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Introduction to a Metrics and Validation Framework Assessing the Performance of the Distributed Energy Resource Management System Platform

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SUMMARY

Distributed Energy Resource Management System (DERMS) is a software platform that monitors and controls Distributed Energy Resources (DERs) in real time on the distribution/sub-transmission system. It also enables higher levels of DERs while maintaining system power quality and reliability. In 2021, Commonwealth Edison Company (ComEd) deployed a DERMS platform for real-time monitoring and management of solar generation output to manage loading on the substation transformer during reverse power flow conditions. This paper provides the framework ComEd has developed for assessing DERMS performance for the desired use case. It also describes the overall strategy, process, and tools for performing the quantitative assessment of DERMS performance and the associated DER control. The implemented measurement and verification tool evaluated DERMS performance during one of the field events that took place on May 1st, with results proving that the DERMS platform functioned as designed.

KEYWORDS

Distributed energy resources, power distribution, benchmark testing, key performance indicator

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INTRODUCTION

High penetration of Distributed Energy Resources (DERs) results in both benefits and challenges to the power system. DERs provide sustainable energy while reducing environmental pollution and CO_2 emissions. However, introducing DERs also presents significant challenges for grid operation, including changes in relay and protection settings, reverse power flow management, power quality issues including voltage sags and swells, flicker, rapid voltage change, phase unbalance, and managing uncertainties [1–3]. Emerging technologies are being developed and deployed to resolve these issues so that grid operators can reliably and safely manage increasing DER penetration in the distribution grid.

The Distributed Energy Resource Management System (DERMS) is an emerging technology that provides forecasting, monitoring, and coordinated control of DERs on the distribution/sub-transmission system. It also supports the integration of renewable generation onto the grid and helps maintain real and reactive power within prescribed limits for distribution circuits [4–6]. Commonwealth Edison Company (ComEd), an electric utility serving 4 million customers in northern Illinois including Chicago, deployed a DERMS solution in an area of its service territory that contains high penetration levels of renewable wind and solar generation. The DERMS technology is being applied as a viable and economical alternative to manage the output of solar generation to avoid reverse power flow going beyond the transformer rating.

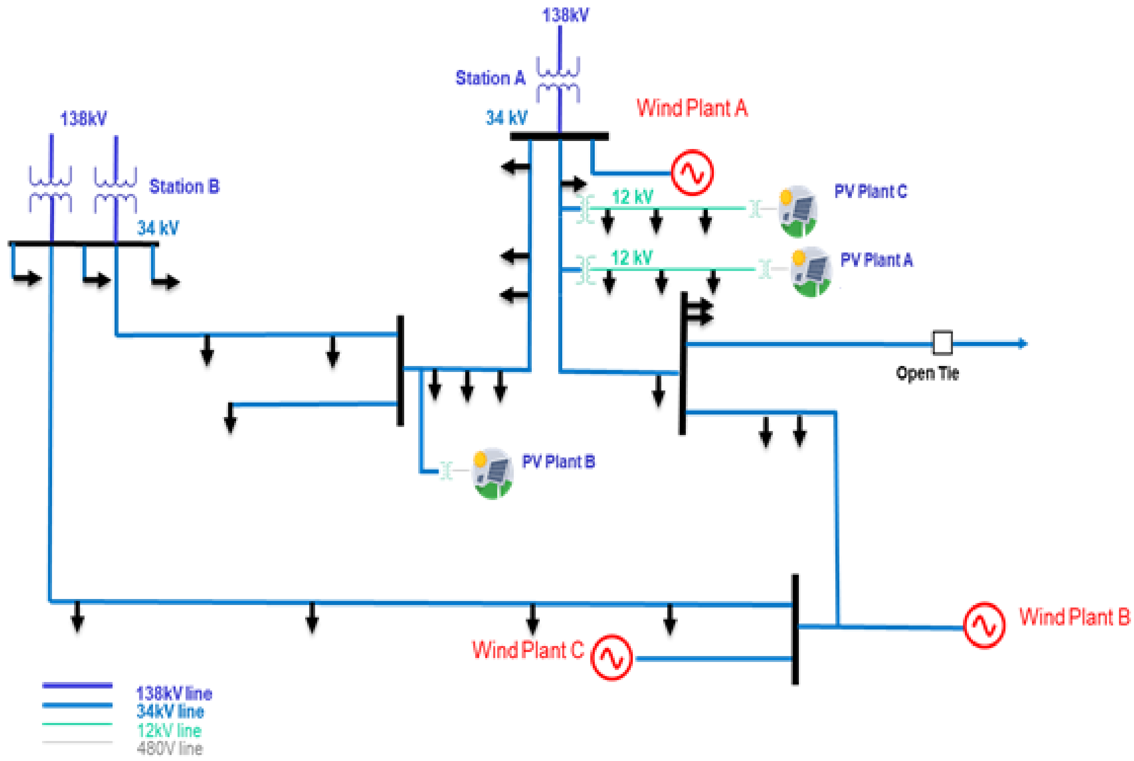
To quantify and assess the performance of DERMS, ComEd's Smart Grid and Emerging Technologies team developed a measurement and verification (M&V) framework. The framework consists of key performance indicators (KPIs), the evaluation process, and a tool developed for the implementation of the strategy. The M&V framework helps users understand control events that took place during the time when DERMS actively managed the output of DERs, providing both an individual perspective of each event and an aggregated view of events over the whole analysis period. During any event, reverse power flow on the substation transformer, control of DERs and management success rate are all monitored and calculated to obtain an understanding of the system's performance.

This paper presents the M&V framework in full detail. The paper is organized as follows: Section 2 provides the background and justification for DERMS, Section 3 describes the list of metrics or KPIs considered as part of the analysis and defined to facilitate their implementation in the tool, Section 4 outlines the DERMS assessment framework implementation, Section 5 provides the first successful control event and its evaluation using the proposed framework, and Section 6 provides the conclusion and a summary of future work.

DERMS BACKGROUND

ComEd deployed the DERMS solution on a meshed network fed by two 34.5kV substations with three wind farms and several future solar PV systems that are scheduled to be installed and commissioned starting in 2021. Figure 1 presents the single-line diagram of the system, which consists of the following:

- Substations A and B with high side 138 kV transmission lines
- Three wind farms: one is directly connected at Station A, while the other two are connected to the 34.5 kV voltage level
- Three newly added solar PV sites, two of which are connected at the 12 kV level with the third connected at the 34 kV level
- Several 12.47kV feeders



Single-line Diagram of Selected Feeder

The DERMS platform only manages output of the PV systems to reduce reverse power flow through the substation A transformer. The DERMS software is engaged when substation A transformer loading surpasses the predefined threshold (threshold 1) during reverse power flow conditions. DERMS detects these conditions and selectively controls one or more of the PV sites to reduce reverse power flow using participation factors, Last-In-First-Out (LIFO) priorities, and other criteria. If the backfeed exceeds the second reverse power flow threshold (threshold 2) and the PVs are fully curtailed, the operations control center (OCC) operator coordinates control of the wind farm(s) with the transmission system operator (TSO) to further reduce loading on the transformer.

DERMS Assessment KPI

ComEd's Smart Grid and Emerging Technologies team developed a metrics and validation (M&V) framework to quantify and assess the performance of DERMS. This framework defines several KPIs that are currently being tracked and assessed as part of the monthly M&V reporting. These KPIs are meant to validate whether the system performed as expected, and to quantify performance that can be reported to stakeholders. The following quantities are being tracked and quantified as part of the M&V plan:

A. Threshold Backfeed Exceedance at Substation Transformer

Threshold backfeed exceedance at substation transformer is an analog value that triggers DERMS to manage the output of PVs. When these events occur, it is important to analyze whether DERMS performed as designed. These exceedance events fall under two types:

- Type 1: Exceedance of reverse power threshold 1, activating DERMS

- Type 2: Exceedance of reverse power threshold 2, when DERMS shall exhaust its controlled resources

Events of these exceedance types are captured separately in the M&V analysis. This not only permits proper interpretation of the control results but also enables accurate verification of the system's performance. Statistics about backfeed exceedance events are developed as well. The calculation is performed for each event, n, that starts at $t = t_{n,0}$, when the backfeed exceeds the reverse power limit, and concludes at $t = t_{n,T}$, when the backfeed first drops below the reverse power limit. The calculations include the following:

1) Exceedance ($\boldsymbol{e_t}$) for reverse apparent power ($\boldsymbol{S_{TR,A}}$):

Type 1 event at any time interval, t, as $e_{t,type1}$ is defined as cases when there is reverse power flow ($P_{TR,A} < 0$) and the magnitude of the apparent power exceeds threshold 1 (TR1) on transformer A, and the exceedance is defined as:

$$e_{t,type1} = \left|S_{TR,\mathrm{A}}\right| - \mathrm{TR1}, when\ P_{TR,\mathrm{A}} < 0, \left|S_{TR,\mathrm{A}}\right| > \mathrm{TR1} \tag{1}$$

Similarly, the exceedance for Type 2 event is given by threshold 2 (TR2):

$$e_{t,type2} = \left|S_{TR,\mathrm{A}}\right| - \mathrm{TR2}, \mathrm{when}\ \ P_{TR,\mathrm{A}} < 0, \left|S_{TR,\mathrm{A}}\right| > \mathrm{TR2} \tag{2}$$

2) Maximum exceedance for event, n:

The maximum exceedance for event, n, that considers all intervals within that event, is defined as the vector of exceedances, $e_{n,0}$ to $e_{n,T}$, and defines $E_{n,max}$ as the maximum value of that vector, that is:

$$E_{n,max} = max(e_{n,0} \quad \cdots \quad e_{n,T}) \tag{3}$$

3) Event duration:

The duration of the event is measured based on the difference of time at the beginning and end of the interval, the end given by the time interval when the exceedance is resolved, and all the PVs are in a fully released state:

$$D_n = t_{n,T+1} - t_{n,0} \tag{4}$$

B. Control Analysis, by DER Location

Each exceedance event triggers one or more control events. The three wind farms are controlled by regional transmission organization (RTO); control analysis for those assets is outside the scope of this M&V framework. A control analysis is only performed for available DERs, which are the PVs in this case.

1) PV Production Estimation:

Control events typically result in management of the output of available DERs (PVs in this case). To estimate how much energy is curtailed during each event, the framework must estimate the total PV generation output without DERMS control during the event, $p_{PVest,kt}$. This is done by PV production "backcast," which uses the data from local weather stations and historical generation for each site to train a random forest regression model. The model is used to estimate the PV generation without DERMS control, as follows:

$$p_{PVest,kt} = p(W_{kt}, \boldsymbol{p}_{PVhist,kt}) \quad (5)$$

where, for time interval, t, W_{kt} is weather information at site k, and $\boldsymbol{p}_{PVhist,kt}$ represents the vector of previous measurements of PV production at site k. The information selected and estimation methodology is described in detail in [7].

2) Calculation of Curtailment:

The curtailment for an interval, t, within a control event n, at PV site k, is given by the following equation which uses the PV site output, $p_{PV,kt}$, and the estimated production defined above:

$$p_{curt,n,kt} = p_{PVest,kt} - p_{PV,kt} \quad (6)$$

The managed energy level for a given event can be calculated as the sum across all intervals associated with the event, multiplied by the number of hours for an interval:

$$E_{curt,n,k} = \sum_{t=0}^{T} p_{curt,n,kt} t \quad (7)$$

The total energy management level for PV site, k, is then given by the sum of total energy managed levels across all events over the period (monthly or quarterly) of analysis:

$$E_{curt,k} = \sum_{n=0}^{N} E_{curt,n,k} \quad (8)$$

3) Event duration:

The duration of the event is analogous to the duration of the exceedance events, defined as follows:

$$D_{curt,n} = t_{n,T} - t_{n,0} \quad (9)$$

DERMS PERFORMANCE

The DERMS success rate is defined to evaluate whether DERMS worked as designed during the backfeed exceedance events or control events. Operations are considered successful under two scenarios:

control occurred and the reverse power flow was reduced/relieved (denoted as $e_{i,n}$)
the reverse power flow limit was exceeded while PVs were fully curtailed, $e_{j,n}$.

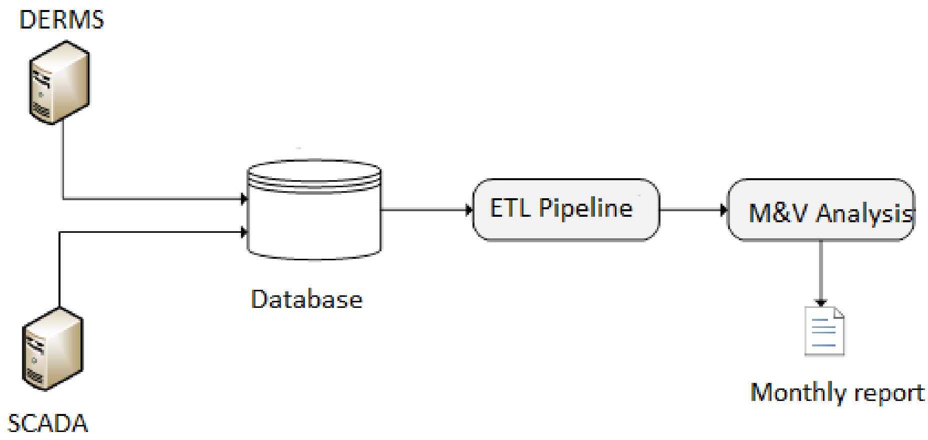
Instances where there was an exceedance but PVs were not controlled to relieve the exceedance are considered unsuccessfully managed events, denoted as $e_{k,n}$.

The DERMS success rate is then given by the number of successfully managed events divided by the number of successfully and unsuccessfully managed events:

$$R_{DERMS} = \frac{\sum_{n=1}^{I} e_{i,n} + \sum_{n=1}^{J} e_{j,n}}{\sum_{n=1}^{I} e_{i,n} + \sum_{n=1}^{J} e_{j,n} + \sum_{n=1}^{K} e_{k,n}} \quad (10)$$

DERMS ASSESSMENT FRAMEWORK IMPLEMENTATION

ComEd developed a tool to calculate the KPIs defined in previous sections. The tool assesses DERMS performance in 3 steps as shown in Figure 2.



Assessment Diagram

Data from DERMS and ComEd SCADA is stored in a database for the M&V framework. During the data acquisition step, a user remotely connects to the PI Historian and downloads the data to their local machine for further processing using PI Historian SDK.

Basic data quality analysis is necessary to ensure data used in the M&V calculations meets data quality criteria. The data reconstruction step consists of identifying any anomalous data caused by issues during measuring, in transit, or in the data archiving process. When data is missing or marked as poor quality and in a time range less than 15 minutes, the data is reconstructed using existing data with a backward-fill function followed by a forward-fill function. When the time range of missing or bad quality is greater than 15 minutes, the dataset is flagged as erroneous, and the tool will search for an alternative data source for the measurement. If the alternative data source is available, the tool will fill in the gap using the alternative data. Otherwise, the periods will be removed from the analysis. The total number of bad data points is recorded and reported if the dataset is discarded. Erroneous data includes points that possess characteristics in Table 1. Additionally, the data resolution of all sets is resampled to 15 minutes to align the resolution of all data coming from the site.

Table 1. Erroneous Data Characteristics

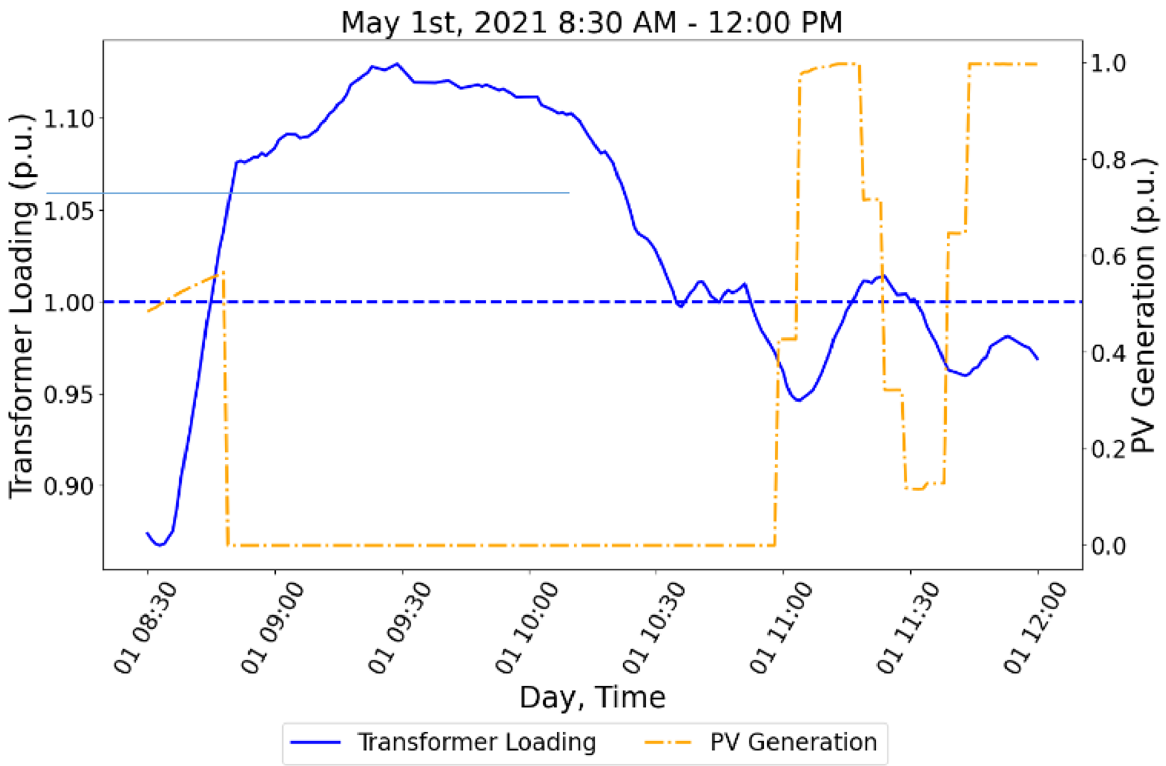
Negative when impossible	Zero when not expected
Non-numeric (NaN)	Missing
For MW: greater than 110% of expected capacity	For MVA: above 110% of nameplate capacity

Each month, data is downloaded, reconstructed, and analyzed from a remote server. The tool automates the analysis process and results of the KPIs described above are exported to an Excel spreadsheet to confirm that DERMS is performing properly. In addition to monthly analysis reporting, the M&V dashboard can select any date range to support additional investigations of system performance.

Assessment of May 1st Events Using the Framework

The DERMS software platform went live on April 1st, 2021 with one PV site online. On May 1st, a scheduled outage due to the maintenance on the 34.5kV feeder resulted in radial system configuration. Meanwhile, both wind farms and the PV site were near their maximum capacity due to the sunny and windy weather. This “light load, full generation” scenario created two backfeed exceedance events on the substation transformer between 8:30 AM and 12:00 PM.

DERMS was triggered during the backfeed exceedance events and managed the PV generation as shown in Figure 3. The values are provided in per unit.



May 1st control event

ComEd developed the M&V tool based on the description in previous sections. The tool was successfully applied to analyze the data during the event on May 1st. Table 2 shows the backfeed exceedance event analysis, which captures the two backfeed exceedance events and lists statistics for each event. The first event lasted 2 hours 9 minutes and the maximum exceedance was 0.13 p.u. which occurred at 9:29 AM. The second event happened at 11:17am and lasted for 16 minutes with a smaller exceedance. This data helps ComEd understand what happened and the severity of the problem during this period.

Table 2. Backfeed exceedance event analysis

ID	Begin	End	Duration	Type	Max Flow	Max Exceedance	Time Stamp
1	08:45	10:54	02:09	1	1.13 p.u.	0.13 p.u.	09:29
2	11:17	11:33	00:16	1	1.014 p.u.	0.014 p.u.	11:24

Table 3 provides control analysis of the PV site. It lists two control events, steps of controls during the events, and the duration:

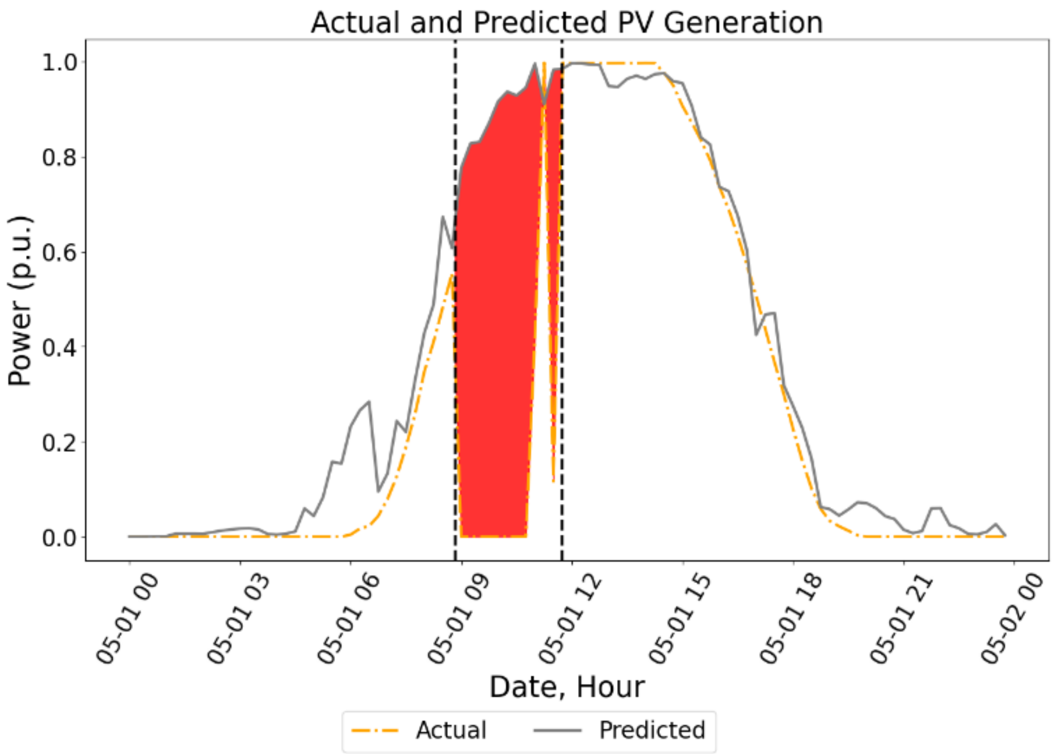
Table 3. Control analysis

Event ID	Site	Begin Time	End Time	Duration	Setpoint p.u.	Curtailed Power p.u.	Curtailed Energy p.u.
1	PV1	8:50 AM	10:58 AM	2:08:00	0	0.555	1.184
1	PV1	10:59 AM	11:03 AM	0:04:00	0.4265	0.138	0.009
2	PV1	11:19 AM	11:23 AM	0:04:00	0.715	0.2805	0.0185

2	PV1	11:24 AM	11:28 AM	0:04:00	0.321	0.6745	0.0445
2	PV1	11:29 AM	11:33 AM	0:04:00	0.1175	0.8275	0.055
2	PV1	11:34 AM	11:38 AM	0:04:00	0.1265	0.8185	0.0545
2	PV1	11:39 AM	11:43 AM	0:04:00	0.646	0.349	0.023

- Event 1 fully curtailed the PV and restored it in two steps. There was a partial release of curtailment between 10:59 AM and 11:03 AM.
- Event 2 was more complicated: it curtailed and released the curtailment in three steps in each direction.

With the PV generation estimation, the M&V tool can calculate PV generation without DERMS intervention. The tool calculated the total PV demand managed during each period, and the total demand management is shown in the highlighted area in Figure 4. Compared to the monthly total PV generation, the total demand management was calculated to be less than 1% of the total generation.



Actual and predicted PV Generation

Finally, ComEd calculated the DERMS success rate during this event. Event 1 is designated when reverse power flow limit is exceeded but PVs are fully curtailed; Event 2 is designated when the PV is curtailed, and reverse power flow is reduced/relieved. Both events are successful control cases and the DERMS success rate was 100%, meaning that DERMS was working as designed during these two events.

YEARLY PERFORMANCE REVIEW

DERMS has been running in ComEd's system for more than fourteen months since it went live. Now we have three integrated solar farms totally 6MW are managed by the DERMS. The statistics shows that, to alleviate the overfeeding of the substation, the DERMS has only curtailed around 0.18% of the total PV generation, which demonstrates the implementation DERMS increases DER hosting capacity with little impact on renewable generation.

CONCLUSION & FUTURE WORKS

This paper presents the M&V framework and tool developed for evaluating the performance of the DERMS platform. It gives a brief introduction to the ComEd's first high voltage DERMS project, explains the KPIs defined for the framework, and describes how the KPIs are calculated. The implementation section describes the strategy for the evaluation process, including data acquisition, data extraction, analysis, and reporting. Based on this framework, ComEd implemented the assessment tool and evaluated it during the control events on May 1st, 2021. The results demonstrate that DERMS worked as designed during this period. Future works include automation of the process, reduction of manual efforts, inclusion of more analysis into the framework, and building a M&V dashboard for better visualization. This framework can be extrapolated to similar DERMS systems to assess their overall performance.

BIBLIOGRAPHY

[1] R. J. Bravo, R. Salas, T. Bialek and C. Sun, "Distributed energy resources challenges for utilities," IEEE 42nd Photovoltaic Specialist Conference (PVSC), pp. 1-5, 2015.

[2] F. Katiraei, B. Mather, A. Momeni, L. Yu, and G. Sanchez, "Field Verification and Data Analysis of High PV Penetration Impacts on Distribution Systems," in Proc. IEEE 42nd Photovoltaic Specialist Conference, 2015.

[3] "IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces", IEEE Std 1547-2018.

[4] Ardani, K. B., E. J.O'Shaughnessy, and P. D.Schwabe.2018. Coordinating Distributed Energy Resources for Grid Services: A Case Study of Pacific Gas and Electric. National Renewable Energy Laboratory (NREL). NREL/TP-7A40-72108.Available at: https://www.nrel.gov/docs/fy19osti/72108.pdf.

[5] L. Strezoski, I. Stefani and B. Brbaklic, "Active Management of Distribution Systems with High Penetration of Distributed Energy Resources," IEEE EUROCON 2019 -18th International Conference on Smart Technologies, Novi Sad, Serbia, 2019, pp. 1-5, doi: 10.1109/EUROCON.2019.8861748.

[6] B. Seal, A. Renjit and B. Deaver, "Understanding DERMS", CA: Electric Power Research Institute, 2018

[7] M. Gutierrez-Hernandez, Y. Liu, and A. Vukojevic, "Photovoltaic Generation Estimation for Curtailment Calculation," in 2021 Grid of the Future Symposium, CIGRE, 2021.