

VP3

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# Virtual Power Plant Metering and Telemetry

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# Executive Summary

**EXECUTIVE SUMMARY**

Virtual power plants are aggregations of distributed energy resources (DERs) that can provide utility-scale and utility-grade grid services.<sup>1</sup> Driven by consumer demand, DER capacity is projected to grow by 170 GW or more over the next five years.<sup>2</sup> VPPs help integrate DERs into the grid. They are also a low-cost, nimble and rapidly deployable solution to help address load growth and other changes challenging the grid’s affordability, reliability, and resilience. This report focuses on one key technical issue with significant policy and program design implications for VPPs: metering and telemetry. The report is intended to educate and support decision-making for regulators, utilities, and other policymakers responsible for advancing VPP rules and policies.

**1: To provide grid services, VPPs need to share reliable, accurate, and timely performance data with grid operators and planners.**

This report focuses on two data communications functions that support grid operations:

- **Metering**, or the measurement of the quantity of energy delivered. Metering data is used to ensure fair and accurate compensation of generators and load, including VPPs.
- **Telemetry**, which is the capability to collect and automatically transmit ongoing, real-time data to a grid operator. Telemetry helps support real-time grid management.

**2: There are at least five options for VPPs to provide performance data to support the grid.**

Given their unique structure, VPPs may collect and

report performance data differently than traditional power plants (which are almost always required to provide data through a revenue-grade meter also known as an ANSI-certified meter). While VPPs are used to provide the same grid services as traditional power plants, technically and operationally an aggregation of smart thermostats (for example) is clearly different than a gas power plant.

Given that, grid operators — working with regulators, technology providers, and aggregators — have developed and implemented several metering and telemetry options for VPPs. How these approaches collect and communicate performance data varies, but the goal of providing accurate and reliable data to support the grid remains unchanged. In this report, we review five options for metering and telemetry of VPPs, which are illustrated below and summarized in [Exhibit ES1](#):

- 1) Revenue-grade metering (ANSI-certified meters)

- 2) AMI-based measurement and verification
- 3) Aggregated accuracy
- 4) Sampling
- 5) Imputed performance

**3: Requirements that force all DERs in all VPPs to collect and report metering and telemetry information in the same way as traditional generators could prevent a wider range of VPPs from supporting grid reliability and affordability.**

Currently multiple utility programs and RTO markets require all DERs in a VPP to collect and communicate data using revenue-grade metering (ANSI-certified meters). Revenue-grade meters are highly accurate. They’re also expensive, and may cost hundreds to thousands of dollars for an individual installation.<sup>3</sup> In some instances (e.g., for large C&I batteries providing ancillary services) these requirements are appropriate and reasonable. In other instances (e.g., for smart thermostats providing peak shaving) these requirements are clearly cost-prohibitive and could prevent a wider range of potential VPPs from supporting the grid.

**4: Grid operators and regulators should evaluate multiple VPP metering and telemetry options to develop guidelines that best support the grid.**

This report recommends a three-step process for determining appropriate metering and telemetry options for a VPP ([see Exhibit ES2](#)):

- 1) Clarify which DER technologies would be involved in a VPP and which grid services the VPP would provide
- 2) Screen out unsuitable metering and telemetry options for those grid services
- 3) Evaluate the remaining options for considerations related to affordability, reliability, fairness, future impacts, and solution readiness

[Section IV](#) provides analysis relevant to step 2.

[Section V](#) provides analysis relevant to step 3.

**5: Complementary policies may be needed to ensure any metering and telemetry option is effectively deployed.**



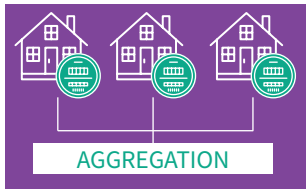


Additional rules, policies, or regulations may be needed to ensure any of these options will deliver as intended. [Section VI](#) provides nine considerations and recommendations for the grid operators and regulators

responsible for developing and enforcing these rules.

Examples of complementary policies to consider include:

- Improve customer and third-party access to customer-meter data
- Coordinate approaches across jurisdictions
- Consider DER integration capabilities as part of future AMI procurement and deployment to future-proof AMI investments

**Exhibit ES 1: Five approaches to metering and telemetry of VPPs**

	 <p><b>Revenue-grade metering</b></p>	 <p><b>Utility AMI</b></p>	 <p><b>Aggregated accuracy</b></p>	 <p><b>Sampling</b></p>	 <p><b>Imputed performance</b></p>
<b>Description of approach</b>	Dedicated ANSI-certified meter used for every DER in VPP	Data from utility-AMI used for performance measurement and potentially telemetry	Less precise device-level meters are statistically aggregated to provide accurate aggregation-level performance data	Aggregation performance is estimated using a statistically valid sample of revenue-grade meter data	Performance is calculated by algorithmic model using device and weather data
<b>High-level pros and cons</b>	Precise but costly	Potentially accurate but limited by disparities in AMI capability and rollout	Low-cost, but accurate only at scale and as an aggregation	Accurate performance for aggregation, but limited granular visibility	Cost-effective approach for heating and cooling, but not suitable for all DERs or grid services

**Exhibit ES 2: Four steps to determine and develop appropriate metering and telemetry policies for VPPS**

**1. Clarify technologies and grid services**

**Which DER technologies?**

- HVAC loads
- Water heating
- EV-managed charging
- C&I demand response
- Customer-sited battery storage

**Which grid services?**

- Capacity
- Energy
- Ancillary
- Distribution-grid services

**Example 1:** Residential heating/cooling loads providing capacity

**Example 2:** Commercial battery providing ancillary services

**2. Screen out unsuitable options**

**Metering/telement options**

- Revenue-grade metering
- Utility AMI
- Aggregated
- Sampling
- Imputed performance

*See Section IV for more details on options and suitability assessment*

**Suitable options**

- Utility AMI

**Usually not suitable**

- Revenue-grade metering (cost)

**Suitable options**

- Revenue grade metering

**Usually not suitable**

- Utility AMI

*Usually not suitable because of granularity of data and latency of communication*

**3. Evaluate remaining options**

**Considerations for policymakers and utilities**

- Affordability
- Reliability
- Fairness
- Future proofing
- Deployment history

*See Section V for analysis of each option based on affordability, reliability, fairness, future proofing, and readiness*

**Considerations related to cost**

will be particularly important, since the individual DER is relatively small

**Considerations related to reliability**

will be particularly important given the nature of the grid service provided and its role in supporting grid stability

**4. Develop rules and policies**

**Considerations and recommendations for grid operators and regulators**

**• Measurement and verification**

1. Allow for calculated approaches
2. Update baseline methodologies
3. Allow metering at dispatch-level

**• Grid services and technical requirements**

4. Clarify technical metering and telemetry requirements needed to provide specific grid
5. Avoid onerous data reporting and registration requirements

**• Customer meters and data**

6. Improve access to customer-meter data
7. Future-proof AMI investments

**• Coordination**

8. Coordinate across jurisdictions
9. Support interoperability

Additional or updated policies related to data access may be warranted

It may be necessary to clarify the technical requirements required for specific ancillary services. This will help determine whether telemetry provided within the battery or inverter will be sufficient or if a separate revenue-grade meter is required.

*See Section VI for recommendations and considerations for grid operators and policymakers*

SECTION I: INTRODUCTION

# Why are VPPs critical for reliable, resilient, and affordable electricity?

# Changing conditions are challenging the power system’s ability to provide reliable, affordable, and resilient electricity<sup>4</sup>

## Reliability

Driven by data centers, industrial load growth, and other uses, projections estimate that peak demand in the United States will grow to 175 GW by 2030 and 270 GW by 2035.<sup>5</sup>

## Affordability

Grid investments in transmission, distribution, and generation are increasing. These growing investments are placing pressure on residential electricity prices.

## Resilience

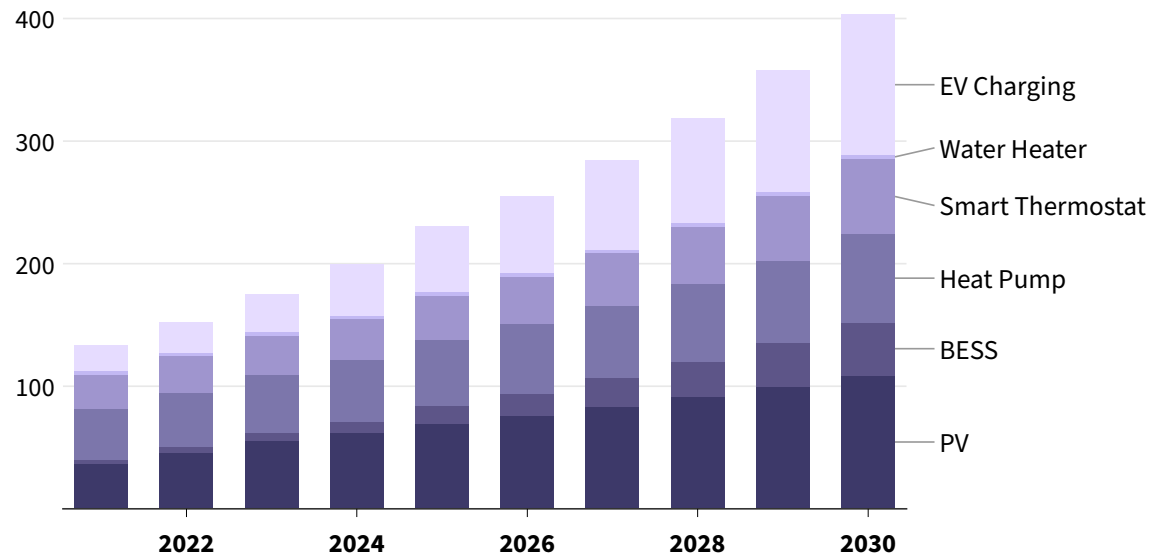
In 2024 the United States faced 27 weather and climate disasters with losses exceeding \$1 billion. This reflects a long-term increase compared to an average of 9 events from 1980 to 2024 (CPI-adjusted).<sup>6</sup>

## Distributed Energy Resources (DERs)

Distributed energy resources are small-scale (sub-utility scale) devices which generate, store, or flexibly consume electricity. DERs are located near or behind the customer meter and are usually connected to the low-voltage distribution grid. Examples of DERs include smart thermostats, HVAC equipment, smart water heaters, EVs and EV chargers, batteries, demand response, and distributed generation.

Driven by consumer demand, DER capacity is projected to grow by 170 GW or more over the next five years. When DERs are not managed, they can strain existing aging distribution grid infrastructure, potentially exacerbating reliability and affordability challenges. However, when they are aggregated into virtual power plants, distribution system impact can be mitigated while avoiding the cost of grid expansions or upgrades and unlocking additional reliability and resilience value for ratepayers.

**Cumulative Installed DER Capacity: Historical and Projected**



Source: Ohm Analytics analysis

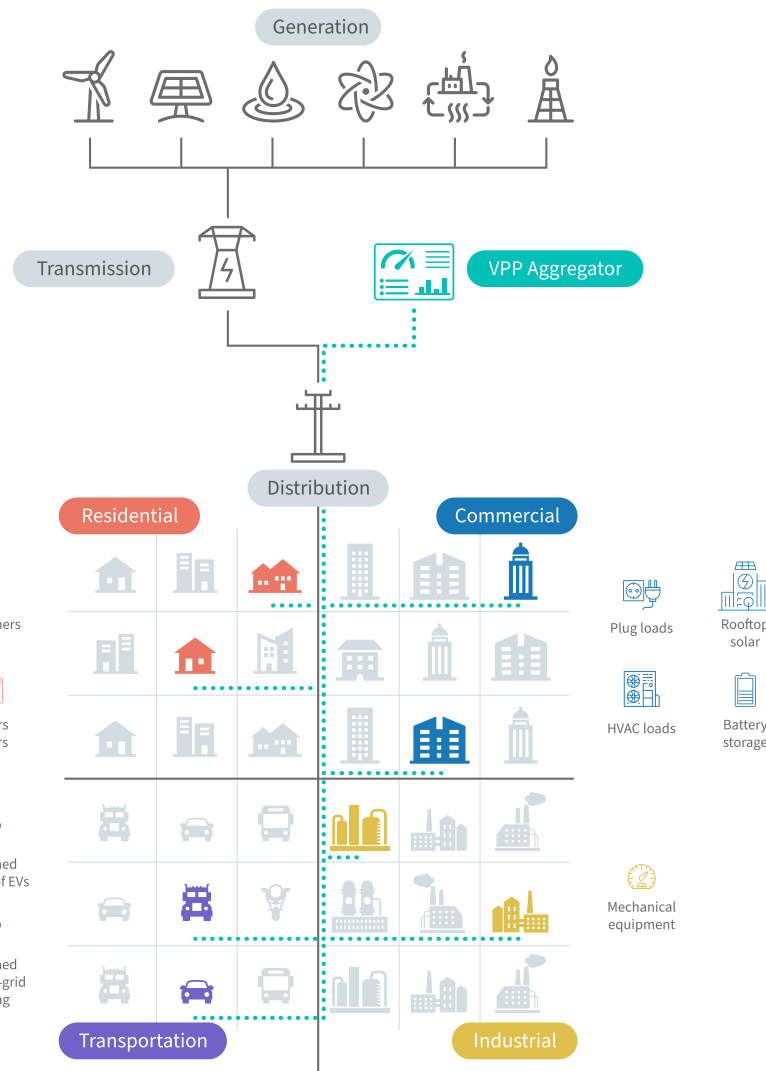
# When DERs are aggregated into VPPs, they can go a long way toward meeting today's grid<sup>8,9</sup> challenges

Grid challenge	How VPPs can help
<b>Load growth and resource adequacy</b>	VPPs can be rapidly and flexibly deployed to manage peak demand
<b>Rising rates and affordability</b>	VPPs can avoid or defer costly investment in generation, transmission, or distribution, and help customers save on bills by avoiding demand during costly peak hours
<b>Extreme weather and resilience</b>	Individual DERs in VPPs can be configured to provide resilient backup power in the event of a grid outage
<b>Grid stability</b>	Fast-acting flexible resources can provide ancillary services to support power quality



## Virtual Power Plants

Virtual power plants (VPPs) are aggregations of distributed energy resources that can be dispatched to support the grid.



SECTION II: INTRODUCTION

# What are metering and telemetry, and why is metering and telemetry of VPPs an important issue?

# What are metering and telemetry?

Metering and telemetry are related functions that often can be provided by the same device, however there are some important differences between the two functions.



Term	Definition/description
<p><b>Metering</b></p>	<p>Metering refers to the <b>measurement of quantities of energy delivered</b>, for example, kilowatt-hours of electricity. It may also involve identifying times of use, or the instantaneous demand for energy (kilowatts).<sup>10</sup></p> <p>In the context of DERs/VPPs, “metering” refers to the rules that determine how individual DERs and DER aggregations have their energy injection and withdrawal measured.</p> <p>Metering data is used for settlement purposes to ensure fair and commensurate compensation to market participants.</p>
<p><b>Telemetry</b></p>	<p>Telemetry refers to the <b>process of collecting data at remote points and automatically transmitting</b> it to receiving equipment for monitoring, analysis, reporting, and operational needs.</p> <p>In the context of DERs/VPPs, it refers to the <b>real-time</b> collection and transmission of data for monitoring and managing distributed energy resources, including real-time data (e.g., load, voltage and frequency, state of charge [SOC]) needed for aggregations to provide fast-response services (e.g., frequency regulation).</p> <p>The primary use of telemetry data is for real-time operational visibility, and for settlement of fast-response ancillary services.</p>

# Why are metering and telemetry of VPPs important?

## Accurate and reliable data on VPP performance is needed to increase trust in VPPs

- Though VPPs are a mature and well-established solution, there is still a trust gap in VPPs for some regulators, utilities, and grid operators
- Regulators, utilities, and grid operators are unlikely to advance VPP enabling policies if they don't fully trust that VPPs will perform reliably

## Research has shown that onerous requirements for metering and telemetry are preventing VPPs from more rapidly scaling to support grid reliability and affordability

- Notable research findings:
  - DOE's VPP Liftoff Update identified metering and telemetry as a key issue related to VPP Liftoff imperative 5 (Integrate into wholesale markets)<sup>11</sup>
  - LBNL found metering and telemetry is one of four main compliance and implementation issues associated with Order 2222 implementation by RTOs/ISOs<sup>12</sup>
  - ESIG research suggests onerous communication and metering rules are one of five critical gaps to increased demand response deployment in wholesale markets<sup>13</sup>
- While the research above relates to VPPs that participate in wholesale markets, metering and telemetry is also an issue for VPPs participating in utility programs and other retail VPPs.

## Balanced metering and telemetry approaches are needed to build confidence in VPP operations and compensation, while enabling VPPs to cost-effectively provide a range of needed grid services

- Successful approaches will:
  - build visibility and confidence in operations
  - ensure accurate compensation
  - unlock additional grid services
- *This will lead to better integration in planning and scaled VPP deployment*

## What other key terms and concepts relate to metering and telemetry of VPPs?

Term	Definition/description
<b>Measurement and verification</b>	<p>Measurement and verification (M&amp;V) is the process of planning, measuring, collecting, and analyzing data to verify performance of grid assets, such as DERs and VPPs. M&amp;V is critical to ensure accurate market settlement and full realization of monetary value to the DER owner. Metering and telemetry data serve as inputs to different M&amp;V approaches.</p>
<b>Baselining</b>	<p>Baselining refers to the process of establishing a reference point or standard against which future performance can be measured. In the context of DERs/VPPs, it is the performance evaluation methodology used to estimate the demand reduction value or the power injection of the product/service provided by a demand response or distributed energy resource.<sup>i</sup></p> <p>VPP performance is assessed by comparing metering data to the baseline.</p>
<b>Ancillary services</b>	<p>Ancillary services are essential functions that support the delivery of electric power while maintaining reliable grid operations. These include services like frequency regulation, voltage support, and spinning reserves.</p> <p>In this report, ancillary services refer to services delivered to the bulk power system, typically through markets. Most market operators have strict metering and telemetry requirements for resources/aggregations participating in ancillary service markets due to their fast-response nature.</p>
<b>Distribution grid services</b>	<p>Distribution grid services encompass a range of functions and operations to ensure the reliable delivery of electric power on the distribution grid. These can include real-time services such as voltage regulation, load balancing, power quality management, and real-time demand response, but also include longer-term service infrastructure upgrade deferral, improving network utilization factor, etc. that support distribution planning and investment.</p> <p>Metering and telemetry play the crucial role of enabling monitoring of distribution system state and serve as inputs to software like ADMS and DERMS.</p>

<sup>i</sup> For more information about baselining, see <https://www.centrefornetzero.org/impact/baselining>

# What are current requirements for metering and telemetry?

- Metering and telemetry requirements vary by jurisdiction and by grid service.
- While utilities and market operators tend to provide some guidance on metering and telemetry requirements within business practice manuals and other similar documents, often requirements can be unclear and subject to interpretation.
- While it is beyond the scope of this document to comprehensively catalogue all metering and telemetry requirements in all jurisdictions and for all grid services, the table below summarizes metering and telemetry requirements for US RTO/ISOs. These requirements are subject to change.
- While this report also discussed implications for VPPs operating through retail programs outside of the RTO/ISO, no utility programs are summarized in the table.

RTO/ISO	Summary of metering/telemetry requirements
<b>SPP</b> <sup>14</sup>	<ul style="list-style-type: none"> <li>• SPP requires revenue grade meters for market participants. It is not clearly stated if DER aggregations have different telemetry requirements compared to large generators.</li> </ul>
<b>ERCOT</b> <sup>15</sup>	<ul style="list-style-type: none"> <li>• Requires accurate, real-time, and high uptime telemetry for ancillary services.</li> <li>• ADER pilot requires telemetry for each participating resource/device, verified against settlement metering data.</li> </ul>
<b>NYISO</b> <sup>16</sup>	<ul style="list-style-type: none"> <li>• Each DER must have a revenue-grade meter.</li> <li>• DER aggregation must provide telemetry.</li> <li>• NYISO compiles a central list of approved metering equipment.</li> <li>• Metering service entities (including aggregators) must complete an annual meter audit.</li> </ul>
<b>PJM</b> <sup>17</sup>	<ul style="list-style-type: none"> <li>• Utility AMI can be used for settlement.</li> <li>• In absence of interval meters, sampling is allowed.</li> <li>• Telemetry is required at DER aggregation-level for large aggregations and certain services.</li> <li>• PJM does not provide a central approved list of metering equipment but will review and approve equipment for each aggregator.</li> </ul>
<b>MISO</b> <sup>18</sup>	<ul style="list-style-type: none"> <li>• Requires ANSI-certified revenue grade metering.</li> <li>• Requires telemetry for ancillary services.</li> </ul>
<b>ISO-NE</b> <sup>19</sup>	<ul style="list-style-type: none"> <li>• Requirements vary by service provided. Aggregations are required to provide 5-minute interval data.</li> </ul>
<b>CAISO</b> <sup>20 21</sup>	<ul style="list-style-type: none"> <li>• Requirements for each DER vary by service provided; 4-second telemetry is required for all DERs providing ancillary services.</li> </ul>

SECTION III

# What's currently not working for metering and telemetry of VPPs?



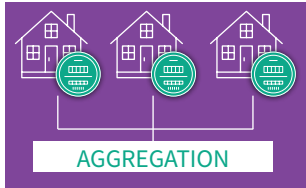


# Overview of challenges associated with metering and telemetry of VPPs

Grid challenge	Description	Issues	Impacts
<b>Extraneous requirements</b>	Grid operators sometimes set requirements based on requirements from legacy resource types like bulk generation, that end up outside of what is necessary and reasonable for the operation of a DER/VPP program	<ul style="list-style-type: none"> <li>• Data requested is not relevant or necessary to operate program</li> <li>• Redundant requirements</li> </ul>	<ul style="list-style-type: none"> <li>• Increases costs for customers; meeting requirements can be cost-prohibitive compared to revenue potential</li> <li>• Slows the deployment of VPPs</li> <li>• Does not add significant value to the grid or grid operator</li> </ul>
<b>Revenue grade meter stipulations</b>	Grid operators require a limited list of accepted revenue grade meter models even when alternate technologies would suffice	Requires use of specific hardware <ul style="list-style-type: none"> <li>• Specifying revenue grade metering – but not defining what that means (resulting in participants defaulting to a set list)</li> <li>• List of accepted revenue-grade meters may differ across jurisdictions</li> </ul>	<ul style="list-style-type: none"> <li>• Increases cost for customers</li> <li>• Slows deployment of VPPs</li> <li>• Does not add significant value to the grid or grid operator</li> </ul>
<b>Insufficient requirements</b>	Current requirements are insufficient to deliver desired outcomes	<ul style="list-style-type: none"> <li>• Third parties have limited access to customer data</li> <li>• Insufficient data from DERs to enable VPPs to provide additional grid services</li> </ul>	<ul style="list-style-type: none"> <li>• Limits effective participation of third parties</li> <li>• Constrains ability to use VPPs to provide some grid services (e.g., locational grid services)</li> <li>• VPPs are less likely to be integrated into grid planning processes</li> </ul>
<b>Inconsistent requirements</b>	Requirements vary within a geography or across geographies	<ul style="list-style-type: none"> <li>• Inconsistent requirements for multiple programs within a single jurisdiction</li> <li>• Inconsistent requirements between operationally similar programs operating in different geographies</li> </ul>	<ul style="list-style-type: none"> <li>• Undermines trust in technical solutions</li> <li>• Potential risk of stranded costs for utilities</li> <li>• Limit DER participation</li> <li>• Technology development pathway for OEM is unclear</li> </ul>

SECTION IV

# What are the options for metering and telemetry of VPPS?

# Overview of metering and telemetry options analyzed in this report

	 <b>Revenue-grade metering</b>	 <b>Utility AMI</b>	 <b>Aggregated accuracy</b>	 <b>Sampling</b>	 <b>Imputed performance</b>
<b>Description of approach</b>	Dedicated ANSI-certified meter used for every DER in VPP	Data from utility-AMI used for performance measurement and potentially telemetry	Less precise device-level meters are statistically aggregated to provide accurate aggregation-level performance data	Aggregation performance is estimated using a statistically valid sample of revenue-grade meter data	Performance is calculated by algorithmic model using device and weather data
<b>High-level pros and cons</b>	Precise but costly	Potentially accurate but limited by disparities in AMI capability and rollout	Low-cost, but accurate only at scale and as an aggregation	Accurate performance for aggregation, but limited granular visibility	Cost-effective approach for heating and cooling, but not suitable for all DERs or grid services

## Dedicated revenue-grade metering (ANSI-certified meters)

Description	Where is it used?	
<p>Revenue-grade meters are meters used primarily for the purpose of making measurements to obtain the basis of charge for electricity supplied to or generated by a customer, that meet specific accuracy standards such as ANSI C12.1 (3).<sup>22</sup> These meters must have an accuracy of 0.5% or higher and are used to provide accurate and reliable energy usage data for billing and utility programs.<sup>23</sup></p>	<p>Accepted for measuring VPP performance across all regions served by ISO/RTO markets in the United States. These meters are used to measure performance at the asset level or the site/account level.</p>	<p>The accuracy requirement varies across markets: for DERs in CAISO and SPP, they must be revenue-quality with 0.2 accuracy class (5), and for MISO 0.3 accuracy class (6).</p>

### Variations

- On-board metering — pre-installed revenue grade meter integrated into a DER device (such as batteries or inverters) that provides measurement at the device-level
- Separate third-party meter installed at the site by a metering services provider
- Revenue grade meter may be installed on device (sub-metering) or at the facility

# AMI-based measurement and verification

Description	Where is it used?	
<p>Metering approach that uses data from utility-installed smart meters to measure and verify customer performance at the household level and sometimes at the device level.</p>	<p>AMI rollout is at various stages across US utilities, with utilities holding the primary responsibility for the execution.</p>	<p>Independently or in conjunction with other grid data, AMI is used to support settlement of VPP services in diverse VPP programs. These include: The DSGS Program (California) and the ADER Pilot (Texas).</p>

**Effective use of this option is uniquely dependent on three conditions:**

- 1) AMI is deployed
- 2) AMI collects sufficiently granular data to verify provision of service
- 3) There are sufficient data sharing provisions for third parties

Utilities may directly share data with third parties or utilities may deploy an open platform whereby third parties can access meter data.

## A note on AMI 1.0 vs. AMI 2.0

### AMI 1.0 versus 2.0

New generations of AMI technology have the potential to provide new and different capabilities compared to legacy AMI. Sometimes these new generations of AMI are referred to as AMI 2.0.<sup>24</sup> In this report we focus on capabilities of AMI 1.0, but also acknowledge some of the potential of AMI 2.0

### Description/Intro

AMI 2.0 refers to the next-generation of advanced metering infrastructure (smart meters) that features meters with enhanced capabilities such as edge computing, distributed AI, improved reliability, and low-latency real-time communication of meter data.

### AMI 1.0 Challenges in the context of DERs

- **Data limitations:** AMI 1.0 meters do not collect sufficiently high-resolution data that can be used by grid operators to monitor and manage DERs on their network (e.g., to manage power quality and reliability concerns).
- **Lack of Real-time Communication:** AMI data does not update real time for grid operators, so its use becomes limited to post-event billing, rather than real-time visibility for operators and third parties.
- Complex data aggregation and access issues.
- Lack of computing power limits the ability of the utility to simultaneously execute reliability, resiliency, and DER management objectives at the grid-edge.

### Select new features of AMI 2.0

- **Real-time communications:** Low-latency communications between grid and customer devices enable real-time demand response and DER orchestration by distribution grid operators.
- **Edge Computing:** Provides compute power at the meter level to enable real-time processing of high-resolution waveform data and intelligent automation.
- **Improved Reliability:** Improved power quality, outage restoration, and resilience.

## Aggregated accuracy

### Description

- Aggregated accuracy is a metering approach that uses data from a large number of non-revenue grade meters to represent the performance of the aggregation.
- Rather than specifying device level hardware accuracy requirements, accuracy is statistically calculated at the aggregated resource level.
- Based on the Law of large numbers — the aggregate of a sufficiently large number of less-accurate measurements will have comparable and even improved accuracy to the aggregate of individual highly-accurate measurements, depending on the size of the aggregation. (insert equation)
- The aggregated cohort thus meets the market operator's accuracy standard even though the individual meters may not.

### Where is it used?

Not in use currently.

# Sampling

## Description

Statistical sampling is defined as measuring the behavior of a representative sample of customers in an aggregation who have revenue-grade meters or advanced metering infrastructure (AMI) and extrapolate the performance to the full aggregation.

## Where is it used?

CAISO, NYISO, SPP, MISO, and PJM allow sampling for DER participation in markets, rather than direct telemetry for each DER.<sup>25</sup>

# Imputed performance

## Description

Basic data (e.g., on/off), typically from an HVAC device, is run through formulas including outdoor ambient temperature and humidity to estimate power demand from device and impact of demand flexibility.

## Where is it used?

Imputed performance is used today for many utility-run smart thermostat programs that pay customers \$X per year regardless of performance. They assess performance based on a set kW value per household. For example, many whole home AC units are assumed to operate at 1kW.

### Example in operation:

- California's updated Demand Side Grid Support (DSGS) program guidelines allow imputed performance.<sup>26</sup>

# Suitability of option by DER technology

Option	HVAC	Water heating	EV managed charging	Large C&I Demand Response	BTM Battery Storage
<b>Revenue-grade metering (ANSI-certified meters)</b>	Likely cost-prohibitive for most residential and commercial applications	Likely cost-prohibitive for most residential and commercial applications	Likely cost-prohibitive for most residential and commercial applications		<ul style="list-style-type: none"> <li>Some home batteries are designed with built-in ANSI-certified meters</li> <li>Revenue-grade metering is suitable for most/all C&amp;I batteries</li> </ul>
<b>AMI-based measurement and verification</b>	Next generation AMI may enable measurement of individual DER performance, but all AMI can assess total performance for the household at the customer meter, though at varying time scales and for different grid services				
<b>Aggregated accuracy</b>				May not provide sufficient accuracy for large demand response	
<b>Sampling</b>				May not provide sufficient accuracy for large demand response	
<b>Imputed performance</b>			Approach is designed primarily for on/off HVAC loads		



Option is suitable for DER



Option may be suitable for DER in most instances



Option will usually not be suitable for DER



Option will almost never be suitable for DER

# Suitability of option by grid service provided

Option	Capacity/ capacity market	Energy/ energy market	Fast-response/ ancillary market	Distribution-grid services
Revenue-grade metering (ANSI-certified meters)				Would also need to be integrated into DERMS/ADMS to provide this service
AMI-based measurement and verification			Likely to be constrained by data granularity and latency without AMI 2.0	Depends on AMI capabilities and nature of distribution grid service
Aggregated accuracy			<ul style="list-style-type: none"> <li>• Can provide service with sufficiently large aggregation.</li> <li>• May be contingent on reliability and latency of Wi-Fi network.</li> </ul>	May not provide sufficient accuracy at specific location
Sampling			Telemetry may not be sufficiently accurate or location specific	May not provide sufficient locational visibility
Imputed performance			Contingent on reliability and latency of Wi-Fi network.	Contingent on reliability and latency of Wi-Fi network.

Option is suitable for providing grid service

Option may be suitable for providing grid service under specific conditions

Option will usually not be suitable for providing grid service

Option will almost never be suitable for providing grid service

SECTION V

# How do metering and telemetry options compare to each other?

# Considerations for policymakers and utilities

Policymakers and utilities should evaluate the following considerations as they decide on preferred approaches for metering and telemetry of VPPs.

Consideration	Component questions
<p><b>DEPLOYMENT HISTORY</b> Has this been implemented, and what risks might first movers need to manage?</p>	<ul style="list-style-type: none"> <li>• <b>Implementation:</b> Has this approach been implemented successfully in other jurisdictions?</li> <li>• <b>First mover risk:</b> What are the risks that first movers might need to manage?</li> </ul>
<p><b>AFFORDABILITY</b> Does this option support low-cost operation of the grid?</p>	<ul style="list-style-type: none"> <li>• <b>Cost for customers:</b> Does this approach introduce costs to customers?</li> <li>• <b>Impact on future metering investment:</b> How will this approach impact future capital investments and operating costs for the grid?</li> </ul>
<p><b>RELIABILITY</b> Does this option support reliable operations of the grid?</p>	<ul style="list-style-type: none"> <li>• <b>Accuracy:</b> Is data sufficiently accurate and granular?</li> <li>• <b>Timeliness:</b> Is real-time communication sufficient to support delivery of grid services?</li> <li>• <b>Speed of deployment:</b> To what extent can this solution be rapidly deployed to support near-term reliability challenges?</li> </ul>
<p><b>FAIRNESS</b> Is this approach fair to participants and non-participants?</p>	<ul style="list-style-type: none"> <li>• <b>Market participants:</b> Does this approach provide preferential (or discriminatory) treatment to any market participants?</li> </ul>
<p><b>FUTURE PROOFING</b> How durable is this approach to changes in technology and policy?</p>	<ul style="list-style-type: none"> <li>• <b>Future relevance:</b> Is this approach likely to become outdated in the future?</li> <li>• <b>High DER penetration:</b> Will this approach work well at significantly higher levels of DERs?</li> </ul>

COMPARISON OF OPTIONS: SUMMARY

# Overview of key advantages and disadvantages for each metering and telemetry option

Option	Advantages	Disadvantages
<b>Revenue-grade metering</b>	<ul style="list-style-type: none"> <li>• Provides precise, granular, accurate, and real-time data.</li> <li>• Widely used in power markets and utility programs today.</li> </ul>	<ul style="list-style-type: none"> <li>• May cost hundreds to thousands of dollars for an individual installation; this is cost-prohibitive compared to VPP revenue potential for many DERs.</li> </ul>
<b>AMI-based M&amp;V</b>	<ul style="list-style-type: none"> <li>• No new metering hardware needed if AMI is already deployed.</li> <li>• Provides accurate data.</li> <li>• Provides location-specific data.</li> </ul>	<ul style="list-style-type: none"> <li>• Latency of AMI 1.0 meters and slow rollout of AMI 2.0 meters cast doubts on ability of AMI to support real-time telemetry needed for some fast-response services.</li> </ul>
<b>Aggregated accuracy</b>	<ul style="list-style-type: none"> <li>• Leverages lower cost meters to reduce costs and barrier to entry for some VPPS.</li> <li>• Aggregation-level accuracy of <math>\pm 0.5\%</math> is still possible in sufficiently large aggregations.</li> </ul>	<ul style="list-style-type: none"> <li>• Accuracy and validity depend on sufficiently large aggregation size and validated accuracy of individual meter data.</li> <li>• Has not yet been fully implemented in markets.</li> </ul>
<b>Sampling</b>	<ul style="list-style-type: none"> <li>• Cuts metering cost by 80%–90% compared to revenue-grade meters by reducing number of revenue-grade meters.</li> <li>• Individual meter accuracy and real-time telemetry capabilities are the same as revenue-grade metering.</li> <li>• Has been adopted in multiple regions (CAISO, NYISO, PJM, SPP, MISO).</li> </ul>	<ul style="list-style-type: none"> <li>• Provides limited location-specific insight so may not be suitable for some grid services.</li> </ul>
<b>Imputed performance</b>	<ul style="list-style-type: none"> <li>• Low cost, because no new hardware is needed.</li> <li>• Enables more heating and cooling loads to cost-effectively participate in VPPs.</li> <li>• Already used in some jurisdictions.</li> </ul>	<ul style="list-style-type: none"> <li>• Based on calculated assumptions, and reliant on modeled outcomes rather than observed data.</li> </ul>

# Deployment history

**Consideration**

Has this been implemented, and what risks might first movers need to manage?

**Component questions**

- **Implementation:** Has this approach been implemented successfully in other jurisdictions?
- **Risk:** What are the risks that first movers might need to manage?

Option	Advantages	Disadvantages
<b>Revenue-grade metering (ANSI-certified meters)</b>	<p><b>Implementation and risk</b></p> <p>Widely used and trusted approach; technology is ready and low risk.</p>	None identified
<b>AMI-based measurement and verification</b>	<p><b>Implementation</b></p> <ul style="list-style-type: none"> <li>• Widely used approach for peak management.</li> <li>• Next generation AMI rollouts are planned anyway in many regions for utility M&amp;V, so this would not be an additional cost solely for DER market participation purposes.</li> <li>• Has been used in some cases to verify delivery of distribution grid services or fast response grid services (NY CSRP &amp; DLRP).</li> </ul>	<p><b>Risks</b></p> <ul style="list-style-type: none"> <li>• Preferred measurement and verification approaches may change over time.</li> <li>• Lack of uniformity in specific metering infrastructure deployed — meter capabilities vary widely, and some types may not have necessary capabilities for ISO market participation and M&amp;V, distribution grid services, or fast-response grid services.</li> <li>• Dependent on utility for AMI rollout — can be delayed or not use meters with the right capabilities.</li> <li>• May require consistent provisioning of AMI data from utility to third parties.</li> <li>• Has not been widely used to verify delivery of distribution grid services or fast-response grid services.</li> </ul>
<b>Aggregated accuracy</b>	<p><b>Risk</b></p> <p>Statistical accuracy of aggregated meters is supported by math.</p>	<p><b>Implementation</b></p> <p>Has not been implemented in any markets or jurisdictions.</p>
<b>Sampling</b>	<p><b>Implementation</b></p> <p>Approach has been supported by FERC and ISOs such as CAISO, NYISO, MISO, SPP, and PJM.</p>	<p><b>Risk</b></p> <p>Developing and implementing a new sampling methodology may be challenging and lead to stakeholder disagreement.</p>
<b>Imputed performance</b>	<p><b>Implementation</b></p> <p>Has been implemented in some jurisdictions/programs including MISO and California DSGS program.</p>	<p><b>Risk</b></p> <p>May require some calibration to specific climates and specific HVAC equipment.</p>

# Affordability

**Consideration**

Does this option support low-cost operation of the grid?

**Component questions**

- **Cost for customers:** Does this approach introduce costs to customers?
- **Impact on future investment:** How will this approach impact future capital investments and operating costs for the grid?

Option	Advantages	Disadvantages
<p><b>Revenue-grade metering (ANSI-certified meters)</b></p>	<p><b>Impact on future investments</b> Enables broad range of grid services to be provided.</p>	<p><b>Cost to customers</b> Many DERs do not have built-in revenue-grade meters, so a separate meter will need to be installed. Cost to purchase and install ANSI-meter is in the range of hundreds to more than a thousand dollars. <sup>ii</sup></p> <p><b>Impact on future investment</b> If cost-prohibitive for customers, DER/VPP deployment may slow, leading to infrastructure investments that might have been avoided through VPPs.</p>
<p><b>AMI-based measurement and verification</b></p>	<p><b>Cost for customers</b> No additional hardware is needed when AMI is already deployed for VPPs providing some grid services.</p> <p><b>Impact on future investment</b> If AMI exists already, or rollout is planned, additional cost of metering equipment would be avoided, thus lowering cost of VPPs and enabling broader participation in grid assuming the AMI had sufficient computing power and data access provisions.</p>	<p><b>Cost for customers</b> New AMI deployment typically costs several hundred dollars per customer. <sup>27</sup></p>
<p><b>Aggregated accuracy</b></p>	<p><b>Cost for customers</b> Enables use of lower cost meters, which may cost &lt; \$100, thus reducing barrier to entry if using metering and telemetry hardware built into DERs, so no additional investment required.</p> <p><b>Impact on future investment</b></p> <ul style="list-style-type: none"> <li>• Potential to lower cost of grid options and avoid infrastructure buildout by increasing VPP capacity.</li> <li>• Could enable participation for smaller DERs/VPPs in capacity markets, thus unlocking and democratizing VPP revenue streams.</li> </ul>	<p><b>Impact on future investment</b> Limited capabilities for fast response and distribution system grid services mean that utilities might need to invest in additional technology to manage and optimize DERs at the local level.</p>

<sup>iii</sup> Revenue-grade (ANSI C12) meters typically cost a few hundred dollars for standard commercial/industrial models (e.g., Leviton MO240-1SW at ~ \$500), while premium ANSI C12.20 0.1-class meters can exceed \$2,000 for hardware alone (e.g., SEL-735 at \$2400). Installation costs can be \$500 or more per meter.

# Affordability

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### Consideration

Does this option support low-cost operation of the grid?

### Component questions

- **Cost for customers:** Does this approach introduce costs to customers?
- **Impact on future investment:** How will this approach impact future capital investments and operating costs for the grid?

Option	Advantages	Disadvantages
<p><b>Sampling</b></p>	<p><b>Cost for customers</b> Significantly reduces number of ANSI-certified meters for an aggregation, slashing total meter costs by 80% to 90%+.</p> <p><b>Impact on future investment</b> Increased VPP participation due to lower cost metering approach will reduce need for grid infrastructure investment.</p>	<p>Limited capabilities for fast response and distribution system grid services mean that utilities might need to invest in additional technology to manage and optimize DERs at the local level.</p>
<p><b>Imputed performance</b></p>	<p><b>Cost for customers</b> No additional hardware needed beyond what is already built into the DER.</p> <p><b>Impact on future investment</b> Increased VPP participation due to lower cost metering approach will reduce need for grid infrastructure investment.</p>	<p>Limited capabilities for fast response and distribution system grid services mean that utilities might need to invest in additional technology to manage and optimize DERs at the local level.</p>

# Reliability

**Consideration**

Does this option support reliable operations of the grid?

**Component questions**

- **Accuracy:** Is data sufficiently accurate and granular?
- **Timeliness:** Is real-time communication sufficient to support delivery of grid services for the bulk system?
- **Speed of deployment:** To what extent can this solution be rapidly deployed to support near-term reliability challenges?

Option	Advantages	Disadvantages
<p><b>Revenue-grade metering (ANSI-certified meters)</b></p>	<p><b>Accuracy</b> Provides precise and accurate data (typically <math>\pm 0.5\%</math> or higher). Meter accuracy has been certified by third-party (ANSI).</p> <p><b>Timeliness</b> Provides real-time telemetry.</p> <p><b>Speed of deployment</b> Unlikely to require new rules at RTO/ISO.</p>	<p><b>Timeliness</b> Live communications could go down periodically, disrupting the flow of data</p> <p><b>Speed of deployment</b> Requires specific hardware and expert installation which may not be readily available.</p>
<p><b>AMI-based measurement and verification</b></p>	<p><b>Accuracy</b> Provides accurate and third-party certified data. In theory it is well-suited to provide location-specific data that can facilitate provision of distribution grid services.</p> <p><b>Timeliness</b> AMI 2.0 may enable local management of DERs without latency challenges</p> <p><b>Speed of deployment</b> AMI 1.0 is already widely deployed</p>	<p><b>Timeliness</b> If AMI lacks sufficient computing power and local communications bandwidth, it will communicate packets of data with significant latency/lag, preventing some real-time telemetry needed to support some grid services.</p> <p><b>Speed of deployment</b> New rollouts of AMI 2.0 are often complicated multi-year projects, and driven by the distribution utility.</p>
<p><b>Aggregated accuracy</b></p>	<p><b>Accuracy</b> Aggregation-level accuracy of <math>\pm 0.5\%</math> or tighter can be achieved.</p> <p><b>Speed of deployment</b> Non-revenue grade meters can usually be easily and quickly installed.</p>	<p><b>Accuracy</b> Not all meters have been verified for precision and accuracy.</p> <p><b>Timeliness</b> Wi-Fi enabled communication may be insufficiently reliable and secure for grid operational requirements.</p>

# Reliability

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### Consideration

Does this option support reliable operations of the grid?

### Component questions

- **Accuracy:** Is data sufficiently accurate and granular?
- **Timeliness:** Is real-time communication sufficient to support delivery of grid services for the bulk system?
- **Speed of deployment:** To what extent can this solution be rapidly deployed to support near-term reliability challenges?

Option	Advantages	Disadvantages
<p><b>Sampling</b></p>	<p><b>Accuracy</b> In theory, can achieve accuracy and granularity similar to revenue-grade metering.</p> <p><b>Timeliness</b> Sampled meters would provide low-latency data to support a range of grid services.</p> <p><b>Speed of deployment</b> Quicker to deploy compared to revenue-grade meter because requires less meter installations.</p>	<p><b>Accuracy</b> Individual meters are highly accurate (revenue-grade meters) but accuracy of the aggregation is a prediction that assumes performance of sampled devices is representative of all devices. May not provide sufficient location-specific data for provision of some grid services.</p>
<p><b>Imputed performance</b></p>	<p><b>Accuracy and timeliness</b> When compared to M&amp;V, using AMI data may allow for more accurate and timely information on performance of HVAC loads.</p> <p><b>Speed of deployment</b> Does not require installation of new metering or telemetry hardware.</p>	<p><b>Accuracy</b> Uses assumptions/heuristics to measure reduction rather than real measurement.</p>

# Fairness

## Consideration

Is this approach fair to participants and non-participants?

## Component question

- **Market participants:** Does this approach provide preferential (or discriminatory) treatment to any market participants?

Option	Advantages	Disadvantages
<b>Revenue-grade metering (ANSI-certified meters)</b>	No explicit preferential treatment. Consistent with market rules used by other market participants.	Potentially onerous and discriminatory toward DER aggregations and smaller-scale individual resources.
<b>AMI-based measurement and verification</b>	<p><b>Market participants:</b> Inclusive of all customers with AMI.</p> <ul style="list-style-type: none"> <li>• Inclusive of behavioral demand response.</li> <li>• Facility meter provides a neutral measurement of facility-level and in some cases individual DER performance, avoiding any potential gaming of device-level performance.</li> </ul>	AMI rollout may not be consistent across all utility service territories even within ISO regions, so utility service territories with AMI rollout may receive an advantage.
<b>Aggregated accuracy</b>	DER aggregation will achieve accuracy consistent with or higher than individual supply assets with revenue-grade meters.	Inconsistent with market rules used by other market participants.
<b>Sampling</b>	DER aggregation will achieve accuracy consistent with individual supply assets with revenue-grade meters.	Potential for sampled asset to not be representative of aggregation of assets.
<b>Imputed performance</b>	Enables participation of DERs which might be excluded by other methods.	Relies not only on measurement, but also on calculated assumptions.

# Future proofing

**Consideration**

How durable is this approach to changes in technology and policy?

**Component questions**

- **Future relevance:** Is this approach likely to become outdated in the future?
- **High DER penetration:** Will this approach work well at significantly higher levels of DERs?

Option	Advantages	Disadvantages
<b>Revenue-grade metering (ANSI-certified meters)</b>	<p><b>Future relevance</b> State-of-the-art granularity, accuracy and precision, and ubiquitous across ISOs today. Unlikely to become outdated.</p>	<p><b>High DER penetration</b> This approach is not scalable if revenue-grade meters are cost-prohibitive for the majority of DERs.</p>
<b>AMI-based measurement and verification</b>	<p><b>Future relevance</b> Utilities are making next-generation AMI investments that will be in place for 15–20 years and have varying abilities to support DER integration.</p> <p><b>High DER penetration</b> AMI 2.0 may have the potential to be used across a utility service territory to support DER monitoring, dispatch, and orchestration</p>	<p><b>Future relevance</b> AMI technology capabilities vary from one generation of investments to the next, and even among vendors within the same generation. This approach may not be consistently applicable, depending on AMI installations, upgrades, and interoperability of the utility’s investments.</p> <p><b>High DER penetration</b> AMI 1.0 promised to enable a range of capabilities to support grid-edge monitoring and orchestration, but it has not consistently led to those capabilities. There is a risk this might happen again for AMI 2.0.</p>
<b>Aggregated accuracy</b>	<p><b>High DER penetration</b> The statistical accuracy of this approach is strengthened if there are larger number of DERs in the aggregation.</p>	<p><b>Future relevance</b></p> <ul style="list-style-type: none"> <li>• Accuracy of cheap meters could improve.</li> <li>• May become unnecessary if more DERs come with built-in revenue-grade meters.</li> </ul>
<b>Sampling</b>	<p><b>High DER penetration</b> Supports increased participation of DERs in providing grid services. Reduces risk that unmanaged DERs can create grid challenges.</p>	<p><b>Future relevance</b> May become less necessary as more DERs come with in-built revenue-grade meters.</p>
<b>Imputed performance</b>	<p><b>High DER penetration</b> Supports increased participation of DERs in providing grid services. Reduces risk that unmanaged DERs can create grid challenges.</p>	<p><b>Future relevance</b> May become outdated if more DERs, including HVAC equipment, come with built-in revenue-grade meters</p>

SECTION VI

**What actions should grid operators and regulators consider to address challenges related to metering and telemetry of VPPs?**

# Metering and telemetry considerations and recommendations for grid operators and regulators

Grid operators and regulators should consider the following nine actions as they develop and implement updated approaches.

<b>Measurement and Verification</b>	<b>Grid Services and Technical Requirements</b>	<b>Customer Meters and Data</b>	<b>Coordination</b>
<ul style="list-style-type: none"> <li>1) Allow for calculated approaches to enable broader participation of DERs.</li> <li>2) Update baseline methodologies to increase accuracy and validity of calculated approaches.</li> <li>3) Allow metering at dispatch level instead of DER level for bulk/wholesale grid services, to reduce costs and administrative burden.</li> </ul>	<ul style="list-style-type: none"> <li>4) Clarify and align on technical metering and telemetry requirements needed to provide specific grid services to enable performance-based as opposed to technology-based requirements.</li> <li>5) Avoid onerous data reporting and registration requirements to reduce barriers to entry.</li> </ul>	<ul style="list-style-type: none"> <li>6) Improve customer and third-party access to customer-meter data to enable AMI-based measurement and verification.</li> <li>7) Consider DER integration capabilities as part of future AMI procurement and deployment to future-proof AMI investments.</li> </ul>	<ul style="list-style-type: none"> <li>8) Coordinate across jurisdictions in a region, including between RTOs, regulated utilities, and other load serving entities to support interoperability and decrease integration costs.</li> <li>9) Support interoperability between LSE, RTO, and third-party DER management platforms to maximize VPP benefits and manage costs.</li> </ul>



## Recommendations related to measurement and verification

**1**

### Allow for approaches that into enable broader participation of DERs

- Decision makers should be open to approaches that involve some form of calculation as opposed to direct measurement only.
- Calculated approaches include sampling, imputed performance, and measurement and verification using AMI data.
- Aggregated accuracy involves direct measurements, but the overall accuracy is calculated.
- Calculated approaches can support fair and reliable grid operation without placing a high cost burden on small DERs.

#### Examples:

- California's DSGS Option 4 allows for estimated load impacts using smart thermostat data (imputed performance).
- Sampling: Allowed in CAISO, NYISO, MISO, SPP, and PJM.

#### Non-examples, or policies to be avoided:

- Requirements for individual DERs that are identical to requirements for large-scale generators for bulk-scale grid services provided at the ISO/RTO level.
  - For example, a +/- 0.2% accuracy requirement on a 1 kW DR load corresponds to a maximum error band of just 20 watts.

**2**

### Update baseline methodologies to increase accuracy and validity of calculated approaches

- VPP performance and compensation is a function of the baseline, or expected demand if not for the VPP dispatch.
  - For example, to determine whether a VPP comprised of smart thermostats reduced demand in response to a grid signal, one needs to have an assumption of what demand would have been if not for VPP dispatch.
- Common 5-in-10 baseline methodology approaches are based on an assumption that the VPP will be dispatched infrequently.
  - These approaches may work well for large C&I loads that dispatch infrequently, but frequently dispatching DERs will impact the baseline.
- Updated approaches include using control groups and prescriptive baselines.<sup>28</sup>

#### Examples:

- California's DSGS program allows for use of prescriptive baselines.<sup>29</sup>

#### Non-examples, or policies to be avoided:

- Using 5-in-10 baselining approaches for all VPPs.

**3**

### Allow performance assessment at dispatch level instead of DER level to reduce costs and administrative burden for wholesale/bulk market grid services

- DERs within VPPs are typically dispatched in aggregations as opposed to as individual assets.
  - Possible exceptions include dispatch to address local constraints and dispatch of large DERs.
- Therefore, it follows that performance can be measured at the level at which dispatch occurs (the aggregation) as opposed to the individual asset.
- This approach is already adopted by some RTOs, such as NYISO and PJM, where performance is measured at the aggregator level.
- Many programs assess performance at the aggregation level and allow aggregators to distribute benefits to households and businesses participating in the VPP.
- The logic of dispatch-level assessment supports the logic of aggregated accuracy and sampling approaches, which may not as precisely measure individual asset performance, but provide a reliable assessment of the aggregators' performance.

#### Example:

- RTOs like NYISO and PJM allow performance assessment at dispatch-level.
  - NYISO DER Participation Model<sup>30</sup>
  - PJM DER Aggregator Participation Model<sup>31</sup>

## Grid services and technical requirements

**4**

### Clarify technical metering and telemetry requirements needed to provide specific grid services to allow for performance-based requirements

- Not all grid services require sub-second or sub-hour telemetry.
- Grid operators should clarify target grid services and the data requirements to enable delivery of those services.
- Elements to clarify include the temporal granularity, latency, and precision of data needed.
- One possible area of focus could be on defining metering and telemetry requirements necessary for VPPs to reliably provide distribution-grid services.
- This will allow grid operators and regulators to develop appropriate requirements to meet specific grid needs.

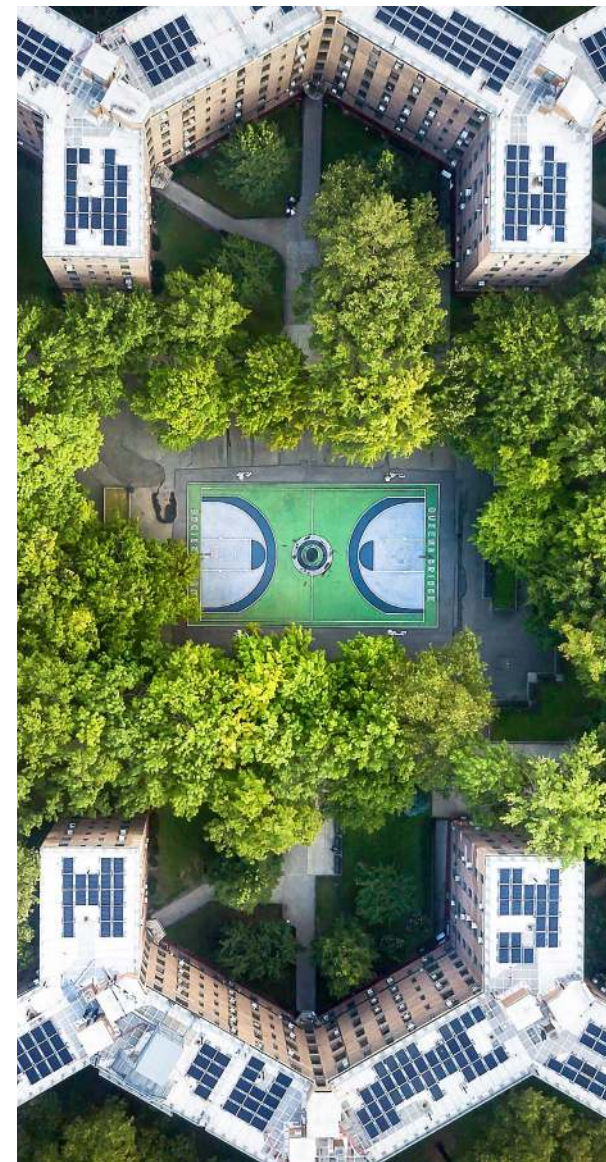
#### Example:

- MISO Demand Response Type 1 assets do not stream telemetry to the market during ancillary service events. Instead, they submit 5-minute data within 5 days of each dispatch.

**5**

### Avoid onerous data reporting and registration requirements

- In some instances, grid operators or utilities require significant data reporting, including data that seems to be extraneous.
  - Some jurisdictions use non-standard baselining approaches that require significant data reporting.
  - In other instances, significant data is required to register a DER or a VPP, even when that data seems to be irrelevant to the grid service or DER.



## Customer meters and data

**6**

### Improve access to customer meter data to enable AMI-based measurement and verification

- AMI-based measurement and verification is one of the options discussed in this brief.
- While AMI data provides a reliable and standardized source of data to support many metering and telemetry requirements, AMI data has been notoriously hard to access for third-party aggregators.
- Even when data access is efficiently allowed, effective access is often plagued by downed services, slow communications, and other issues.

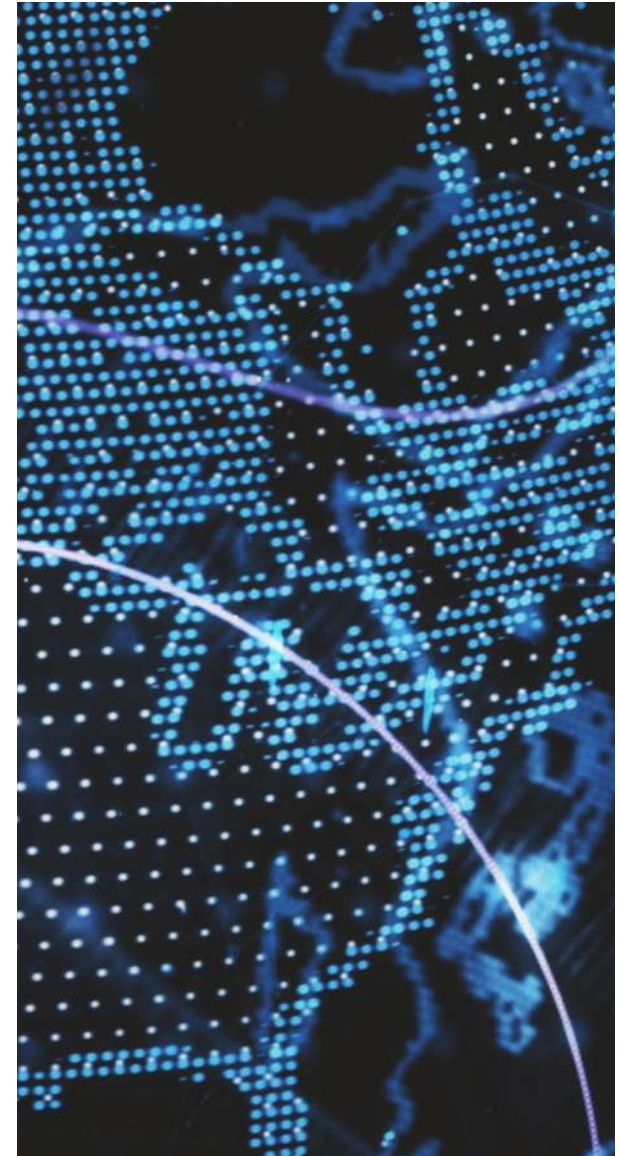
#### Example:

- Smart Meter Texas facilitates easy access of customer meter data to its selected retail electricity provider.<sup>32</sup>

**7**

### Consider DER integration capabilities as part of future AMI procurement and deployment to future-proof AMI investments

- Many AMI that was deployed 15–20 years ago isproaching the end of its useful life.
- New customer meters are being equipped with more powerful computing and intelligence to support a variety of grid-edge functions.
- Regulators should ensure any future AMI investments support DER integration.



## Coordination

**8**

**Coordinate across jurisdictions in a region, including between RTOs, regulated utilities, and other load-serving entities to support interoperability and decrease integration costs**

- Coordination is critical to ensuring harmonized requirements and allowing VPP markets to achieve scale.
- In its report on VPPs in Wholesale Markets, LBNL points out three coordination activities which utilities can lead:
  - 1) Establish stakeholder engagement processes: investigatory dockets, working groups
  - 2) Inter-state regional coordination
  - 3) Coordination with wholesale market operators
- Coordination can ensure assessment approaches and component equipment across jurisdictions.

**Example:**

- In 2024, Pennsylvania's PUC initiated an Advance Notice of Proposed Rulemaking Order to implement FERC Order 2222.<sup>33</sup>

**9**

**Support interoperability between LSE, RTO, and third-party DER management platforms to maximize VPP benefits and manage costs**

- One aspect of coordination is interoperability between the systems used to manage VPP-related data.
- This includes consolidating platforms used for individual devices (e.g., thermostat, electric vehicle, building management systems).<sup>34</sup>
- Interoperability is supported by aligning data communications protocols, for example by full alignment around IEEE 2030.5 or other data-sharing standards.



# Appendix

## Statistics supporting aggregated accuracy

The following section was provided by Voltus Energy.

Assume:

- $x_1, x_2, \dots, x_n$  are the true values of electricity flow at  $n$  measurement assets that are statistically similar.
- $\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n$  are the random errors associated with each measurement. These errors are assumed to be independent, identically distributed (i.i.d.), and symmetrically distributed about zero.

The values reported by each metering device are therefore:

$$\hat{x}_i = x_i + \varepsilon_i \text{ for } i = 1, \dots, n$$

The total true value is:

$$S = \sum_{i=1}^n x_i$$

while the total observed value is:

$$\hat{S} = \sum_{i=1}^n \hat{x}_i = \sum_{i=1}^n x_i + \sum_{i=1}^n \varepsilon_i$$

The total error of the summed measurement is:

$$\Delta S = S - \hat{S} = \sum_{i=1}^n \varepsilon_i$$

Given each measured assets are statistically similar, errors  $\varepsilon_i$  have an approximate variance of  $\sigma^2$  and are i.i.d., allowing the following simplification for summing the variances:

$$\text{Var}(\Delta S) = \text{Var}(\sum_{i=1}^n \varepsilon_i) = n\sigma^2$$

The standard deviation of the total error represents the upper bound covering one standard deviation of error when  $\text{mean}(\varepsilon)$  is 0 and is:

$$\text{Std}(\Delta S) = \sqrt{(n\sigma^2)} = \sqrt{n}\sigma$$

The absolute percent error (APE) for the summed measurements is then:

$$\text{APE} = \frac{|\Delta S|}{S} \cdot 100\% = \frac{\sqrt{n}\sigma}{S} \cdot 100\%$$

As the number of measurements  $n$  increases, the true value of the sum,  $S$ , is estimated by:

$$S \approx n \cdot \text{mean}(x_i)$$

If  $S$  grows linearly with  $n$  while  $|\Delta S|$  grows proportionally to the  $\sqrt{n}$ , then the  $\text{APE}$  as defined above will grow smaller as  $n$  grows larger. Specifically,  $\text{APE}$  will decrease by a factor of  $\frac{1}{\sqrt{n}}$

Sixty-eight percent of errors fall within a single standard deviation for a normally distributed set of errors (i.e., a 68% confidence interval). This is an unacceptably poor confidence for metering accuracy; a more commonly accepted confidence interval is 95%, which corresponds to a z-score of 1.96 as  $\Delta S$  is normally distributed. The desired confidence interval can be applied to the  $\text{APE}$  calculation as shown in the example below:

$$\text{APE}_{95\%} = \frac{1.96 \cdot \sigma_{\Delta S}}{S} \cdot 100\% = \frac{1.96 \cdot \sqrt{n}\sigma}{S} \cdot 100\%$$

This result demonstrates that as the number of meters increases, the relative error of the summed loads decreases proportionally to the inverse square root of that number. Said practically, as long as all sites have similar loads, the **percentage error of meter data decreases as aggregations increase in site count.**

The table below demonstrates the relationship between relative and absolute error for a number of sites whose energy use is approximately 1 kWh using a meter with a  $\sigma$  of  $\pm 0.0102$  kWh at this mean load.

For example, the expected  $APE_{95\%}$  for 10 sites is:

$$APE_{95\%} = \frac{1.96 \cdot \sqrt{n}\sigma}{s} \cdot 100\% = \frac{1.96 \cdot \sqrt{10} \cdot 0.0102}{10 \cdot 1} \cdot 100\% = 0.632\%$$

Number of sites	Expected absolute error in sum of energy (kWh, 95% confidence)	Relative Error ( $\pm$ %)
1	0.02	2.000%
10	0.063	0.632%
100	0.2	0.200%
1,000	0.632	0.063%
10,000	2	0.020%
50,000	4.472	0.009%
100,000	6.324	0.006%
500,000	14.142	0.003%
1,000,000	20	0.002%

As shown, market operators can have a high degree of confidence that aggregated meter data from even relatively small aggregations of 100 or more sites is more accurate than is required for even large, conventional generators.<sup>iv</sup>

<sup>iv</sup>The most stringent meter accuracy requirements are found in SPP and IESO, which require ANSI Class 0.2 hardware, or  $\pm 0.2\%$  accuracy. Other markets typically require Class 0.5 hardware, or  $\pm 0.5\%$  accuracy.

# Footnotes

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