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D3.4: Interoperability requirements, methodologies and test equipment

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1. Executive Summary

The overall project objective is to optimize the entire charging chain - from energy provision to the end user - to create a clear benefit for all stakeholders. Therefore, a ubiquitous on-demand charging solution based on an optimized charging network considering human, technical and economic factors along the entire charging chain shall be developed.

The investigation of the user behaviour as well as the analysis of the energy system and grid will form the basis from a research side, to predict the future behaviour of EV owners and fleet operators as well as possible shortcomings in the electric grid and energy system.

The development of advanced charging technologies and control mechanisms as well as advanced charging and sector coupling concepts, will form the basis for the virtual and real evaluations/demonstrations conducted in 4 different European countries (Belgium, Germany, Italy, Portugal).

In parallel a smart charging simulation environment (digital twin of the charging chain with a holistic simulation environment with multilevel component models and representative information flow between all agents) will be built up. This digital twin will incorporate the results of the demonstration actions and enable an upscaling to show the impact of these technologies.

To ensure the interoperability and the optimization along this charging chain, the consortium comprises all relevant partners/stakeholders (energy providers, grid operators, charge point operator, EV equipment providers as well a vehicle manufacturer).

Keywords: Smart charging, V2X&V1G functionalities, Grid (DSO, aggregator), Smart charging entities (CP, Smart Homes, EVSE’s).

2. Introduction

The main objective of this document is to provide a comprehensive and detailed overview of the interoperability testing activities that will be performed at IDIADA facilities regarding the XL-CONNECT project. This document serves as a foundational reference for understanding the technical scope, methodological approach, and safety protocols that will govern the testing procedures throughout the project lifecycle.

XL-CONNECT represents a paradigm shift in electric vehicle charging infrastructure, with its primary goal being the optimization of the entire charging ecosystem - from energy generation at the source to final delivery at the user interface. The project encompasses a holistic approach that addresses not only traditional charging methodologies but also embraces the revolutionary potential of Vehicle-to-Everything (V2X) technology. This technology capitalizes on the fact that electric vehicles spend approximately 95% of their operational lifetime in a parked state, presenting an unprecedented opportunity to transform these vehicles into mobile energy storage units capable of contributing to grid stabilization and energy management.

The significance of V2X technology extends beyond simple energy storage. It enables a bidirectional energy flow that allows electric vehicles to act as distributed energy resources, contributing to peak shaving, load balancing, and renewable energy integration. This capability is particularly crucial as the energy sector transitions toward more sustainable and resilient grid architectures. The XL-CONNECT project addresses critical challenges in this domain, including:

- Grid stability enhancement through distributed energy storage
- Renewable energy integration optimization
- Peak demand management and load levelling
- Emergency power supply capabilities during grid outages
- Economic optimization for both vehicle owners and grid operators

To address these complex requirements and validate the innovative solutions developed within the XL-CONNECT project, IDIADA has developed state-of-the-art testing tools and methodologies. These tools are specifically designed to comprehensively evaluate the new features and functionalities emerging from this groundbreaking project. The centrepiece of IDIADA's testing infrastructure is a sophisticated V2X emulator system that has been engineered to validate multiple critical aspects of the charging ecosystem:

- Charging sequence validation across various operational scenarios
- Communication protocol verification ensuring seamless interoperability
- Integration testing with central management systems
- Bidirectional energy flow validation for grid-tied applications
- Safety and compliance verification according to international standards

The testing program will be conducted using an upgraded DC bidirectional charging solution that implements the latest ISO15118-20 standard, developed in collaboration with Circontrol. This advanced charging infrastructure represents the cutting edge of EV charging technology, incorporating sophisticated communication protocols and safety mechanisms required for reliable V2X operations.

The validation methodology employed by IDIADA follows rigorous international standards and incorporates all relevant specifications developed within the XL-CONNECT project consortium. This comprehensive approach ensures that the testing results will be globally applicable and contribute to the broader adoption of V2X technologies in the international market.

3. IDIADA test bench facilities

3.1. General overview of test installations

The reference test installation represents a world-class facility strategically located at IDIADA 2 in the municipality of Santa Oliva, Tarragona, Spain. This facility is an integral component of the globally recognized Applus+ IDIADA test and engineering complex, which has established itself as a leading authority in automotive testing and validation services worldwide.

Figure 1: IDIADA overview

3.1.1. Facility Infrastructure and Capabilities

The IDIADA test facility spans over 1,678 hectares of purpose-built testing infrastructure, making it one of Europe's most comprehensive automotive proving grounds. The facility features:

Physical Infrastructure:

- 30+ specialized test tracks including high-speed ovals, handling circuits, and durability courses
- Advanced laboratory facilities equipped with cutting-edge measurement and analysis equipment
- Climate-controlled testing environments capable of simulating diverse environmental conditions
- Electromagnetic compatibility (EMC) chambers for interference testing
- Specialized power infrastructure capable of handling high-power charging and V2X applications

Power Grid Integration:

- Medium voltage connection (25kV) providing stable and reliable power supply
- Grid-tie capabilities enabling bidirectional power flow testing
- Power quality monitoring systems ensuring compliance with grid codes
- Backup power systems maintaining continuity during testing operations
- Renewable energy integration through on-site solar installations

Safety and Security Systems:

- 24/7 security monitoring with restricted access protocols
- Emergency response capabilities including fire suppression and medical services
- Environmental monitoring ensuring compliance with safety and environmental standards
- Hazardous material handling facilities for battery testing and disposal

3.1.2. Strategic Location Advantages

The Santa Oliva location provides several strategic advantages for XL-CONNECT testing activities:

Geographical Benefits:

- Mediterranean climate offering year-round testing capabilities
- Proximity to major European markets facilitating stakeholder collaboration
- Advanced transportation infrastructure enabling efficient logistics
- Regulatory environment supportive of innovative testing methodologies

Technical Infrastructure:

- Stable electrical grid connection minimizing power quality variations
- Low electromagnetic interference environment crucial for communication protocol testing
- Adequate space allocation for large-scale testing scenarios
- Flexible facility configuration allowing adaptation to specific project requirements

3.1.3. Regulatory Compliance and Certification

The facility maintains comprehensive accreditation and certification status:

- ISO/IEC 17025 accreditation for testing and calibration laboratories
- ISO 9001 quality management system certification
- ISO 14001 environmental management system certification
- OHSAS 18001 occupational health and safety management certification
- Various national and international type approval authorities recognition

3.2. Interoperability testing tools

IDIADA has established itself as a global leader in the development and deployment of sophisticated EV & EVSE emulation systems. The crown jewel of IDIADA's testing capabilities is the Multi-Charging Test System (MCTS), a state-of-the-art platform that represents the pinnacle of electric vehicle charging testing technology.

Figure 2: High-Power Charging simulators

3.2.1. MCTS - Multi-Charging Test System Overview

The MCTS platform by IDIADA Digital Solutions represents a revolutionary approach to electric vehicle charging infrastructure testing. This comprehensive system has been specifically engineered to address the complex testing requirements of modern EV charging ecosystems, including the advanced bidirectional charging capabilities required for V2X applications in the XL-CONNECT project.

Advanced System Architecture:

- Modular testing platform enabling simultaneous multi-protocol testing scenarios
- Real-time simulation capabilities providing accurate representation of diverse charging conditions
- Comprehensive protocol support covering all major international charging standards
- Bidirectional power flow testing specifically designed for V2X validation
- Cloud-integrated data management enabling remote monitoring and analysis

3.2.2. Key MCTS Capabilities for XL-CONNECT

Multi-Protocol Testing Excellence

The MCTS system provides unparalleled support for diverse charging protocols, making it ideally suited for the interoperability testing requirements of XL-CONNECT:

- ISO 15118-20 full implementation including all message sequences and parameter validation
- CCS (Combined Charging System) Combo 1 and Combo 2 connector support
- CHAdeMO protocol for comprehensive interoperability testing
- Tesla NACS (North American Charging Standard) compatibility
- GB/T Chinese standard support for global market validation
- Emerging V2X protocols including bidirectional communication standards

Advanced Power Simulation

- Scalable power handling from residential AC charging (3.7kW) to ultra-fast DC charging (500kW+)
- Bidirectional power flow with regenerative capabilities for V2X discharge testing
- Grid simulation capabilities for testing grid-tie interactions
- Power quality analysis including harmonics, power factor, and voltage regulation
- Dynamic load profiling simulating real-world energy demand patterns

Communication Protocol Analysis

The MCTS platform excels in deep communication protocol analysis, crucial for XL-CONNECT interoperability validation:

- Real-time message monitoring with millisecond-level timestamp precision
- Protocol conformance testing ensuring compliance with international standards
- Error injection capabilities for robustness testing
- Security testing features validating cybersecurity implementations
- Performance benchmarking against industry standards

3.2.3. MCTS Integration with XL-CONNECT V2X Emulator

For the XL-CONNECT project, IDIADA has enhanced the standard MCTS platform with specialized V2X emulation capabilities. This enhanced configuration transforms the MCTS from a traditional charging tester into a comprehensive V2X validation platform.

Enhanced V2X Features:

- Bidirectional energy management simulating grid-tie operations with utility-grade precision

- Smart grid integration testing validating coordination with energy management systems
- Vehicle-to-Grid (V2G) simulation testing energy discharge scenarios
- Vehicle-to-Home (V2H) capabilities validating residential energy backup systems
- Vehicle-to-Load (V2L) testing for portable power applications
- Dynamic pricing simulation testing economic optimization algorithms

Advanced Testing Scenarios:
The MCTS-enhanced V2X emulator enables comprehensive testing of complex operational scenarios:

- Peak shaving operations testing grid load management capabilities
- Renewable energy integration simulating solar/wind power coordination
- Emergency power supply validating backup power during grid outages
- Load balancing optimization testing multi-vehicle coordination scenarios
- Frequency regulation services validating grid stability contributions
- Technical Specifications - MCTS Enhanced for XL-CONNECT

Power Handling Capabilities:

- AC Testing Range: 1-phase: 3.7kW to 22kW / 3-phase: 11kW to 50kW
- DC Testing Range: 50kW to 500kW with expandable architecture
- Bidirectional Power Flow: Full regenerative capability up to maximum power ratings
- Voltage Range: AC: 100V-800V / DC: 50V-1000V
- Current Range: AC: up to 63A per phase / DC: up to 500A

Communication Interfaces:

- Primary Communication: Ethernet, CAN, PLC (Power Line Communication)
- Wireless Capabilities: WiFi, Bluetooth, cellular connectivity options
- Connector Support: CCS1/CCS2, CHAdeMO, Tesla NACS, Type 1/Type 2, GB/T
- Industrial Protocols: Modbus, DNP3, IEC 61850 for grid integration
- Cloud Connectivity: MQTT, RESTful APIs for remote monitoring

Testing and Analysis Features:

- Real-time Data Acquisition: 1MHz sampling rate for high-precision measurements
- Automated Test Sequencing: Scripted test execution with comprehensive reporting

- Compliance Testing Modules: Pre-configured test suites for major international standards
- Fault Simulation: Comprehensive error injection for robustness testing
- Environmental Simulation: Temperature, humidity, and vibration testing capabilities

Safety and Protection Systems:

- Multi-level Safety Interlocks: Hardware and software-based protection systems
- Arc Flash Protection: Advanced detection and suppression systems
- Ground Fault Monitoring: Continuous insulation monitoring
- Emergency Stop Systems: Multiple emergency disconnection mechanisms
- Cybersecurity Features: Encrypted communication and secure authentication

3.2.4. MCTS Advantages for XL-CONNECT Validation

Comprehensive Interoperability Testing: The MCTS platform enables systematic validation of interoperability between different charging standards and V2X implementations, ensuring seamless operation across diverse infrastructure deployments.

Accelerated Development Cycles: Advanced automation capabilities and pre-configured test suites significantly reduce testing time while improving test coverage and repeatability.

Future-Proof Architecture: The modular design ensures adaptability to emerging standards and protocols, protecting the investment in testing infrastructure as the EV charging landscape evolves.

Global Market Validation: Support for international charging standards enables validation for global market deployment, crucial for the commercial success of XL-CONNECT innovations.

Regulatory Compliance Assurance: Built-in compliance testing modules ensure adherence to international safety and performance standards, streamlining certification processes.

The integration of the MCTS Multi-Charging Test System into the XL-CONNECT testing program represents a significant technological advantage, providing IDIADA with the most advanced testing capabilities available in the industry. This platform ensures comprehensive validation of all project innovations while maintaining the highest standards of safety, accuracy, and regulatory compliance. The MCTS for XL-Connect includes:

Technical Data	
Concept	**Description**
Weight	100 – 200 Kg without Power Supply
Input Power	Power Supply
Input Voltage	Power Supply
Output Power	Power Supply
Communication Interfaces	Ethernet, CAN
Available Charging Interfaces	CCS2 and Type 2 AC
Available Standards	ISO 15118, DIN 70121, OCPP 1.6
Maximum Rated Power	Nominal DC Drawer: 200kW CCS High Power DC Drawer: 500kW CCS Nominal AC Drawer: 50kW AC
Maximum Rated Current	Nominal DC Drawer: 200A CCS High Power DC Drawer: 500A CCS Nominal AC Drawer: 36A AC x phase
Maximum Rated Voltage	Nominal DC Drawer: 1000V CCS Nominal AC Drawer: 800V AC x phase

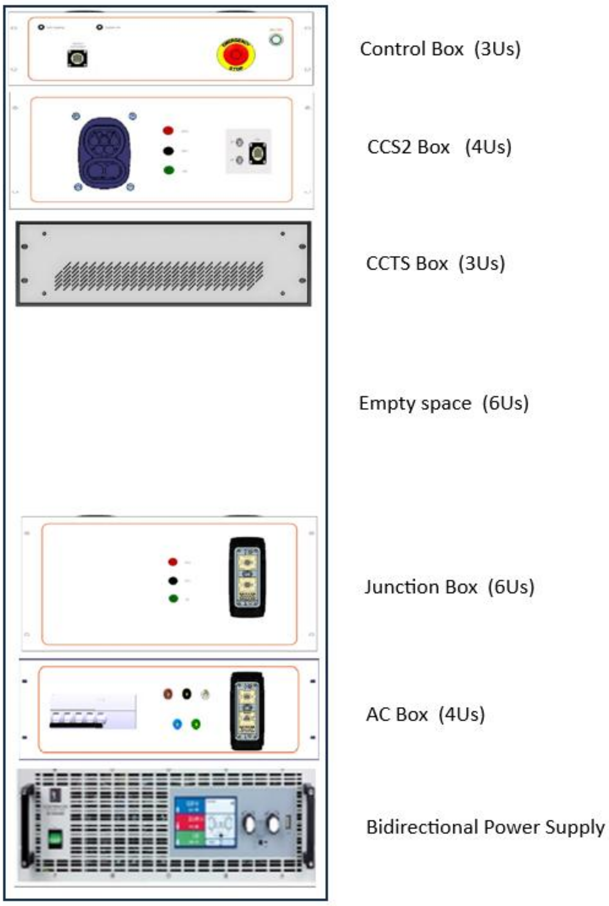

Figure 3: EV & EVSE simulator schematic

3.2.5. Charging connector specifications

When using the simulator as EVSE, the maximum electrical characteristics of the charging cable in DC and AC for CCS2 interface are as follow.

Figure 4. Simulator DC and AC charging connector

Table 1. Charging cable electrical specifications for DC and AC CCS2

Electrical Properties	DC CCS2	AC CCS2
Rated Voltage for power contacts	DC 1000 V (acc. UL)	AC 480V
Rated Current for power contacts	up to 250A	up to 63A
Maximum charging power	-	-
Overvoltage category	CATIII	CATIII
Number of power contacts	3 (DC+/DC-/PE)	(L1/L2/L3/N/PE)
Rated Voltage for signal contacts	AC 30 V / DC 48 V	-
Rated current for signal contacts	2 A	-
Number of signal contacts	2 (CP, PP)	2 (CP, PP)

3.2.6. Inlet specifications

For the simulator acting as EV, the maximum electrical characteristics of the inlet for both AC and DC charging interfaces are:

Figure 5. Simulator CCS2 inlet

Table 2. Inlet electrical specifications

CCS2 Inlet electrical properties	
Rated voltage for power contacts	DC 1000 V
Rated current for power contacts	up to 250 A
Maximum charging power	-
Overvoltage category	CATIII
Number of power contacts	3 (DC+/DC-/PE)
Rated Voltage for signal contacts	AC 30 V / DC 48 V
Rated current for signal contacts	2 A
Number of signal contacts	2 (CP, PP)

4. Interoperability baseline protocol

This chapter will give an overview of the utilisation of the communication protocols for the charging applications released so far. The purpose is to summarize the scope of these standards to identify the different steps needed for V2X communication and energy transfer.

Afterwards, ISO15118-20 will be presented including a preliminary testing plan based on this regulation.

4.1. Baseline communication protocols overview

In order to analyse the protocols from zero, it is important to understand the application of each with regards to EV charging. The first concept that needs to be remarked is "communication". Two general types can be differentiated, "high-level communication" and "low-level communication" or basic/safety signalling.

"High-level communication" is used for exchange of charging parameters such as voltage, currents, remaining time for full/bulk SOC etc. It is mostly implemented via Power Line Communication (PLC) but for automated connection devices WLAN is also utilized. High level communication is specified in ISO 15118-2, which is included in ISO 15118-20, where an explanation of how to implement the following features is detailed.

- Identification
- Payment
- Load levelling
- Value Added Services.

"Low-level communication" is used to control the state of the charge, giving means to the EV and EV supply equipment to notify each other whether there are no issues, and the power flow is allowed, or it failure or potential error exists that needs the charging event to be stopped immediately. It is specified in IEC 61851-1, -23 and the items explained are the following:

- Vehicle states
- Control pilot handling for safety
- Control pilot handling for energy transfer initialization

Both types of communication need to be applied as the norm mandates, otherwise there cannot be interoperability.

Figure 16 is taken from ISO 15118-20 and shows the layer structure followed in the vehicle-to-grid communication and the protocols used per layer. Such communication between EVCC and SECC is based on a client/server architecture, which needs to move upwards on the OSI layer scheme to transfer a request/response and then go back, decoding all the added packets to process the data sent by the other part (SECC/EVCC).

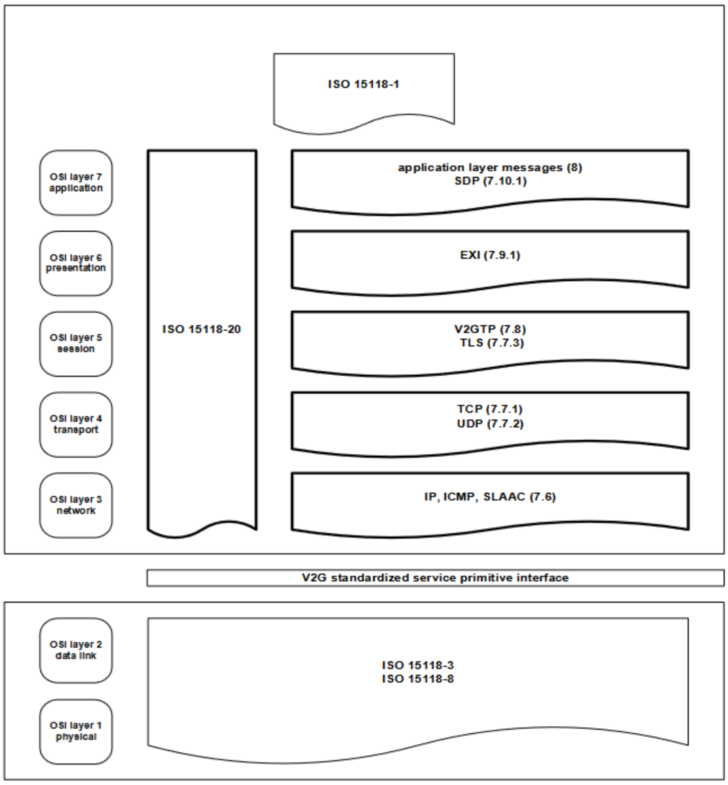

Figure 6: OSI Layers for V2G communication

Either for the communication protocols or electrical safety standards, a common sequence is identified for V2G charging. As it can be observed in *Figure 7*, the first step is the connection, followed by an initialization and validation of the service selected, and finally enabling the power flow itself.

Each step has multiple tests that need to be passed to move forward to the next phase.

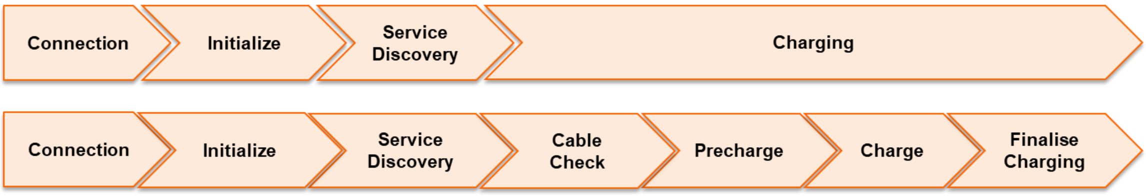

Figure 7: EV charging phases

The significance of ISO 15118-20 is so important, adding more complexity to the process of EV charging. The market pushes for new methodologies in accordance with the inclusion of new technologies like autonomous driving, wireless charging, bidirectional charging, smart charging etc. To cover this complexity, extensive testing needs to be performed.

To facilitate the task of validating the vehicle-to-grid communication, a basic test protocol is provided. The basic test plan is focused on performing the essential high-level communication parameter checks, which produce a high rate of charging failures.

4.2. ISO 15118 - 20 protocol

The significant change with ISO 15118-20 is that it includes all layers needed to communicate between EV and EVSE, such as:

- ISO 15118-2 Network and application protocol requirements
- ISO 15118-3 Physical data link requirements
- ISO 15118-8 Physical layer and data

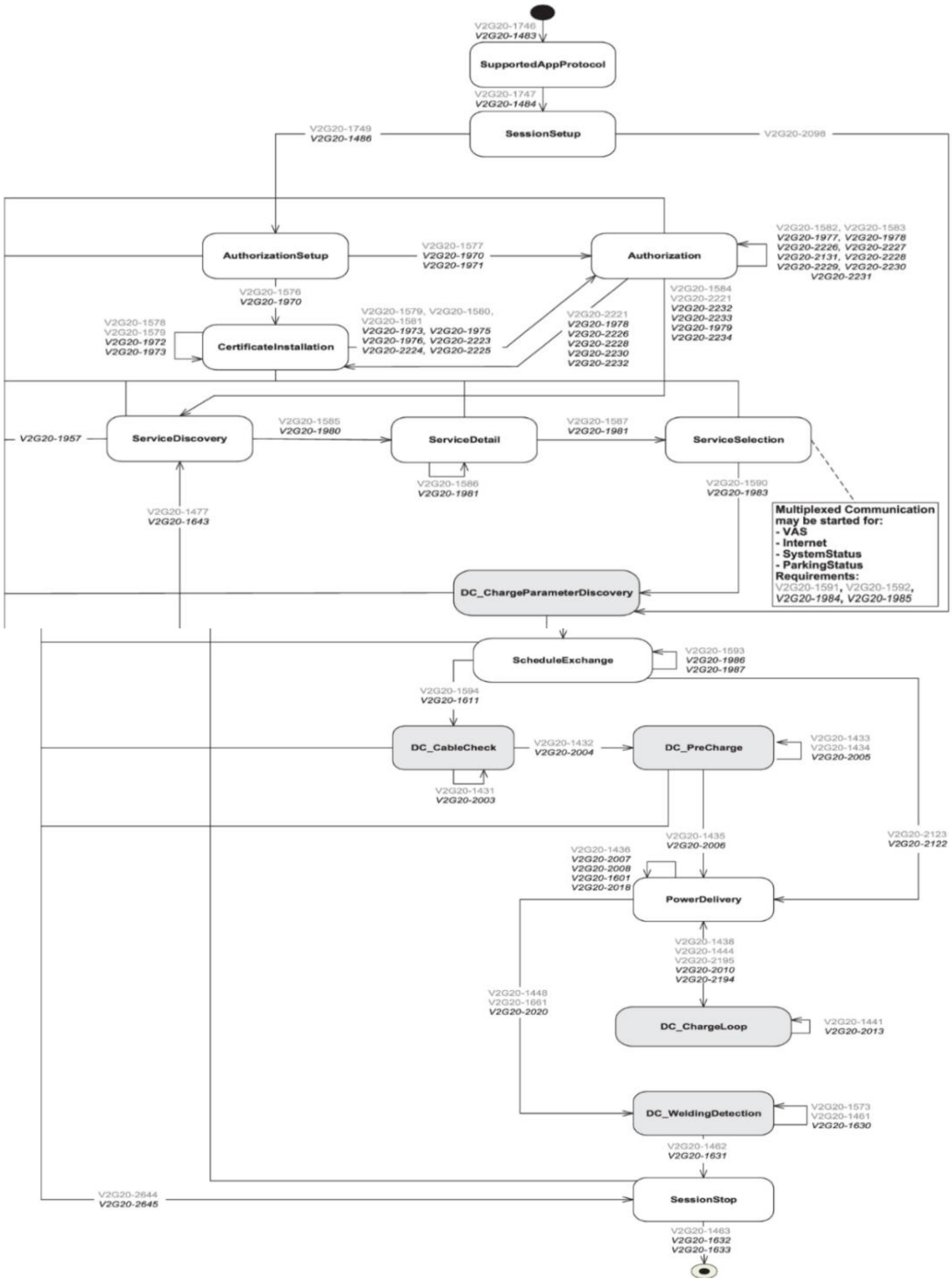

Figure 8: DC message sequence diagram from ISO 15118-20

Figure 8 shows a DC message sequence diagram that needs to be followed during a DC charge. By adding these messages, plenty of information from the EV and EVSE equipment configuration (SW and HW) is analysed at every attempt. If the specifications written over those parameters are not compatible between them (e.g. EVCC requires target voltage higher than SECC capabilities), the process is stopped safely.

During all these charging flow messages, EV and EVSE are both communicating its parameters (e.g Maximum Power Limit, Maximum Current Limit…) and also announcing if they are able to offer specific Value Added Services (VAS) and Bidirectional Power Transfer services (BPT).

This document will be focused on covering BPT services, including all messages and parameters that EV and EV Supply Equipment shall use in order to charge or discharge the Electric Vehicle.

4.3. Charging test plan

The charging test plan includes a deep and dedicated analysis of the V2G communication parameters and CP changing states. The charging steps followed in this tables are referred on ISO 15118 – 20

A V2G message uses the EXI-based Presentation Layer. The communication between EVCC and SECC is based on a client/server architecture. Throughout the charging process, the EVCC always functions as a client (service requester), whereas the SECC always functions as a server (service responder). As a result, the EVCC always starts communication by sending a request message to the SECC, which responds with a response message.

V2G communication consists of two different message sets:

- V2G application layer protocol handshake messages
- V2G application layer messages

This document will describe a test plan all the charging stages listed below. The normal charge session sequence will cover BPT parameters and regulations that will be followed when this service is demanded based on ISO 15118-20.

1. Pre-Test verifications
2. Normal Charge session sequence
3. Timing Application layer tests
4. Normal Stop process test
5. Energency Stop process test
6. Abuse Test
7. Power quality test

5. Interoperability safety recommendations

The safety framework employed for XL-CONNECT testing activities is based on a quantitative risk assessment approach that systematically identifies, analyses, and mitigates potential hazards. This methodology provides a structured foundation for developing effective safety protocols and ensuring consistent risk management throughout the project lifecycle.

5.1. Risk Evaluation Parameters:

Severity Classification (1-5 Scale):

- Level 1 (Minimal): Minor discomfort or inconvenience, no lasting effects
- Level 2 (Minor): Temporary injury requiring basic first aid
- Level 3 (Moderate): Injury requiring medical attention but no permanent disability
- Level 4 (Major): Serious injury resulting in significant disability or extended recovery
- Level 5 (Catastrophic): Life-threatening injury or fatality

Probability Assessment (1-5 Scale):

- Level 1 (Highly Unlikely): Extremely rare occurrence, theoretical possibility only
- Level 2 (Unlikely): Possible but improbable under normal conditions
- Level 3 (Possible): May occur occasionally under specific circumstances
- Level 4 (Likely): Probable occurrence during normal operations
- Level 5 (Highly Likely): Expected to occur frequently

Risk Level Calculation: Risk Level = Probability × Severity

Table 3: Risk and safety recommendations

#	Risk Category	Detailed Risk Description	Probability (1-5)	Severity (1-5)	Risk Level	Comprehensive Mitigation Strategies
1	Manual Handling Operations	Physical injuries associated with manual manipulation of heavy testing equipment, components, and infrastructure materials including musculoskeletal injuries, foot/toe crushing from dropped objects, back strain from improper lifting techniques, repetitive stress injuries	2	2	4	Primary Controls: Mandatory use of steel-toed safety boots (EN ISO 20345), implementation of mechanical lifting aids (cranes, hoists, dollies), ergonomic training programs for personnel, maximum weight limits for manual handling (25kg individual, 50kg team lift). Secondary Controls: Regular health monitoring, job rotation to prevent repetitive stress, proper warm-up exercises before physical tasks
2	Hand Tool Operations	Injuries resulting from use of manual tools during equipment installation, maintenance, and modification including: lacerations from sharp edges, puncture wounds from pointed tools, contusions from impact tools, eye injuries from debris/particles, minor electrical shocks from powered tools	3	2	6	Tool Management: Daily tool inspection protocols, tool-specific training certification, proper PPE (safety glasses, cut-resistant gloves, hearing protection). Work Procedures: Lockout/tagout procedures during modifications, proper tool selection matrices, mandatory tool maintenance schedules, secure tool storage systems
3	Slip, Trip, and Fall Hazards	Accidents caused by environmental conditions in testing areas including: cable routing across walkways, fluid spills from equipment, uneven surfaces, poor lighting conditions, weather-related surface conditions	2	2	4	Environmental Controls: Dedicated cable management systems with protective covers, immediate spill cleanup protocols, adequate lighting (minimum 500 lux in work areas), anti-slip surface treatments. Administrative Controls: Regular housekeeping inspections, designated walkways marked with high-visibility tape, weather monitoring protocols
4	Chemical Exposure	Health risks from exposure to chemicals used in battery systems, coolants, and cleaning agents including: respiratory irritation from vapours, skin contact with corrosive substances, eye contact with hazardous materials, fire/explosion risks from flammable materials	2	3	6	Engineering Controls: Proper ventilation systems (minimum 6 air changes/hour), chemical storage cabinets meeting regulatory requirements, emergency eyewash/shower stations within 15 meters of chemical use areas. Administrative Controls: Comprehensive SDS management system, chemical inventory tracking, spill response procedures, regular air quality monitoring

5	Thermal Hazards	Burns and heat-related injuries from equipment operating at elevated temperatures including: contact burns from charging cable handles, thermal burns from power electronics, heat stress from prolonged exposure, fire risks from overheated components	3	4	12	Engineering Controls: Thermal insulation on all surfaces exceeding 60°C, automatic temperature monitoring with alarm systems, heat-resistant marking labels on hot surfaces. PPE Requirements: Heat-resistant gloves (minimum 200°C rating), thermal imaging cameras for hot spot identification, cooling systems in enclosed work areas
6	Electrical Hazards	Life-threatening risks associated with high-voltage DC and AC systems including: electrocution from direct contact, electrical burns from arc flash, secondary injuries from electrical shock (falls, muscle contractions), equipment damage from short circuits	3	5	15	Engineering Controls: Double-insulated electrical systems, ground fault circuit interrupters (GFCI), arc fault detection systems, physical barriers preventing accidental contact. Administrative Controls: High-voltage work permits, qualified electrician requirements, minimum two-person rule for HV work, 10-minute discharge waiting period after disconnection. PPE: Class 1 insulated gloves (minimum 1000V rating), arc flash suits (minimum 8 cal/cm²), insulated tools, voltage testers
7	Vehicle Movement Hazards	Risks associated with vehicle operations in testing areas including: pedestrian strikes by moving vehicles, collision with stationary equipment, backing accidents, loss of vehicle control	2	4	8	Traffic Control: Designated vehicle routes with clear signage, speed limits (maximum 10 km/h in test areas), mandatory spotters for backing operations, vehicle-to-pedestrian communication systems. Infrastructure: Physical barriers separating pedestrian and vehicle areas, backup alarms on all vehicles, adequate lighting for nighttime operations
8	Electro-magnetic Interference	Equipment malfunction and data corruption caused by high-current operations including: electronic device failure, pacemaker interference, data acquisition system disruption, communication system interference	3	2	6	Technical Controls: EMI shielding on sensitive equipment, minimum safe distances for electronic devices (5 meters from high-current operations), regular EMC compliance testing. Administrative Controls: Electronic device restrictions in testing areas, pacemaker wearer identification and protection protocols, backup data systems
9	Fire and Explosion Hazards	Risks associated with high-energy electrical systems and battery operations including: electrical fires from system faults, battery thermal runaway, explosion from hydrogen gas accumulation, facility fire from external sources	2	5	10	Fire Prevention: Automatic fire detection and suppression systems (FM-200 gas systems in electrical areas), regular electrical system inspections, hydrogen gas monitoring in battery areas. Emergency Response: Trained fire response teams, specialized electrical fire extinguishers (Class C), emergency evacuation

						procedures, coordination with local fire department
10	Pressure System Hazards	Risks from pneumatic and hydraulic systems used in testing equipment including: high-pressure line rupture, compressed gas cylinder accidents, system overpressurization, flying debris from system failures	2	3	6	System Design: Pressure relief valves on all systems, regular pressure testing (annual certification), proper cylinder securing and handling procedures. Maintenance: Preventive maintenance schedules, qualified technician requirements, pressure system isolation procedures

5.2. Enhanced Safety Protocols and Procedures

5.2.1. Pre-Test Safety Verification:

- Comprehensive safety briefing for all personnel entering testing areas
- PPE inspection and verification ensuring proper fit and condition
- Equipment safety checks including electrical testing and mechanical inspection
- Environmental assessment evaluating weather, lighting, and workspace conditions
- Emergency procedure review confirming evacuation routes and emergency contacts

5.2.2. Ongoing Safety Management:

- Continuous safety monitoring with designated safety observers during high-risk operations
- Regular safety audits conducted by qualified safety professionals
- Incident reporting system with immediate investigation and corrective action protocols
- Safety performance metrics tracking leading and lagging safety indicators
- Continuous improvement process incorporating lessons learned and industry best practices

5.2.3. Emergency Response Capabilities:

- On-site medical facilities staffed with trained emergency medical technicians
- Direct communication with local emergency services and hospitals
- Specialized emergency equipment including electrical rescue tools and defibrillators
- Regular emergency drills testing response procedures and evacuation protocols
- Post-incident analysis with comprehensive investigation and corrective action implementation

6. Test results with CIRCONTROL

6.1. Testing methodology and scope

The comprehensive testing program executed in collaboration with CIRCONTROL represents a milestone validation effort for the XL-CONNECT project's bidirectional charging infrastructure. This extensive evaluation was structured as a multi-phase testing campaign designed to systematically validate all critical aspects of the V2X charging ecosystem.

6.1.1. Strategic Testing Framework

Testing Timeline and Milestones:

- Phase I (August 28th, 2024): Initial system integration and baseline functionality validation
- Interim Analysis Period: Data analysis, system optimization, and preparation for advanced testing
- Phase II (February 5th, 2025): Advanced V2X functionality and real-world scenario validation
- Total Program Duration: 6-month comprehensive evaluation with continuous monitoring
- Post-Testing Analysis: Extended 2-month period for results analysis and optimization recommendations

Comprehensive Test Objectives

Bidirectional Power Module Integration

- System-Level Compatibility Assessment: Validation of seamless integration between IDIADA's V2X emulator and CIRCONTROL's bidirectional charging infrastructure
- Power Electronics Validation: Assessment of power conversion efficiency, thermal management, and electromagnetic compatibility
- Safety System Integration: Verification of coordinated safety responses between vehicle emulator and charging station
- Performance Benchmarking: Comparison against industry standards and project specifications

ISO Standard Compliance Validation

- ISO15118-2 Protocol Testing: Comprehensive validation of digital communication protocols including message sequencing, timing requirements, and error handling
- ISO15118-20 Advanced Features: Testing of enhanced communication capabilities including bidirectional power transfer negotiations and advanced security features
- Interoperability Assessment: Cross-platform compatibility validation ensuring seamless operation across different manufacturer implementations
- Conformance Testing: Systematic verification of compliance with international charging standards

V2X Energy Management Optimisation

- Bidirectional Energy Flow Control: Validation of precise power flow management in both charging and discharging modes
- Grid Integration Testing: Assessment of grid-tie capabilities and utility-grade power quality requirements
- Energy Efficiency Analysis: Measurement of round-trip efficiency and system losses during V2X operations
- Dynamic Load Management: Testing of real-time load balancing and demand response capabilities

Departure Time Functionality Implementation

- Smart Scheduling Algorithms: Validation of intelligent charging/discharging scheduling based on user preferences and grid conditions
- Dynamic Control Mode Optimization: Critical functionality for managing charging and discharging power to the grid based on real-time conditions
- Predictive Energy Management: Testing of algorithms that optimize energy usage based on predicted departure times and energy costs
- User Interface Integration: Validation of seamless user interaction for departure time configuration and monitoring

6.1.2. Advanced Testing Methodologies

Automated Test Execution Framework:

- Scripted Test Sequences: Automated execution of repetitive test scenarios ensuring consistency and reducing human error
- Real-Time Data Acquisition: Continuous monitoring of electrical parameters, communication messages, and system status
- Comprehensive Logging System: Detailed recording of all test events for post-analysis and troubleshooting
- Statistical Analysis Tools: Advanced data processing for trend identification and performance optimization

Environmental Testing Conditions:

- Power Quality Variation Testing: Assessment of system performance under grid voltage and frequency variations

6.2. Technical assessment results

6.2.1. Bidirectional Power Module Evaluation

Initial Focus Area: *System integration validation of the bidirectional power module*

The primary testing phase concentrated on the bidirectional power module as this component had not undergone previous system-level integration testing. Critical assessment parameters included:

- Power flow direction management
- System response timing
- Integration stability metrics
- ISO Protocol Compliance Testing

Standards Evaluated:

- ISO15118-2 - Digital communication protocol validation
- ISO15118-20 - Advanced communication standard assessment

Both protocols were demonstrated as being successful implementated with the Demo charger architecture, confirming compliance with international charging standards.

6.2.2. OPERATIONAL TESTING SCENARIOS

EV Charging and Discharging Operations

Testing Platform: BPT Dynamic System

Key Test Parameters:

- Charging termination protocol from EV side
- Maximum Current management (set to 0 A for termination)
- Power reduction validation (threshold: <5 A detection)

Departure Time Functionality Assessment

Simulated Testing Phase

- Status: Completed without issues
- Performance: ***All simulated departure time scenarios executed successfully***

Real-World Testing Phase

- Critical Issue Identified: ***Discharge functionality complications***
- Specific Problem: Voltage increase anomaly during charging resumption
- Impact Level: ***High priority resolution required***

6.2.3. ADVANCED SYSTEM ANALYSIS

BSIM Mode Operational Issues

Problem Identification:

- Mode Switching Error: BSIM mode inappropriately transitions to Constant Voltage (CV) mode
- Trigger Condition: ***Occurs during charging-to-discharging transition***
- System Impact: ***Operational stability compromised***

System Updates and Enhancements

Implemented Improvements:

- Departure Time Counter - ***Updated algorithm implementation***
- V2X Energy Request States - ***Enhanced functionality development***
- Operational Parameters - ***Refined state management protocols***

6.2.4. V2X CYCLING VALIDATION

Cycling Test Parameters

- Test Protocol: V2X bidirectional energy cycling
- Timing Configuration: ***Charge termination 3 minutes before Departure Time***
- Performance Metric: Successful implementation achieved

6.2.5. ADVANCED PARAMETERS TESTING

Validated Parameters:

- ParameterSetID - ***Configuration identification protocols***
- ServiceID - ***Service classification management***
- StateB in Cable Check - ***Connection state validation***

Additional Test Scenarios:

- Incorrect Message Sequence Handling - ***System robustness validation***
- V2X Zone Management - ***Dynamic zone increase/decrease operations***

6.3. Test conclusions and recommendations

6.3.1. Critical Findings

- Successful ISO Standard Implementation - *Both ISO15118-2 and ISO15118-20 protocols validated*
- Bidirectional Power Management - ***Core functionality operational with noted optimization areas***
- System Integration Challenges - ***Specific issues identified requiring resolution***

6.3.2. Priority Action Items

- BSIM Mode Stability - ***Address CV mode transition issues***
- Departure Time Optimization - ***Resolve voltage anomaly during charge resumption***
- V2X Parameter Refinement - ***Continue advanced parameter testing protocols***

6.3.3. Strategic Recommendations

- Immediate: ***Address critical operational issues identified during real-world testing***
- Short-term: ***Implement enhanced V2X energy management algorithms***
- Long-term: ***Develop comprehensive system monitoring and diagnostic capabilities***

7. Test results with ABB

7.1. Testing methodology and scope

A comprehensive series of tests has been conducted with ABB within the scope of the European innovation project XL CONNECT. The objective is to perform the maximum possible range of tests to provide support for new market products in the V2X charging sector.

7.1.1. Strategic Testing Framework

- Phase I (September 2025): Initial system integration and baseline functionality validation
- Total Program Duration: 6-month comprehensive evaluation with continuous monitoring
- Post-Testing Analysis: Extended 2-month period for results analysis and optimization recommendations

Comprehensive Test Objectives

Bidirectional Power Module Integration

- Commissioning of the ***ABB Terra Nova 11 J 11kW*** charger. It has a CHADEMO version, and now, in conjunction with the project XL CONNECT, a CCS2 version with ISO15118-20 has been launched to meet the objective of implementing Vehicle-to-Grid (V2G) functionality.
- Power Electronics Validation: Assessment of power conversion efficiency, thermal management, and electromagnetic compatibility
- Safety System Integration: Verification of coordinated safety responses between vehicle emulator and charging station

V2X Energy Management Optimisation

- Implementation of ABB backend system for generating V2X charging and discharging profiles. With this backend infrastructure, ABB will be capable of generating charging profiles and adjusting in real-time the charging or discharging of multiple vehicles in Dynamic Control Mode through ISO15118-20 protocol.

- The energy consumed by the charger will be considered to ensure that the grid is capable of both delivering and absorbing the power that may be injected back into the grid

ISO Standard Compliance Validation

- ISO15118-2 Protocol Testing: Comprehensive validation of digital communication protocols including message sequencing, timing requirements, and error handling
- ISO15118-20 Advanced Features: Testing of enhanced communication capabilities including bidirectional power transfer negotiations and advanced security features
- Conformance Testing: Systematic verification from IDIADA of compliance with international charging standards checking all charging stages that involve V2X

7.1.1. Advanced Testing Methodologies

Automated Test Execution Framework:

- Usage of an internal IDIADA plugin for ISO 15118-20 which decodes frames exchanged between EV and EVSE to observe the entire payload and verify compliance with regulatory standards
- Real-Time Data Acquisition: Continuous monitoring of electrical parameters from IDIADA emulator side, in both communication between EV and EVSE, and real voltage and current values measured on both EV (IDIADA simulator) and EVSE (ABB Charger) sides

Environmental Testing Conditions:

- Power Quality Variation Testing: Assessment of system performance under grid voltage and frequency variations

7.2. Technical assessment results

7.2.1. Bidirectional Power Module Evaluation

The primary testing phase concentrated on the bidirectional power module as this component had not undergone previous system-level integration testing. Critical assessment parameters included:

- Power flow direction management (Normal DC Service and DC BPT Service)
- System response timing (Timeouts and Performance timings updated on ISO 15118-20)
- Integration stability metrics within ABB module

Standards Evaluated:

- ISO15118-2 - Digital communication protocol validation
- ISO15118-20 - Advanced communication standard assessment

Both protocols were demonstrated as being successful implementated with the ABB charger architecture, confirming compliance with international charging standards.

7.2.1. OPERATIONAL TESTING SCENARIOS

EV Charging and Discharging Operations

Testing Platform: BPT Dynamic System

Key Test Parameters:

- Charging termination protocol from EVSE side
- Manage charging /discharging profiles on real time checked by ABB backend

7.2.2. V2X CYCLING VALIDATION

Cycling Test Parameters

- Test Protocol: V2X bidirectional energy cycling
- Performance Metric: Configure ABB charger ***1 minute charging / 1 minute discharging*** cycling at maximum power (11kW)

7.2.3. ADVANCED PARAMETERS TESTING

- ParameterSetID – ***Different services and control modes offered (only Dynamic tested)***
- ServiceID - ***Service classification management (2 – DC & 6 – DC BPT)***
- Invalid CP state at critical stages (Insulation and chargign stages) – ***Error state before and during charging***
- Incorrect Message Sequence Handling - ***System robustness validation***
- EV and EVSE normal stop – ***Normal stop before and during charging from both sides***
- Timeouts and Sequcence timings check – ***Force ABB charger to timeout messages and check the performance timings at every chargng stage***

7.3. Test conclusions and recommendations

7.3.1. Critical Findings

- Integration of charging profiles with their backend system and power module ***- Initiation of sessions in discharge mode***

7.3.2. Strategic Recommendations

- Incorporate CharIN recommendations regarding the Annex of IEC 61851-23 focused on bidirectionality - ***EV Maximum Current Charge / EV Maximum Current Discharge and Departure Time for stops in Dynamic Control Mode***
- Incorporate enhanced V2X energy management algorithms – ***Update and incorporate V2X features for ABB backend***
- Integrate to ISO 15118-20 new parameters used previously for DC Service – ***EVSE Present Current***

8. Normative list

List of normatives that affects the development for the XL-CONNECT project

Table 4: List of normatives that apply

Primary Charging and Communication Standards	ISO 15118 Series - Vehicle to Grid Communication Interface: • ISO 15118-1:2019 - General information and use-case definition • ISO 15118-2:2019 - Network and application protocol requirements • ISO 15118-3:2015 - Physical and data link layer requirements • ISO 15118-4:2018 - Network and application protocol conformance test • ISO 15118-8:2020 - Physical layer and data link layer requirements for wireless communication • ISO 15118-20:2022 - Network and application protocol requirements (2nd generation) IEC 61851 Series - Electric Vehicle Conductive Charging System: • IEC 61851-1:2017 - General requirements • IEC 61851-21:2001 - Electric vehicle requirements for conductive connection to an AC/DC supply • IEC 61851-22:2001 - AC electric vehicle charging station • IEC 61851-23:2014 - DC electric vehicle charging station • IEC 61851-24:2014 - Digital communication between a DC EV charging station and an electric vehicle

9. Conclusions

The XL-CONNECT project has successfully demonstrated the technical feasibility and operational capability of advanced V2X charging technology through comprehensive testing at IDIADA facilities. The collaboration with CIRCONTROL and ABB have validated both ISO 15118-2 and ISO 15118-20 protocol implementations while identifying specific optimization areas for commercial deployment.

Key Achievements:

- Successful bidirectional power module integration at system level
- Complete validation of V2X energy management and departure time functionality
- Comprehensive safety framework development with quantitative risk assessment
- Advanced testing infrastructure demonstration with global standards support.

Critical Areas for Resolution:

- BSIM mode stability issues requiring algorithm optimization
- Departure time and more parameters for EV stop in Dynamic mode functionality nomaly resolution
- Continued V2X parameter refinement for enhanced performance from grid's perspective

Project Status:

- Advanced development stage with identified optimization requirements for commercial readiness.

Commercial Timeline:

- Dependent on resolution of identified critical issues and continued system enhancement

Market Impact:

- Significant potential for transforming EV charging infrastructure with proven V2X capabilities and comprehensive international standards compliance.

The project has established a solid foundation for V2X technology deployment while providing clear guidance for final optimization steps required for commercial success.

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11. Abbreviations and Definitions

Abbreviation	Term
AC	Alternative Current
ACD	Automatic Connection Device
CAN	Controller Area Network
CCS	Combined Charging System
CP	Charging Point
CPO	Charging Point Operator
DC	Direct current
DSO	Distribution System Operator
EMC	Electro Magnetic Compatibility
EOL	End-Of-Life
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
MF-WPT	Magnetic Field Wireless Power Transfer
PLC	Power-Line Communication
PPP	Public Private Partnership
USA	United States of America
V1G	Vehicle unidirectional to Grid
V2G	Vehicle to Grid
V2X	Vehicle to Everything
WP	Work Package
WPT	Wireless Power Transfer

12. List of figures and tables