Recommendations for

Minimum Required Error Codes

for Electric Vehicle Charging Infrastructure

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Working Group 3: Solutions for Scaling Reliability Diagnostics Taskforce

CHARGEX consortium

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List of Abbreviations

Abbreviation	Description
CSO	Charging Station Operator, also referred to as a Charge Point Operator
CSMS	Charging Station Management System
EIM	External Identification Means
EMSP	Electric Mobility Service Provider
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
ISO	International Standards Organization
MREC	Minimum Required Error Code
OCA	Open Charge Alliance
OCPI	Open Charge Point Interface
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OICP	Open Intercharge Protocol
SAE	Society of Automotive Engineers
TLS	Transport Layer Security

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1. Introduction

The increasing global demand for EVs signifies a transformative shift in the transportation sector. As the industry moves towards a more sustainable future, EV sales account for a rapidly growing portion of the automotive market. However, the growth of EV adoption is inherently tied to the availability and reliability of EV charging infrastructure. As shown in Figure 1, the EV charging ecosystem is a complex landscape of interconnected entities, each with a unique role and responsibility to ensure a seamless, reliable charging experience.[2]

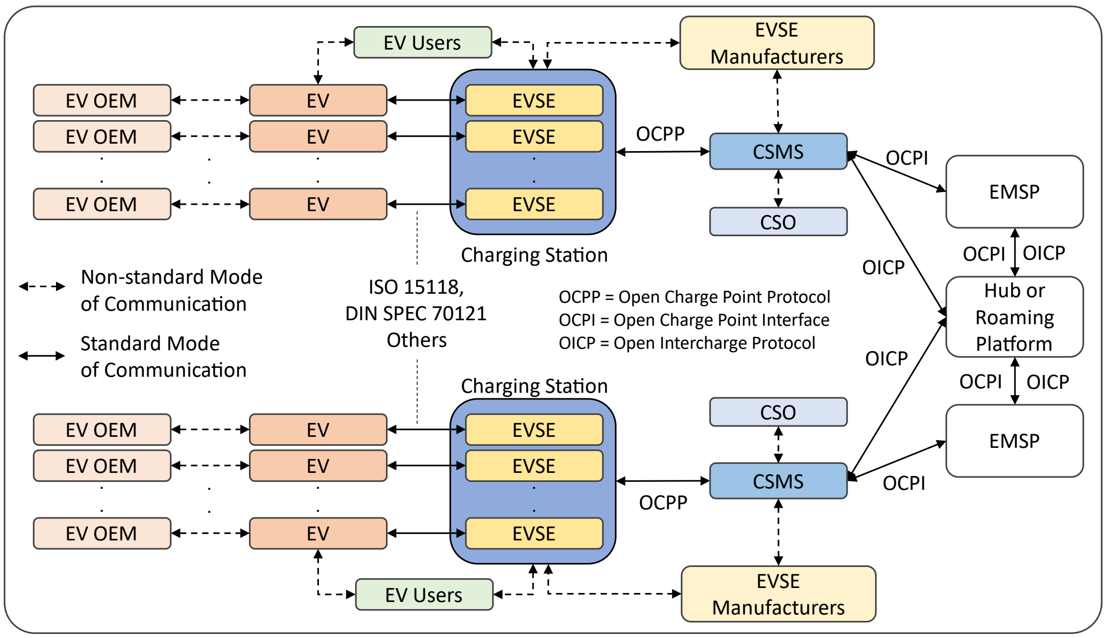

Figure 1 Electric vehicle charging ecosystem and its major stakeholders.

To tackle the challenges presented by this diversity, communication standards and protocols such as ISO 15118,[3] DIN SPEC 70121,[4] OCPP,[5] OCPI,[6] and OICP[7] have been widely employed by the industry. OCPP manages the interaction between the EVSE and its respective back-end communication network and plays a pivotal role in both error reporting and troubleshooting, carried out primarily through the CSMS. OCPP defines a few standard error codes and a flexible framework for creating and communicating custom error codes. These error codes

[2] https://www.goelectricdrive.org/charging-ev/charging-equipment-showroom
[3] https://www.iso.org/standard/55365.html
[4] https://webstore.ansi.org/standards/din/dinspec701212014
[5] https://www.openchargealliance.org/protocols/ocpp-201/
[6] https://evroaming.org/app/uploads/2021/11/OCPI-2.2.1.pdf
[7] https://assets.website-files.com/602cf2b08109ccbc93d7f9ed/60534f2e20d0f87be17ba21b_oicp-cpo-2.2.pdf

are instrumental in pinpointing and rectifying issues that can surface prior to, during, or after charging operations, fortifying the reliability and resilience of the EV charging infrastructure.

The flexibility offered by the OCPP and OCPI frameworks through the introduction of custom error codes also creates its own set of challenges. While the integration of custom error codes allows for enhanced granularity, it also introduces inconsistencies and fragmentation within the overarching diagnostic reporting system. Consequently, these custom error codes add an additional layer of complexity to the already intricate tasks of error reporting, diagnostics, and resolution. The variation in the definition of custom error codes makes it difficult to assess which entity in the charging ecosystem is responsible to correct errors and hinders the implementation of uniform error handling procedures across diverse charging stations and management systems. This results in prolonged resolution times and increased maintenance costs, resulting in decreased charging reliability. The challenge of charging reliability can be a significant obstacle to the widespread adoption of EVs, emphasizing the urgent need for a more robust approach to error handling across the EV charging ecosystem. More details on the challenges in error reporting in OCPP are presented in Appendix A.

A. Approach to Standardizing Error Codes

To address the challenges associated with custom error codes, this report proposes a set of Minimum Required Error Codes (MRECs) and recommends that the industry implement these uniformly across the North American EV charging ecosystem to streamline error reporting, interpretability, and diagnostics. Recommendations in this report are based on independent analysis of custom error codes from multiple stakeholders within the EV charging ecosystem. For better error resolution, this report also assigns one or more entities responsible for the resolution of every mentioned error code. Finally, a functional classification for each mentioned error code is also identified to describe the nature of the error. In summary, the purpose of this document is to simplify the troubleshooting process and increase charging reliability for all EV users. This report serves as a recommendation for industry stakeholders, encouraging a unified methodology to define and classify a minimum required set of error codes.

B. Scope

The scope of this report is limited to OCPP versions 1.6[8] and above. The primary focus on OCPP is due to its central role in error reporting and resolution in the EV charging ecosystem. Industry-wide consensus on OCPP error codes can potentially improve broader error reporting across various standards and protocols within the charging ecosystem. Other

[8] https://www.openchargealliance.org/protocols/ocpp-16/

errors, such as communication failures, or internet connection failures that cannot be conveyed over OCPP in real time, will be addressed in future work.

2. Minimum Required Error Codes

Table 1 presents the proposed minimum set of required error codes along with their detailed descriptions. These error codes were chosen to convey detailed, actionable error information and provide the necessary simplicity, standardization, and effective communication.

Table 1 Proposed Minimum Required Error Codes and descriptions.

Number	Error Code	Description
1.	ConnectorLockFailure	Failure to lock or unlock connector on the vehicle side.
2.	GroundFailure	Ground fault circuit interrupter has been activated.
3.	HighTemperature	High temperature inside the EVSE is derating power delivery.
4.	OverCurrentFailure	Over current protection device has tripped.
5.	OverVoltage	Input voltage to the vehicle has risen above an acceptable level.
6.	UnderVoltage	Input voltage to the vehicle has dropped below an acceptable level.
7.	WeakSignal	Wireless communication device reported a weak signal.
8.	EmergencyStop	Emergency stop is pressed by the user (required if equipped).
9.	AuthorizationTimeout	The user plugs in but fails to authorize a charging session prior to the connection timeout between the vehicle and EVSE.
10.	InvalidVehicleMode	The vehicle is in an invalid mode for charging.
11.	CableCheckFailure	Failure during the cable check phase. Includes isolation failure
12.	PreChargeFailure	The EVSE did not reach the correct pre-charge voltage.
13.	NoInternet	The EVSE has no internet connectivity.
14.	PilotFault	The control pilot voltage is out of range.
15.	PowerLoss	The EVSE is unable to supply any power due to mains failure.
16.	EVContactorFault	Contactors fail to open or close on the vehicle side. May also include welding related errors.
17.	EVSEContactorFault	Contactors fail to open or close on EVSE's side. May also include welding related errors.
18.	CableOverTempDerate	Temperature of charging cable or connector assembly is too high, resulting in reduced power operation.
19.	CableOverTempStop	Temperature of charging cable or connector assembly is too high, resulting in a stopped charging session.

20.	PartialInsertion	Cable latch is raised due to incomplete insertion into the vehicle charging port.
21.	CapacitanceFault	An Isolation Monitoring Device tripped due to high capacitance during active charging.
22.	ResistanceFault	An Isolation Monitoring Device tripped due to low resistance to the chassis during active charging.
23.	ProximityFault	The proximity voltage is out of range.
24.	ConnectorVoltageHigh	The output voltage of EVSE is high before charging starts or after charging ends.
25.	BrokenLatch	The latch on the connector is broken.
26.	CutCable	The output cable has been severed from the EVSE.

In this report, the MRECs listed in Table 1 are recommended to be reported by relevant stakeholders and be included in future versions of OCPP. Although this may require the deployment of additional sensors and capabilities, capturing these errors is essential to improve the reliability of the EV charging ecosystem. Absolute thresholds for different parameters triggering the error codes listed in Table 1 can be found in the respective standards governing the underlying failure modes.

3. Responsibility and Functional Classifications

Although custom error codes enhance diagnostic capabilities and provide detailed system insights, the lack of common definitions and a minimum required set can negatively impact interoperability troubleshooting and EV user charging experience. This report builds on prior MREC work from ChargeX Consortium members General Motors and EVgo[9] and is based on input from numerous other stakeholders in the EV charging ecosystem.

A. Responsibility Classification

A systematic responsibility classification system is proposed to address the ambiguity surrounding the source of errors and their resolution responsibility within the EV charging ecosystem. In this new system, each error code given in Table 1 is classified into one of four distinct categories – **EV User**, **CSO**, **EVSE**, or **EV**. This classification identifies the primary stakeholder responsible for error resolution, facilitating a streamlined troubleshooting process.

- Errors classified under the **EV User** category imply a user error during the charge initiation process, such as incorrectly plugging in the charging connector or not properly following the indicated sequence of events. For such errors, retrying the initiation process, better HMI guidance from the EVSE, and EV customer education can play a significant role in resolution.

[9] https://mrec.evgo.com/intro.html

- Errors classified under the **CSO** category imply a fault at the charging site, such as payment or network connectivity issues. Such errors require technical assistance from the CSO for resolution.
- Errors classified under the **EVSE** category imply a fault within the EVSE itself or the related charging infrastructure, such as a malfunctioning component. Such errors require remote and/or in-person intervention by maintenance personnel for resolution.
- Errors classified under the **EV** category imply a fault within the EV itself, such as issues with the vehicle's onboard charging system or the battery management system. In such instances, technical assistance by the vehicle manufacturer is required for resolution.

Through such a responsibility classification schema, all involved stakeholders, including the repair technicians, can be directed to the potential source of a problem and initiate appropriate resolution measures. The proposed responsibility classification is given in Table 2.

Table 2 Responsibility classification for the Minimum Required Error Codes.

Number	Error Code	Responsibility Classification			
		EV User	CSO	EVSE	EV
1.	ConnectorLockFailure	✓	-	-	✓
2.	GroundFailure	-	-	✓	✓
3.	HighTemperature	-	-	✓	-
4.	OverCurrentFailure	-	-	✓	✓
5.	OverVoltage	-	-	✓	✓
6.	UnderVoltage	-	-	✓	✓
7.	WeakSignal	-	✓	✓	-
8.	EmergencyStop	✓	-	✓	-
9.	AuthorizationTimeout	✓	✓	✓	✓
10.	InvalidVehicleMode	✓	-	-	✓
11.	CableCheckFailure	-	-	✓	✓
12.	PreChargeFailure	-	-	✓	✓
13.	NoInternet	-	✓	✓	-
14.	PilotFault	-	-	✓	✓
15.	PowerLoss	-	-	✓	-
16.	EVContactorFault	-	-	-	✓
17.	EVSEContactorFault	-	-	✓	-
18.	CableOverTempDerate	-	-	✓	-

19.	CableOverTempStop	-	-	✓	✓
20.	PartialInsertion	✓	-	✓	✓
21.	CapacitanceFault	-	-	✓	✓
22.	ResistanceFault	-	-	✓	✓
23.	ProximityFault	-	-	✓	✓
24.	ConnectorVoltageHigh	-	-	✓	-
25.	BrokenLatch	-	✓	✓	-
26.	CutCable	-	✓	✓	-

B. Functional Classification

Building on the foundation of a responsibility classification system, a functional classification approach is proposed to gain an understanding of the reduced functionality that accompanies an error code. Functional classification refers to segregating the errors based on the functions or operations they disrupt or compromise in the charging process, such as safety, security, maintenance, financial, and communication.

- Errors classified under the **Safety** category are related to scenarios that compromise the safety of the user, the vehicle, or the charging infrastructure. This includes events such as overheating, over-voltage, under-voltage, grounding faults, or any other conditions that pose a safety risk.
- Errors classified under **Security** are related to issues around user authentication, data privacy, and secure operation of the charging system. This includes scenarios such as unauthorized access to the system, failure in secure data transmission, or breaches in user privacy. These errors underscore the importance of robust security protocols within the charging infrastructure.
- Errors classified under **Maintenance** are related to issues with hardware and software malfunctions or wear-and-tear issues within the EVSE. These errors often signal a need for technical service, component repair, or replacement.
- Errors classified under **Financial** are related to issues with payment processing, pricing, or billing. These range from failed payment transactions to discrepancies in pricing and invoicing.
- Errors classified under the **Authorization** are related to issues around user access control, communication failures between the EV and EVSE during authorization processes, or the failure of user authorization mechanisms.

Such a functional classification of errors can facilitate efficient diagnosis, improve preventive measures, and lead to more robust system design by allowing the identification of patterns and commonalities across error types and functionalities. The proposed functional classification of error codes is outlined in Table 3.

Table 3 Functional classification for the Minimum Required Error Codes.

Number	Error Code	Functional Classification				
		Safety	Security	Mainten-ance	Financial	Authoriza-tion
1.	ConnectorLockFailure	✓	✓	-	-	-
2.	GroundFailure	✓	-	✓	-	-
3.	HighTemperature	✓	-	-	-	-
4.	OverCurrentFailure	✓	-	-	-	-
5.	OverVoltage	✓	-	-	-	-
6.	UnderVoltage	✓	-	-	-	-
7.	WeakSignal	-	-	-	-	✓
8.	EmergencyStop	✓	-	-	-	-
9.	AuthorizationTimeout	-	✓	-	-	✓
10.	InvalidVehicleMode	✓	-	-	-	-
11.	CableCheckFailure	✓	-	✓	-	-
12.	PreChargeFailure	✓	-	-	-	-
13.	NoInternet	-	-	-	-	✓
14.	PilotFault	-	-	✓	-	-
15.	PowerLoss	✓	-	✓	-	-
16.	EVContactorFault	✓	-	-	-	-
17.	EVSEContactorFault	✓	-	-	-	-
18.	CableOverTempDerate	✓	-	-	-	-
19.	CableOverTempStop	✓	-	-	-	-
20.	PartialInsertion	✓	-	-	-	-
21.	CapacitanceFault	✓	-	-	-	-
22.	ResistanceFault	✓	-	-	-	-
23.	ProximityFault	✓	-	✓	-	-
24.	ConnectorVoltageHigh	✓	-	-	-	-
25.	BrokenLatch	✓	✓	-	-	-
26.	CutCable	✓	-	✓	-	-

The error codes listed in Table 1, 2, and 3 although suitably generic, do not represent an exhaustive list applicable to all OCPP versions. For instance, certain specific errors, such as those related to the Transport Layer Security (TLS) protocol in OCPP 2.0.1, are not directly represented. However, the dual classification strategy proposed above—both for responsibility and functionality—is versatile and detailed to accommodate all OCPP versions within the scope of this study.

4. Summary and Recommendations

The standardization of error reporting in the EV charging ecosystem is critical to improving EV charging reliability. This study, while rigorous, was limited to a review of the current state of the art in industry and focused on charger-to-cloud communication via OCPP. Although the latest OCPP version, 2.0.1, was utilized as a benchmark in this document, a version-agnostic approach is beneficial at this stage. Therefore, the selection of minimum required error codes was guided by the following principle*: if an error poses a significant challenge to a critical function within the EV charging process, such as safety, security, maintenance, financial operations, or authorization, resulting in a disruption to the charging process, it should be designated as an MREC.* This approach ensures that errors which influence the charging infrastructure's performance, reliability, and overall user experience are quickly detected, reported, and addressed. This philosophy is represented in Figure 2.

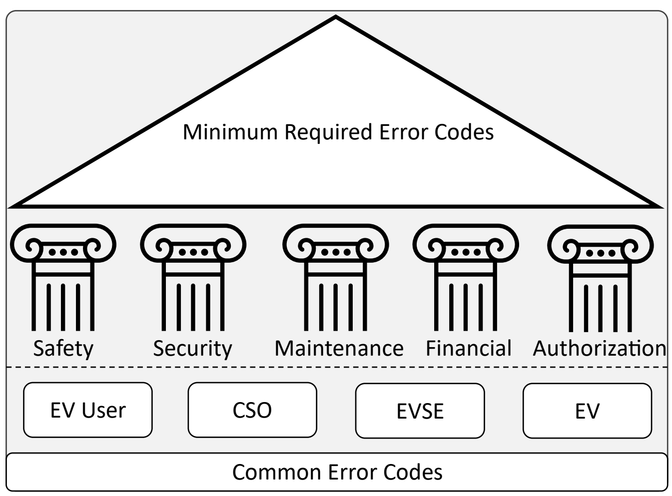

Figure 2 Guiding pillars for defining the Minimum Required Error Codes.

In the event of nested error trails or concurrent, the minimum error code(s) for the root error(s) should be reported and any available error information provided in subsequent messages.

The MRECs and the classification strategies proposed in this document establish a fundamental framework for error code reporting and diagnostic problem-solving. However, it is necessary to extend this effort to include EV-to-charger communication.

As part of future efforts, the ChargeX Consortium intends to formulate diagnostic troubleshooting codes based on the recommended MRECs from this document. This work will include a concentrated effort to develop guidelines for error code interpretation and response actions. In addition, periodic updates are proposed to the list of MRECs to align with newer technologies and address any potential customer issues that may arise in the EV charging ecosystem.

Appendix A: Open Charge Point Protocol

This section provides a brief overview of OCPP, emphasizing its prominent features, benefits, and significance, particularly for diagnostics and error resolution in the EV charging ecosystem.

A. Overview

OCPP establishes a framework for communication between EVSE and the CSMS. It defines a comprehensive set of rules, commands, and data structures that facilitate seamless interaction and efficient data exchange. OCPP specifies features essential for charging operations, including the initiation and termination of charging sessions, real-time monitoring of charging status, collection of transactional data, and user authentication management. It also facilitates remote monitoring, diagnostics, and firmware updates on the EVSEs. OCPP enables interoperability and compatibility across different EVSE manufacturers, CSMS providers, and CSOs. By adhering to OCPP, different stakeholders can seamlessly integrate their components into the EV charging infrastructure, irrespective of their unique hardware or software implementations. A few challenges associated with custom error codes used within the OCPP and the implications they have on the reliability and interoperability of the EV charging infrastructure are briefly mentioned below.

B. Error Reporting in OCPP

In OCPP 1.6, the management system primarily relies on the *websocket ping mechanism* and the configurable *heartbeat interval* to check the availability of the EVSE. In addition, the charging station could actively report errors as they occur via the *StatusNotification* message. These core functionalities persist in the latest OCPP version (OCPP 2.0.1), with the *websocket ping* and *heartbeat interval* mechanisms still serving as vital checks for charging station availability. However, the error reporting mechanism has been updated. To better support customization, these messages often extend their scope by incorporating custom error codes, housed within the *vendorErrorCode* field in OCPP 1.6 and the *techCode* field in OCPP 2.0.1. It is worth noting that the report does not mention/enforce any thresholds for triggering these errors since such thresholds may be configured by the manufacturer/CSO in OCPP 2.0.1. In OCPP 2.0.1, the *NotifyEvent* message is the primary field for conveying error information. Unlike OCPP 1.6, this message can relay errors related to multiple subsystems and components using the device model architecture, enabling detailed error diagnostics. A summary of differences in error reporting between OCPP versions can be found in a recent white paper[10] by the Open

[10] https://www.openchargealliance.org/uploads/files/improving_uptime_with_ocpp-v10.pdf

Charge Alliance (OCA) and a technical report by SAE International[11]. OCPP commonly facilitates robust communication between various stakeholders. This information exchange within OCPP is depicted in Figure 3. OCPP's flexibility results in a variety of custom error codes, which are unique to individual manufacturers or software providers. This feature can offer detailed, context-specific diagnostics that potentially enhance the system's ability to detect, analyze, and resolve issues. However, a lack of standardization of these codes results in challenges with interoperability and serviceability of chargers.

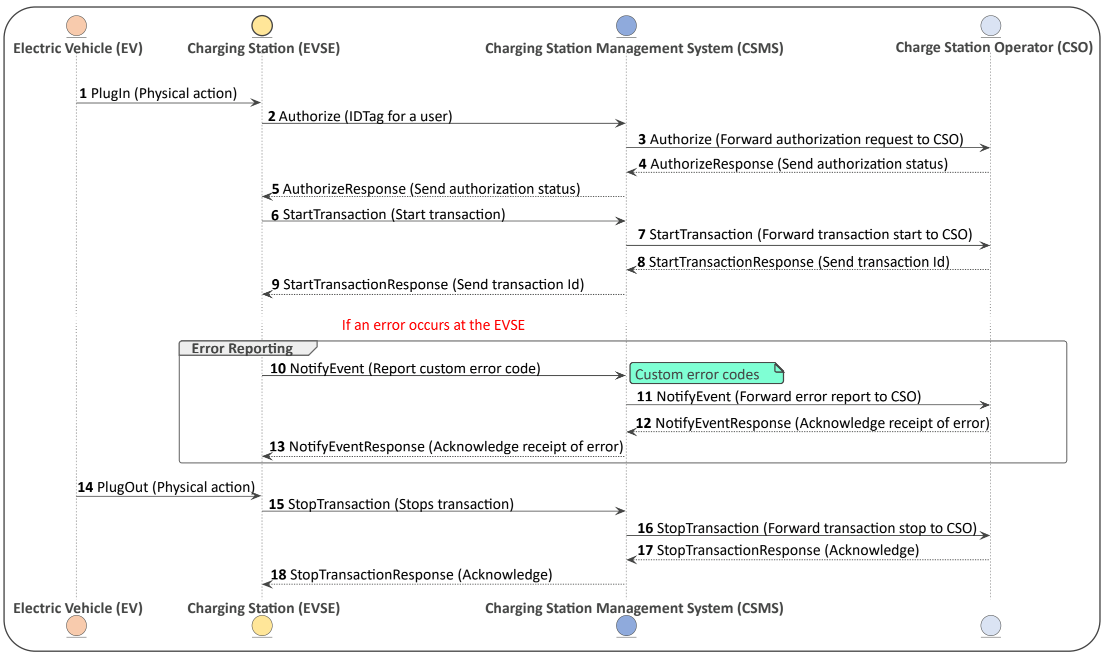

Figure 3 Flow of information using OCPP 2.0.1 in the EV charging ecosystem.

It is important to note that the problem of custom error codes is not exclusive to OCPP and exists in other parts of the EV charging ecosystem. However, most of these custom codes are within the EV-EVSE communication, handled by OCPP, at the time of this report.

[11] https://sms.sae.org/resources/electric-vehicle-charging-data-performance-and-reporting