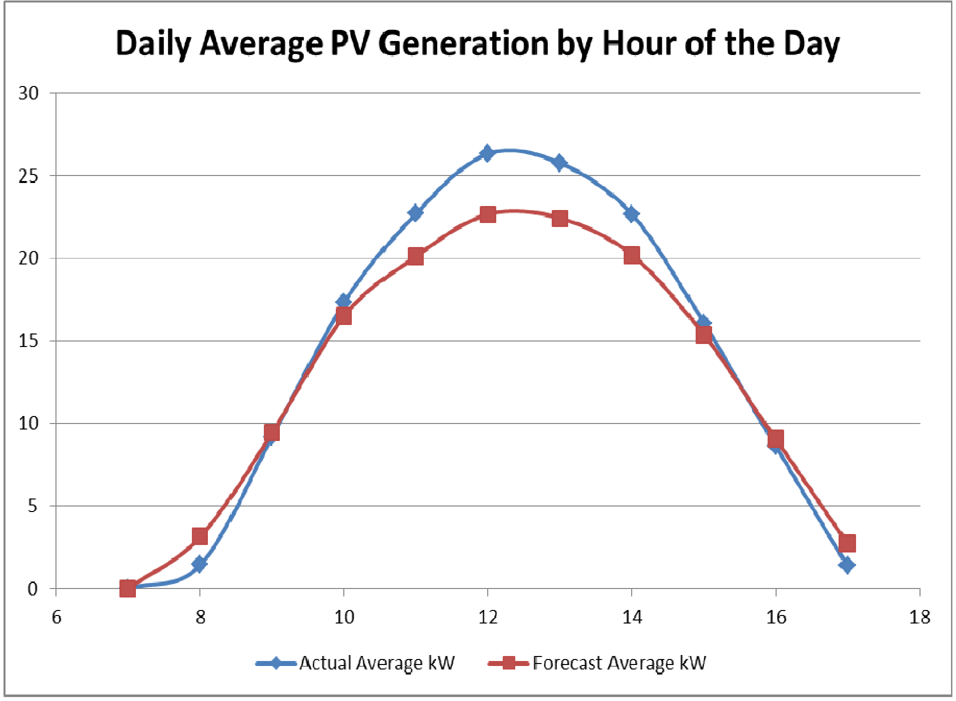


Figure 3 Comparison between daily average forecast PV generation and actual PV generation

Battery-only DERs impacted feeder loading as well. DERMS dispatched three BTM BESS for their full capacity and the impact to the feeder loading was observed, shown in Figure 4. The feeder load with the dispatch was compared with the previous day's feeder load with no dispatch.

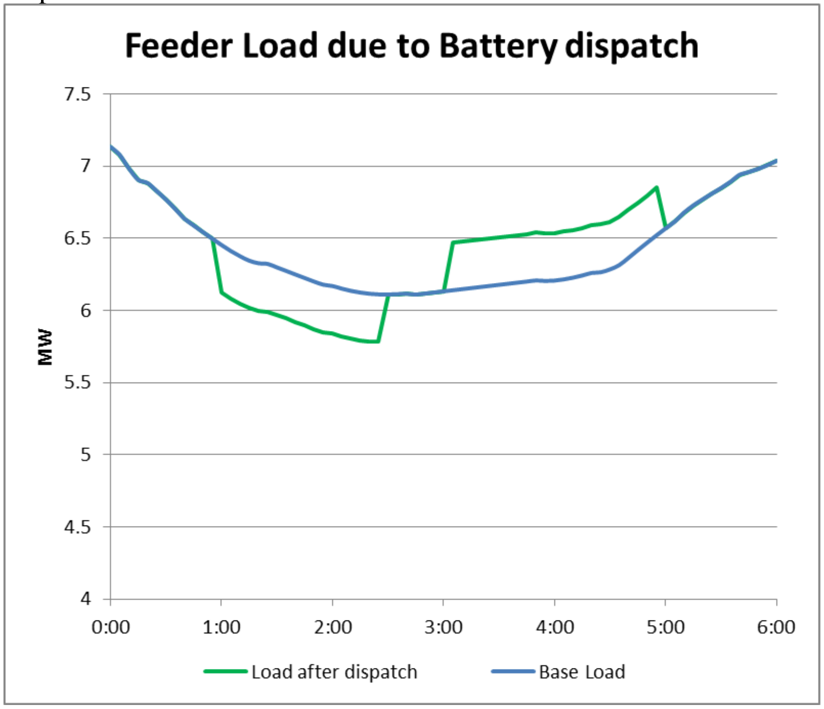


Figure 4 Effect on feeder load due to battery dispatch from the DERMS

2.2 UC2: Manage Capacity Violations and Reverse Power Flow

Among the types of distribution operational constraints, the DERMS was most effective at detecting and mitigating capacity violations, both real-time and forecasted. The DERMS consistently mitigated capacity violations through real power dispatch of available capacity while considering state of charge (SOC) constraints for DERs with BESS components.

The load forecast accounted for day-ahead energy market awards to determine if capacity violations occur, and if so the DERMS created an optimized plan to dispatch the resources to avoid the capacity violations. Frequency regulation awards were not automatically considered in the determination of capacity violations.

The DERMS reliably and consistently alarmed and mitigated overload conditions both forecasted and in real time. Examples are shown in Table 1 and Table 2.

Time	Device	Initial Load (A)	Default Load Limit (A)	New Load Limit (A)	Load Limit Changed (Time)	DERMS Alert Disp (Time)	Plan Time	DERs Flex.to Mitigate Issue (A)	DERMS Mitigates Issue to Extent Possible	Plan Dispatch (kW)	Calc. New Load (A)
14:40	CB2102	245	600	200	14:40	14:42	15:40	110	Yes	3850	128

Table 1 The DERMS mitigated overload violations with real power dispatch

Time	Device	Initial Loading (kW)	Default Backfeed Limit (kW)	Dispatch Changed (Time)	DER Initial Dispatch (kW)	DERMS Alarm Disp (Time)	Plan Time	DERMS Mitigates Issue to Extent Possible	Plan Dispatch (kW)	Calc. New Load (kW)
11:00	BK1	-34	0	11:00	3850	11:23	12:11	Yes	-1832	948

Table 2 The DERMS mitigated backfeed violations by dispatching BESS assets to charge

Multiple hours were considered in the optimization, shown in Figure 5.

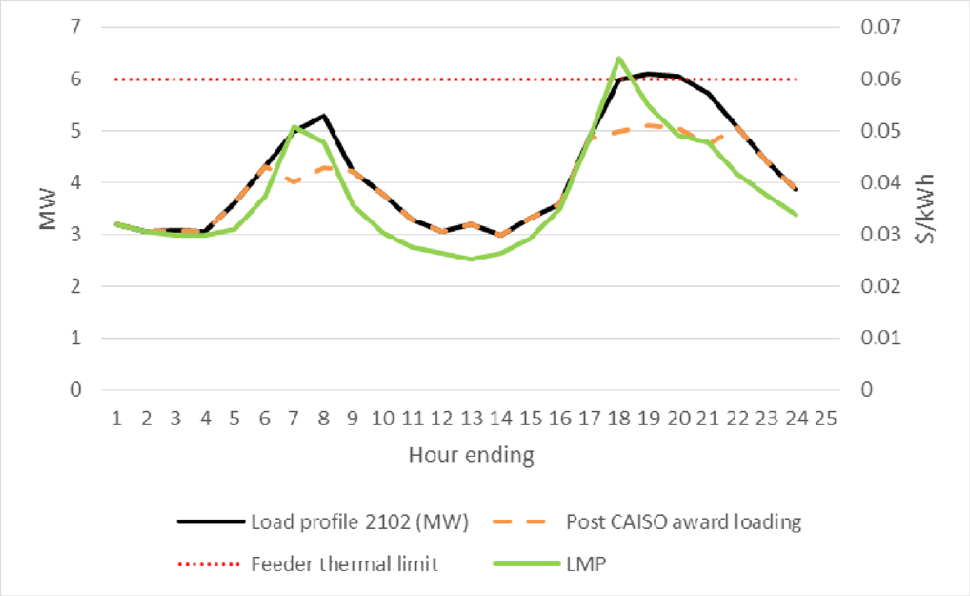


Figure 5 The DERMS optimization considered each hour of the 24 hour window

2.3 UC3: Mitigate Voltage Issues with Real Power

The DERMS successfully mitigated voltage violations using real power, both real-time and forecasted violations. The forecast voltage levels, shown in Figure 6, were less accurate than the load forecast, due to not dynamically forecasting reactive power and assuming balanced voltage in the voltage forecast.

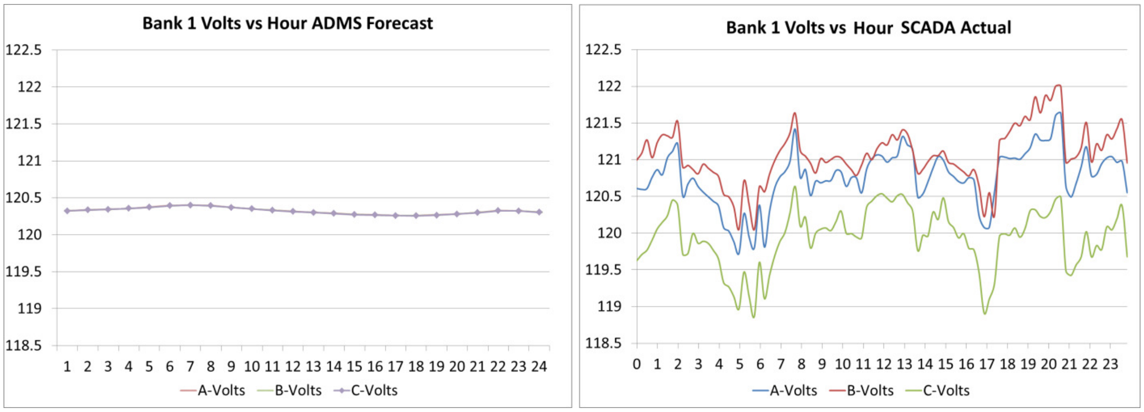


Figure 6 Three phase forecasted voltage vs hour (left) and measured voltage vs hour (right)

The DERMS consistently used real power dispatch to mitigate voltage violations, although reactive power affected the voltage more than real power on a per unit basis for the specific feeders involved. Examples of mitigating high voltage violations are in Table 3.

Time	Device	Initial Voltage (V)	Default Voltage Limit (V)	New Voltage Limit (V)	Voltage Limit Changed (Time)	Available DERs to Mitigate Issue (kW)	DERMS Alert Disp (Time)	Plan Time	Plan Dispatch (kW)*	Violation Mitigated to Extent Possible	Calc. New Voltage (V)
09:53	XR440	120.26	126	120.06	09:56	4000	09:56	10:38	-2264	Yes	119.88
11:35	X1298	120.74	126	120.5	11:37	4000	11:42	13:35	-1433	Yes	119.73

Table 3 The DERMS mitigated distribution primary high voltage violations with real power dispatch

Simultaneous capacity and voltage violations were studied, such as an upstream overload with a simultaneous high voltage violation, resulting in conflicting signals for the DERMS optimization. The violation cost for each type of violation determined how the DERMS optimized resources to mitigate the simultaneous voltage and overload violations at minimal cost. An example of a load profile pre- and post-optimization is Figure 7.

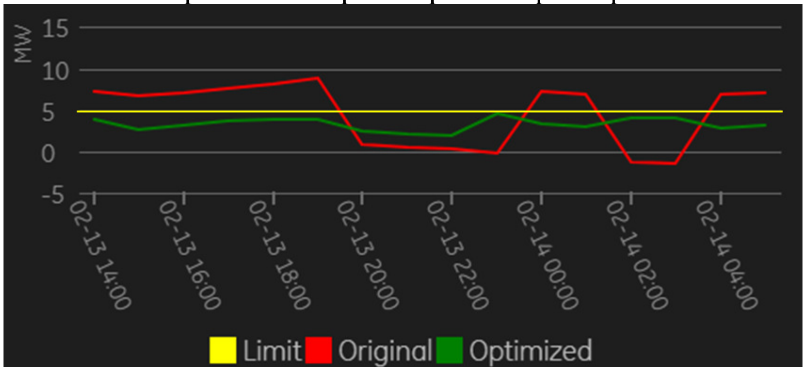


Figure 7 Original load profile (red) with DERMS optimized load profile (green) with multiple violations

2.4 UC4: Mitigate Voltage Issues with Reactive Power

The DERMS created reactive power optimization plans for only real-time voltage violations, since it was set up to use the Volt/VAR management built into the ADMS. The DERs in the field responded to reactive power dispatches, but reactive power was sometimes limited by the apparent power rating of the inverter. Reactive power dispatch was up to three times more effective than real power dispatch to influence feeder primary voltage for the same per unit amount for these specific feeders. This was quantified through dispatch of YB BESS and observing voltage changes at SCADA-enabled equipment.

High capacity DERs were dispatched to mitigate voltage violations using their reactive power capacity. The DERMS successfully mitigated low and high voltage violations in Table 4 and Table 5, respectively. The dispatches use generation sign convention, where positive values mean export (discharge) and negative values mean import (charge) for both real and reactive power.

Time	Device	Initial Voltage (V)	Default Voltage Limit (V)	New Voltage Limit (V)	Voltage Limit Changed (Time)	Available DERs to Mitigate Issue (kVAR)	DERMS Alert Disp (Time)	kVAR Plan Time	Plan Dispatch (kVAR)	Violation Mitigated to Extent Possible	Calc. New Voltage (V)
8:45	X1796	121.65	117	123	8:45	3000	8:46	9:29	2818	Yes	123.62
12:56	X2000	120.71	114	121.35	12:56	3000	12:59	13:49	1889	Yes	121.65

Table 4 The DERMS mitigated distribution primary low voltage violations with reactive power dispatch

Time	Device	Initial Voltage (V)	Default Voltage Limit (V)	New Voltage Limit (V)	Voltage Limit Changed (Time)	Available DERs to Mitigate Issue (kVAR)	DERMS Alert Disp (Time)	kVAR Plan ID / Time	Plan Dispatch (kVAR)	Violation Mitigated to Extent Possible	Calc. New Voltage (V)
12:08	X1796	121.27	126	121	12:08	3000	12:15	12:46	-564	Yes	120.87
16:33	X2132	123.06	126	121.2	16:34	3000	16:35	16:38	-3000	Yes	121.16

Table 5 The DERMS mitigated distribution primary high voltage violations with reactive power dispatch

When dispatching reactive power in the field with the YB BESS, the bank voltage moved enough to cause LTC operation, which sometimes counteracted the voltage improvement. This was due to the DERMS not taking into account LTC movement with its dispatch and showed that coordinating DER reactive power dispatch with LTC controller settings is often required for optimal performance, particularly for larger scale DER portfolios.

2.5 UC5: Economic Optimization

The DERMS optimization was set up to dispatch assets based on a least cost basis. In the absence of distribution grid violations, the DERMS system optimized for energy arbitrage to minimize energy costs for both day-ahead and real-time operation, shown in Table 6 and Figure 8.

Date & Time	Plan Time	Peak LMP Hour	Peak LMP $/kWh	Pre-plan Cost	Post-plan Cost	DERMS Dispatch Hours	DERMS Dispatch kW at peak hour
10/21/17 16:34	16:35	18	0.0866	$18,706	$16,604	17-21	3850
10/29/17 16:51	16:51	19	0.0626	$17,490	$15,805	7, 17-20	3850

Table 6 The DERMS dispatched DERs to charge at low prices and discharge at high prices

The DERMS dispatched the YB BESS to discharge during peak pricing hours as part of energy arbitrage.

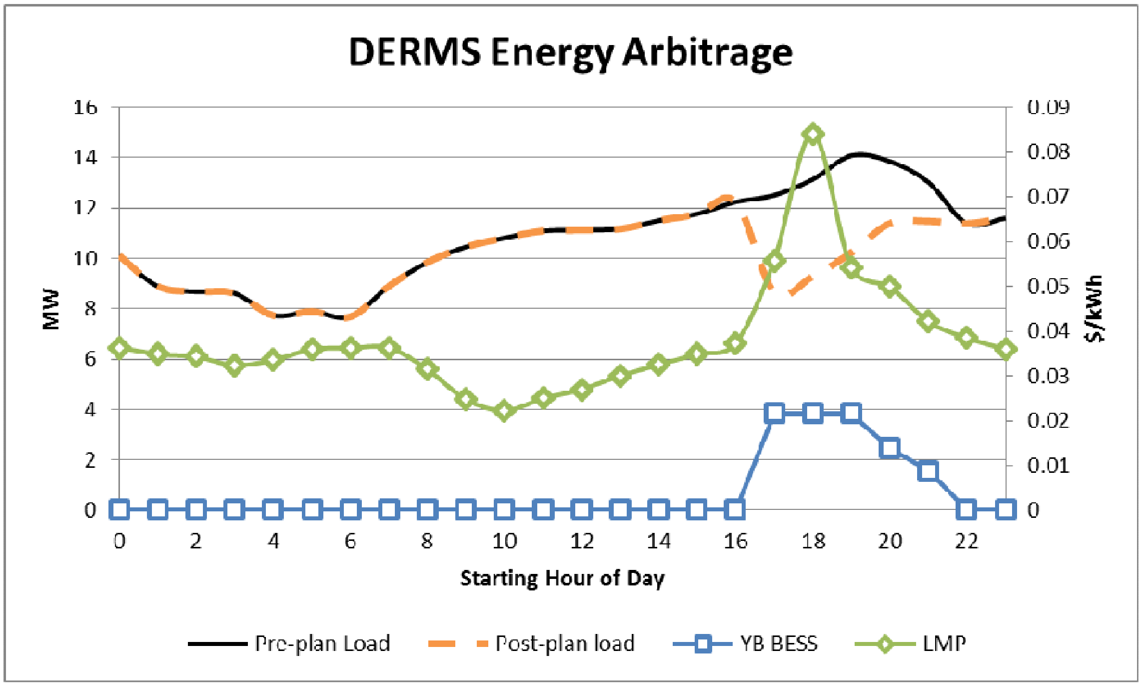


Figure 8 YB BESS was discharged at peak pricing to minimize cost

Wholesale energy pricing was varied for different DER assets to verify the DERMS performed the least cost dispatch by using the lower priced assets. The price for BTM assets for both aggregators was set to zero. Arbitrary cost values were assigned to various violation types to prioritize dispatch for mitigating the violations instead of energy arbitrage when violations were present. This resulted in the DERMS dispatching all the assets to mitigate the violations while prioritizing the lowest price DERs, shown in Table 7 and Figure 9.

	Pre-Plan Energy (kWh)	Post-Plan Energy (kWh)	Pre-Plan Cost ($)	Post-Plan Cost ($)	
CAISO					
DAM GN001 Energy	267,895	262,125	6,611	6,481	
AGGREGATORS					
Agg1 Down Flex	0	-449**	0*	0	
Agg1 Up Flex	0	97	0*	0	
Agg2 Charge Down Flex	0	-621**	0*	0	
Agg2 Charge Up Flex	0	744	0*	0	
PG&E ASSETS					
YB BESS Discharge	0	5,651	0	-135	
YB BESS Charge	-680	-329**	1	1	
		Pre-Plan($)	**Post-Plan($)**	**Delta($)**	**Delta(%)**
CAISO Market		6,611	6,481	-130	
Aggregator Assets		0	0	0	
PG&E Assets		1	-134	-135	
Penalty of Violations		11,066,992	4,345,384	-6,721,608	-60.7
Total		11,073,604	4,351,731	-6,721,873	-60.7

Table 7 The DERMS dispatched the lowest price DERs first followed by the higher price ones

*Prices for both aggregators were set to zero to prioritize dispatch

**Due to initial SOC of the DERs, charging was needed prior to discharge for mitigating violations for multiple hours.

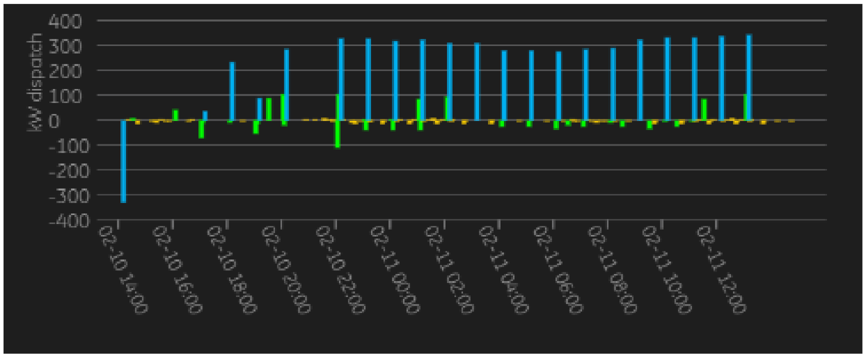


Figure 9 The DERMS prioritized the least cost assets in its dispatch to mitigate violations

An additional test ran with Aggregator 1 price set high to $50/kWh while Aggregator 2 price was zero. Arbitrary cost values were assigned to various violation types to prioritize dispatch for mitigating the violations instead of energy arbitrage when violations were present. This resulted in the DERMS dispatching the lowest price DERs, shown in Table 8 and Figure 10. Due to hard constraints for SOC, the DERMS honored the constraints and did not completely mitigate the violations.

	Pre-Plan Energy (kWh)	Post-Plan Energy (kWh)	Pre-Plan Cost ($)	Post-Plan Cost ($)	
CAISO					
DAM GN001 Energy	408,688	404,417	10,453	10,423	
AGGREGATORS					
Agg1 Down Flex	0	0	0	0	
Agg1 Up Flex	0	0	0	0	
Agg2 Charge Down Flex	0	-407**	0	0	
Agg2 Charge Up Flex	0	485	0	0	
PG&E ASSETS					
YB BESS Discharge	0	7,714	0	-170	
YB BESS Charge	-332	-3,851**	10	152	
		Pre-Plan($)	**Post-Plan($)**	**Delta($)**	**Delta(%)**
CAISO Market		10,423	-30	10,453	
Aggregator Assets		0	0	0	
PG&E Assets		-18	-28	10	
Penalty of Violations		3,845,003	1,037,619	-2,807,384	-73.0
Total		3,855,466	1,048,024	-2,807,442	-72.8

Table 8 The DERMS dispatched Aggregator 2 with a price of zero and YB Battery at LMP price

**Due to initial SOC of the DERs, charging was needed prior to discharge for mitigating violations for multiple hours.

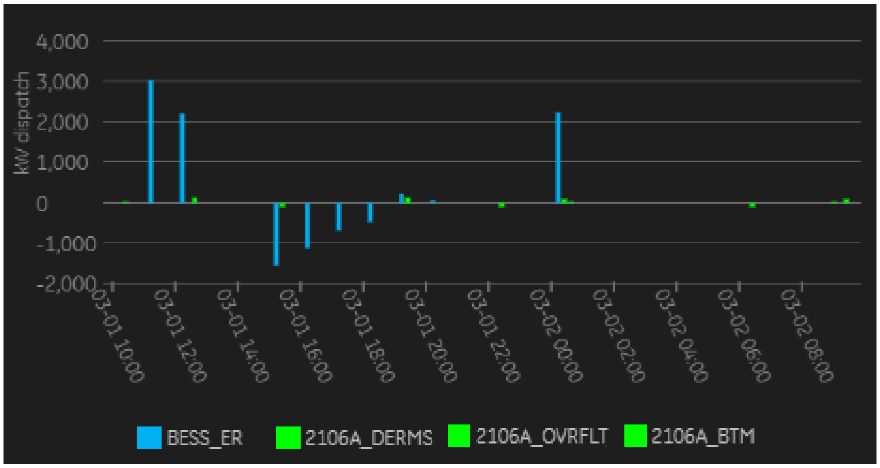


Figure 10 The DERMS did not dispatch Aggregator 1 due to its high price

2.6 UC6: Operational Flexibility

The ADMS updated with field circuit topology every five minutes with data from the production DMS and SCADA. The DERMS was able to optimize and mitigate violations as circuit topology changed throughout testing. Even after switching operation tied YB BESS to an adjacent feeder instead, the DERMS mitigated an overload there, shown in Figure 11 and Table 9.

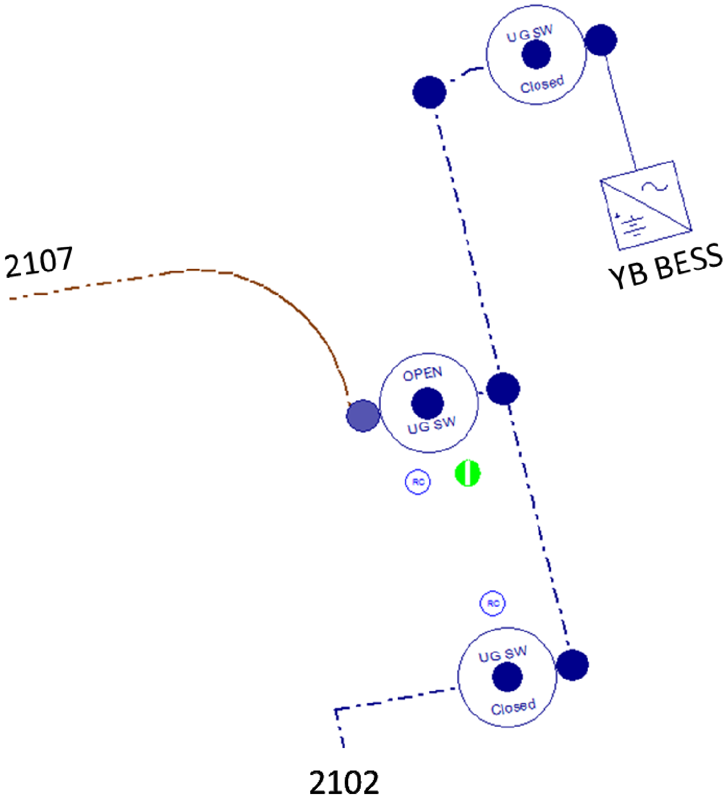


Figure 11 YB BESS was switched from 2102 circuit to 2107 circuit to mitigate an overload

Time	Device	Forecast Load (A)	Default Load Limit (A)	New Load Limit (A)	Load Limit Changed (Time)	DER Total Flex. to Mitigate Issue (A)	DERMS Alarm Disp (Time)	DERMS Mitigates Issue to Extent Possible	Plan Time	Plan Dispatch (kW)	Calc. New Load (A)
16:00	XR102	139.8	600	130	16:10	110	16:43	Yes	17:40	500	130

Table 9 The DERMS mitigated an overload on an adjacent feeder after a DER was back tied

3. Practical Challenges

As mentioned earlier, this project demonstrated that DERMS technology possesses the technical capabilities to coordinate DERs for distribution grid services to mitigate capacity and voltage violations. While the technical ability exists at test scale for a DERMS to orchestrate distribution grid services, the project indicates that the industry is still in the early stages. This project highlighted several challenges for potentially implementing DERMS at scale:

Scalability:
- Scalable systems and processes continue to evolve and will need to leverage ongoing and planned utility investments in foundational grid modernization in order for a DERMS to be implemented at scale
- Large variable loads/generators, such as the YB BESS participating in the frequency regulation market, can cause challenges for real-time and forecasted situational awareness
- Dynamic aggregations and groupings will be needed to optimize DER services under abnormal switching conditions

Standardization:
- DERMS is currently not available “off the shelf”
- Standards will need to continue to evolve and be adopted to ensure common rules and understanding among the different participants
- Implementing the aggregator interface based on IEEE 2030.5 with third party aggregators was new and required custom extensions and thorough testing

Targeted DER Deployment:
- Customer acquisition for BTM assets participating in the project was more challenging than anticipated, highlighting the complexity of targeted DER deployments to provide distribution services
- The sensitivities of particular DERs to provide capacity and voltage support are circuit and location specific

Valuation:
- PG&E did not address the valuation of DER provided distribution services, this is an area for further research

Market Design and Coordination:
- While multiple market designs were tested, PG&E did not make any conclusions on the best type of market (if any) to provide distribution services
- Regulatory and policy rules will need to be established to govern both operation and compensation of DERs across wholesale and distribution uses
- Further development in transparency and coordination is required to enable DERs to provide customer (e.g. demand charge reduction), distribution, and wholesale markets to properly provide and settle services

4. Future Work

DERMS technology is evolving and this project demonstrated the technical capabilities and the remaining challenges of implementing a centralized DERMS. Learnings from this project informed PG&E's modernization plans around situational awareness and DER integrations, as well as helping define what is included in a DER-aware ADMS vs a DERMS.

Future work is planned to further explore some of the challenges cited earlier. Proposed projects include evaluating a decentralized approach involving multiple smaller DER management systems, utility DER head-ends, DER coordination with grid operations, and interconnection enhancements. Personnel from this project are also participating in various working groups and standards around DERs, including enhancing the IEEE 2030.5 standard based on project learnings.

End of text

BIBLIOGRAPHY

[1] EPRI "Understanding DERMS" (Integration of Distributed Energy Resources June 2018)
[2] A. Dobos. "PVWatts Version 5 Manual" (NREL/TP-6A20-62641 September 2014)