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Evaluation of Various Home Charging Systems for Electrical Protection and Data Communications

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Abstract: Electric Vehicles (EVs) are revolutionizing transportation, impacting users and infrastructure system. Reliable EV chargers require robust electrical protection and data communication. This work aims to evaluate the performance of EV chargers to improve the product's capability by experimentally studying several EV chargers using multi-functional measuring instruments and software referring to standards and protocols. The EV charger's electrical protection is evaluated through residual current protection, voltage drop, and impedance testing. The Open Charge Point Protocol (OCPP) parameters are used for data communication testing. This study revealed that the leakage current on the input side is below 30 mA, but the protection response time of CS 4 is more than 140 ms. On the output side, the leakage current of CS 2 and 4 is more than 30 mA, with a protection response time of CS 1 and 4 more than 140 ms. The voltage drop of CS 1 is higher than 3%. The neutral-to-ground voltage of CS 1, 2, and 3 is more than 5 V. The most significant phase-to-neutral impedance is obtained by CS 3, while CS 4 has a lower phase-to-ground impedance. Data communications testing results are captured for CS 1 to CS 4 responses for status availability and heartbeat no longer than 5 s. Meanwhile, CS 2 could not send the metervalue after charging, and CS 2 and CS 3 did not have reservation features to anticipate the waiting time. These findings demonstrate the performance quality of EV chargers and might serve as a reference for further development and enhancement by relevant standards and protocols.

Keywords: charger testing; protection system; data communication; charger performance

1. Introduction

Given the rise in carbon emissions, green technology is starting to gain traction[1)]. Electric cars are one of the green technologies that are in style and gained right now, especially in Indonesia[2)]. The cost, the car's estimated distance, and the chargers' availability are still barriers to electric vehicle ownership[3)]. Furthermore, a comprehensive infrastructure dispersed throughout the user's location is necessary for electric automobiles[4)]. There are several challenges and problems regarding these circumstances. Firstly, there are concerns regarding the accessibility of infrastructure, especially charging stations which are required to support the growing number of electric vehicles. Hence, this condition underscores the importance of efficient and effective planning, technical installation, and routine maintenance, as these aspects are crucial and interconnected with both cost and operational considerations[5–7)]. Moreover, numerous charger types are installed in different settings, including both indoor and outdoor ones, therefore it's important to examine the physical condition of each charger, paying particular attention to the body and plug.

The charging station system includes an internal system for performing charging operations, such as an electrical system, protection system, data transmission system, and instrumentation[8)] also new technology such as internet of things that enticed in green technology[9)]. It is composed of different brands, plug types, and total power. It is necessary to measure and maintain the primary support system while considering the various locations of charging stations and the variations in electricity quality at each site. International standards, national standards that apply in that nation, and communication protocols are some of the references available for maintenance and measurements to ascertain the charger's quality.

In the term of electrical protection systems, residual current device testing is one of the crucial aspects in the protective system in order to assess the charger safety[10]. In addition, other measures include voltage drop and impedance as part of electrical safety requirements[11,12], also managing quality of voltage in the environmental of smart grid [13]. Tools that correspond to standards linked to charging stations, such as IEC 61851-1 and EN 61001, will be used for quality measurements utilizing electrical parameters. Several publications review charger quality using standard. The distinction is that every nation implements standards differently. As an example, a study which focuses on mode 2 charging and pays particular attention to universally accessible connectors and plugs has been conducted. The IEC 61851-1 standard is one of the standards which is referred to in this study[14].

In the meantime, charger quality maintenance is done in the data communication system by sending messages and data to the charger from a centralized system and determining each charger's response time and reconfiguration. Because they come with both DC and AC plug types, some charger systems use a centralized communication system. Conversely, some chargers are designed specifically for plug types that are DC-only or AC-only[15]. The OCPP is the protocol system that is utilized to evaluate data transmission networks. There are many manufacture and operator industries of electric vehicle supply equipment (EVSE) which have created and implemented OCPP[16,17].

The prior studies were commonly concerned in creating test devices[18,19], evaluating the EVSE's quality and system[20], and figuring out the placement of the charger[21]. which has not explicitly chosen the kind and quantity of charger power. However, AC-type chargers are the most common type of charger and most found in houses[22]. In addition, the installation variation which is found in every house, apartment, and housing complex might potentially relate to the electrical protection and data communication quality. Despite of these problems and challenges, users must be able to charge comfortably without experiencing issues while charging, either in terms of electricity or data communications. Therefore, the novel experiment in order to specifically examine home chargers with Type 2 AC connectors and powers ranging from 7 to 22 kW is conducted in this study.

J. Jency Joseph et al. has also conducted a number of tests by evaluating the EV charger's life cycle, charging effectiveness, and battery management[23]. We are unable to determine the charger's performance once it is placed at the customer's location, though, because this test is conducted before installation. However, the significance of charging safety and charging safety protection for electric vehicles has also been discussed by Linru Jiang et al[24]. But rather than giving specific test findings for the protection system, his study concentrated more on strategies, estimates, and sources for safeguarding the charging system. The objective of this experimental study is to draw more attention to the quality of chargers with low power capacity (slow charging and medium charging) in a variety of settings, including housing complexes, apartments, malls, government offices, and amusement parks. By doing standard-based and protocol-based testing and evaluation, the required maintenance or improvement of the installed infrastructure can be addressed correctly.

2. Methodology

2.1 Electrical testing

Global standards and protocol are used in the measurements and conformance testing. Additionally, some of these criteria have been modified to conform to Indonesia's current national standards. In compliance with the test instrument specifications, a number of standards are used as references. The AC charger tests were conducted in accordance with IEC 61851-1 and EN 61010-1 standards[25]. A scope for charging systems in hybrid and electric cars is provided by IEC 61851 series. This paper obtained residual current, impedance, and voltage drop as testing parameters. Another standard is EV 61010-1, which covers the general requirements for safety in the use of electrical equipment for measurement, control, and laboratory applications. These standards are considered for electrical test and measurement equipment.

To assure an EVSE's quality, several standards have been released. The IEC 62196[26] and IEC 62752 series of plug standards are the ones that are most commonly used. In addition, the IEC 61851-21 series covers charging systems; this includes IEC 61851-21-2: 2018 for off-board chargers and IEC 61851-21-21 for on-board chargers. These standards cover electromagnetic compatibility and relate to EV charging. The IEC 61851-23 applies to the EV supply equipment to provide energy transfer between the supply network and EVs[27]. The digital communication between a EV supply equipment and an EV is included in IEC 61851-24[28]. Regarding these standards, the testing procedure in this study is shown in Fig 1.

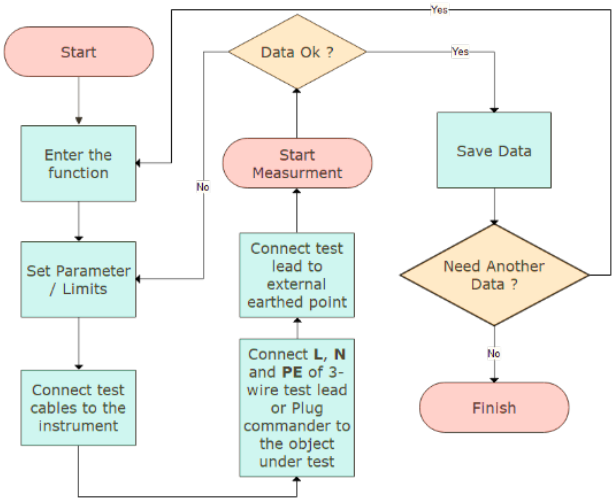

Fig. 1: Electrical testing steps.

The testing device used the Metrel Eurotest MI3155 tool and the A1532 module to test the protective system[29]. This instrument can test the charger's functionality and performance in accordance with DIN 5032, IEC 61851-1, EN 61557, and EN 61010 serial standards; it can also test the charger's protection and installation in accordance with EN 61008, EN 61009, and IEC 60364-4-41 standards. Moreover, Table 1 describes the specifications of the EV chargers in this study based on the datasheet provided by the EV charger manufacturer.

Table 1. Specifications of the chargers.

Input Parameter	**EV Charger**			
	CS 1	**CS 2**	**CS 3**	**CS 4**
Power supply	3P+PE	3P+PE	1P+N+PE	3P+N+PE
Voltage	480 V_{AC} ±10%	480 V_{AC} ±10%	220 V_{AC} ±10%	400 V_{AC}
Power factor	>0.96	>0.96	>0.96	>0.98
Efficiency	94%	94%	95%	95%
Frequency	50/60 Hz	50/60 Hz	50/60 Hz	50/60 Hz
Over-current protection	Circuit Breaker	Circuit Breaker	Circuit Breaker, SPD	Circuit Breaker
Earth leakage protection	30 mA RCD Type B	RCD Type B side AC	40 A 30 mA Type A RCD	30 mA Type A RCD
Ethernet	10/100 Base TX (TCP/IP)	10/100 Base TX (TCP/IP)	-	10/100 Base TX (TCP/IP)
Wireless comm.	3G/GPRS /GSM	3G/GPRS/ GSM	wifi	3G/GPRS /GSM
Comm. protocol	OCPP 1.6 J	OCPP 1.5, 1.6 J	OCPP 1.6 J	OCPP 1.5, 1.6 J
RFID system	"ISO/IEC 14443A/ B, ISO/IEC 15393, FeliCa™ 1, NFC reader mode, Mifare, Calypso, (option: Legic)"	"ISO/IEC 14443A/B, ISO/IEC 15393, FeliCa™ 1, NFC reader mode, Mifare, Calypso, (option: Legic)"	"ISO/IEC 14443A/ B, ISO/IEC 15393,"	ISO 14443A/ B, Mifare DESFire, ISO 18092/EC MA-340 (NFC) 13,56 MHz

2.1.1 Residual current protection

Because of the potential operating conditions of the electric vehicles, direct residual current (DC) protection is in place. It is conceivable for DC residual currents, whether pulsed or smooth, to arise when high-frequency chargers are operating. RCD Type B is therefore advised for Mode 3 and Mode 4 charging. Using a charger that generates more than 6 mA of DC residual current is prohibited for Mode 1[30].

To lessen the chance of harm occurring when the charging station is being used, safety measuring techniques against an electrical insulation failure caused by an indirect contact are used. With a maximum residual current rating of 30 mA, a residual current device (RCD) is a device that cuts off a circuit anytime it senses an imbalanced current passing through the neutral and live conductors. In a circuit with a maximum current of 6 mA, residual pulsing DC current can be handled by the RCD Type A. The smooth residual DC current brought on by a malfunction in the power electronics circuitry's intermediate DC link circuit is then handled by the RCD Type B, which is capable of handling all forms of faults.

The EN 61557-6 standard states that RCD testing, including contact voltage measurement, trip-out time, trip-out current, and RCD auto test, must be carried out. The trip-out current (RCD I) measurement was done in this investigation. The installed RCD's rating determined the parameters and upper limit. In the event that the RCD does not trip out, the device steadily raises the test current until it reaches the final amount[31].

2.1.2 Impedance

The majority of EV charging stations are wired into the electrical grid via an AC bus. An inductor, a resistor, and a capacitor are linked in series and parallel to form the grid equivalent model. Regarding a charging station that uses the Vienna rectifier architecture, the impedance is defined as follows[12]:

$$z_{evse}(s) = \frac{1+G_{PN}G_2(s)}{G_1(s)} + \frac{(1+G_V(s))(1+G_C(s))}{G_1(s)G_V(s)G_C(s)} \quad (1)$$

Where G_c and G_v are the closed-loop transfer functions of the current and voltage control loops of the Vienna topology; Gpli is the current PI control transfer function; and G_1 and G_2 are the input and output voltage, input current, inductance, and capacitance. Z auto

test sequence for fast line and loop was used in this study. The configuration of parameters and their limits within the testing instrument is set in accordance with the rating of the EV charger. This includes the protection type, fuse type, rated current, and maximum fuse breaking time.

2.1.3 Voltage drop

The voltage drop is calculated based on the difference of line impedance at connection points and the line impedance at the reference point, as follows[32]:

$$\Delta U[\%] = \frac{\Delta U}{U_N} = \frac{(Z - Z_{REF}).I_N}{U_N} \times 100 \qquad (2)$$

Where,
ΔU : voltage drop
Z_{REF} : impedance at reference point
Z : impedance at test point
U_N : nominal voltage
I_N : rated current of selected fuse

2.2 Data communication (OCPP) testing

Response time, message packages received on each charger, and reception response to the charger are among the responses that are measured during communication data testing using Charging Station Management System (CSMS) and OCPP[33]. Heartbeat, metervalue, remote start, and reservation messages are among the message bundles that CSMS will deliver. Subsequently, as illustrated in Fig. 2, the charger will offer a configuration to initiate the machine and subsequently send a message back to the CSMS or central system. In the meanwhile, Fig. 3 displays the test specifics.

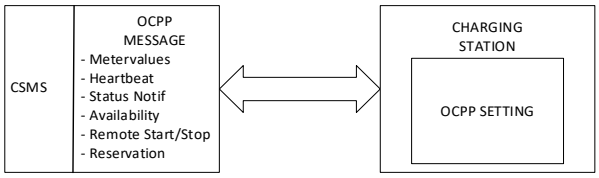

Fig. 2: Configurations and communication between EVSE or CS and CSMS.

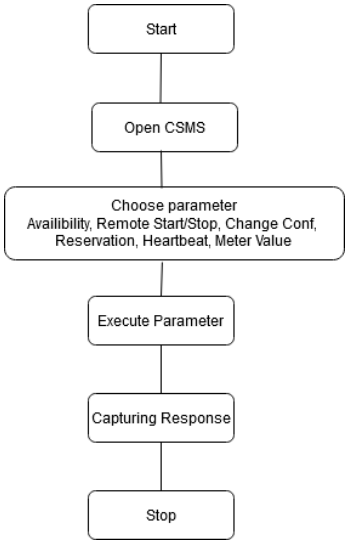

Fig. 3: Data testing procedure for communication.

Start is the first step in the procedure by entering the CSMS application dashboard. Open CSMS is the next step. Choose the process menu next: Select the following parameters: Reservation, Heartbeat, Meter Value, Change Conf, Remote Start/Stop, and Availability. Execute Parameters is the next stage. Based on these outcomes, Capturing the Response is done (by documenting response times, messages, and charger modifications). The process concludes with Stop, which involves closing the program. Fig. 3 illustrates the entire procedure.

This study concerned on the protocol that links the EVSE to the Central System or CSMS when conducting testing based on communication protocols. OCPP is one protocol that many EVSE manufacturers have widely implemented. The broad protocol implementation across many EVSE brands, user-to-user interaction during transactions, operator-set charger management parameters, and communication data security are the foundations for our testing use of OCPP. CSMS has been discussed by several scholars, including the creation of urban CSMS, the performance testing of CSMS[34], the study of communication protocols between EVSE and Backend or CSMS[35,36], and data modeling in CSMS[37].

The OCPP protocol enables the management of charge points as well as remote start transactions, remote stop transactions, change of availability, clear cache, reserve now, data transfer, etc.[38]. Additionally, there are standardizations for OCPP, such as ISO 15118, which is commonly applicable in Europe. Meanwhile, in the Americas, standardizations typically derive from The American Society of Automotive Engineers (SAE)[39]. For example, the different versions of the OCPP (1.2, 1.5, 1.6. or 2.0) only allow a reservation at the time of booking[40]. In this paper, the functions remote start/stop, reservation, heartbeat, metervalues and availability are tested for the OCPP used. The most important messages of the functions contained in the OCPP are then recorded.

2.2.1 Heartbeat

The Heartbeat.conf signal, which contains current time information that can be used as a system clock, is returned by the CSMS in response to the Heartbeat signal, which is used to indicate that the CS connection to the CSMS is still active. The Heartbeat signal appears as "Hearbeat.req" at specific intervals.

2.2.2 Meter values

Hardware specs and sensor/transducer data are included in MeterValues.req. Meter values are set to data acquisition intervals and indicate the data to be collected and reported using the ChangeConfiguration.req message. It includes the primary energy meter, transactionId, and One or more items of the type MeterValue, each of which represents a collection of one or more data values obtained at a specific moment in time. There is just one value datum per sampled value element. The optional measure, context, location, unit, phase, and format fields define SampledValue.

2.2.3 Status of notifications

Notifications of all status changes and errors are transmitted to the CSMS from the charging point. Charge Point sends out status notifications. The statements on preparation, charging, suspended EV, suspended EVSE, and finishing included in the part of the state of charge could be important for battery management[41)].

2.2.4 Change availability

The CSMS can request a charge point to change its availability. The response device shall indicate whether the charge point is able to change to the requested availability or not. In the event that CSMS requests CS to change to a status it is already in, CS shall respond with availability status `Accepted`. When an availability change requested with a ChangeAvailability.req device has happened, the CS shall inform the CSMS of its new availability status with a StatusNotification.req.

2.2.5 Change configuration

Since each charging station's default configuration might differ, the change configuration message plays a pivotal role, enabling the management system to modify the configuration of chargers remotely. It serves as a cornerstone for effective charger management, facilitating centralized control and standardization. The central system can request a CS to change configuration parameters. This request contains a key-value pair, where “key“ is the name of the configuration setting to change and “value“ contains the new setting for the configuration setting. Upon receipt of a change configuration request, the charge point shall reply with a configuration configuration indicating whether the change could be applied to its configuration.

2.2.6 Remote start transaction

The CSMS can request a Charging Point to start a transaction by sending a RemoteStartTransaction.req. Upon receipt, the CS shall reply with RemoteStartTransaction.conf and a status indicating whether it has accepted the request and will attempt to start a transaction. If the value of AuthorizeRemoteTxRequests is true, the CS shall behave as if in response to a local action at the CS to start a transaction with the idTag given in the RemoteStartTransaction. This means that the CS will first try to authorize the idTag, using the Local Authorization List, Authorization Cache and/or an Authorize.req request. If the value of AuthorizeRemoteTxRequests is false, the CS shall immediately try to start a transaction for the idTag given in the RemoteStartTransaction.req message. After the transaction has been started, the CS will send a StartTransaction request to the CSMS, and the Central System will check the authorization status of the idTag when processing this StartTransaction request.

2.2.7 Remote stop transaction

The CS shall reply with RemoteStopTransaction.conf and a status indicating whether it has accepted the request and a transaction with the given transactionId is ongoing and will be stopped. Therefore, the transaction shall be stopped, The CS send a StopTransaction.req and, if applicable, unlock the connector.

2.2.7 Reserve now

To request a reservation the CSMS send a ReserveNow.req to a CS. If the reservationId does not match any reservation in the CS, then the CS shall return the status value `Accepted` if it succeeds in reserving a connector. The CS shall return `Rejected` if it is configured not to accept reservations. If the configuration key:ReserveConnectorZeroSupported is not set or set to false, the CS should return `Rejected` The CS shall send a notification to notify the CSMS that the reserved connector is now available.

3. Result and Discussion

3.1 Electrical protection test results

The test results on the input side are shown in Table 2. The RCD test from CS 1 to CS 3 has a leakage current ($i\Delta$) on the input side that can be turned off by a charger if it is less than 30 mA. Concurrently, CS 4 achieved a leakage current detection result of 33 mA, which is greater than 30 mA and non complience with IEC 61851-1.

Table 1. Electrical input test results for RCD, V, Z and R_{iso}.

CS	Result-RCD			
	$I\Delta$ (mA)	U_C (V)	$U_C I\Delta$ (V)	$tI\Delta$ (ms)
1	22.5	0.9	0.7	73.8
2	28.5	0.7	0.6	55.6
3	24	0.9	0.7	18
4	33	0.1	0.1	161.7
RCD type: A; $I\Delta N$: 30 mA; Phase: (+); Selectivity: G				
CS	Result-Voltage			
	U_{ln} (V)	U_C (V)	U_{ln} (V)	f (Hz)
1	222	1	222	50
2	221	2	221	50
3	221	216	5	50.1
4	233	233	1	50.1
Earthing: TT/TN; Low limit U_{ln}: 207 V; High limit U_{ln}: 253 V; Low limit U_{lpe}: 207 V				

CS	Result-Z						
	U_{ln} (V)	z_{ln} (Ω)	Z_{lpe} (Ω)	U_c (V)	ΔU (%)	I_{PSC} L_N (kA)	I_{PSC} L_{LPE} (A)
1	221	0.19	17.5	0.4	3.3	1.22	13.1
2	221	0.16	18.5	0.8	0.4	1.46	12.4
3	221	0.3	18.2	0.8	0.8	0.76	12.6
4	233	0.1	0.38	0	0.3	2.3	604
Protection: TN rcd; Fuse type: Gg; Fuse I: 6A; Fuse t: 0.0035 s ; I_{sc} factor: 1; LPE: 229; PEN: 6; LN: 225							

CS	Result-R_{iso}					
	R_{iso} N/PE (MΩ)	R_{iso} L/PE (MΩ)	R_{iso} L/N (MΩ)	U_m N/PE (V)	U_m L/PE (V)	U_m L/N (V)
1	>200	>200	0.1	263	262	14
2	>200	>200	0.39	263	262	262
3	>200	>200	0.1	263	262	11
4	>200	>200	0.79	263	262	262
U_{iso}: 250 V; Limit R_{in}: 1MΩ; Limit R_{ipe}: 1MΩ; Limit R_{npe}: 1MΩ						

The measurement data acquired on CS 3 showed that the response time for leakage current was the fastest, at 18 ms. The response times for CS 1, 2, and 4 are 73.8 ms, 55.6 ms, and 161.7 ms, respectively. This indicates that CS 4 has the slowest response

The voltage drop percentage values at CS 1, CS 2, CS 3, and CS 4 are 3.3%, 0.4%, 0.8%, and 0.3%, which means CS 1 does not meet the requirements. The neutral voltage to ground U_{npe} on CS 1 to CS 3, the measured voltage between phases is $\geq$ 5 V, while CS 4's measured voltage is less than 5 V, indicating that the installation satisfies specifications and has sufficient grounding. Meanwhile, the phase-to-ground voltage ranges from 221 V to 233 V. The frequency of CS 3 and CS 4 are slightly higher but still within the tolerance limits. The test results indicate that the input side impedance between phase and neutral at CS 1, CS 2, and 4 was 0.19 Ω, 0.16 Ω, and 0.1 Ω, respectively. In the meantime, CS 1, 2, and 4 have phase-to-ground values of 17.5 Ω, 18.5 Ω, and 0.38 Ω. Phase-to-neutral and phase-to-ground findings for CS 3 were 0.3 Ω and 18.2 Ω, respectively. The CS 3 has a larger phase-to-neutral impedance than CS 1, CS 2, and CS 4. Compared to CS 1, CS 2, and CS 4, CS 4's impedance value is substantially lower in phase-to-ground tests.

The phase to neutral resistance values of CS 1 to CS 4 are 0.1 Ω, 0.39 Ω, 0.1 Ω, and 0.79 MΩ, which are below the measurement limit of 1 MΩ. Just CS 4 has a value that approaches 1 MΩ. There are CS 1 and CS 3 that have values of 14 V and 11 V for phase to neutral insulation voltage, which are below 250 V.

Moreover, on the output side utilized parameters presented in Table 3 and Table 4. During RCD testing, only CS 1 and CS 3 exhibited leakage current (iΔ) that could be interrupted by the charger below 30 mA. However, despite CS-1's ability to disconnect electric current before the 30 mA limit, it demonstrated a prolonged response time to the leakage current, specifically exceeding >140 ms. Meanwhile, for CS 2 and CS 4, values of leakage current detection were obtained, surpassing 30 mA, specifically 34.5 mA for CS 2 and 66 mA for CS 4 as shown in Fig. 4, which is non-compliance with the specifications. Concerning response time, measurement results for CS 4 and CS 1 are exceeding >140 ms.

Fig. 4: RCD testing

Table 2. Electrical output test results for RCD & Voltage.

CS	Result-RCD			
	$I\Delta$ (mA)	U_C (V)	$U_C I\Delta$ (V)	$tI\Delta$ (ms)
1	5.5	0.4	0.2	>140
2	34.5	0.8	0.9	45.1
3	24.5	0.8	0.6	18.2
4	66	0.1	0.1	>140
RCD type: B; $I\Delta N$: 30 mA; Phase: (+); Selectivity: G				
CS	Result-Voltage			
	U_{ln} (V)	U_{lpe} (V)	U_{npe} (V)	f (Hz)
1	226	121	6	50
2	221	216	6	50.1
3	222	217	5	50

4	232	232	1	50.1
Earthing: TT/TN; Low limit U_{ln}: 207 V; High limit U_{ln}: 253 V; Low limit U_{lpe}: 207 V				

During the impedance testing, specifically on the voltage drop side, the percentage voltage drop value at CS 1 is more than 3%. Meanwhile, CS 2 to CS 4 have values below 3%, specifically 0.5% for CS 2, 0.8% for CS 3, and 0.3% for CS 4. The AC EV supply equipment and general specifications for electric vehicle charging stations are provided by IEC 61851, standard series 1. It applies to EVSE powered by on-site storage systems and can charge EVs with input and output voltage ratings of 1000 Vac or 1500 Vdc.

Table 3. Electrical output test results for Z & R iso.

CS	Result-Z						
	U_{ln} (V)	z_{ln} (Ω)	Z_{lpe} (Ω)	U_c (V)	ΔU (%)	I_{PSC} L_N (kA)	I_{PSC} L_{LPE} (A)
1	221	0.19	17.5	0.4	3.3	1.22	13.1
2	221	0.16	18.5	0.8	0.4	1.46	12.4
3	221	0.3	18.2	0.8	0.8	764	12.6
4	233	0.1	0.38	0	0.3	2.3	604
Protection: TN rcd; Fuse type: Gg; Fuse I: 6A; Fuse t: 0.0035 s ; I_{sc} factor: 1; LPE: 229; PEN: 6; LN: 225							
CS	Result-R_{iso}						
	R_{iso} N/PE (MΩ)	R_{iso} L/PE (MΩ)	R_{iso} L/N (MΩ)	U_m N/PE (V)	U_m L/PE (V)	U_m L/N (V)	
1	184.5	185	0.1	525	525	14	
2	>200	>200	0.1	263	262	14	
3	>200	>200	0.1	263	262	11	
4	191.4	186.9	0	263	262	1	
U_{iso}: 250 V; Limit R_{in}: 1MΩ; Limit R_{ipe}: 1MΩ; Limit R_{npe}: 1MΩ							

The IEC 61581-1 states that an RCD with a rating of no more than 30 mA and at least type A must protect an EVSE that does not employ electrical safety measures. Conductors must be disconnected by those RCDs. However, EVSEs equipped with vehicle connectors or socket-outlets for AC usage must incorporate protections against DC fault current, such as RCD type A or B, which have a DC fault current rating of up to 6 mA. Insulation resistance should be more than 1 MΩ for a class I EVSE and 7 MΩ for a class II EVSE when 500 Vdc is applied.

During the test, the measurement should be detached from the protective impedances and attached to every reachable component. Within one minute, the test voltage should be applied at 93% relative humidity. When a fault current to ground exceeds a certain value below the required value of an overcurrent protective device, the grounding path opens or becomes high impedance or a path to ground is detected on an isolated system, system protection is used to interrupt the electric circuit.

Values for the EV control pilot circuit and parameters should be preserved for the duration of the device's useful life and in the intended environmental settings. Typically, the voltage drop should have a minimum value of 0.55 V and a maximum value of 0.85 V, or around 0.07 V. All of the test could prevent the production of sparks and risk for hazard when the higher current and voltage are pervaded in the charging[42)]. For the future research, the authors could involve another testing such as efficiency of charger that impact the standby losses, energy management on the charger or vehicle[43)], and the benefit of internal protection.

3.2 Data communication test results

According to OCPP, the test results utilizing CSMS to ascertain the response to several existing messages are displayed in Table 5, and Fig 5 shows the result displayed in the testing software. All chargers, CS 1 through 4, demonstrated a successful response in the Change Availability test, with a reaction time of five seconds in accordance with the CSMS standard. In contrast, CS 1 and CS 4 respond more slowly in the Heartbeat Interval message when the interval is set to anything shorter than 10 seconds, such 5 seconds. Between 20% and 50% of the allotted time is lost in reaction time before it is detected by the CSMS. In contrast, CS 2 has a quicker response time, even though there is a delay of about 20% of the scheduled time for settings lower than 10 s.

Nearly all CS in remote transaction testing refused to allow transactions with invalid IDs, necessitating the termination of the transaction with a valid ID. All chargers refuse to comply with the command to cease charging when the EV is detached; this means that while they all react passively to requests from the car and the charger, they are unable to alter the settings. This feature is not available in reservation testing for CS 2 because it must be activated individually, which carries an additional cost. CS 1, 3, and 4 have this feature, in contrast to CS 2, so that reservations can be made by that kind of CS. Multiple parameters can be provided to CS 1, CS 3, and CS 4 during metervalue testing. Although it may communicate two parameters, this capability is not yet operational on CS 2.

Table 4. Data communication testing with several messages

	CS 1	CS 2	CS 3	CS 4
Change availability	Accepted, Successfully, Response Time 5 s.	Accepted, Successfully, Response Time 5 s.	Accepted, Successfully, Response Time 5 s.	Accepted, Successfully, Response Time 5 s.
Heartbeat Interval	Accepted, Successfully, Response Time 5 s, Actual	Accepted, Successfully, Response Time 5 s,	Accepted, Successfully, Response Time 5 s,	Accepted, Successfully, Response Time 5 s,

	implementation delay time with tolerance more than 100%	Heartbeat: as ordered, miss 10% tolerance, 20-50% below 10 s	Heartbeat Interval=real 5 s as ordered, tolerance 10% delay time, below 10 s to be miss 20-50%	Heartbeat Interval=real 5 s as ordered, tolerance 10% delay time, below 10 s to be miss 20-50%
Remote Start/Stop	AllowRemoteTxreq=rejected(false,readonly), StopTxOnInvalidID=rejected(true,readonly), StopTxOnEcDiscon=Rejected(True,readonly)	AllowRemoteTxreq=rejected(false,readonly), StopTxOnInvalidID=rejected(true,readonly), StopTxOnEcDiscon=Rejected(True,readonly)	AllowRemoteTxreq=rejected(false,readonly), StopTxOnInvalidID=rejected(true,readonly), StopTxOnEcDiscon=Rejected(True,readonly)	AllowRemoteTxreq=notsupported(false,Readonly), StopTxOnInvalidID=rejected(false,notreadonly), StopTxOnEcDiscon=notsupported(true,readonly)
Reservation	Accepted, Successfully, Reservation as ordered, Response Time 5 s.	Code: NotImplemented, Description: unknown action: ReserveNowRejected	Code: NotImplemented, Description: unknown action: ReserveNow	Accepted, Successfully, Reservation as ordered, Response Time 4 s.
Metervalue	Accepted, Supported, 3 parameter electricity such as Energy Active, Power Active, and Current.	Metervalueinttime=notsupported, metervaluesample=Accepted, 2 Parameter electricity such as SoC and Energy Active	Accepted, Supported, 9 parameter electricity such as Energy Active, Power Active, Current, etc, except SoC.	Accepted, Supported, 9 parameter electricity such as Energy Active, Power Active, Current, etc, except SoC.

Key	Value	Read only?
AllowOfflineTxForUnknownId	FALSE	FALSE
AuthorizationCacheEnabled	TRUE	FALSE
AuthorizeRemoteTxRequests	FALSE	TRUE
ChargeProfileMaxStackLevel	10	TRUE
ChargingScheduleAllowedChargingRateUnit	Current	TRUE
ChargingScheduleMaxPeriods	24	TRUE
ClockAlignedDataInterval	0	FALSE
ConnectionTimeOut	30	FALSE
ConnectorPhaseRotation	Unknown	FALSE
GetConfigurationMaxKeys	200	TRUE
HeartbeatInterval	14400	FALSE
LocalAuthListEnabled	TRUE	FALSE
LocalAuthListMaxLength	10000	TRUE
LocalAuthorizeOffline	TRUE	FALSE
LocalPreAuthorize	TRUE	FALSE
MaxChargingProfilesInstalled	10	FALSE
MeterValueSampleInterval	0	FALSE
MeterValuesAlignedData	SoC,Energy.Active.Import.Register	FALSE
MeterValuesSampledData	SoC,Energy.Active.Import.Register	FALSE
MinimumStatusDuration	5	FALSE
NumberOfConnectors	3	TRUE
ReserveConnectorZeroSupported	FALSE	TRUE
ResetRetries	5	FALSE

Fig. 5: Data communication testing

3.2.1 Vehicle owners perspective

Metervalue time interval signal indicates that the consumer will receive a certain amount of energy value sent in a certain time unit[44)], so that when the consumer stops charging or when charging has been completed, an energy value will be sent with the energy value sending time when the CSMS receives the value according to the request consumer. If this value changes too quickly, the server will be overloaded, but the accuracy is good because there is almost no difference between the value in the payment application, charger, and on the server or CSMS.

Heartbeat, Status Notification, and Availability signals indicate that the charger or EVSE is operational, allowing consumers to place orders or charge directly at the spot. If the charger does not correctly and rapidly reset the heartbeat, the availability indication may alter, causing the consumer to fail or be ahead of other consumers. An enhanced availability of EV charging stations would foster greater trust among EV users, thereby alleviating range anxiety concern[45)].

The Reservation signal indicates that the consumer can make a reservation, and the response from the charger should offer the reservation to the customer as soon as possible. If another customer orders, it should be refused. Aside from that, if reservations are made over a long period of time, there should be a sign on the charger indicating that one or all of the plugs have been reserved, as this could be damaging to users charging directly and cause confusion.

The Remote Start or cease signal informs users that if they request a specific kwh or notional value, the charger will cease charging. If there is any damage when stopping or starting charging, the charger or CSMS will communicate information indicating whether the damage is accepted or denied. The long response time from remote start or stop can cause the difference in energy sent via meter value signals to be inconsistent with demand, resulting in consumers losing money even if the price difference is not significant given that the EVSE's energy meter has accuracy at the required value.

3.2.2 Operator recommendations

The Metervalue signal informs the operator that the energy value requested by the consumer must match that recorded on the CSMS. If there is a discrepancy, the consumer must be compensated, even if the compensation is not always received through the same manner (for example, payment via bank is replaced with the value of

the digital wallet).

The Heartbeat signal shows that the EVSE is functioning, allowing operators to tell users that the device can be charged. If the reaction time on the Heartbeat differs, it can result in different activity signals, preventing the operator from confirming the operational hours and activity of the charger, which could imply problems in reading transactions or charger availability[46].

The reservation signal indicates to the operator that an EVSE message should be sent to create a reservation at the customer's request[47]. What is concerning is that both the CS location and the plug being rented could be refused if the desired reservation is not fulfilled by the client or does not match their request. Customers may not receive certainty as a result of inconsistent service or misplaced bookings since their expectations may not be met. The implementation of a reservation system would empower users with the certainty and flexibility to schedule their charging sessions[48].

By transmitting a command via the operator's backend or CSMS, the customer can request to begin charging by using the remote start and stop signals. Operators are responsible for making sure that issues like delays and malfunctions do not interfere with the remote start/stop feature, which is used to initiate or terminate charging. Customer service is impacted by this, particularly if one of the messages works (such Remote Start) but not Remote Stop. In order to prevent consumer complaints, it is necessary to foresee the aforementioned incidents.

4. Conclusions and Recommendations

An evaluation of electrical protection systems across various EV charging stations revealed discrepancies in performance. Notably, some chargers demonstrated compliant installations adhering to the standards. This study revealed that although CS 4's protection response time is more than 140 ms, the input side leakage current is less than 30 mA. On the output side, CS 1 and 4 have more than 140 ms protection response times and leakage currents of more than 30 mA. CS 1 has a voltage drop that exceeds 3%. The neutral-to-ground voltage of CS 1, 2, and 3 is more than 5 V. CS 4 has a lower phase-to-ground impedance, while CS 3 has the biggest phase-to-neutral impedance.

Moreover, data communication tests were conducted to determine how well the test charger responds and what features it has following the OCPP 1.6 protocol, including reservation, heartbeat, remote start/stop, and metervalue. Reservations and other features are held by CS 1 and CS 4, whereas CS 2 and CS 3 are unavailable because they have not been enabled or because doing so would incur additional fees. While CS 2 must be active to provide parameters like SoC and Energy, CS 1, 3, and 4 can send data with several parameters for meter values based on various settings. The Heartbeat test was also completed with a good response time; however, nearly all chargers have a waiting period if the response time is set to less than 10 seconds.

Further research is suggested to elaborate on other significant parameters, such as electromagnetic, assess the accuracy of current readings or metering, analyze communication data following OCPP scenarios, and parse messages for several crucial messages, such as remote stop and meter value related to the payment process.

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