

Optimizing EV Charging Uptime:
A Framework for Fault Detection and
Diagnostics, Performance Monitoring,
and O&M Workflows



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Introduction

Unreliable electric vehicle supply equipment (EVSE) remains one of the biggest obstacles to widespread confidence in electric vehicles (EVs). EVSE that are broken, difficult to start charging, or delivering less power than expected frustrate drivers and create operational headaches.

These challenges have driven efforts like the ChargeX Consortium — a collaboration among U.S. national laboratories, EV charging industry experts, and consumer advocates — to define industry-standard Key Performance Indicators (KPIs) for EV charging. Making those KPIs actionable in the field requires answering questions like: When did charge attempts fail or charge sessions end prematurely? What caused them? How and when is the equipment considered down? What actions should be taken to optimize EV charging uptime? These are the questions that Operations and Maintenance (O&M) teams face every day.

This paper introduces a vendor-neutral framework for optimizing EV charging uptime and other industry KPIs. It defines a hierarchy of events and derived KPIs — which can be extended or adapted — and shows how they support diagnostics and O&M workflows. Concepts are illustrated using SkyFoundry's SkySpark®, an analytics platform proven in nearly two billion square feet across all types of facilities in the built environment.

Event Detection

Measuring charging performance and detecting failures requires a shared vocabulary for what's happening in the field. A driver plugs in — does charging start? Does it finish? Were the vehicle's charging needs met? Each of these outcomes is an event — detectable from the streams of operational data that EVSE continuously report, including plug state, power levels, state of charge, and energy.

The events build on one another: a *Charge Session* is a *Charge Attempt* that delivered energy above a minimum threshold, and a *Charge End Failed* is a *Charge Session* in which the vehicle's charging needs were not met. This hierarchy matters because each failure calls for a distinct response. Repeated *Charge Start Failed* events call for a different repair than *Charge End Failed* events.

Grouping events this way gives O&M teams a consistent framework for spotting patterns and guiding root-cause investigations.

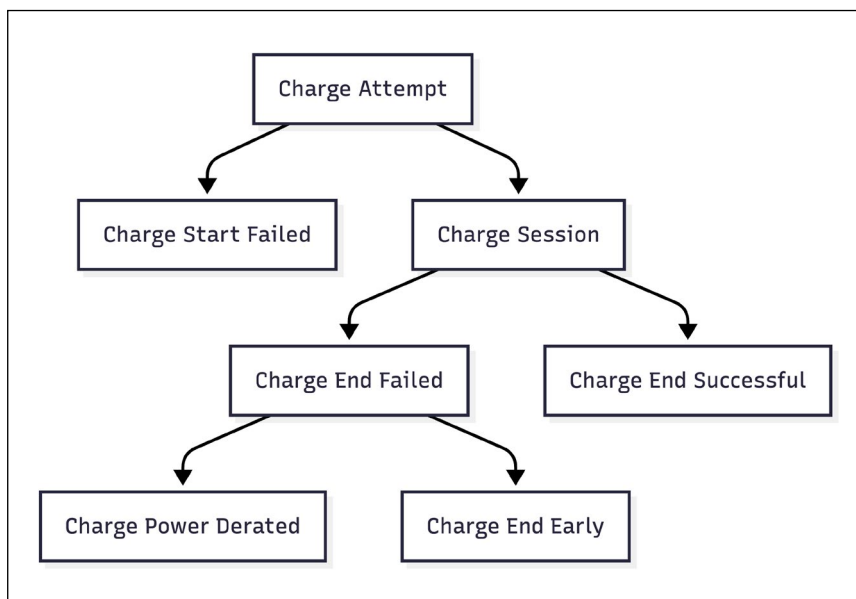


Figure 1: Charge Attempt Event Hierarchy

Measuring Energy Delivery

The events defined in this section rely on data from the EVSE port's energy register. An energy register stores a running total of cumulative energy delivered. Energy delivered for a period can be determined by subtracting the value at the start timestamp from the value at the stop timestamp.

For example, if the register reads 150 kWh at the first sample within a *Charge Session* (defined later in this paper) and 162 kWh at the last, 12 kWh was delivered.

Charge Attempt

A *Charge Attempt* begins when the charging cable plugs into the vehicle's inlet and ends when it is removed.

Charge Start Failed

A *Charge Start Failed* is a *Charge Attempt* in which the EVSE port delivers less than an operator-configured energy threshold to the vehicle.

Note: For Level 3 DC EVSE, a common fault pattern is for less than 0.5 kWh to be delivered before charging stops.

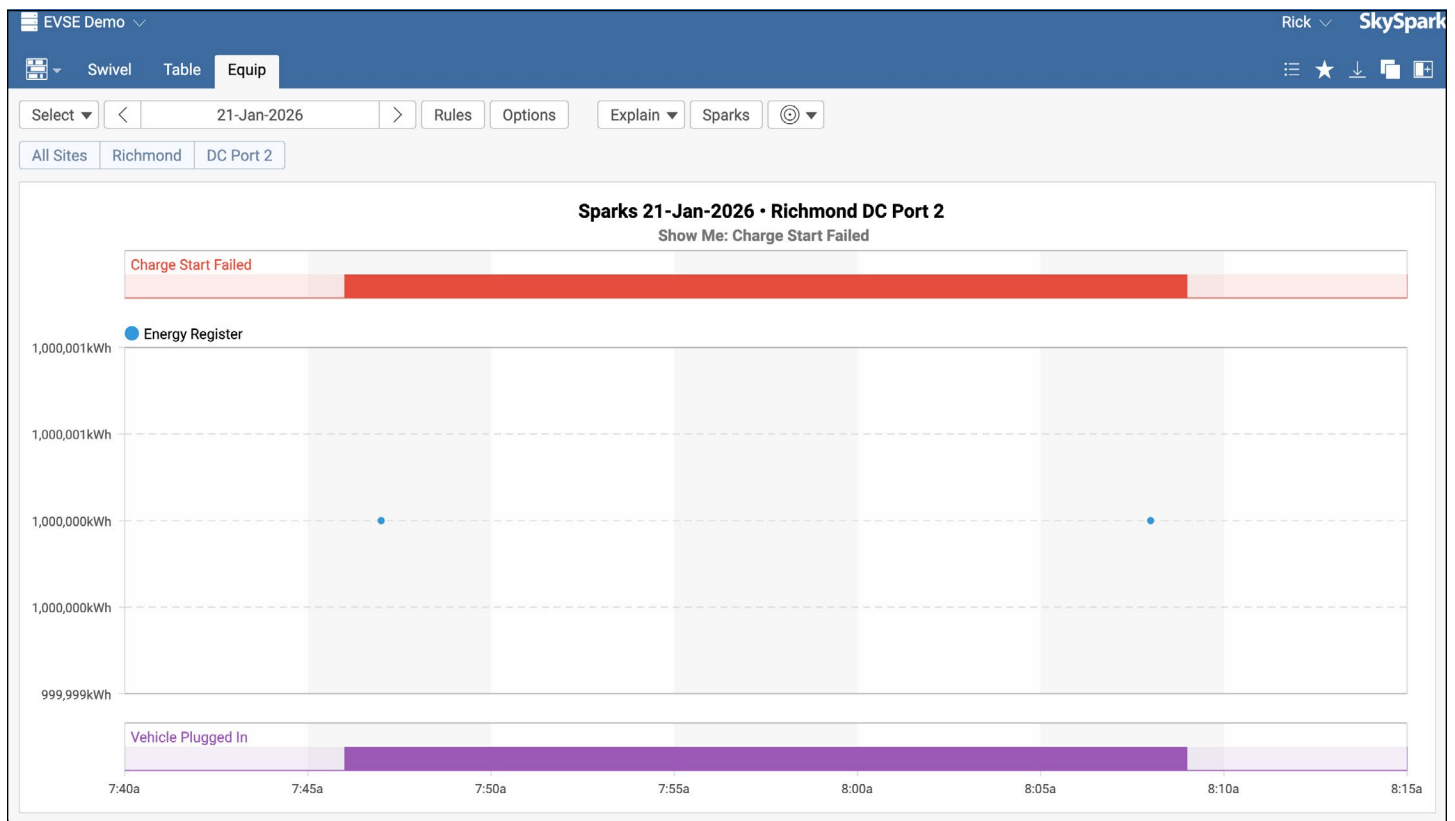


Figure 2: A Charge Start Failed in SkySpark

Charge Session

A *Charge Session* is a *Charge Attempt* during which more than an operator-configured energy threshold (e.g., 0.5 kWh) is delivered to the vehicle.

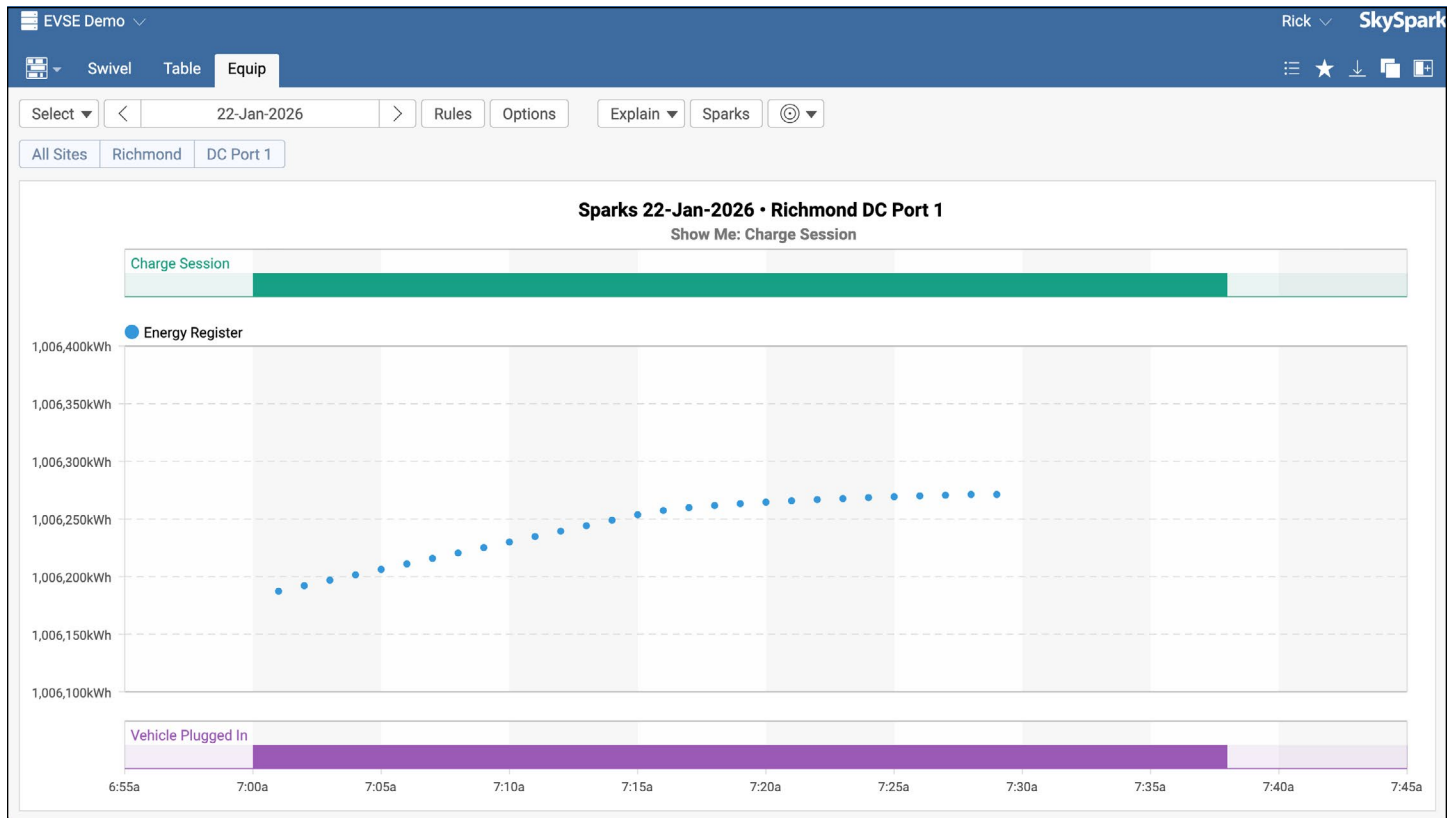


Figure 3: A Charge Session in SkySpark

Charge End Failed

Once a *Charge Session* begins, it may not complete successfully. Power modules or a cooling system in a Level 3 DC EVSE may fail, causing the charger to deliver less energy to the vehicle than expected or stop charging entirely. A load management system may cause a Level 2 AC EVSE to stop charging before the vehicle reaches the desired state of charge. The vehicle may also cause charging to stop early.

A *Charge End Failed* is a *Charge Session* in which the vehicle's charging needs were not met.

Regardless of whether the EVSE or the vehicle is responsible, a *Charge End Failed* can negatively impact operations, resulting in lost revenue from undelivered energy or a missed opportunity to charge another vehicle.

Charge Power Derated

A *Charge Power Derated* is a *Charge End Failed* in which the average charging power falls below an operator-configured percentage of the average negotiated limit (e.g., 90%). The negotiated limit at each sample is the lesser of the power requested by the vehicle and the maximum power offered by the EVSE port.

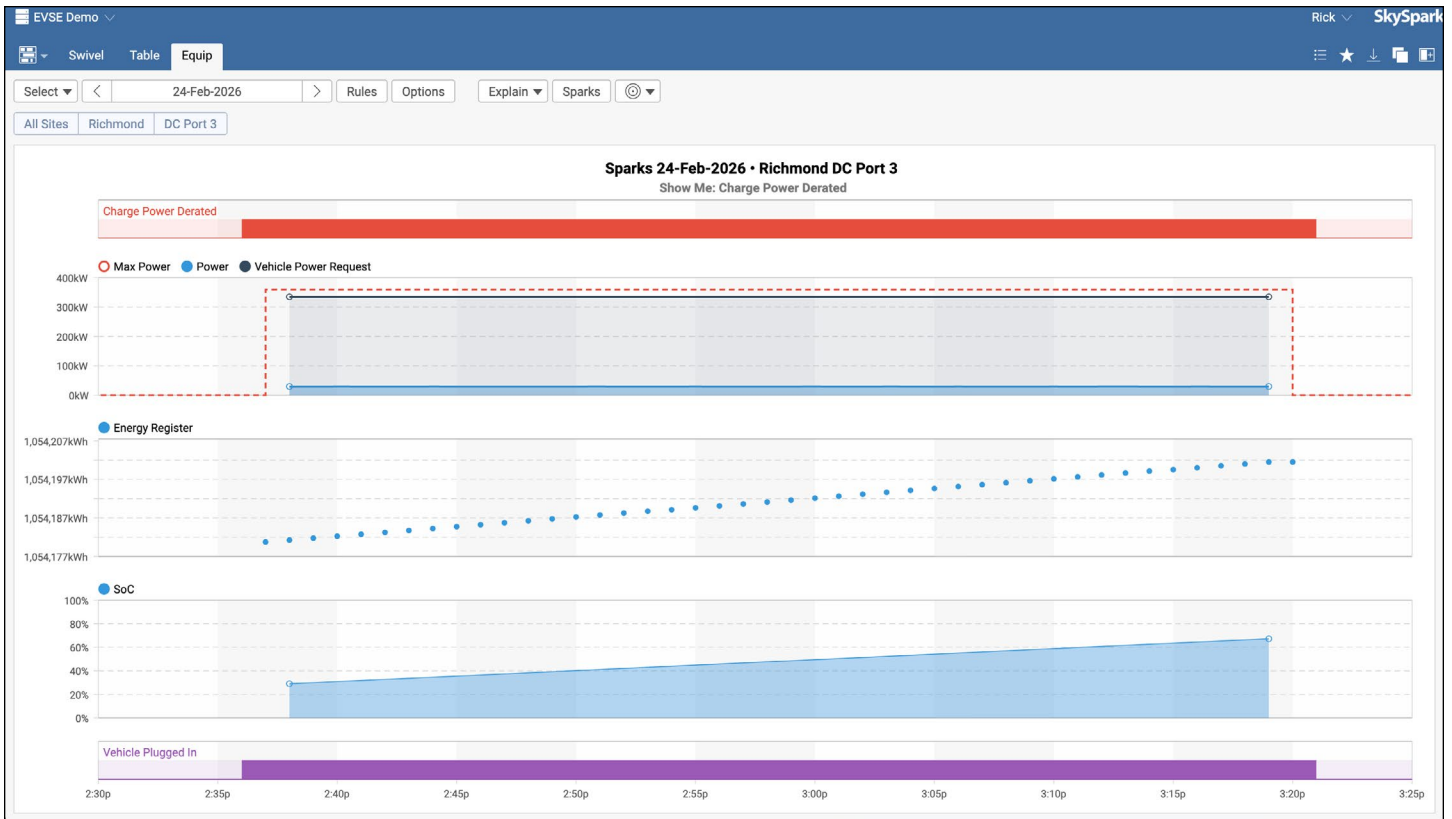


Figure 4: A Charge Power Derated in SkySpark

Charge End Early

A *Charge End Early* is a *Charge End Failed* in which both of the following conditions are true:

- The duration between when energy delivery ends and when the charging cable unplugs from the vehicle’s inlet exceeds an operator-configured limit (e.g., 2 minutes).
- The vehicle’s last recorded state of charge is below an operator-configured threshold (e.g., 78%).

Note: Drivers and operators may configure the vehicle to stop charging before 100% state of charge.

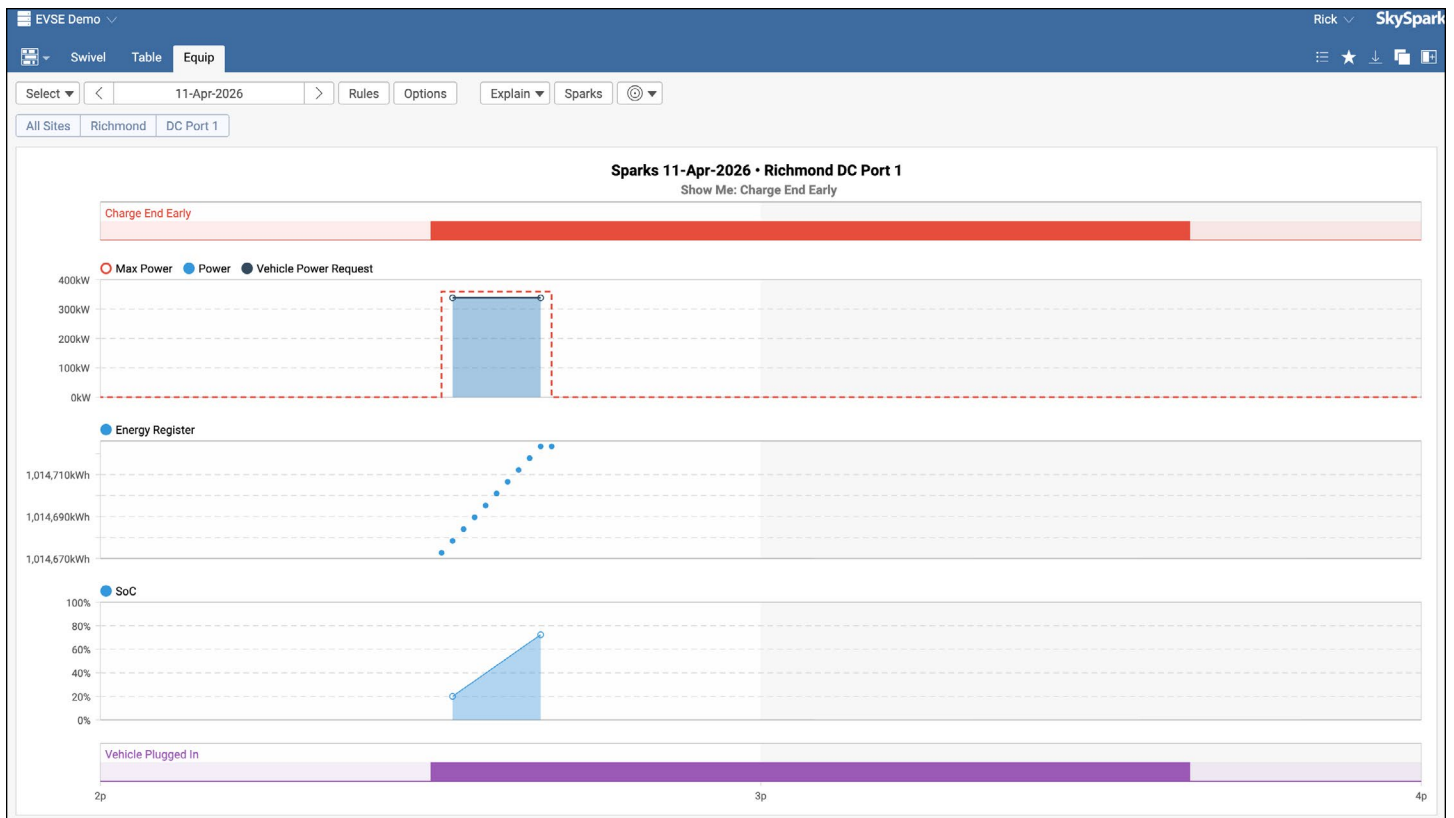


Figure 5: A Charge End Early in SkySpark

Charge End Successful

A *Charge End Successful* is a *Charge Session* in which the vehicle's charging needs were met.

Parking Visit

A *Parking Visit* is the period from when a vehicle parks in the space designated for an EVSE port to when it departs.

Charge Visit

A *Charge Visit* is a *Parking Visit* with at least one *Charge Attempt*.

First Charge Failed

A *First Charge Failed* is a *Charge Visit* in which the driver's initial *Charge Attempt* does not result in a *Charge End Successful*.

First Charge Successful

A *First Charge Successful* is a *Charge Visit* in which the driver's initial *Charge Attempt* results in a *Charge End Successful*.

EVSE Port Down

An *EVSE Port Down* detects when either of the following conditions is true:

- A configurable number of consecutive *Charge Start Failed* events occur with no intervening *Charge Session*
- A configurable number of consecutive *Charge End Failed* events occur with no intervening *Charge End Successful*

The down period spans from the start of the first event in the triggering streak to the start of the first event that breaks the streak.

Note: The down period begins at the start of the first event in the triggering streak, meaning downtime is attributed retroactively once the streak threshold is reached.

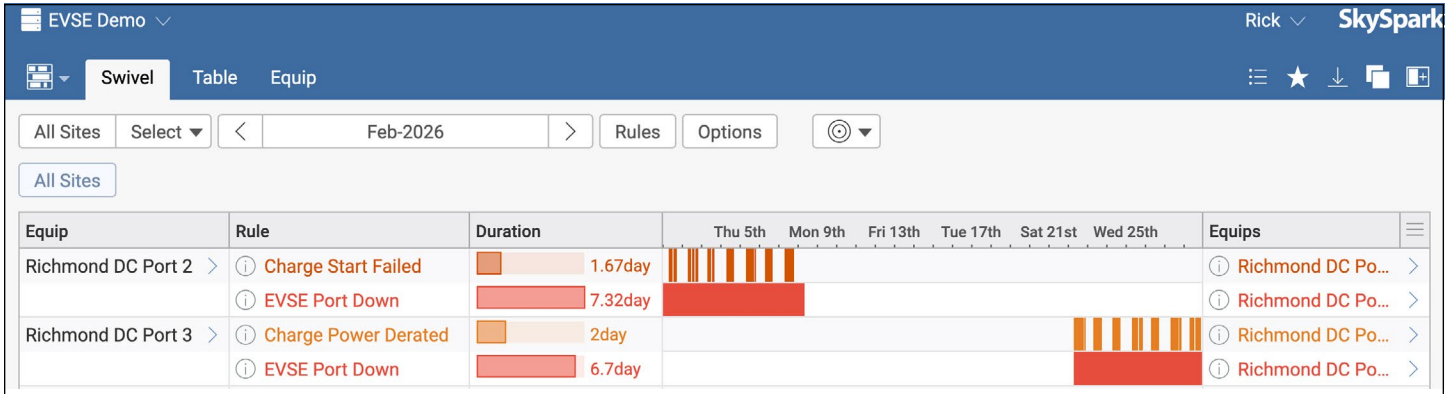


Figure 6: Two EVSE Port Down events caused by Charge Start Failed and Charge Power Derated events in SkySpark

Charge Start

A *Charge Start* is a period within a *Charge Session* that begins when the charging cable plugs into the vehicle's inlet and ends when energy delivery starts.

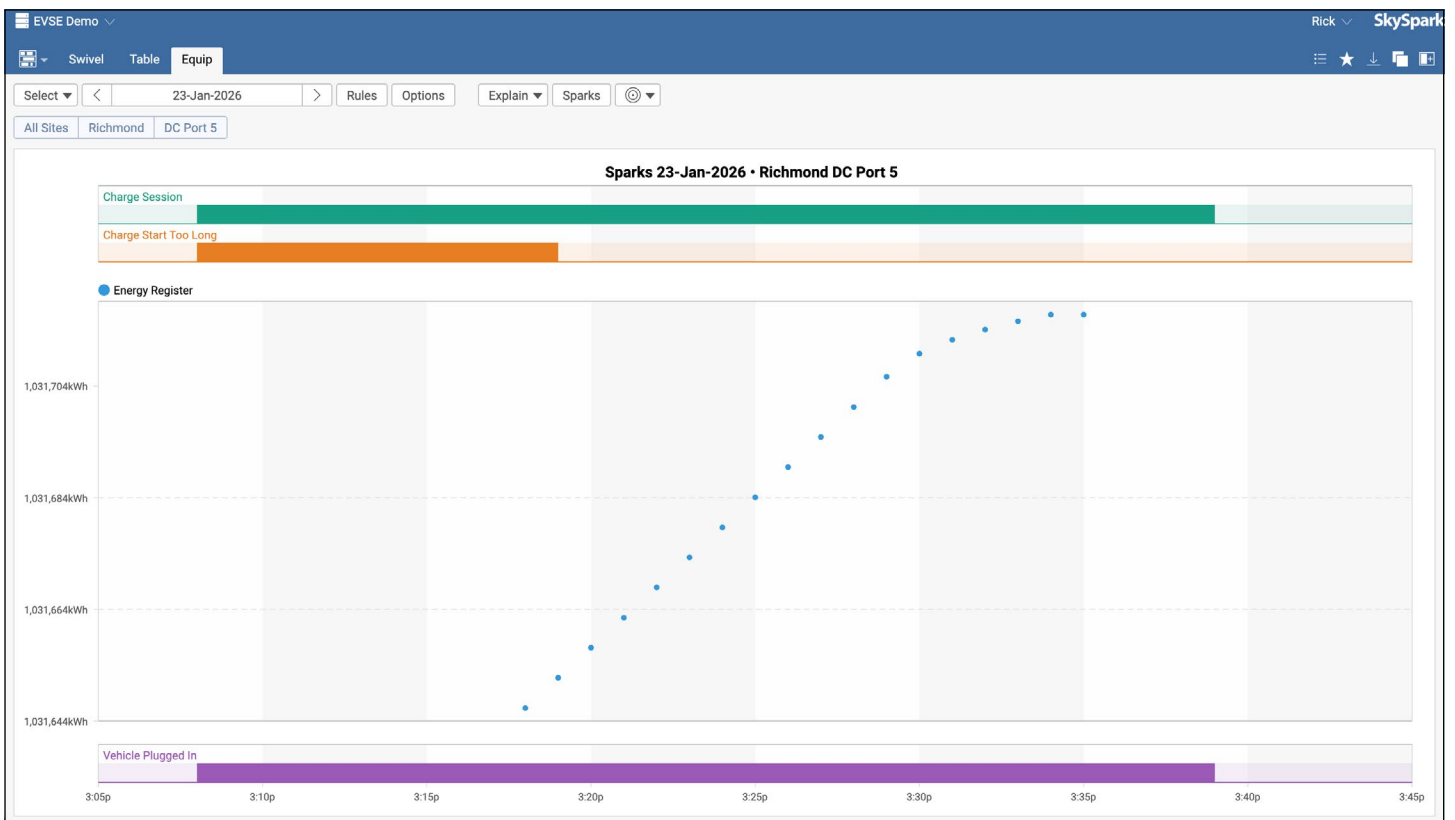


Figure 7: A Charge Start exceeding a configured duration threshold in SkySpark

Charge Idle

A *Charge Idle* is a period within a *Charge Session* that begins when energy delivery stops and ends when the charging cable unplugs from the vehicle's inlet.

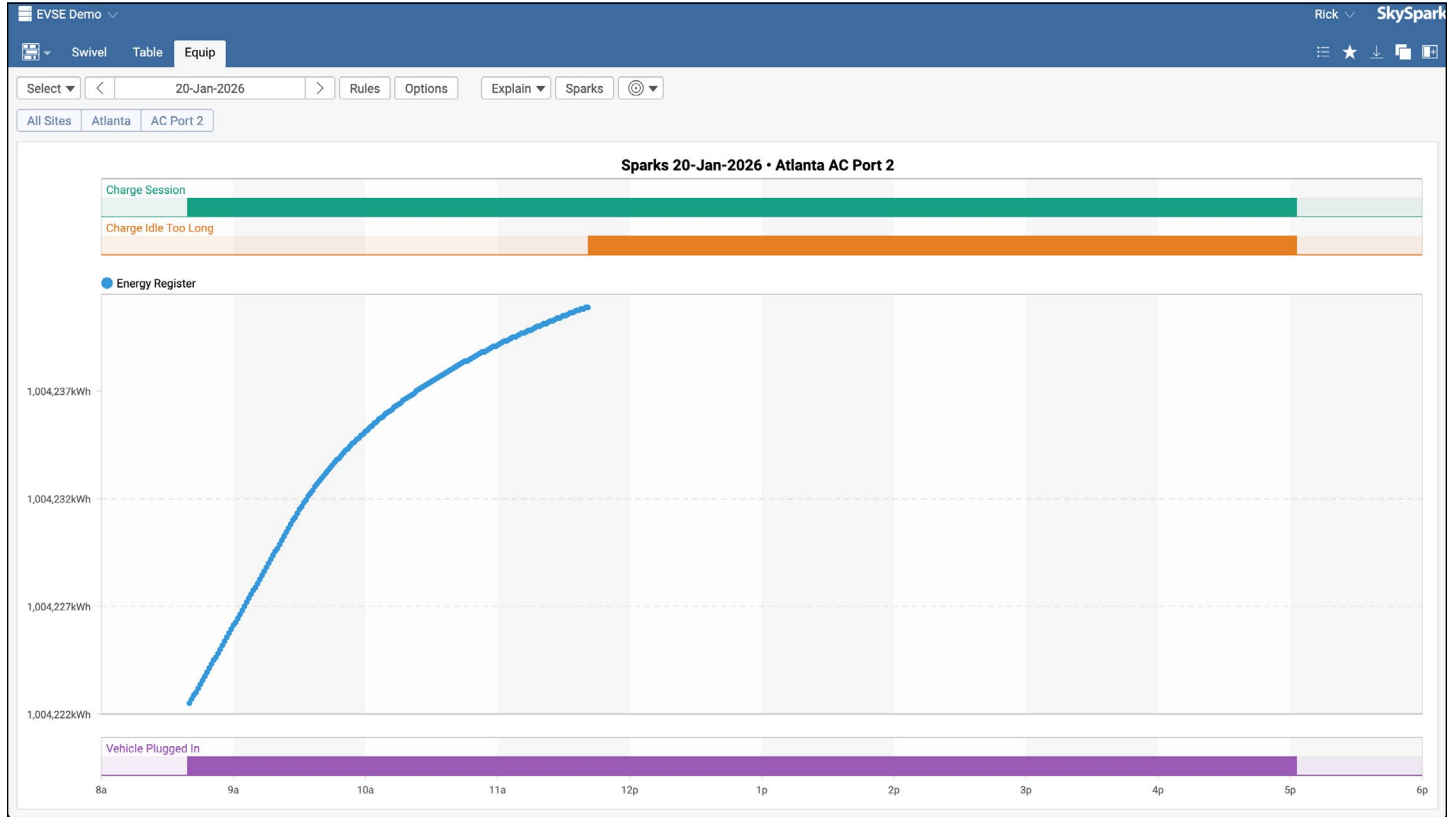


Figure 8: A *Charge Idle* exceeding a configured duration threshold in SkySpark

Authorization Attempt

An *Authorization Attempt* starts when a driver initiates an authorization request and ends when it succeeds or fails. Authorization methods include, but are not limited to:

- RFID card
- Mobile app
- Payment terminal
- Plug & Charge (ISO 15118)

An *Authorization Attempt* may occur before or during a *Charge Attempt*. Multiple *Authorization Attempts* may occur concurrently on the same EVSE port.

Authorization Attempts are challenging to detect in a consistent way and remain an area of active industry development. They have been excluded from the KPIs presented in this paper. Operators who can reliably detect *Authorization Attempts* may revise the KPIs to account for them to provide a more complete view of success from the driver's experience.

Calculating and Reporting KPIs

KPIs should be computed and stored daily. They should be viewable:

- For a specific EVSE port or operator-defined group of EVSE ports

- Individually or aggregated across a date range (e.g., weekly, monthly)

Since events may span multiple dates, the KPI definitions in this paper register each event on the date it started. Operators could alternatively register events on the date they ended or split them across dates proportionally.

The following KPIs are defined using the events and conventions described earlier.

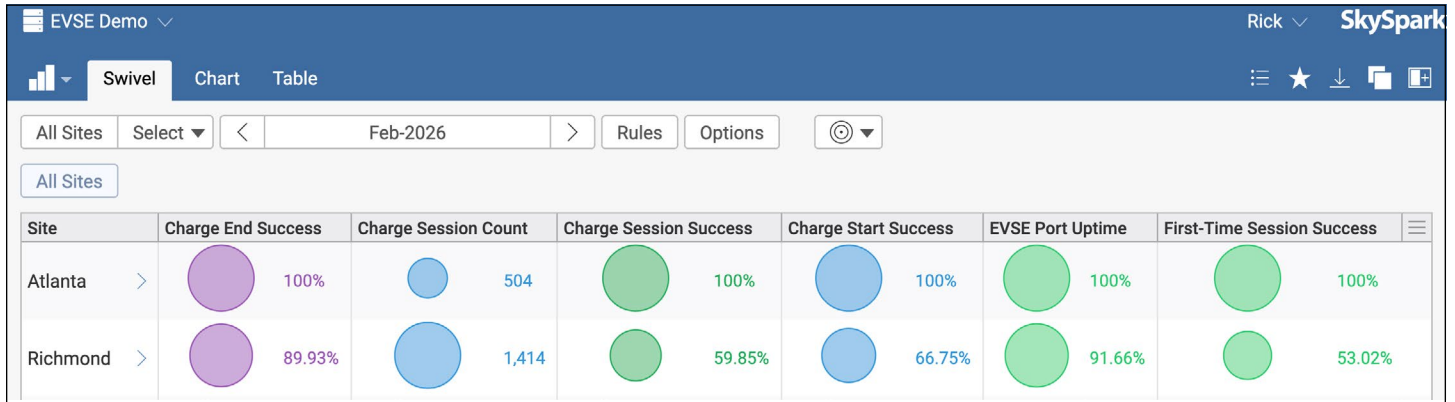


Figure 9: Example KPIs Reported in SkySpark

Charge Start Success

$$\text{Charge Start Success} = \frac{\# \text{ of Charge Sessions}}{\# \text{ of Charge Attempts}}$$

A low value suggests a high percentage of *Charge Attempts* result in *Charge Start Failed* events.

Charge End Success

$$\text{Charge End Success} = \frac{\# \text{ of Charge End Successful Events}}{\# \text{ of Charge Sessions}}$$

A low value suggests a high percentage of *Charge Sessions* result in *Charge End Failed* events.

Charge Session Success

$$\text{Charge Session Success} = \frac{\# \text{ of Charge End Successful Events}}{\# \text{ of Charge Attempt}}$$

A low value suggests a high percentage of *Charge Attempts* result in *Charge Start Failed* or *Charge End Failed* events.

First Charge Session Success

$$\text{First Charge Session Success} = \frac{\# \text{ of First Charge Successful Events}}{\# \text{ of Charge Visits}}$$

A low value suggests a high percentage of *Charge Visits* result in *First Charge Failed* events.

EVSE Port Uptime

$$\text{EVSE Port Uptime} = \frac{\text{Total Time} - \text{Time EVSE Port Down is Active}}{\text{Total Time}} \times 100\%$$

A low value suggests excessive EVSE port downtime caused by sequences of *Charge Start Failed* or *Charge End Failed* events with no intervening *Charge Session* or *Charge End Successful*.

Charge Start Time Average

$$\text{Charge Start Time Average} = \text{Average Duration of Charge Start Events}$$

A high average suggests delays in communication or issues with *Charge Session* authorization.

Charge Idle Time Average

$$\text{Charge Idle Time Average} = \text{Average Duration of Charge Idle Events}$$

A high average suggests cables are being left plugged into vehicles after charging stops, reducing EVSE port availability for other drivers.

Data Considerations

Reliable data is essential for accurate event detection and KPI calculations.

The methodology in this paper is based on the use of normalized timeseries data that can be collected via various communication protocols across different EVSE and CSMS vendors. This provides a more reliable foundation than protocol-defined event records, which are often missing, misinterpreted, or incorrectly implemented.

For example, Open Charge Point Protocol (OCPP) transaction events capture when charging started and stopped and the authorization method. However, industry experience has shown that these events are not always reliable — start and stop events may not be paired, there may be more than one transaction for a *Charge Session*, or protocol versions may define a transaction inconsistently.

Even so, the timeseries data used is not immune to quality issues or gaps. Analytical rules can detect and flag these issues. The sections below describe common examples and approaches for handling them.

Data Quality

Real-world examples of data quality issues include:

- Energy register values that reset unexpectedly or decrease outside of planned resets
- Meter values not reported at the expected interval (e.g., every 60 sec) during charging
- Unreliable signals indicating when an EVSE cable is plugged into a vehicle's inlet
- 0.0% state of charge values reported as a substitute for null (i.e., missing or unknown)
- The last energy register value in a *Charge Attempt* not matching the first value in the next, for consecutive *Charge Attempts* that both involved energy delivered to the vehicle
- Energy register values not reported just before power delivery started or just after it stopped, within a *Charge Attempt* that involved energy delivered to the vehicle

Where possible, poor-quality data should be identified and either discarded or imputed before it influences event detection. For example, a state of charge value of 0.0% followed by a sudden jump in subsequent readings is more likely a null substitute than a valid measurement and should be excluded.

Data Availability

The following data points referenced in this paper are frequently unavailable:

1. Vehicle-requested max power
2. Parking bay occupancy
3. State of charge (for Level 2 AC EVSE)

Machine learning or AI may be used to estimate missing values for these points — for example, inferring approximate state of charge from the charge taper in the charging power curve.

If estimation is not possible, operators must decide how strictly to apply each event definition: Should an event like *Charge End Failed* be triggered in the absence of state of charge data? Should null be reported for the *Charge End Success* and related KPIs? Operators focused on catching all failures should lean toward triggering events on incomplete data; those minimizing false positives should require the data to be present.

Similarly, when aggregating daily reported KPIs across dates, operators must decide how to handle a mix of null and non-null values — whether to exclude dates with null KPIs or report null on the aggregate.

Diagnostics

The defined events do more than detect failures — they also point toward probable causes and form the basis for effective diagnostics. A *Charge Start Failed* suggests a different fault than a *Charge Power Derated*.

Ultimately, operations teams want to know the root cause of a failure. Technicians should be able to drill into the raw timeseries data behind each detected event alongside EVSE manufacturer-provided diagnostic information, so they can see exactly what the equipment was doing when the fault occurred.

For example, a *Charge Power Derated* may be associated with a vendor error code that maps to a suggested root cause and repair instruction. And when no vendor diagnostic is available, the event itself becomes the starting point for investigation.

Triggering O&M Workflows

Workflows tailor-made to a service organization's needs can be triggered on the events introduced in this paper, as well as additional events defined using the same approach. When an *EVSE Port Down* event occurs, for example, an email or text notification can be sent, a work order generated, or the EVSE port marked unavailable, so drivers are not directed to it.

Extending the Framework

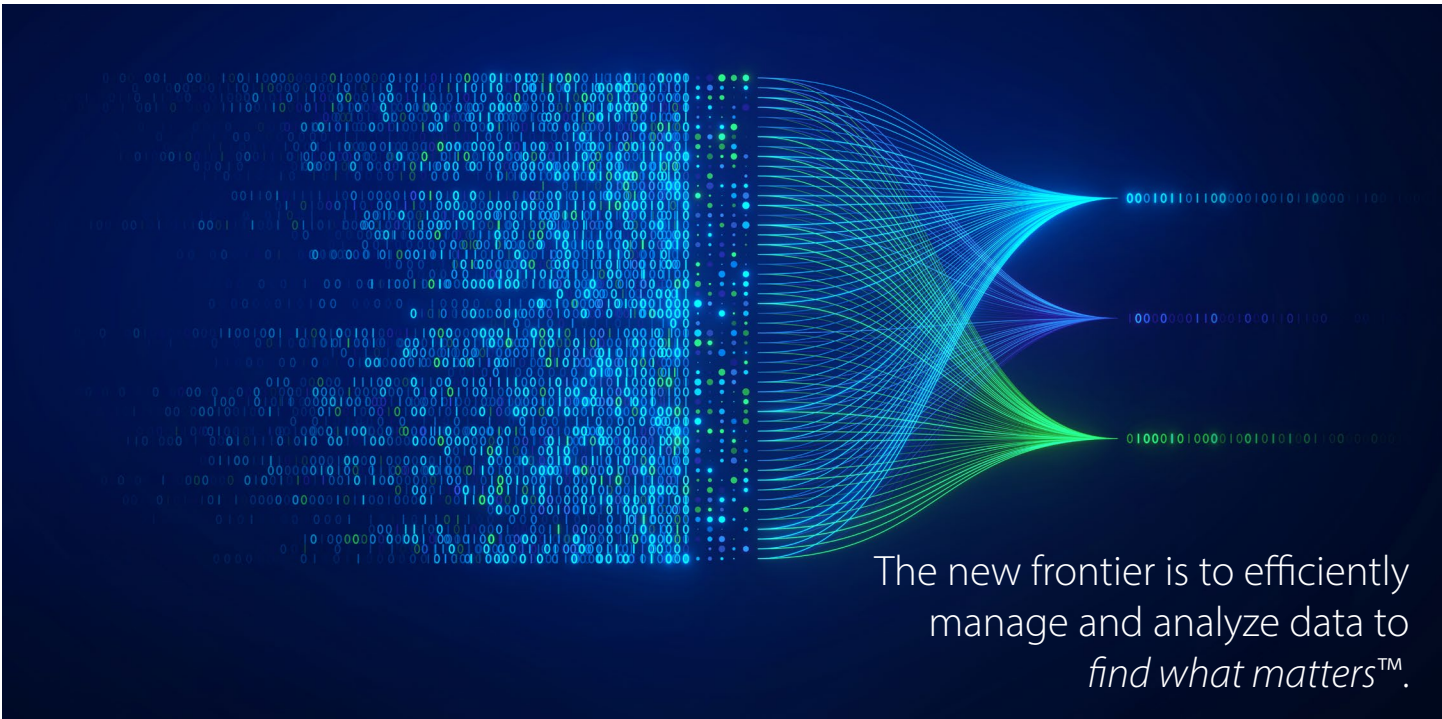
Operators can adapt and extend the framework to suit their needs. Examples include:

- Power quality monitoring to help diagnose whether incoming utility power is contributing to *Charge End Failed* events
- Average energy delivered or total count KPIs for *Charge Sessions*
- Refinements to the EVSE Port Down event — requiring consecutive failed *Charge Visits* to reduce false positives from single-vehicle issues
- An alert when an EVSE port shows no *Charge Attempts* over an extended period — a broken cable may stop drivers from plugging in

Conclusion

In the EV charging industry, an EVSE that shows as available but can't deliver a charge is a notorious problem, and it's just one of many failure modes that burden O&M teams. The story of what went wrong is often hidden in the data. This paper introduced a framework for fault detection and diagnostics, performance monitoring, and O&M workflows that help make these failures visible and actionable.

The events and KPIs in this framework were inspired by the ChargeX Consortium's work to define industry-standard KPIs for EV charging. O&M teams can deploy them today, and each deployment contributes to a growing body of operational data — the foundation for meaningful benchmarking across sites.



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Access to this data opens up new opportunities for the creation of value-added services to help businesses reduce energy consumption and cost, and to identify opportunities to enhance operations through improved control, and replacement or repair of capital equipment. Access to the data is just the first step in that journey, however. The new challenge is how to manage and derive value from the exploding amount of data available from these smart and connected devices. SkyFoundry's SkySpark directly addresses this challenge.

SkyFoundry

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