

Key Performance Indicators for Vehicle Grid Integration



JUNE 2025



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This report was prepared for the U.S. Department of Energy under DOE Idaho Operations Office Contract No: AC07-05ID14517, U.S. Department of Energy M&O Contract No: DE-AC36-08GO28308, and U.S. Department of Energy Office of Science Laboratory Contract No: DE-AC02-06CH11357. Funding was provided by the Joint Office of Energy and Transportation

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Acknowledgments

The National Charging Experience Consortium (ChargeX Consortium) is a collaborative effort between Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, electric vehicle charging industry experts, consumer advocates, and other stakeholders. This document was produced by the ChargeX Consortium's Vehicle Grid Integration Working Group.

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Revision Log

Version	Description	Author
V 1.0	First release for internal ChargeX team input	All authors and contributors
V 1.1	Final formatting edits	S. Glass

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List of Abbreviations

Abbreviation	Description
CSMS	Charging station management system
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
KPI	Key performance indicator
OEM	Original equipment manufacturer
SCM	Smart charge management
SOC	State of charge
VGI	Vehicle grid integration

1. Introduction

Electric vehicle (EV) sales account for a rapidly growing portion of the light-duty vehicle market and a portion of medium and heavy-duty fleet vehicles. The charging station network to support those vehicles is growing as well. However, in many locations, charging stations will require costly utility grid upgrades with long lead times. Also, growing charging demand for electricity has the potential to negatively impact the electric grid. To prevent these adverse impacts, it is crucial for the EV charging industry to seamlessly integrate EV charging with the grid. The industry is in the early stages of this process, known as vehicle grid integration (VGI). Today, there are a few methods of smart charge management (SCM), which can reduce the costs and wait times for electric vehicle supply equipment (EVSE) interconnection approvals, as well as reduce the impacts of the charging stations on the grid and potentially lower costs for EV drivers and ratepayers alike.

1.1 Measurement is Required for Improvement

To make systematic improvements, EV charging industry and utility industry stakeholders need to define and measure VGI impacts. Many stakeholders currently measure specific aspects or individual connections that facilitate VGI, but they typically do not examine end-to-end connectivity or use overarching customer-facing metrics, such as EVSE uptime, which make targeted improvement difficult. High charging station and communications reliability is required for successful VGI projects, especially with regards to enabling SCM. Industry practitioners need granular metrics to know the performance of specific connections and interfaces and what data are needed to evaluate those metrics. This report defines such metrics, and they are referred to as key performance indicators (KPIs).

2. Purpose of this Report

This report provides the EV charging industry with clearly defined KPIs that can measure key aspects of VGI, with a focus on enabling SCM. SCM supports VGI by avoiding charging during periods of peak demand, providing basic grid services, allowing smoother and faster interconnection of charging stations, and reducing installation and operating costs. This effort is envisioned to initiate the foundation for standardizing these metrics across the industry.

2.1 Intended Audience

The intended audience for this report is industry stakeholders, including utilities, EV and EVSE original equipment manufacturers (OEMs), and charging station management system (CSMS) providers. This report does not provide policy recommendations. The intent of the report is to mature both individual industry stakeholders' capabilities and the industry's collective capability to improve VGI by establishing uniform methods for measurement.

3. Key Performance Indicators

The KPIs described in this report are intended to capture the performance of each element of potential VGI programs, including technology-to-technology interfaces, communications protocols, and customer impacts. These KPIs are organized into five categories (Reliability; Responsiveness; Participation; Energy; Interoperability) and three groupings (Integrity; Availability; Durability).

The Reliability KPIs (Table 1) focus on charging and communications hardware uptime, reliability of SCM services, and success of SCM services. The Responsiveness KPIs (Table 2) focus on the communication speed and response times for SCM programs to react to control signals either from a utility or a different entity managing charging. Participation KPIs (Table 3) focus on tracking customer participation and how participation impacts SCM programs and load profiles. Energy KPIs (Table 4) relate to efficiency, meter accuracy, and resolution of managed charging. Interoperability KPIs (Table 5) focus on the interfaces between the different stakeholders and how the various communication pathways impact SCM programs. In addition to these categories, the three groupings identify which metrics impact the integrity (i.e., how robust the system is), the availability (i.e., whether the system is online and ready, when needed), and the durability (the capability of the system to scale and resist perturbations over time) of VGI and SCM programs.

Some KPIs are easier to measure than others. Early on in a performance improvement plan, easy-to-measure KPIs may be sufficient to realize program improvement. However, increasing SCM adoption levels may require increased program reliability, which in turn will require additional KPIs that are more difficult to measure.

The tables include each recommended KPI, the stakeholders who would be most concerned with the KPI, who would be best suited to record the metric, units to record the KPI in, and a description.

Table 1. Reliability KPIs

Grouping	KPI Name	Stakeholder	Units	Description
Availability	Uptime of SCM Service	EVSE OEM / Utility	%	Percentage of time a resource is available to utility. This is the portion of operational time in which the EVSE can respond to a direct control signal. This encompasses the direct response compliance rate and data exchange success rate. Latency, communication standards compliance, and message parsing errors are covered by other KPIs.
Availability	Event Response Reliability	Utility	%	Percentage of event signals executed successfully (i.e., control signals executed as intended). This is different from opt-out rates because it encompasses communications and controls failures.

Grouping	KPI Name	Stakeholder	Units	Description
Integrity	Energy Delivery Reliability	Reliability Customer	kWh	Cumulative energy deficit (i.e., EV battery charging energy shortfall per period). Observed at the end of the dwell period when the driver expects to be able to depart and experienced by the EV owner over an interval of time. A cumulative score ensures both the case in which one session came up short by a large amount of energy (e.g., 100 kWh), which is one very bad incident, and cases in which many sessions came up short by a small amount of energy (many smaller incidents) are incorporated.
Availability	SCM Session Start Success	Utility / EV OEM / EVSE OEM	%	Percent of the time that the SCM command initializes control successfully. This does not come with a time limit, so any timeout would be considered unsuccessful.
Integrity	SCM Session End Success	EV Owner / Utility / EV OEM	%	Percent of the time that the SCM session ends successfully with power regulation returning to normal operations by releasing control back to the local EVSE or CSMS.

Table 2. Responsiveness KPIs.

Grouping	KPI Name	Stakeholder	Units	Description
Integrity	Data Exchange Latency	Utility / EV OEM / EVSE OEM	Seconds	Average time taken for a message to travel between systems (i.e., Acknowledgment Round-Trip Time). This is measured for each link between the controller and EV.
Availability	Full Activation Time	Utility / EV OEM / EVSE OEM	Seconds	Time from command sent by the controller to EVSE or EV to the time that the reported measurement of load change received by the controller reflects final managed power value.
Integrity	Response Time	Utility / EV OEM / EVSE OEM	Seconds	Time from command received by EVSE or EV to time when power is at managed value.
Integrity	Ramp Time	Utility / EV OEM / EVSE OEM	Seconds	Time taken by EVSE or EV to ramp from unmanaged power to managed power value.
Integrity	SCM Session End Success	Utility	Seconds	Time taken by EVSE or EV to ramp from unmanaged power to managed power value.
Integrity	Fault/Timeout Error Report Latency	Utility	Seconds	Time elapsed before an EV or EVSE reports an error to the controller if managed charging command is not executed.
Integrity	Closed-loop Time	Utility	Seconds	Measures the end-to-end latency in a utility demand-side management program that includes EVs, microgrid controllers, and

Grouping	KPI Name	Stakeholder	Units	Description
	Constant for Load Control			other distributed energy resources. Defines the dynamic time constant used to coordinate with breakers, generators, and other traditional load management assets.

Table 3. Participation KPIs.

Grouping	KPI Name	Stakeholder	Units	Description
Availability	SCM Vehicle Availability	Utility / EV OEM / EVSE OEM	%	The percentage of the plugged-in time that the EV is available for SCM. This metric helps capture the fraction of time that an EV is plugged in and has capacity to provide SCM services.
Availability	Charge Time Flexibility	Customer / Utility	Seconds	The amount of time that a charge could have been delayed while still meeting energy needs. Calculated at the end of the dwell time to avoid introducing errors from departure time forecasting.
Integrity	Incentive Responsiveness	Customer	kWh/\$	Quantifies the change in schedule in response to an incentive. Defined here as the sum of hourly deviations from unmanaged kWh delivered over the entire charge session, divided by a notional dollar value. This value could be delivered to the customer as a variety of incentives. Change in tolerated energy deviation per change in incentive (e.g., example: $\sum_{hr} [\Delta kWh]/\$$).
Durability	Peak Load Reduction	Utility	kW	The peak energy reduced per participant. Measures the demand-side outcome per customer to quantify how much an enrolled customer (on average) reduces their contribution to system peak demand thanks to SCM. Depending on the SCM target, this could be the site peak, transformer peak, feeder peak, system peak, etc. The time resolution of the peak reduction measurement is also dependent on the SCM objective and ranges in duration.
Durability	SCM Session Count	Utility	Seconds	Total number of managed charge events per time period.
Durability	Charging Session Count	Customer / Utility	#	Total number of charging sessions the customer performed per time period, including both managed and unmanaged.

Table 4. Energy KPIs

Grouping	KPI Name	Stakeholder	Units	Description
Availability	Charge Session Energy	Customer/ Utility	kWh	The energy delivered at each charge session to determine how people change charging habits based on tariffs and messaging.
Durability	SCM Charge	Customer	%	Percentage of energy EV battery gained divided by the total energy delivered from EVSE. Captures any losses from charging inefficiencies at different charge levels or pre-conditioning needs.
Integrity	Integral Meter Accuracy	EVSE OEM / EV OEM	kW or kWh	Cumulative or average deviation of power or energy delivered. Describes how closely the EVSE tracks power or energy and can be compared to the revenue meter accuracy. Even if the EVSE meter accuracy is better than the revenue meter, the discrepancy can impact actions taken.
Integrity	Resolution of EVSE Response to Direct Control Signal	Utility / EVSE OEM	kW (or A)	Describes the resolution of the EVSE response to a control signal. Some EVSE can only receive commands down to integer values, but others have higher resolution.

Table 5. Interoperability KPIs.

Grouping	KPI Name	Stakeholder	Units	Description
Integrity	Data Exchange Success	All	%	The percentage of successful data exchanges for all links in a managed charging system. Recorded for each link (includes timeout retries, session resets, failed initializations, authentication failures).
Integrity	Schema Compliance Rate	All	%	Percentage of data exchanges that follow the defined data schema or format.
Integrity	Parsing Errors	All	#	The number of errors encountered in a managed charging session when interpreting data purported to be in a specific schema. Primarily an issue with using a library to parse and encode. Relevant to reliably processing incoming signals from external systems (e.g., OpenADR or hourly rate tables that have corrupted fields).
Integrity	Authentication / Authorization Success Rate	All	%	The percentage of successful authentications/authorizations (secure connections) established between

Grouping	KPI Name	Stakeholder	Units	Description
				systems (e.g., issues with expired credentials, transport layer security session start issues, application programming interface registration, token expiration).
Integrity	Data Mapping Accuracy	Utility	%	Measures the percentage of data fields that map from one system map to another to measure consistency in meaning. This is related to protocols specifically.
Integrity	Ontology Alignment Accuracy	Utility	%	Measures the percentage to which different data models or vocabularies are aligned across systems.
Integrity	Data Consistency Rate	Utility	%	Percentage of data exchanges in which the meaning remains consistent across systems. This quantifies data type or unit transformation errors. This is related to internal logic, representing data from one side to another.
Availability	System Downtime Due to Integration Issues	Utility	%	Tracks whether the time systems are nonfunctional due to interoperability problems. No errors from each side, but the communications broke down somewhere.
Availability	Error Resolution Time	EV OEM	Seconds	Measures the time taken to detect and fix interoperability-related issues. Helps determine buy vs. build decisions for software libraries and feature upgrades.

3.1 Improving Metrics

Different metrics have different associated strategies for improvement depending on the stakeholders and technology components involved. These improvement strategies typically align with the category the metric falls into.

To improve VGI and SCM reliability, industry stakeholders should focus on infrastructure quality and connectivity. This includes using reliable communication protocols and networks. Some utilities and charging network providers have moved from Wi-Fi to cellular or multinet network approaches to reduce dropouts. They also set up monitoring and alerts so that if a managed session fails or a charger goes offline, the utility is notified of the loss of asset control. The best practice for monitoring is to implement dashboards that show the utility and/or site owner real-time and aggregate performance at each site. Regular audits or reports can verify the data integrity. Firmware updates and interoperability testing (i.e., making sure different EV models and charger brands work with the managed charging system) are part of maintaining high

reliability. On the customer side, educating users to trust the system and providing a clear opt-out or override can help maintain smooth operations, prevent unnecessary overrides, and avoid undesirable hard resets. Ensuring transportation energy needs are met is critical for SCM implementation and customer trust. Good communication of energy needs and clear communication on what customers should expect and how to opt-out of management sessions will improve reliable delivery of energy.

Metrics in the Responsiveness and Interoperability categories can be improved with end-to-end testing and standardization. As standards take hold and end-to-end testing improves, the frequency of issues should drop. Project teams and network operators should log all incidents in which the equipment did not interoperate properly, then they should categorize them (e.g., communication error, protocol mismatch) and calculate these metrics. Industry best practice will use conformance test tools, industry test events (e.g. “Plugfests” and “Testivals”), and/or third-party testing laboratories, to quickly validate new components. Industry can accelerate improvement by establishing a central registry or scorecard, possibly maintained by a standards alliance or national lab, that publishes progress (e.g., which protocols each program uses, how many devices are certified). Utilities and program administrators should also require standards compliance in procurements.

Metrics in the Participation category could be improved with clear messaging, outreach, increased customer trust, and incentives. Marketing around consistent participation, incentivizing EV drivers to plug in a vehicle when it is stationary, or incentivizing managed sessions would increase the likelihood that users plug their vehicles in and thus allow charging to be managed. This may also require some messaging to abate range anxiety and prevent EV drivers from always charging their vehicles to a high state of charge (SOC) when it is not needed. Customer trust can be built with opt-out options or guarantees that energy needs will be met. Some programs guarantee that the car will reach the desired charge by the driver’s departure time, which increases the customer’s willingness to participate. Incentives and rewards are common (e.g., paying bill credit or earning a cash reward for each demand response event a customer honors). Larger savings from minimal charging habit changes are desirable from the customer’s perspective. Increased automation can also improve customer perspective and participation so INL/RPT-25-85695 9 Revision: 0 customers do not need to remember to complete tasks. If customers do not notice the change in their transportation needs being met, then they will be more likely to accept different charging patterns. Maintaining high satisfaction is also linked to following standards; for instance, smooth end-to-end integration can prevent charging disruptions, thereby keeping customers happy. Utilities should monitor enrollment counts in cohorts and use surveys from those who drop out to reveal reasons why there may be trouble with retention.

Energy metrics can mostly be improved by manufacturers. Accurate reporting of EVSE efficiency, meter accuracy, precision, and response resolution will enable comparisons between implementations and improvement. Software and communications implementations can also improve these metrics by enabling better tracking with float values instead of integers.

There are many ways to improve VGI performance. Improvements in each metric should be logged to determine which strategies are the most successful and yield the highest benefit for the cost involved.

4. Next Steps

This document details a list of KPIs for VGI programs when evaluated at the EV or EVSE level for individuals rather than in aggregate. The next logical steps that the industry should do to establish these KPIs are as follows:

- Select a key set of the KPIs recommended in this document for implementation.
- Identify the necessary data to calculate the key set of KPIs.
- Develop detailed instructions on how to implement the key set of KPIs.
- Implement the key set of KPIs.
- Work with a standards development organization to codify the KPIs in a formal standard.



About the ChargeX Consortium

The National Charging Experience Consortium (ChargeX Consortium) is a collaborative effort between Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, electric vehicle charging industry experts, consumer advocates, and other stakeholders. The ChargeX Consortium's mission is to work together to measure and significantly improve public charging reliability and usability by June 2025.

For more information, visit chargex.inl.gov.

JUNE 2025

