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Development of Portable Electric Vehicle Charging System Based-on Combined Charging System Standard

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Abstract: In the current step into the era of electrified transportation, the shortage of charging stations, limited driving ranges in vehicles, and the time required for charging, due to current energy storage or battery technology, remain bottlenecks in motivating consumers to switch from fossil-fuel vehicles to electric vehicles (EV). This paper addresses these challenges by focusing on the development of portable fast charging solutions for EV, utilizing the Combined Charging System (CCS) standard. Charging from Electric Vehicle Supply Equipment (EVSE) to EV requires communication signals or protocol command sets to initiate forward mode charging, i.e., charging from the charger or grid to the electric vehicle (G2V). Additionally, the research explores communication protocols between EVSE and EV, utilizing the ISO 15118 standard. The Raspberry Pi 4 Model B serves as the Microcontroller Unit (MCU) for communication commands of EVSE and EV, using White-beet EVSE and EV boards to generate and receive Control Pilot (CP), Proximity Pilot (PP), and Protective Earth (PE) protocol signals. These signals facilitate essential digital communication between the Raspberry Pi, EVSE, and EV during charging operations. Python scripts on the Raspberry Pi control digital commands, managing the initiation, monitoring, and termination of charging sessions with precision and efficiency.

***Keywords*— Electric Vehicle, Portable fast charging, Combined Charging System, Vehicle to Grid**

I. INTRODUCTION

A. Background

The transportation industry is swiftly shifting from gasoline vehicles to EV due to concerns about pollution and climate change which has led to EV being increasingly recognized as a viable mode of transport and are gaining greater acceptance in the automotive market, pushing by government policies worldwide aimed at reducing greenhouse gas emissions [1-2]. Despite substantial advancements in EV technology offering significant reductions in carbon emissions and energy use, challenges such as limited driving ranges, charging speed, and accessibility to charging stations hinder widespread adoption. A critical limitation remains the restricted range of EV, posing a significant hurdle for broader acceptance and integration [3].

At present, the number of EVSE stations is increasing, it remains insufficient to meet the growing demand for EV [4]. For instance, in Thailand, long-distance travel with an EV may be inconvenient due to the limited availability of charging stations in different provinces. Drivers must plan their trips carefully to ensure they reach destinations with charging stations to recharge their EV batteries and continue their journeys without running out of power

A portable charger is an innovative type of electric vehicle charging equipment designed to provide immediate charging services wherever and whenever needed, addressing challenges that mentioned before. This system not only offers immediate solutions in the absence of fixed stations but also empowers small shop owners to establish EV charging stations, significantly expanding the network of charging facilities and enhancing accessibility for EV users [5-6].

This paper aims to implement the communication and signals transmitted during the charging process between EVSE and EV as the first step to the goal of developing a portable EV fast charging system that will address the short driving distances, charging speed, and current inadequacies of charging stations. EVSE and EV must comply with industrial standards. Various organizations worldwide have explored different standards for EV charging systems [7]. Thailand has adopted IEC 61851 as TIS 61815 Electric Vehicle Conductive Charging System. Aiming to develop a portable fast charger for EV, this study focuses on the

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Combined Charging System (CCS) Level 3, commonly referred to as direct current (DC) fast charging. For safety and compatibility of operation, various hardwired signaling including Control Pilot (CP) and Proximity Pilot (PP) must be firstly detected and subsequently the digital communication between EVSE and EV has to be securely established before hardwired power connection between EVSE and EV taking placed [7-8]. The digital communication is based on robust power-line carrier communication (PLC) featuring encryption client-server approach as per the ISO 15118 requirement [10]. The digital communication required by the ISO 15118 is quite complex and requires extensive development. To remedy this, EVSE PLC communication modules and software stack are available from various suppliers.

In this paper, the White-beet module from 8devices [11-12] is utilized for communication between EVSE and EV. Another PLC communication module is used as an EV emulator during experiments. Python-based application, FreeV2G, is adopted as a host controller for charging control. The experimental setup includes a DC electronic load for EV battery emulation, a programmable DC power supply for power converter emulation, and Raspberry Pi 4 units as host controllers and communication modules. Successful charging communication was established. This configuration supports educational use and can be further developed into a portable fast charger, as shown in Fig. 1.

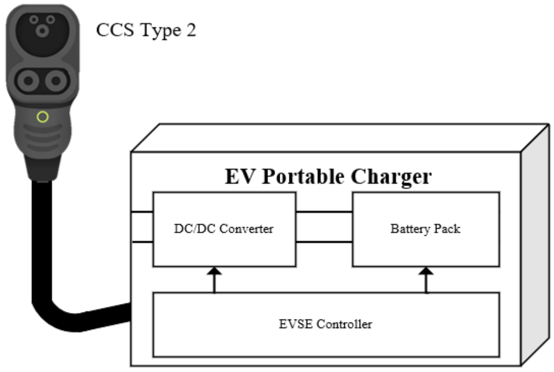


Fig. 1 Configuration of Portable EV Charger System

B. *Charging Infrastructure*

Charging infrastructure refers to the comprehensive network of facilities and equipment needed to support EV charging. This includes EVSE with standardized connectors, electrical supply systems, and digital communication protocols for safe and efficient power transfer. It also encompasses software for management and user interaction, installation and maintenance services, and supporting facilities like parking spaces. Charging infrastructure ensures the reliable, accessible, and efficient recharging of EV, promoting their widespread adoption and integration into the energy grid [10-11].

Charging EV generally involves various methods and standards. This paper focuses on the charging levels defined by SAE J1772 [15] and the charging modes and requirements for DC fast charging systems as outlined in TIS 61851-1 and TIS 61851-2, which reference IEC 61851-1 and IEC 61851, respectively [16-17].

The SAE J1772 standard defines general physical, electrical, and performance requirements for electric connectors for EV. It is supported by SAE International and is commonly use in the USA and Japan [18]. Table 1 shows the various charging levels, which are commonly divided into three types based on specified electrical power, voltage, and current [19].

The IEC uses the terminology “Charging modes” to classify the methods of power distribution, protection installation, communication and management of the EV charging system [20]. Consequently, the international standard IEC 61851-1 describes four distinct EV charging modes. Table 2 will provide details of charging modes [16,18]

The IEC 61851-24 standard plays a crucial role in developing portable fast charging with the CCS. This standard specifies the digital communication protocols necessary for controlling DC charging [17].

Table 1.
SAE J1772 charging levels

Limits	Level 1	Level 2	Level 3
Voltage	120 VAC	230 VAC	480 VDC
Current	12-16 A	12-80 A	<125 A
Charging loads	1.4-1.9 kW	2.5-19.2 kW	<90 kW
Charge time	3-8 km/hr	16-48 km/hr	80% in 30 min.

Table 2.
IEC 61851-1 charging modes

Mode	Limits		Supply & Interface	Function
	Current	Voltage		
1	16 A	250-480 VAC	AC, non-dedicated	e-bikes & scooters
2	32 A	250-480 VAC	AC, non-dedicated	slow AC
3	32 A	250-480 VAC	AC, dedicated	slow and quick AC
4	200 A	400 VDC	DC, dedicated	fast DC

C. *EV Charger Connector*

Current charging stations support various types of EV charger connectors, including Type 1 (SAE J1772), Type 2)IEC 62196), CHAdeMO, and Combined Charging System (CCS).

Type 1 connectors, also known as SAE J1772 connectors, consist of a single-phase connector primarily used for AC charging. They are characterized by their five-pin design, which includes two power conductors, a ground, and two CP pins for communication between the vehicle and the charging station.

Type 2 connectors, also known as IEC 62196 connectors, are widely used in Europe and are becoming increasingly popular globally. They support AC and DC charging with higher capacities than Type 1 connectors. Type 2 connectors feature a seven-pin design, which includes three power conductors, a ground, and three additional pins for communication and control purposes.

CHAdeMO is a DC quick charger was developed by Japan and has been widely used in Japan, Europe, and the USA [21]. CHAdeMO connectors are characterized by their large, round shape and unique locking mechanism. They can deliver high-power DC charging, allowing EV to charge quickly at dedicated fast-charging stations [20].

CCS is another DC fast-charging standard that has gained widespread adoption, particularly in Europe and North America. It combines the functionality of Type 2 connectors for AC charging with additional DC pins for high-power charging. CCS connectors feature both a Type 2 AC connector and two additional DC pins, allowing EV to charge using AC or DC power from the same port.

In Thailand, Type 2 connectors are commonly used for AC charging, but they can also support three-phase charging. Additionally, DC charging is typically done using CCS Type 2 connectors, which have been developed from Type 2 connectors.

II. COMMUNICATIONS PROTOCOL AND CONNECTIONS

A. *CCS Combo 2 Connector*

CCS Combo 2, also known as CCS Type 2, is a standard charging connector used for EV. It integrates both AC and DC charging capabilities into a single plug, allowing EV to be charged from various charging stations. CCS Combo 2 connectors have been widely adopted in Europe and are gaining popularity in other regions as well as Thailand.

Therefore, the experiments in this paper will utilize the connection and communication signals according to CCS Combo 2. The CCS Combo 2 has pinout and signal wires as depicted in Fig.2.

One of the key advantages of CCS Combo 2 is its ability to support high-power DC charging, which significantly reduces charging time compared to standard AC charging [22]. Hence, it is suitable for long-distance travel for a short waiting time.

CCS Combo 2 then plays a crucial role in promoting the widespread adoption of EV by offering fast and convenient charging solutions for EV owners [23].

The reason for choosing CCS DC Fast charge is to provide an emergency power source when the EV battery runs out. This Portable DC Fast charge can charge the battery so that the EV can drive to a nearby charging station to recharge at a later time.

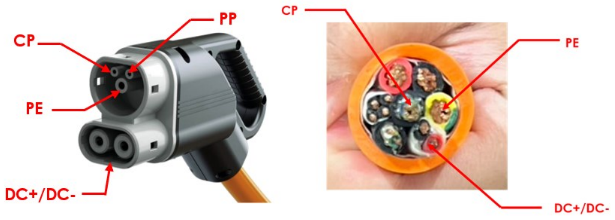


Fig. 2 CCS Combo 2 connector [23].

Table 3.
CCS Combo 2/ CCS Type 2

Function	**Notes**
L1	AC Line 1
L2	AC Line 2
L3	AC Line 3
N	AC Neutral
PE	Protective Earth
PP	Proximity Pilot
CP	Control Pilot
DC+/DC-	DC charge pins

B. *Signaling*

Communication and signaling are designed to work in the following charging order.

1) The power supply sends a signal indicating the presence of power input.
2) The EV detects the plug using Proximity circuit (to prevent the vehicle from being driven while connected) and can also detect when the latch is pressed in preparation for unplugging.
3) Subsequently, the CP function begins, wherein the power supply unit can detect EV to determine if they are ready to charge. The power supply unit indicates the charging current capacity for EV.
4) Then, the EV controls the energy flow.

Meanwhile, the charger and the vehicle continue to monitor the continuous charging process, which depends on the EV's requirements. Charging may be disrupted by a plug-to-vehicle disconnection. The power supply sends CP signal 12 V and PP signals for measuring voltage differences in plug-in detection [24].

C. *ISO-15118*

This paper aims to focus on digital communication between EVSE and EV according to the TIS 61815-24 standard, which references ISO 15118.

TIS 61851-24 Annex C is an extension of the TIS 61851-24 standard, for Thailand's EV charging infrastructure with international best practices outlined in ISO 15118. This annex adopts ISO 15118 protocols to suit Thailand's regulatory environment and technical needs, ensuring interoperability and compatibility with global standards [25].

The most relevant sections of ISO 15118 related to portable fast charging are;

1) *ISO 15118-1, Defines the overall structure and use cases for EV and EVSE communication.*
2) *ISO 15118-2, Related to Specifies network and usage layer protocols for efficient communication and management of charging sessions.*
3) *ISO 15118-3, Covers physical and data link layer protocols ensuring hardware communication, power management, and safety during charging.*

These three sections collectively ensure seamless integration, reliability, and safety for portable fast chargers for EV.

III. EXPERIMENTAL

This paper focuses on the study and development of a portable DC fast charging system. To achieve this objective, the FreeV2G charging program was analyzed and implemented using the White-Beet tool, which integrates a software stack for the ISO 15118 charging protocol, the current industry standard for EV charging. This implementation serves as a foundational step toward future advancements in the creation of portable EV fast chargers.

The simulation is performed using a Raspberry Pi 4 Model B as a controller, which sends control commands to a White-Beet device containing the ISO 15118 software stack. The entire experimental setup consists of a Raspberry Pi 4 Model B connected to a White-Beet EVSE, acting as an EV charger, and another Raspberry Pi 4 Model B connected to a White-Beet EV, acting as an EV. The connections between the Raspberry Pi 4 Model B and the White-Beet are shown in Fig. 3.

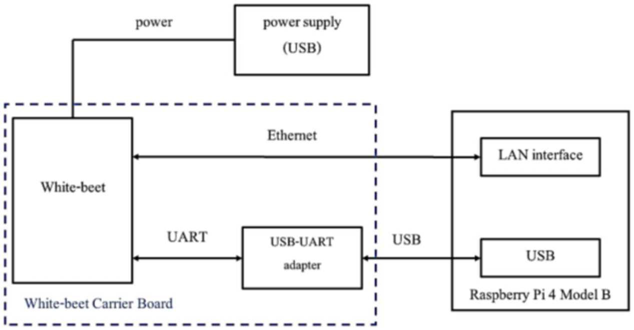


Fig. 3 Connection between White-beet and Rasp Pi 4

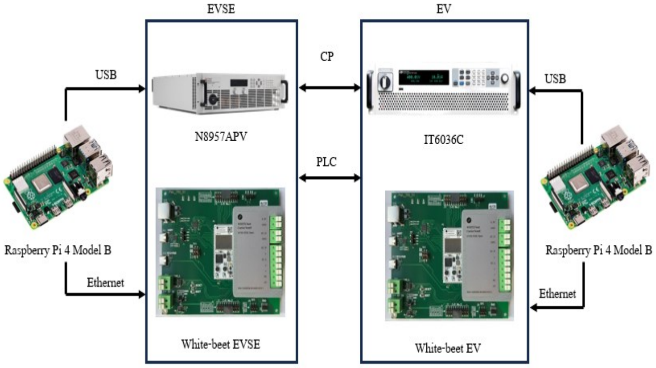


Fig. 4 Connection between EVSE and EV via PLC

During this phase, the module is prepared to receive the Signal Level Attenuation Characterization (SLAC) request from the EV. Once the charging process is complete, the CP signal automatically ceases. The working principle of the CP signal is illustrated in Fig. 5.

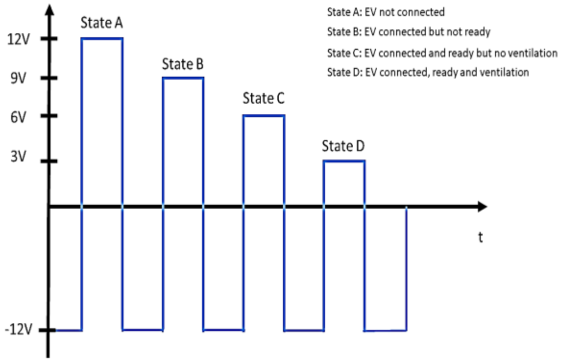


Fig. 5 Control Pilot signal

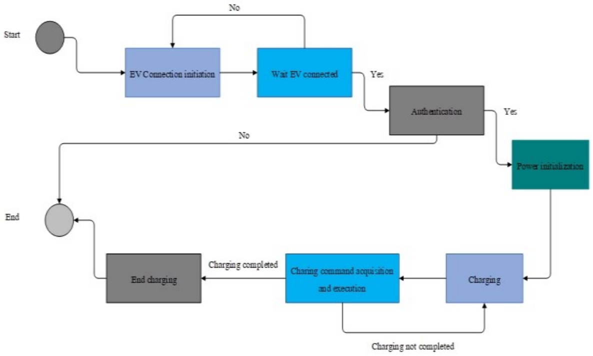


Fig. 6 State diagram of charging system

For high-level communication, the EVSE (Electric Vehicle Supply Equipment) establishes a HomePlug GreenPHY (HPGP) network. After the successful completion of the SLAC process, both the EVSE and the EV are integrated into the same network, enabling high-level communication to commence. The charging program then automatically proceeds, initiating the charging cycle.

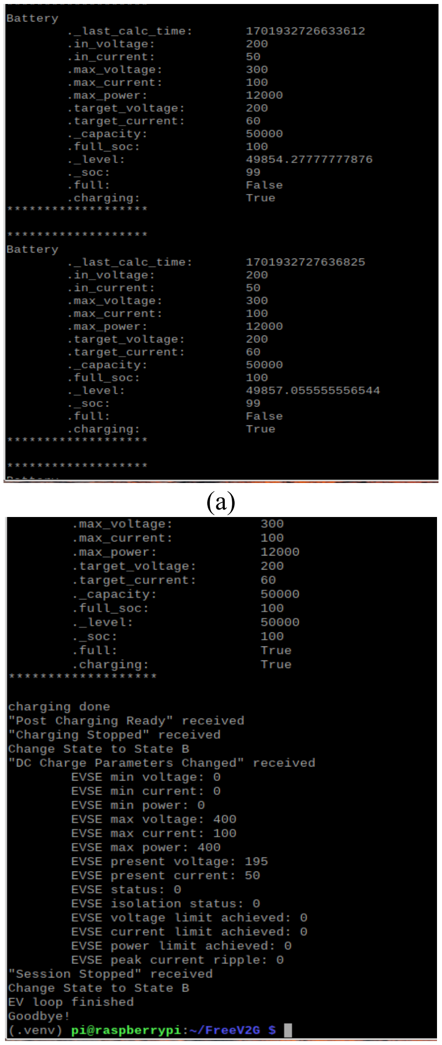
The system continuously monitors and updates the charging parameters in real-time until the charging process is completed. The operation of this charging program is governed by the state diagram depicted in Fig. 6.

IV. EXPERIMENTAL RESULTS

From the simulation of charging using the program, it was found that while the charging program is running, the system monitors the status of the EV battery in a loop process via the Command Line Interface (CLI) displayed on the Raspberry Pi 4 Model B, as shown in Fig. 7. This indicates that the charging simulation through the program was successful.

After simulation, the next step is to test it with an actual EV. The EV used in this experiment is the MG ES (EV) Long Range 2023 [26]. Its characteristics are shown in Table 4.

This experiment focuses on DC charging. Therefore, the White-beet EVSE module is connected to a CCS Type 2 charging connector, as shown in Fig. 1



```
Battery
        ._last_calc_time:        1701932726633612
        .in_voltage:             200
        .in_current:             50
        .max_voltage:            300
        .max_current:            100
        .max_power:              12000
        .target_voltage:         200
        .target_current:         60
        ._capacity:              50000
        .full_soc:               100
        ._level:                 49854.27777777876
        ._soc:                   99
        .full:                   False
        .charging:               True
********************

********************
Battery
        ._last_calc_time:        1701932727636825
        .in_voltage:             200
        .in_current:             50
        .max_voltage:            300
        .max_current:            100
        .max_power:              12000
        .target_voltage:         200
        .target_current:         60
        ._capacity:              50000
        .full_soc:               100
        ._level:                 49857.055555556544
        ._soc:                   99
        .full:                   False
        .charging:               True
********************

********************
```

(a)

```
        .max_voltage:            300
        .max_current:            100
        .max_power:              12000
        .target_voltage:         200
        .target_current:         60
        ._capacity:              50000
        .full_soc:               100
        ._level:                 50000
        ._soc:                   100
        .full:                   True
        .charging:               True
********************

charging done
"Post Charging Ready" received
"Charging Stopped" received
Change State to State B
"DC Charge Parameters Changed" received
        EVSE min voltage: 0
        EVSE min current: 0
        EVSE min power: 0
        EVSE max voltage: 400
        EVSE max current: 100
        EVSE max power: 400
        EVSE present voltage: 195
        EVSE present current: 50
        EVSE status: 0
        EVSE isolation status: 0
        EVSE voltage limit achieved: 0
        EVSE current limit achieved: 0
        EVSE power limit achieved: 0
        EVSE peak current ripple: 0
"Session Stopped" received
Change State to State B
EV loop finished
Goodbye!
(.venv) pi@raspberrypi:~/FreeV2G $
```

(b)

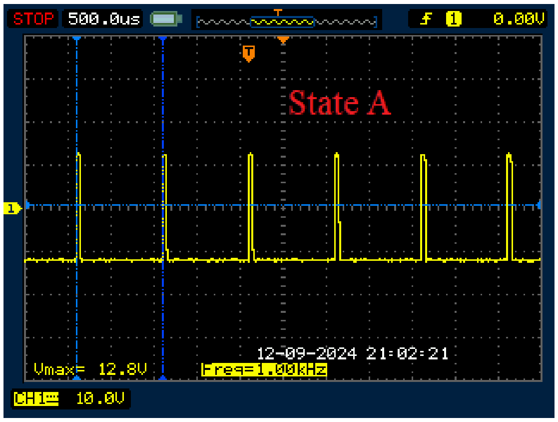
Fig. 7 EV loop charging operation: (a) loop process (b) completed loop

Fig. 8 Testing charging system program with MG ES

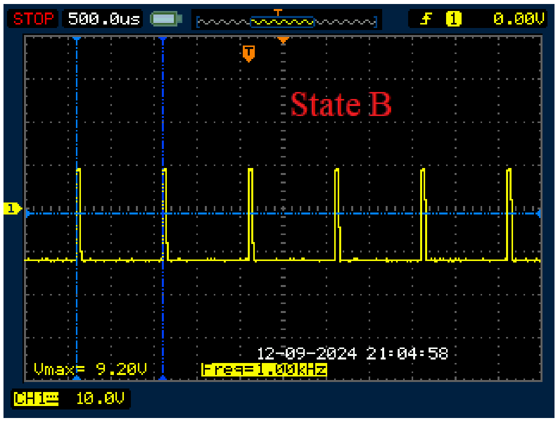
Table 4.
Characteristics of MG ES Long Range 2023

Attribute	Specification
Battery Capacity	72.6 kWh
Battery Type	Lithium-ion
Max Voltage	400 - 450 V
AC Charge Port	Type 2
DC Charge Port	CCS
AC Charge Power	7.4 kW AC
DC Charge Power	94 kW DC

Upon initiating the charging program, the CP signal enters State A, indicating that no EV is connected. In this state, the program pre-configures the charging settings in preparation for an eventual connection. The next step involves plugging the CCS Type 2 connector into the MG ES (EV) Long Range 2023. The PP signal within the CCS connector secures the plug within the EV's charging socket, preventing any movement during the charging process. This action transitions the system from State A to State B, signifying that an EV has been successfully connected to the EVSE. The transition from State A to State B is characterized by a change in the voltage amplitude of the CP signal, oscillating at a frequency of 1 kHz, from 12 V to 9 V, as illustrated in Fig. 9(a) and Fig. 9(b).



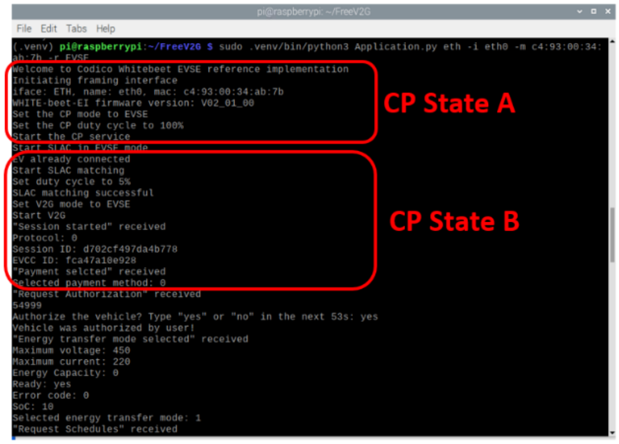
(a)



(b)

Fig. 9 Changing of Control Pilot signals: state A (a) to state B (b)

This transition is confirmed and displayed via the command line interface (CLI) on the Raspberry Pi 4 Model B, as illustrated in Fig. 10



```
(.venv) pi@raspberrypi:~/FreeV2G $ sudo .venv/bin/python3 Application.py eth -i eth0 -m c4:93:00:34:
ab:7b -r EVSE
Welcome to Codico Whitebeet EVSE reference implementation
Initiating framing interface
iface: ETH, name: eth0, mac: c4:93:00:34:ab:7b
WHITE-beet-EI firmware version: V02_01_00
Set the CP mode to EVSE
Set the CP duty cycle to 100%
Start the CP service
Start SLAC in EVSE mode
EV already connected
Start SLAC matching
Set duty cycle to 5%
SLAC matching successful
Set V2G mode to EVSE
Start V2G
"Session started" received
Protocol: 0
Session ID: d702cf497da4b778
EVCC ID: fca47a10e928
"Payment selcted" received
Selected payment method: 0
"Request Authorization" received
54999
Authorize the vehicle? Type "yes" or "no" in the next 53s: yes
Vehicle was authorized by user!
"Energy transfer mode selected" received
Maximum voltage: 450
Maximum current: 220
Energy Capacity: 0
Ready: yes
Error code: 0
SoC: 10
Selected energy transfer mode: 1
"Request Schedules" received
```

Fig. 10 EVSE loop charging operation with CP State A and State B

The charging process begins with the transition of the CP signal from State B to State C, marked by changing of CP voltage from 9 V to 6 V, as illustrated in Figure 11. This transition triggers the initiation of the charging loop, as depicted in Figure 12, enabling continuous charging and real-time monitoring of the charging status. Once the EV battery reaches a 1000% State of Charge (SoC), the system exits the charging loop. At this point, the EV sends a termination signal to the EVSE, causing the CP signal to stop operating, as shown in Figure 13, marking the completion of the charging process.

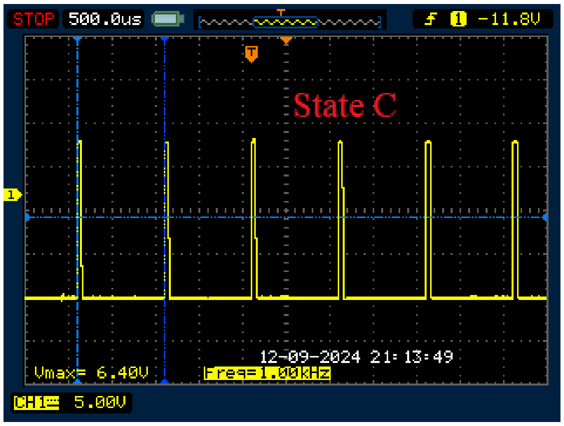
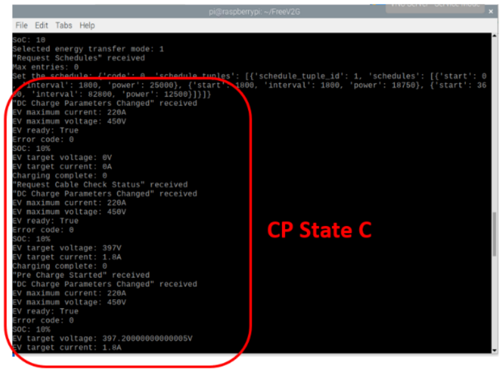


Fig. 11 Changing of Control Pilot signals to state C



```
SoC: 10
Selected energy transfer mode: 1
"Request Schedules" received
Max entries: 0
Set the schedule: {'code': 0, 'schedule_tuples': [{'schedule_tuple_id': 1, 'schedules': [{'start': 0
, 'interval': 1800, 'power': 25000}, {'start': 1800, 'interval': 1800, 'power': 18750}, {'start': 36
00, 'interval': 82800, 'power': 12500}]}]}
"DC Charge Parameters Changed" received
EV maximum current: 220A
EV maximum voltage: 450V
EV ready: True
Error code: 0
SOC: 10%
EV target voltage: 0V
EV target current: 0A
Charging complete: 0
"Request Cable Check Status" received
"DC Charge Parameters Changed" received
EV maximum current: 220A
EV maximum voltage: 450V
EV ready: True
Error code: 0
SOC: 10%
EV target voltage: 397V
EV target current: 1.8A
Charging complete: 0
"Pre Charge Started" received
"DC Charge Parameters Changed" received
EV maximum current: 220A
EV maximum voltage: 450V
EV ready: True
Error code: 0
SOC: 10%
EV target voltage: 397.20000000000005V
EV target current: 1.8A
```

Fig. 12 EVSE loop charging operation with CP State C

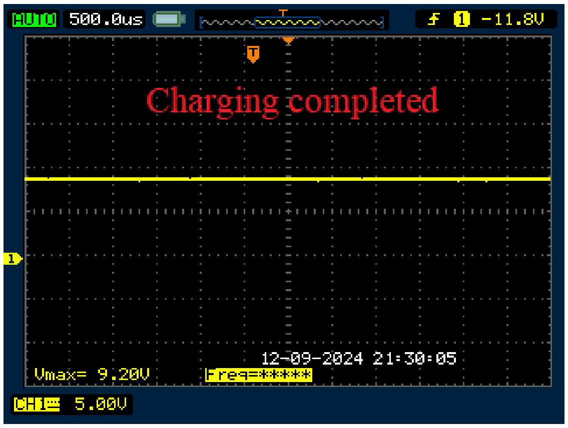


Fig. 13 CP signals at end of charging program

From the experiment, it clearly showed that this charging can be carried out according to the designed set of instructions. At the start of the experiment, White-beet EVSE sent PP signals from CCS connector to locking of the charger connector when connected to the EV's socket and sent CP signal to start the charging process. Then EV sent a request message signals to request charging authorization from White-beet EVSE.

The system operated in a loop to continuously check the current charging status compared to the full battery capacity of the EV. When the current charge reaches the full capacity, the charging is then stopped. There is no CP signal transmission, causing the EV charger connector to unlock and leading to the end of EV charging.

V. CONCLUSION

In this paper, the DC charging system is explored using the CCS connector according to the ISO 15118 communication protocol. The experiment began with a simulation of the charging system using White-beet EVSE and White-beet EV devices controlled by Raspberry Pi 4 Model B, simulating a charger and an EV, respectively. The designed charging system was successfully implemented. Subsequently, the White-beet EVSE module was tested with the MG ES (EV) Long Range 2023. The CP signal emitted by the White-beet EVSE successfully communicated and performed the charging process with the EV according to the CP signal status until the charging was complete. The results and knowledge gained from this experiment can be applied and utilized for developing a CCS portable charging system in the future.

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