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Demonstration of bidirectional charging using ISO 15118-20

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Executive Summary

This project shows a cutting-edge bidirectional charger from Watt&Well, compatible with CHAdeMO and CCS2 plugs and compliant with the ISO 15118-20 standard. Laboratory testing at the Technical University of Denmark and ElaadNL paired the charger with Keysight and Trialog emulators and commercial vehicles (Kia EV9 prototype, EV9 production, EV3, Nissan Leaf). Interoperable energy transfer was achieved, including 11 kW vehicle-to-grid discharge with the EV9 and an 800 V emulator, validating automatic service negotiation and dynamic power reversal. The study confirms that ISO 15118-20 bidirectional charging is technically mature, highlights remaining certificate-management barriers, and positions EVs as reliable, distributed storage assets that can support renewable integration and grid stability, enabling fast field deployment.

1 Introduction

Boosting electric vehicle (EV) adoption is key to achieving a sustainable energy shift in transportation [1]. While EVs are mainly bought for mobility, they remain parked and unused about 95% of the time [2], creating an opportunity to serve as energy storage units and bridge the transportation and power sectors [3]. Different studies highlight that bidirectional charging greatly benefits the renewable energy integration (extra 40% PV integration) [4] , alleviating congestion management [5], empowering end-users (prosumers) and improving power system resilience. Bi-directional charging has been feasible since Japan's CHAdeMO protocol [6], with commercial projects in Japan, Denmark [7],the Netherlands [8], the UK [9], Australia, and the US [10]. However, European automakers have largely shifted to the CCS2 protocol, limiting CHAdeMO's market reach. When CCS was first brought to market by means of the communication protocols DIN SPEC 70121 and ISO 15118-2, it did not support bidirectional energy transfer in an interoperable way. Only with the introduction of the second-generation communication protocol ISO 115118-20 in year 2022 was bidirectional charging for CCS standardized. Challenges with bidirectional charging—like battery degradation, user acceptance, regulatory, and efficiency concerns [11], [12], [13]—persist even with the newer ISO 15118-20 standard for AC and DC plugs. In addition, ISO 15118-20 has also faced implementation challenges due to increased complexity. One can connect such difficulties with the fact that CCS2 was designed with fast charging as the main focus, and bidirectional charging is something added retroactively, while CHAdeMO was primarily designed to enable bidirectional power transfer.
Another critical challenge is the security aspect by means of a requirement for transport layer security version 1.3 (TLS 1.3) in all ISO 15118-20 sessions, which is different from the predecessor ISO 15118-2 that only required TLS 1.2 and only for Plug&Charge authorization [14]. This means that to facilitate an ISO 15118-20 session according to the standard, the EVSE needs to trust a specific OEM Root CA certificate to be able

to validate the EVs identity during the TLS handshake, by verifying the vehicle certificate chain presented by the EVCC[1]. If the EV's vehicle certificate originates from an OEM Root CA chain and the SECC[2] does not possess the corresponding OEM Root CA certificate (or trust it via cross-signing), TLS cannot be established. To summarize, the challenges with ISO 15118-20 are: i) interoperability of communication and power flow, ii) strict security requirements, and iii) lack of adoption.
Therefore, this manuscript presents the bidirectional charger from Watt&Well with successful integration of ISO 15118-20 performed by Technical University of Denmark (DTU) researchers against different units such as the Keysight Charging Discovery Dystem emulator, the Trialog communication emulator, and different EV models. The following sections present the methodology used during the testing campaign, results in the charger integration and testing and finally the conclusions from such investigation.

2 Methods

The bidirectional charger tested is an off-board DC charger, meaning AC-to-DC and DC-to-AC conversion occurs within the charger, connected to the EV via DC connection. The Watt&Well bidirectional EVSE is shown in Figure 1 and it can achieve a full-range test using 400 and 800 V architectures using CHAdeMO and CCS2 connectors. The EVSE has two bidirectional power modules (BMPUs) each able to provide 10.5 kW charging and 11 kW discharging. The bidirectional EVSE was tested against the Keysight Charging Discovery System and commercial vehicles in the laboratory facilities of DTU (Denmark) and ElaadNL (Netherlands). Figure 2 ilustrates the network setup for the control and acces needed to carry out the tests. A more detailed explanation can be found at [15]. When a CCS charging session is established, digital communication will be intitited by the EV as described in the ISO 15118-3 standard. Following an initial handshake using Signal Level Attenuation Characterization (SLAC), the EV will initiate the Service Discovery Protocol (SDP) and optionally establish a secure connection using TLS. Finally, the EV will send the Supported Application Protocol Request (SupportedAppProtocolReq), indicating to the EVSE which protocols are supported. By intercepting and decoding this and following messages, it is possible to determine if an EV tested against the Watt&Well EVSE supports ISO 15118-20 BPT[3].

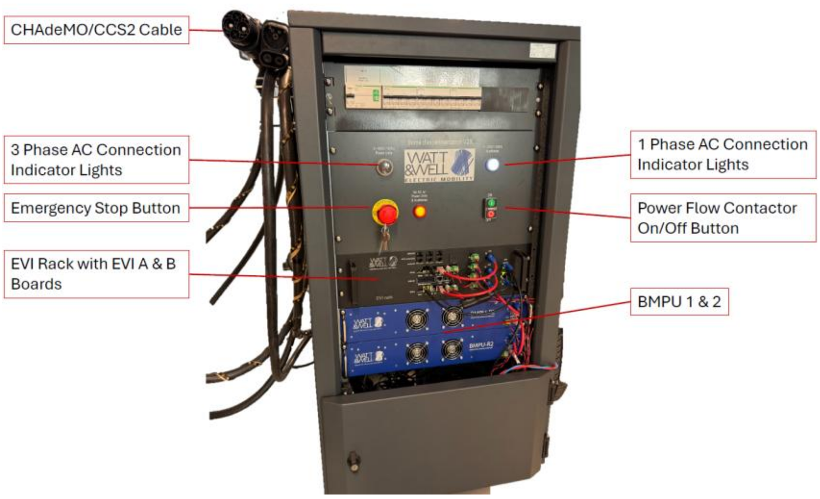

Figure 1: Watt&Well bidirectional charger consisting of BMPUs with CHAdeMO and CCS2 plugs.

Figure 2 shows the networking setup used to facilitate experiments with the Watt&Well EVSE. The EVSE itself contains two SECCs, EVIS A for CCS and EVIS B for CHAdeMO, connected in an Ethernet network with a switch. EVIS A also held a secondary interface for digital communication with vehicle EVCC using HomePlugGreenPHY. For automated control of the EVSE, a Raspberry Pi single-board computer was placed on the same subnet, as well as a laptop to configure and control the experimental setup. Finally, a 4G modem/router was used to establish an Internet connection via cellular 4G network, for the purpose of time synchronization and Open Charge Point Protocol (OCPP) control.

[1] Electric Vehicle Communication Controller
[2] Supply Equipment Communication Controller
[3] Bidirectional Power Transfer

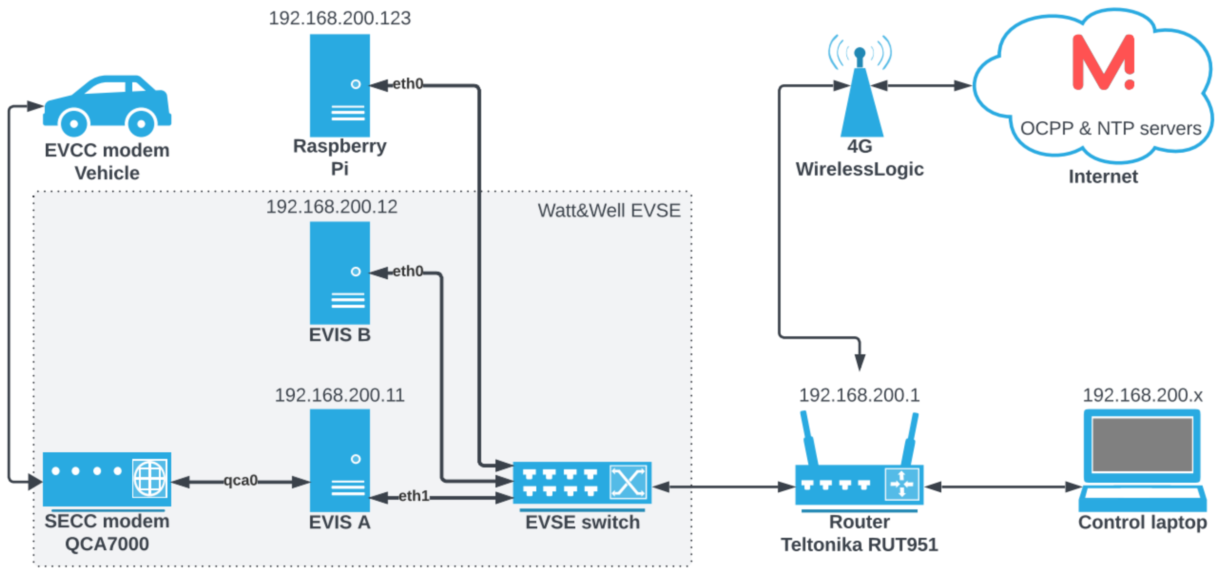

Figure 2. Diagram of the Internet Protocol-based networking setup used when carrying out experiments with the Watt&Well charger.

Furthermore, Fig.3 illustrates the graphical user interface (GUI) for local control of the Watt&Well bidirectional charger, specifically the SECC. This interface is engineered to visually present all essential indicators of system status, configuration, operational modes, and critical electrical measurements during active charging sessions.

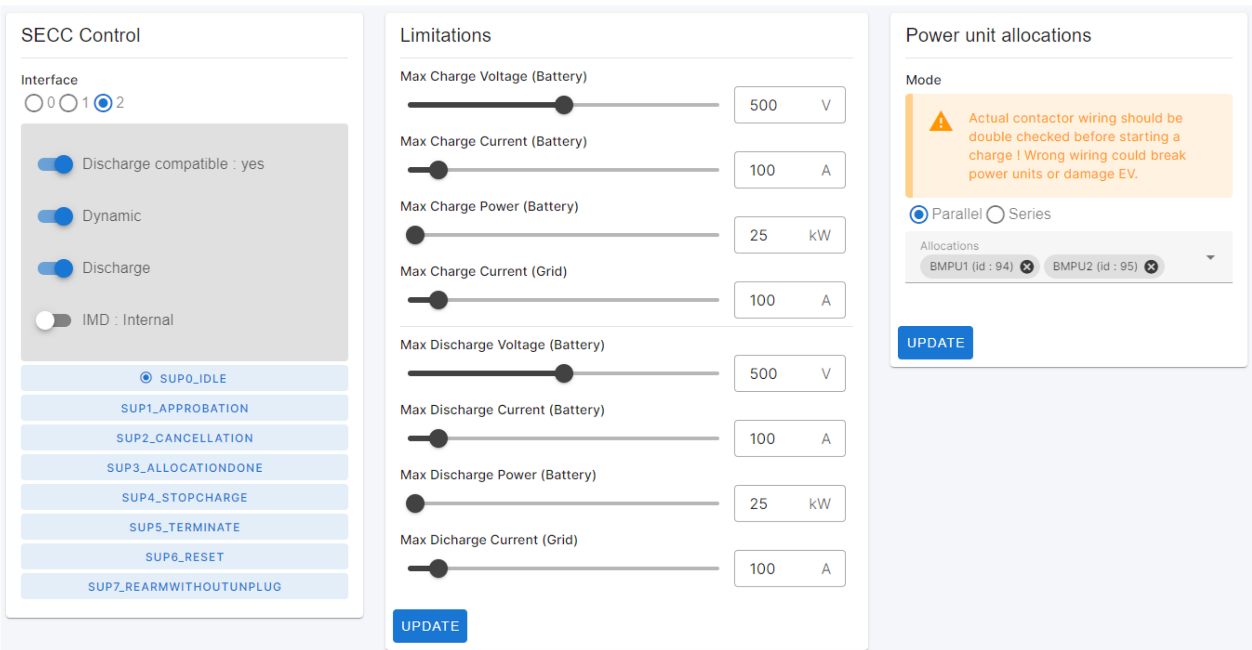

Figure 3. Watt&Well EVI SECC interface.

The following is an overview of the SECC GUI and its operation for the Watt&Well EVSE.

SECC Controller: Facilitates manual operation of the EVSE.

- **Toggles:** Indicate whether the connected EV is discharge compatible, the EVSE's operational mode (Scheduled/Dynamic), the Charge/Discharge mode, and the activation status of the internal Insulation Monitoring Device (IMD). Only the Charge/Discharge toggle can be altered during a session, enabling the EVSE to reverse power flow direction and either charge or discharge the connected EV.
- **SUP# Buttons:** Initiate and terminate a session manually.
    1. **SUP0_IDLE**: Positions the EVSE in idle mode, prepared to commence a session.

2. **SUP1_APPROBATION**: Establishes communication with the EV and awaits the requested voltage. Upon successful communication, it anticipates power unit allocation.
3. **SUP2_CANCELLATION**: Immediately halts an active session, placing the EVSE in a fault state.
4. **SUP3_ALLOCATIONDONE**: Allocates power units to the session. Upon allocation, the EVSE/EV secures the cable to the EV and conducts a cable check to verify proper connection. If successful, the session begins, and power flow commences.
5. **SUP4_STOPCHARGE**: Terminates the charging session by reducing current to zero. Power units are halted, safety checks are performed, communication with the EV is concluded, and power units are deallocated from the session.
6. **SUP5_TERMINATE**: Releases the cable from the EV.
7. **SUP6_RESET**: Clears any error states and faults.
8. **SUP7_REARMWITHOUTUNPLUG**: Permits a new session without detaching the cable from the EV. While this simulates unplugging and reattaching, many EVs necessitate physical cable removal before initiating a new session.

- **EVSE Limitations:** Specify the upper EVSE limits here. The EV determines the actual value of each parameter provided the limit exceeds the requested value. Limits can be modified during an active session, although a limit can only be increased to its initial value established during communication with the EV, as these values are defined as static in the initial handshake.
- **Power Unit Configuration:** Select individual power units for the specific setup. Power units are configured in either parallel or series, dependent on the architecture of the connected vehicle.

3 Results

The result section follows the steps taken during the test campaign and offers insight into the successful bidirectional power transfer of the Watt&Well charger with vehicle emulation systems and commercial vehicles. Figure 4 showcases the test setup at ElaadNL (Netherlands) with Kia EV9 and Keysight charging discovery system (CDS) and Charging communication interface Tester (CCIT, formerly Verisco) emulation system. Both Kia EV9 and Keysight emulation systems can achieve 800V system architecture for bidirectional charging. The CCIT/Verisco communication box offers the possibility to communicate using the ISO 15118-20 standardized protocol.

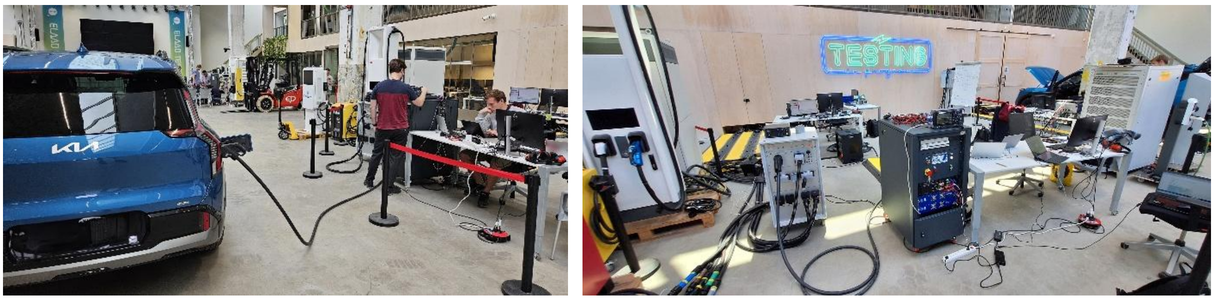

Figure 4. Test setup at ElaadNL with Kia EV9 (left) and Keysight charging discovery system (right).

Figure 5 illustrates the Keysight CCIT interface during a successful bidirectional charging process and gives the following real-time information:
The top bar in green is the communications exchange between the EVSE and Keysight system acting as the vehicle. One can observe that it is green from SLAC, SDP to Cable Check, PreCharger and entering the Charge Loop phase. Above the green bar are the details of the Keysight such as: i) Mode: EV (acting as an EV), ii) Proximity: 1499 Ohm (Proximity pilot resistance value), iii) Control Pilot (CP) State showing C for charging state and 5.1% modulation for digital communication, and lastly iv) Power displaying -17.32 kW (where minus means discharging). The middle part of Fig.5 displays the time series of voltage, amperes and wattage values. The negative value of amperes represents the discharging mode, reflected also on the negative power. Finally, at the bottom of Fig.5 can be observed the chosen profile CID-ISO-20-DC-BPT-TCP. “CID-ISO-20-DC-BPT-TCP” is a compact way of saying: This interface supports ISO 15118-20 direct-current charging with bidirectional power transfer, communicated over an unencrypted TCP connection.

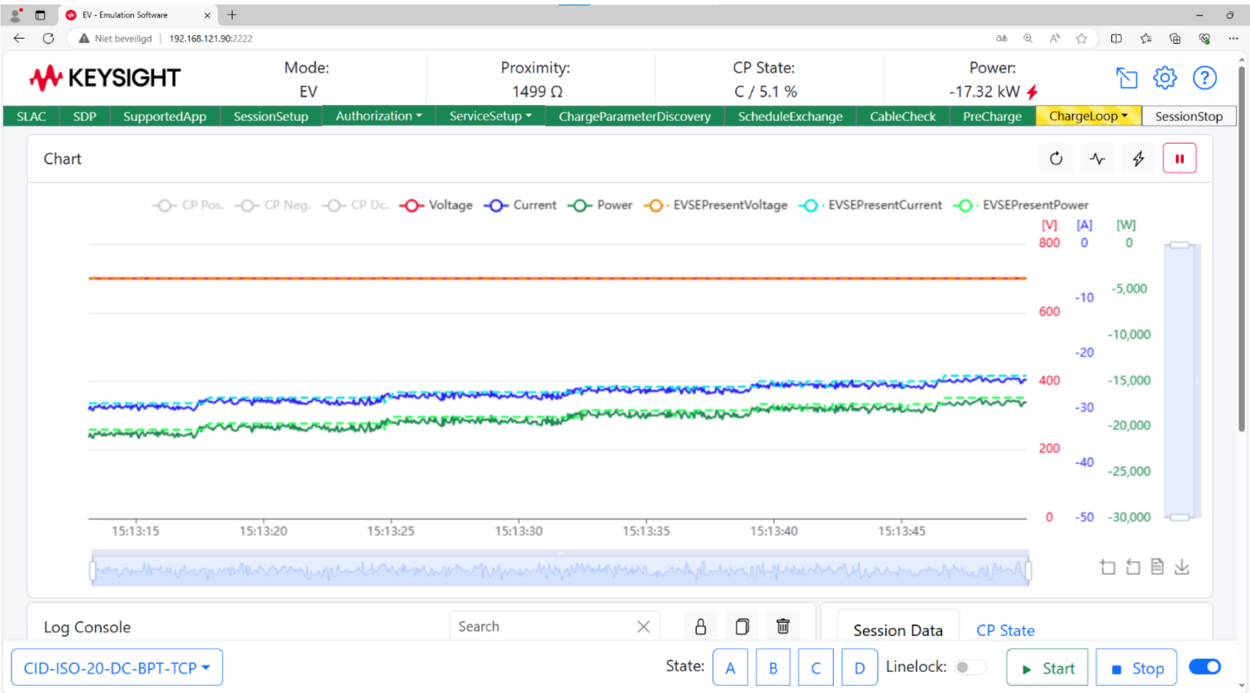

Figure 5. Keysight CCIT (Verisco) control interface during testing with Watt&Well bidirectional charger.

Moreover, Fig.6 shows a power profile produced based on several electrical parameters measured when running an efficiency test of the EVSE against a Nissan LEAF e+ using CHAdeMO. The test protocol was designed to increase the current by 1 A in 10 second intervals until reaching max charging power, followed by a similar decrease until reaching a max discharge power. Through this process, it is intended to test the BMPU operating area. The positive power values mean charging and negative power reflects discharging process. However, the bidirectional power flow with CHAdeMO protocol is not a novel feature. The same testing procedure is followed by the second plug (CCS2) of bidirectional charger that employs ISO 15118-20 standard.

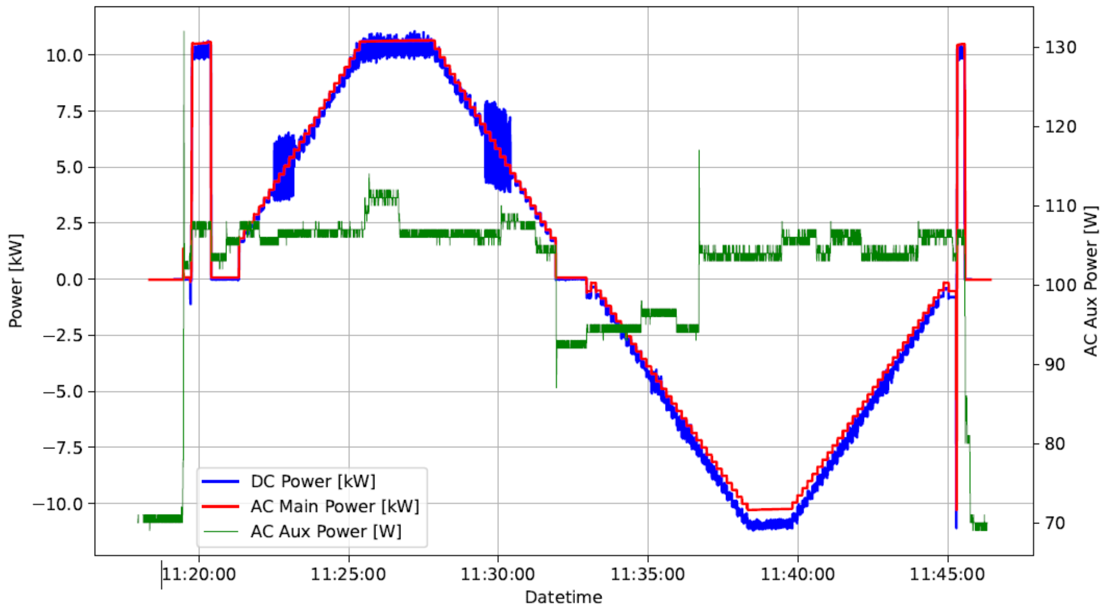

Figure 6. Electrical measurements of efficiency test of a BMPU over a relevant power operating area, conducted using CHAdeMO on a Nissan Leaf with a starting battery voltage of 345V.

The power profile results from testing the bidirectional power transfer with Kia EV9 are presented on Fig.7. For this test with successful bidirectional power transfer, the Kia EV9 was at approximately 50% SoC with a starting battery voltage of 575V. Due to Kia EV9 800V architecture feature, two BMPU power modules in series were used to reach the desired voltage. Similarly to Fig. 6, positive power values mean charging and negative power reflects discharging process. In addition to the real vehicle test, Fig.8 provides the power profile of a CCS-based session utilizing only a single power module testing against the Keysight Charging Discovery System emulator.

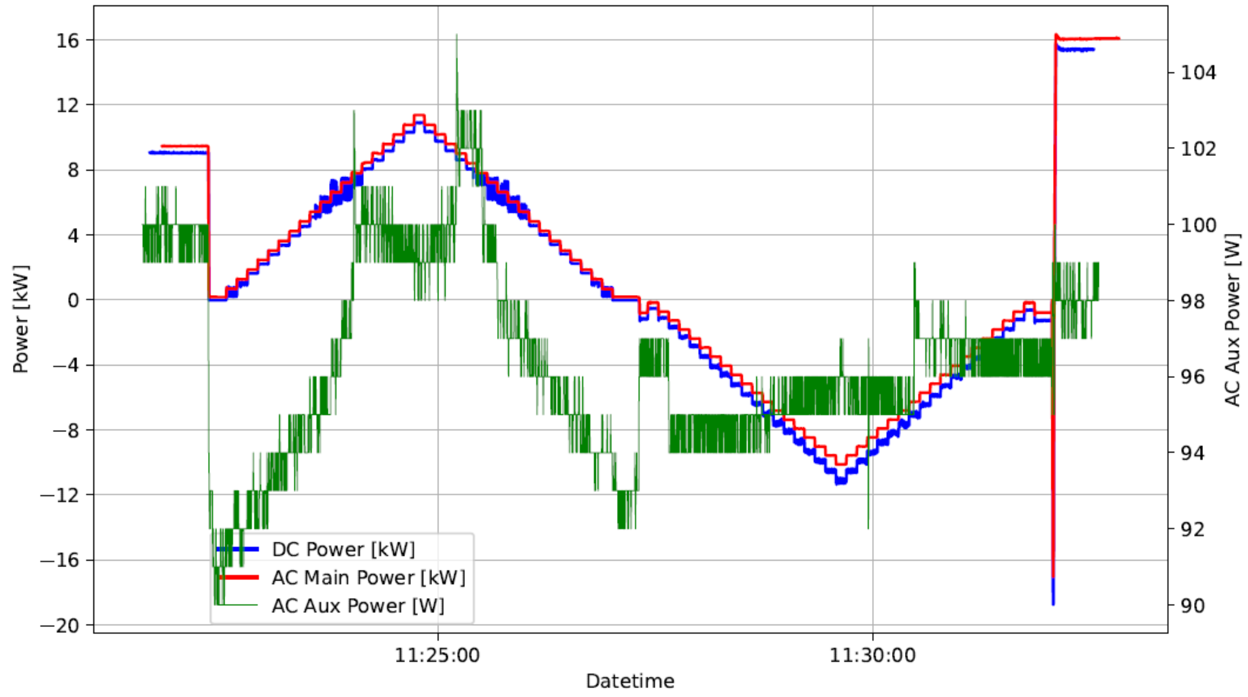

Figure 7. Power measurements from Kia EV9 using two BMPUs due to 800V vehicle architecture.

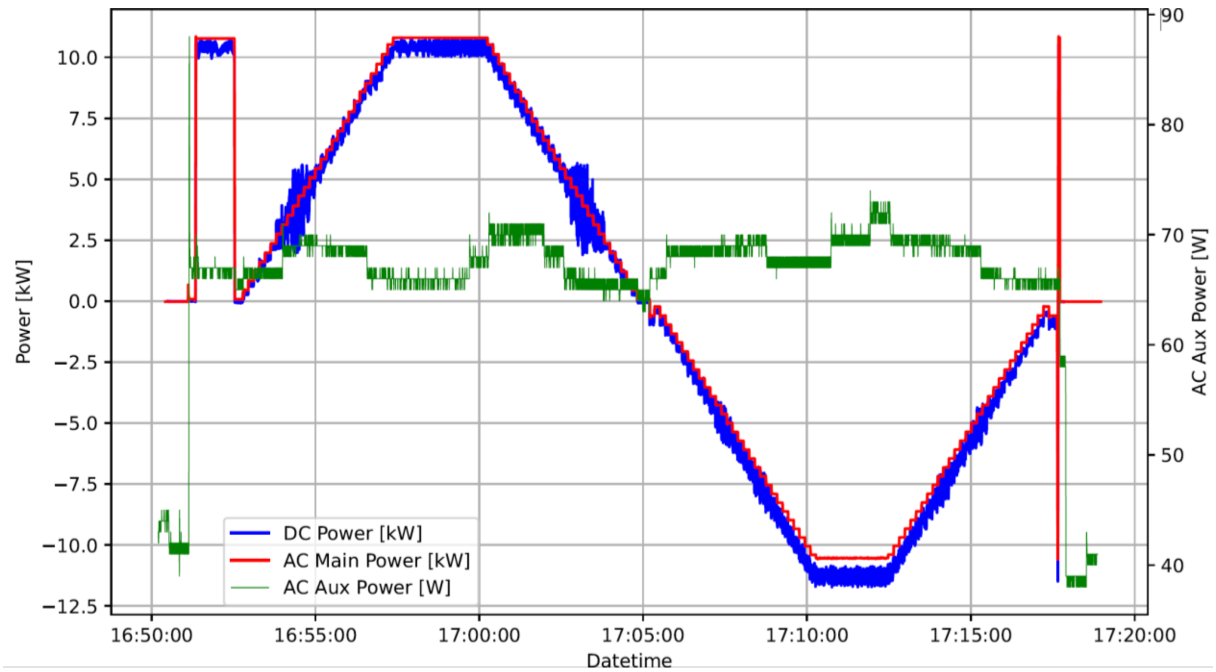

Figure 8. Power measurements from Keysight charging discovery system using one BMPU with 400V architecture.

Table 1. shows an excerpt of internal logs from the Watt&Well EVI SECC while bidirectional DC charging is negotiated with Kia EV9. First, the SupportedAppProtocolReq message is received. In this message, the EV indicates it supports DIN SPEC 70121, ISO 15118-2, ISO 15118-20:DC and ISO 15118-20:AC_HMG, the latter likely to be a proprietary schema of Hyundai Motor Group. This is followed by SupportedAppProtocolRes, where the EVSE picks SchemaID #2, which is ISO 15118-20:DC. Finally, service ID #6 is negotiated, which is DC

BPT. It is noteworthy that this exchange as well as the following messages setting up and establishing bidirectional charging, remain unencrypted. This is not compliant with the standard which demands TLS 1.3 encryption, but very useful for testing where the EVSE may not hold or cross-sign the OEM Root CA in use by the vehicle.

Table 1. Log excerpt from the Watt&Well EVSE showing negotiation and selection of DC BPT service

```
[22T09:17:07.137 | MessageStateMachineManager:140:3042866208]MsgStM::WaitForSupportedAppProtocolReq

[22T09:17:07.207 | TcpHandlerConnection:51:3042866208] TcpHandlerConnection: start

[22T09:17:07.207 | TcpHandler:230:3042866208] TcpHandler: begin connection on port: 52116

[22T09:17:07.208 | TcpHandler:239:3042866208] TcpHandler: close existing TCP server

[22T09:17:07.214 | Handshake:38:3042866208] #10 urn:din:70121:2012:MsgDef DIN (priority 1)

[22T09:17:07.214 | Handshake:38:3042866208] #20 urn:iso:15118:2:2013:MsgDef ISO2 (priority 2)

[22T09:17:07.215 | Handshake:38:3042866208] #1 urn:iso:std:iso:15118:-20:AC_HMG Not_Selected (priority 4)

[22T09:17:07.215 | Handshake:38:3042866208] #2 urn:iso:std:iso:15118:-20:DC ISO20_DC (priority 3)

[22T09:17:07.216 | MessageStateMachineManager:140:3042866208]MsgStM::ProcessSupportedAppProtocolReq

[22T09:17:07.217 | Handshake:68:3042866208] Selected SchemaId #2 ISO20_DC

[22T09:17:07.218 | MessageStateMachineManager:140:3042866208]MsgStM::WaitForSessionSetupReq

[22T09:17:07.327 | TcpHandlerExtended:66:3042866208] < Rx 4 SessionSetupReq

[22T09:17:07.328 | EvisIso15118Adapter:190:3042866208] Configured DC BPT Charge Service

[22T09:17:07.328 | EvisIso15118Adapter:221:3042866208] DC BPT service offered to EVCC
```

Table 2 shows the results from testing different EV and EV emulators against the Watt\&Well EVSE. The table lists vehicles and emulators tested with the brand, model, and for the vehicles additional information trim/configuration, the model year, and software version shown in the on-board infotainment system. Also listed are the schemas sent via the SupportedAppProtocolsReq message and their priority. This data was obtained by dissection of Watt&Well SECC logs. Finally, the rightmost column indicates whether it was possible to achieve Bidirectional Power Transfer with the specific EV or not.

From the table, it is seen that the Kia EV9 with special, prototype software supported ISO 15118-20 DC BPT. Another EV9 with production software was also tested and did not indicate support for ISO 15118-20, which made BPT impossible. Finally, testing against a production Kia model EV3 with the V2X option installed from the factory, the vehicle indicated it did support ISO 15118-20:DC and BPT, but terminated session right after the BPT service was selected.

With the EV emulators tested against the Watt&Well EVSE, it was possible to pick the schemas, and in the case of the Trialog ComboCS4M even pick multiple schemas and set their priority. To not list all the possible schemas, only the ISO 15118-20 based schema expected to be able to support BPT has been listed. With the Keysight Charging Communication Interface Tester (CCIT/Verisco box), BPT was achieved with the Keysight CDS and SL18000A series DC emulator handling physical power transfer. For the Trialog ComboCS4M, no power converters were connected. As a result, it was possible to configure a DC BPT session and enable discharge mode, but no power was flowing.

Table 2. Overview of tested vehicles and emulation systems with their SupportedAppProtocols listed

Brand	Model	Trim/year	Software version	Priority / SupportedAppProtocols	BPT working
Kia	EV9	GT line 2024	MV1.EUR.116	1 urn:din:70121:2012:MsgDef DIN 2 urn:iso:15118:2:2013:MsgDef ISO2	No
Kia	EV3	Prestige with V2X option	25.3.1	1 urn:din:70121:2012:MsgDef DIN 2 urn:iso:15118:2:2013:MsgDef ISO2 3 urn:iso:std:iso:15118:-20:DC ISO20_DC 4 urn:iso:std:iso:15118:-20:AC_HMG	No - terminated after ServiceSelection
Kia	EV9	Unknown	Prototype	1 urn:din:70121:2012:MsgDef DIN 2 urn:iso:15118:2:2013:MsgDef ISO2 3 urn:iso:std:iso:15118:-20:DC ISO20_DC 4 urn:iso:std:iso:15118:-20:AC_HMG	Yes
Keysight	CCIT	N/A	N/A	urn:iso:std:iso:15118:-20:DC ISO20_DC	Yes - via CDS
Trialog	Combo CS4M	N/A	N/A	urn:iso:std:iso:15118:-20:DC ISO20_DC	Yes - unpowered

4 Conclusions

The test campaign confirms that Watt&Well's off-board DC charger—with two bidirectional power-modules rated at 10.5 kW for charging and 11 kW for discharging—can deliver Bidirectional Power Transfer (BPT) through both CHAdeMO and CCS2 connectors while running the full ISO 15118-20 communication stack.

On the CHAdeMO side, a Nissan Leaf completed repeated charge–discharge ramps that were used to characterise the power-module operating area. Using CCS2, BPT was successfully negotiated and executed with (i) a Kia EV9 prototype—requiring two modules in series to match the vehicle's 800 V architecture—and (ii) both Keysight CDS/CCIT and Trialog ComboCS4M emulators.

The measured discharge from the Keysight test bench (-17.3 kW) demonstrates stable power reversal under real load conditions. Conversely, a production-software EV9 and a Kia EV3 equipped with the factory V2X option terminated the session immediately after ServiceSelection, underlining that vehicle firmware remains the main bottleneck for widespread CCS2 BPT adoption.

Across all CCS2 trials, the mandatory TLS 1.3 handshake proved the critical deployment hurdle: the charger could only start encrypted sessions when it already trusted the relevant OEM Root-CA certificate, and most successful tests therefore used temporarily unencrypted links.

In summary, the hardware and protocol defined by ISO 15118-20 are operational today; what is still missing are (1) consistent vehicle firmware support and (2) an industry mechanism for distributing and cross-signing Root-CA certificates. Addressing these two procedural gaps will enable the rapid field roll-out of bidirectional chargers and unlock the grid services and customer value that BPT can provide.

Acknowledgments

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Presenter Biography

Kristian Sevdari received the Ph.D. degree from the Technical University of Denmark-DTU in February 2024. Since 2020 he has been working with the Technical University of Denmark-DTU, Denmark, where he is currently a Postdoctoral researcher involved in multiple projects such as AHEAD, FLOW, EV4EU, ACDC, FUSE and Repurposing secondhand Tesla batteries. His research interests include power system dynamics, renewable energy and electric vehicle grid integration, as well as providing grid services from distributed energy resources. In addition, he is the founder of IEEE REST (Renewable Energy and Smart Technologies) conferences, member and task leader for the IEEE PES Task Force on electric vehicle grid integration and IEA Task 53.