unIT-e²: ACHIEVING SYSTEM INTEROPERABILITY – A LONG AND ROCKY ROAD AHEAD?

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Abstract

Interoperability is crucial in the electromobility ecosystem as it ensures seamless integration and operation of electric vehicles (EVs) across energy grids and charging infrastructures. In this context, interoperability is vital to prevent disruptions in EV charging and support the scaling of e-mobility solutions. The unIT-e² project highlights the importance of interoperability through its standard-based smart charging solutions and comprehensive testing efforts, especially during the unIT-e² Plugfest. This event was a key platform for evaluating interoperability across various systems and components involved in the so-called clusters of the project. Interoperability was measured in terms of semantic, pragmatic, and dynamic aspects, with each layer addressing different communication and operational needs. The findings from the Plugfest indicated that while pragmatic interoperability was achieved, dynamic interoperability—related to the interchangeability of components—presented challenges. Based on these insights, the project recommends increased standardization of communication protocols alongside continuous and rigorous testing of system integration in real-world scenarios. These recommendations aim to enhance the reliability and efficiency of the electromobility ecosystem, paving the way for broader adoption and smoother operation of EVs in the future.

1 Introduction

During the energy transition, power generation in the energy supply system is becoming increasingly decentralized, increasing the need for control effort and requiring more digitalization and interconnection of the individual components. Therefore, interoperability is becoming increasingly important to ensure the smooth interaction of components. Without interoperability, systems may face significant challenges, including compatibility issues, data silos, and inefficiencies that can hinder innovation and the integration of modern technologies. Interoperability also supports scalability, as it allows for the easy integration of new components or technologies into existing systems without requiring extensive reconfigurations. Additionally, in a rapidly evolving technological landscape, ensuring interoperability helps protect investments in infrastructure by allowing them to adapt to future advancements, such as bidirectional charging or more sophisticated energy management systems. This flexibility is vital for the long-term success and sustainability of complex systems like the smart charging ecosystem.

The unIT-e² project, funded by the German Federal Ministry for Economic Affairs and Climate Action, is driving the integration of electric vehicles in energy grids, markets, and functional chains by developing and testing smart charging concepts. The solutions developed in four so-called clusters are intended to be interoperable and contribute to target-oriented standardization to ensure a successful market ramp-up of electromobility. The field trials in the clusters focus on EV smart charging at work and charging at home and the integration into the energy system. To this end, partners from all sectors with interfaces to electromobility are involved in the project, including companies from the automotive industry, grid operators, energy suppliers, charging infrastructure operators, aggregators, and research. During the project, the developed solutions were evaluated and tested regarding their interoperability as part of a Plugfest. This paper describes the results and provides recommendations for action.

2 Interoperability: A methodological basis

The subject of interoperability is used in many industries, such as healthcare, aviation, military, and energy. Definitions of interoperability have been created in each of these domains based on the demands of their respective disciplines [1]. Ford et al. discovered 34 established different meanings of the term [2]. The Institute of Electrical and Electronics Engineers (IEEE) defines interoperability as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged” [3]. The International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) stipulates that functionality must be guaranteed, even if there is little or no knowledge of the specific characteristics of the individual units. Due to the broad nature of the term, interoperability has been subdivided. Rezaei provides a solid overview of the four categories that make up the most frequent division, which is technical, syntactical, semantical, and organizational interoperability [1].

Common standards must be established to achieve interoperability. These standards include a wide range of components, including data displays, system borders, user interfaces, protocols for data interchange, and interfaces for data access or system operations. Effective collaboration across varied systems from different sources is more likely when several suppliers widely accept these standards. It is crucial to understand that, despite its advantages, standards compliance does not ensure interoperability. The presence of choices within standards and the many product releases and versions increase this complexity. Furthermore, it is essential to recognize that technical standards are fundamental yet intrinsically inadequate for designers of systems or components. [4]

Interoperability across different software systems is becoming increasingly necessary, highlighting its expanding significance [1]. Interoperability is acknowledged as a fundamental component in system-of-systems engineering, and finding the ideal balance calls for creating more organized and effective technical approaches [5]. Numerous advantages can result from interoperability, such as decreased system integration costs and efforts, increased performance and efficiency, improved cybersecurity and security procedures, increased customer choice and participation, the creation of industry-wide best practices, and the ability to spur innovation [6].

Various measuring techniques have also been created based on the many interpretations of interoperability and the different domains it applies to. Rezaei offers a thorough analysis of them [1]. This work uses Level of Conceptual Interoperability (LCIM) method which was originally developed by Tolk and adapted by Axelsson [5,7]. It follows the seven level model shown in Table 1.

Table 1 Levels of Conceptual Interoperability (LCIM) [5]

Level	Layer	Premise	Information defined
6	Conceptual	Conceptual model	Assumptions, constraints
5	Dynamic	Execution model	Data effect
4	Pragmatic	Workflow model	Use of data
3	Semantic	Reference model	Data meaning
2	Syntactic	Data structure	Data structure
1	Technical	Communication protocol	Bits and bytes
0	None	No connection	None

LCIM describes the maturity levels of interoperability in seven gradations. A system with level 0 is not interoperable. A system with level 6 is fully interoperable. If the digital interfaces have a common reference model (e.g., OSI or TCP/IP), level 3 (semantic) interoperability can be assumed. A system has reached level 4 (pragmatic) interoperability if the transmitted data can be processed correctly. Further Tolk defines pragmatic interoperability "when the interoperating systems are aware of the methods and procedures that each other are employing. In other words, the use of the data – or the context of its application – is understood by the participating systems; the context in which the information is exchanged is unambiguously defined" [8]. If the system performs the desired actions with the received data, this is referred to as level 5 (dynamic) interoperability. Tolk states that "as a system operates on data over time, the state of that system will change, and this includes the assumptions and constraints that affect its data interchange. If systems have attained Dynamic Interoperability, then they are able to comprehend the state changes that occur in the assumptions and constraints [8]." In terms of the Plugfest, we define pragmatic interoperability when the base case instant charging works. Dynamic interoperability is achieved when a state change takes place, i.e. when a use case other than the base case is implemented.

One of the main benefits of interoperability is that it gives charging station operators independence by removing their reliance on certain system vendors. Operator resilience is conferred using universal communication protocols like the Open Charge Point Protocol (OCPP). Existing components readily integrate into another provider's infrastructure if a system supplier ceases operations, guaranteeing continuity and operational stability. The smooth charging process is an essential component of the electric vehicle (EV) user experience. Interoperability is essential for resolving compatibility issues across various EV models and charging stations [9]. Interoperability is no longer only a technical consideration; it now plays a significant role in determining how well electric mobility solutions penetrate the market and are received by the public [10]. The need for compatibility is a severe problem affecting EV charging networks' dependability and user experience. Customer discontent can result in a loss in market acceptance due to frustrating encounters caused by a lack of interoperability.

Interoperability affects everything from the immediate field of EV charging to the field where e-mobility and the energy environment intersect. New stakeholders such as energy suppliers, aggregators, distribution and transmission grid operators, metering operators and new components such as smart meters, home energy management system, and other control devices increases the complexity of the ecosystem and the underlying IT landscape experiences a substantial increase. Additionally, new charging solutions such as wireless, bidirectional, or high-powered charging present further challenges. Multiple, frequently conflicting protocols add layers of complexity. For example, communication standards in energy-oriented field are derived from automation standards for electrical devices. In contrast, specialized standards are found in industrial systems, building automation, and automotive technology industries. The complex web of interoperability issues at the technical and communication protocol levels reflects how dynamically dispersed energy supplies are integrated into the changing electromobility scenario. [11] Regarding communication protocols used in the electromobility ecosystem, Schriewer provides an overview of used standards and their maturity [10]. Further, Ostermann et al. describe the most relevant norms and standards regarding this work [12].

As interoperable solutions are one the main the goals of the unIT-e^2 project, the project developed standard-based solutions to improve seamless grid integration of EVs, enable various smart charging use cases, enhance experience for end users, promote collaboration and improve the implementation of standards and norms.

3 The unIT-e² Plugfest: Evaluating Interoperability

To achieve reliable and comparable results, the four different smart charging systems developed in the four unIT e² implementation clusters were tested in parallel and interchangeably during the so-called unIT-e² Plugfest. The technical systems of the four clusters differ regarding the technical components and corresponding digital interfaces for communication and data transmission. The findings below are based on [13,14].

The systems can be described as so-called functional chains (see Figure 1). The functional chains of the Harmon-E, sun-E, and Cit-E-Life clusters consist of an EV, a charging station (EVSE), an energy management system (EMS), an intelligent measuring system (iMSys) - consisting of a smart meter gateway (SMWG), a modern measuring device (mME) and a control device (CD) - as well as downstream systems of the metering point operators (MPO) [15]. The functional chains, therefore, have four relevant interfaces (1 to 4 in Figure 1), which were tested for interoperability. In contrast, the Heav-E cluster controls the EVSE from an EVSE backend. Consequently, only interface 1 between EV and EVSE could be tested for interoperability.

During the two-day event, over 50 experts from 26 companies discussed the interoperability of 21 technical systems and components at the four interfaces shown in Figure 1.

Interoperability was systematically determined in three test sessions:

- Session 1 aimed to first test the respective cluster chains as initially designed and test for pragmatic interoperability (Instant Charging) and afterward for dynamic interoperability (LPC, CEVC, MPC, MGCP).
- In session 2 the EVs were swapped one after the other on interface 1 (EV to EVSE). The other components and interfaces remained unchanged. As in session 1, pragmatic interoperability was tested first and dynamic interoperability second.
- In session 3, the interoperability of interfaces 2 and 3 was tested by swapping the EMS systems.
- In session 4, it was possible to test self-defined test cases outside the systemic determination of interoperability. The results obtained of session four are not part of this work.

To ensure the comparability of the various test cases, a structured test execution is essential in addition to the systematic modification of the test setups. To this end, detailed test steps were defined and provided to every participant in a document. Each test step could thus be directly documented as being carried out (successful, failed, or aborted) and commented on via a separate free text field.

The following use cases were examined:

- Base case: Instant charging
- Power limitation of the charging process to test the implementation of § 14a EnWG (e.g., via EEBus Limit of Power Consumption - LPC)
- Smart charging (e.g., via EEBus Coordinated EV Charging - CEVC) to implement self-consumption optimization, peak shaving, or price-optimized charging
- Meter values acquisition for querying relevant measured values (e.g., via EEBus Monitoring of Power Consumption - MPC and Monitoring of Grid Connection Point - MGCP)

3.1 Semantic Interoperability: LCIM Level 3

The interoperability between the systems developed and field-tested in the four unIT e² implementation clusters, Harmon-E, Heav-E, Sun-E, and Cit-E-Life, was measured up to LCIM Level 3 using a questionnaire that examines the interfaces for standard reference models. Tolk explains that semantic, syntactical, and technological interoperability may be presumed if a standard information exchange reference model is employed, as stated for the third level in the LCIM [7]. It is widely recognized that both the OSI and the TCP/IP paradigm are useful for creating interoperability, especially regarding semantics [16,17]. These models provide an standardized method for specifying the syntactic, semantic, and technological interoperability components with their multiple levels. The OSI model is essential for standardizing network systems, streamlining product development, and guaranteeing smooth communication across various networks. It comprises seven layers, ranging from Physical to Application [16]. The outcomes of the questionnaire were then contrasted for every interface to achieve interoperability in terms of semantics. Interoperability up to semantics (LCIM Level 3) can be presumed if the components of an interface employ the same standards and reference models. This is confirmed by examining if both parties have completed compliance tests or similar tests. A comparison is also made about whether the same IT security requirements have been implemented to

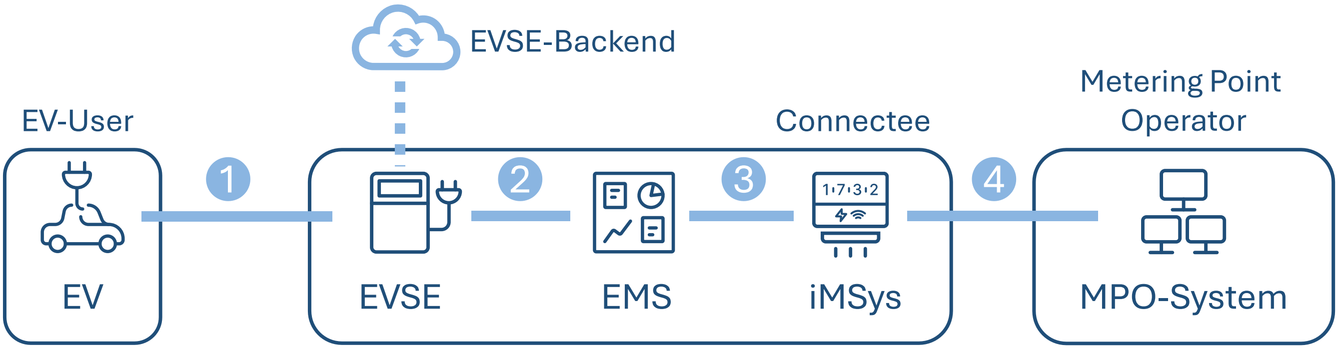

Fig. 1 Simplified functional chain for the unIT-e² field trials; four relevant interfaces highlighted with numbers 1 to 4

ensure no barriers to data interchange. Level 3 interoperability is given in all clusters.

Interface 1 uses ISO 15118-2 in all clusters or ISO 15118-20 in exceptional cases. Semantic interoperability can be assumed here due to the (partially) simultaneous application of the standard in EV and EVSE.

Except for Heav-E, all clusters at interface 2 use EEBus with the corresponding reference models (SHIP and SPI-NE). For these cases, semantic interoperability is also given if the corresponding EEBus use cases are implemented on both sides of the interface. Heav E uses the OCPP 1.6J protocol, supported by the EVSEs used in Harmon-E, Sun-E, and Cit-E-Life, in the above-mentioned deviating structure at interface 2 to control the EVSE. This ensures semantic interoperability across cluster boundaries for all EVSEs except Heav E.

The cluster Sun-E combines EMS and CD in one technical component. Interface 3 exhibits semantic interoperability but cannot be tested for pragmatic and dynamic interoperability due to the inseparability of EMS and CD. Two different EMS manufacturers are represented in Harmon-E, which, as in Cit-E-Life, use the same reference models (EEBus SHIP and SPINE). Semantic interoperability is therefore guaranteed here. Different protocols are used at interface 4 (e.g., in Harmon-E CLS.EEDI, Sun-E IEC 61850). Semantic interoperability in the clusters is guaranteed here, but dynamic interoperability is impossible due to the different communication protocols.

3.2 Pragmatic Interoperability: LCIM Level 4

The instant charging of all vehicles without a particular use case was successfully demonstrated in Session 1-3. Therefore, all clusters and sessions demonstrated pragmatic interoperability.

3.3 Dynamic Interoperability: LCIM Level 5

The dynamic interoperability at interface 1 (EV to EVSE) examined in sessions 1-3 was achieved for most tested cases. However, problems were observed when implementing the power limitation (EEBus LPC and CEVC) when the power limit was gradually lowered. Testing the power limitation via EEBus LPC and CEVC on interfaces 2 and 3 in conjunction with ISO 15118-2 on interface 1, problems occurred with low power specifications.

The charging process was interrupted in several cases when the power limit was below 1.5 kW. In the tests, restarting the charging process was only possible by disconnecting and reconnecting the EV to the EVSE. Deleting the power limitation was not sufficient. This behavior might be because the minimum charging power required by the EV was not reached in these cases. If a power limitation with low power is applied via EEBus LPC during a smart charging process via EEBus CEVC using an ISO 15118-2 EV, the charging problems described above can also occur if no renegotiation of the charging plan is triggered. The reason for this may be an excessive deviation from the charging power agreed via ISO 15118-2 for the duration of the power limitation. This is not a problem in practice for the LPC use case, as the legally prescribed minimum power according to § 14a EnWG is 4.2 kW.

The tests carried out during session 3 at interfaces 2 could not be completed without errors in any of the cases. The evaluation of the test protocols shows that there is room for improvement in various areas.

The results show that using standards is needed for the goal of interoperability in the future energy system. Standard reference models already ensure semantic interoperability at every interface under consideration. The most important findings from the unIT-e² Plugfest relate to dynamic interoperability (LCIM Level 5), i.e., to cases where components are exchanged along the functional chain. This shows that there is still room for improvement at the three interfaces where interoperability makes sense. Although dynamic interoperability could be demonstrated at interface 1 for the use cases examined, unexpected problems also occurred here.

4 Conclusion

In general, the testing approach and evaluation methodology of the unIT-e² Plugfest is regarded as a blueprint of assessing interoperability of the complex technical system associated with smart and bidirectional charging of electric vehicles.

One reason for the identified interoperability problems is that, despite uniform reference models, there is often scope for interpretation in the technical implementation of the standards, which applies to ISO 15118-2 (interface 1). One example is the reference times for charging plans and incentive tables, where the EVSE must monitor compliance with the charging plan and offer scope for interpretation. Another is the minimal and maximal number of nodes to calculate the charging plans. ISO 15118-20 already represents a significant improvement in this respect.

More specifically, the findings reveal four recommendations for action:

Recommendation 1: Since the implementation of power limitation with EEBus LPC, CEVC, and ISO 15118-2 can currently still lead to errors in the charging process, it is currently recommended to use pulse width modulation (PWM) charging for the implementation of § 14a EnWG in a mass market geared towards customer satisfaction.

Recommendation 2: The EEBus CEVC standard should be revised. Better matching the data points to the equivalents of ISO 15118-2 can lead to better compatibility of the two standards and resolve the problems described.

The findings from unIT-e² will be incorporated before the CEVC standard is republished.

Recommendation 3: Renegotiating the charging plan is necessary if an LPC limit is to be applied to an active CEVC charging process with ISO 15118-2 EVs. This renegotiation should be implemented so robustly that it does not lead to the charging process being aborted.

Recommendation 4: In the future, ISO 15118-20 Dynamic Mode should be established as the standard for smart charging (uni- and bidirectional). Due to the more mature specification of section -20 of the standard, fewer implementation complications are expected here.

Finally, testing the functional chains in different constellations, such as the unIT-e² Plugfest, is an essential means of identifying the development potential of standards. Comparable events such as the "EEBus Plugfest" or the "CharIN Testival" are therefore highly recommended for the successful ramp-up of smart and bidirectional charging in the future.

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6 References

References

[1] Rezaei, R.; Chiew, T.K.; Lee, S.P.; Shams Aliee, Z. Interoperability evaluation models: A systematic review. Computers in Industry 2014, 65, 1–23, doi:10.1016/j.compind.2013.09.001.

[2] Ford, T.; Colombi, J.; Graham, S.; Jacques, D. Survey on Interoperability Measurement 2007, 67.

[3] Geraci, A.; Katki, F.; McMonegal, L.; Meyer, B.; Lane, J.; Wilson, P.; Radatz, J.; Yee, M.; Porteous, H.; Springsteel, F. IEEE Standard Computer Dictionary: Compilation of IEEE Standard Computer Glossaries. In , 1991.

[4] Kasunic, M. Measuring Systems Interoperability: Challenges and Opportunities 2001, 40.

[5] Axelsson, J. Achieving System-of-Systems Interoperability Levels Using Linked Data and Ontologies. INCOSE International Symp 2020, 30, 651–665, doi:10.1002/j.2334-5837.2020.00746.x.

[6] Widergren, S.; Melton, R.; Khandekar, A.; Nordman, B.; Knight, M. The Plug-and-Play Electricity Era: Interoperability to Integrate Anything, Anywhere, Anytime. IEEE Power and Energy Mag. 2019, 17, 47–58, doi:10.1109/MPE.2019.2921742.

[7] Tolk, A.; Muguira, J. The Levels of Conceptual Interoperability Model. In , 2003.

[8] Tolk, A.; Turnitsa, C.; Diallo, S. Ontological implications of the levels of conceptual interoperability model. Proc. 10th World Multi-conf. on Systemics, Cybernetics and Informatics 2006, 105–111.

[9] Buamod, I.; Abdelmoghith, E.; Mouftah, H.T. A review of OSI-based charging standards and eMobility open protocols. In 2015 6th International Conference on the Network of the Future (NOF). 2015 6th International Conference on the Network of the Future (NOF), Montreal, QC, Canada, 30 Sep.–02 Oct. 2015; IEEE, 2015; pp 1–7, ISBN 978-1-4673-8386-8.

[10] Schriewer, L.; Farkas, J. Importance of Interoperability for a seamless EV Charging Experience. 36th International Electric Vehicle Symposium and Exhibition (EVS36).

[11] Kippke, M.A.; Arboleya, P.; El Sayed, I. Communication Infrastructure for E-Mobility Charging Stations V2G Applications. In 2020 8th International Conference on Power Electronics Systems and Applications (PESA). 2020 8th International Conference on Power Electronics Systems and Applications (PESA), Hong Kong, China, 07–10 Dec. 2020; IEEE, 2020; pp 1–3, ISBN 978-1-7281-9382-3.

[12] Ostermann, A.; Hawran, J.; Sylla, S.; Dossow, P. From Electromobility Use Cases to an Interactive System Architecture: the Harmon-E SysArc in the unIT-e² Project. In ETG Congress 2023, 2023; pp 1–8.

[13] Hawran, J.; Ostermann, A.; Vollmuth, P.; Boldt, M.; Abromeit, A.; Krug, F.; Behringer, C.; Zilg, J.; Ruland, H.; Werduen Guido; et al. Umsetzung der Leistungslimitierung (§ 14a EnWG) über EEBus LPC und Smart Charging über EEBus CEVC in Verbindung mit ISO 15118-2 und -20: Herausforderungen und Handlungsempfehlungen aus dem unIT-e² Plugfest. Available online: https://unit-e2.de/media/unIT-e%C2%B2-Plugfest-Whitepaper-Auswertungen-Leistungslimitierung.pdf (accessed on 19 June 2024).

[14] Vollmuth, P.; Hawran, J.; Ostermann, A.; Krug, F.; Boldt, M.; Abromeit, A.; Behringer, C. Interoperabilität im Energiesystem der Zukunft: Erkenntnisse aus dem unIT-e² Plugfest. Available online: https://unit-e2.de/media/unIT-e%C2%B2-Plugfest-Whitepaper-Ergebnisse-Handlungsempfehlungen.pdf (accessed on 18 June 2024).

[15] Köppl, S.; Hinterstocker, M.; Wendlinger, E.; Battersby, D. unIT-e² - Reallabor für verNETZte E-Mobilität. Available online: https://unit-e2.de/.

[16] Howser, G. The OSI Seven Layer Model. In Computer Networks and the Internet; Howser, G., Ed.; Springer International Publishing: Cham, 2020; pp 7–32, ISBN 978-3-030-34495-5.

[17] Meinel, C.; Asjoma, M. TCP/IP-Protokoll Betriebssystem des Internets. In Die neue digitale Welt verstehen; Meinel, C., Asjoma, M., Eds.; Springer Berlin Heidelberg: Berlin, Heidelberg, 2021; pp 78–83, ISBN 978-3-662-63700-5.