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OFF-GRID ELECTRIC VEHICLE CHARGING STATION WITH INTEGRATED LOCAL SERVER OCPP PROTOCOL AS A MANAGEMENT SYSTEM

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Electric vehicles are widely regarded as pivotal in driving the sustainability of transportation networks forward, thanks to their capacity to diminish carbon emissions, enhance air quality, and bolster the robustness of electricity grids. The accessibility of charging infrastructure and the subjective norms that endorse electric mobility actively shape the electric vehicles acceptance. In this study, Our main goal is to provide off-grid electric vehicle charging infrastructures and the data communication protocols that connect to servers. We analyze the specifications of the OCPP (Open Charge Point Protocol) with an emphasis on its applicability for electric charging stations for vehicles. Our research concludes that off-grid electric vehicle charging systems can be effectively applied to small electric vehicles such as electric motorcycles, scooters, and bicycles. The OCPP data communication protocol can also support interactions between small electric vehicle charging stations and central server management systems (CSMS). Furthermore, we tested the electric vehicle charging process for a duration of two hours, and the charging station consistently produced stable voltage, current, and power output, matching the inverter outputs and fulfilling the specifications required by electric vehicle charging adapters. Analysis of throughput data indicates a positive correlation between the number of operational ports at a charging station and the volume of data processed by the server. However, beyond a certain threshold a decline in data transactions was observed, attributable to data loss.

Keywords: Charging station, OCPP, data communication, server, off grid system, interface

1. Introduction

The surge in popularity of battery-powered electric vehicles (EVs) is a global phenomenon, with rapid adoption across many countries as they are increasingly recognized as a pivotal component in the sustainable transformation of transportation systems. EVs are at the forefront of eco-friendly policy agendas due to their potential to considerably cut carbon emissions, improve air quality, and strengthen national power grid reliability. (Wang *et al.*, 2022; Marques *et al.*, 2023; Wang *et al.*, 2021; Woodley *et al.*, 2023). The International Energy Agency has documented a marked escalation in EV usage, from 10 million cars in 2020 to over 16.5 million in 2021, forecasting an expansion to more than 85 million by 2025 and 270 million by 2030 (Borge-Diez *et al.*, 2021).

Consumer acceptance of EVs is closely linked to the availability of charging infrastructure, which hinges on subjective norms favoring electric mobility. While electric vehicle plug-ins (PEVs) presently come with a higher price tag compared to internal combustion engine vehicles (ICEVs), the decreasing costs of batteries and other technological improvements are swiftly narrowing this cost disparity (Hsieh and Green, 2020; Lavee and Parsha, 2021). The intention to embrace EVs is greatly influenced by socio-economic factors, as well as governmental policies and incentives. (Kapustin and Grushevenko, 2020; Li *et al.*, 2019).

In Indonesia, the proliferation of electric charging stations is in its infancy, with the number expected to rise in line with the global EV uptrend. Research by Huang Y (Huang and Kockelman, 2020) outlines three main methods for powering battery-based EVs, while Khalid MR *et al.* (2021) categorize charging locations based on charging speed and infrastructure. Afshar S *et al.* (2021) classify various types of electric vehicle supply equipment, with a focus on fixed charging stations, which are frequently outfitted with the OCPP for public use.

One of the most important advanced features of the central system is conformity with OCPP (Raboaca *et al.*, 2022; Alcaraz *et al.*, 2023; Garofalaki *et al.*, 2022). This adherence guarantees smooth interaction between central systems and charging stations, enabling efficient management and monitoring of their operations while delivering up-to-date information regarding the status of both charging stations and vehicles undergoing charging. Therefore, conformity with OCPP becomes a must for the central system responsible for the management of electric vehicle charging stations (Devendra *et al.*, 2021). In this study, the manufacture of small electric vehicle charging systems with the output of AC level 1 source (about 220-240 VAC) as well as off grid systems as its power source and OCPP protocol as the reference of its data communication protocol. The main focus in the study lies in the success of a server-designed and connected charging system (CSMS) to charge small electric vehicles.

This study presents innovative advancements in electric vehicle (EV) infrastructure, particularly by filling in the crucial knowledge void surrounding off-grid charging systems. Departing from the commonly studied grid-connected frameworks, our research focuses on the deployment of off-grid systems designed for small electric vehicles, a niche that has received minimal attention thus far. Incorporating the Open Charge Point Protocol (OCPP) into an off-grid context, our research is at the forefront of creating a communicative structure that improves the management and functionality of remote EV charging stations. Additionally, the creation of a Charging Station Management System (CSMS) functioning off the grid directly confronts the lack of infrastructure in areas with poor grid connectivity. This strategy not only broadens the horizons for EV uptake in remote locations but also establishes a new direction for subsequent sustainable transport system research. The purpose of this research is to reconcile the discrepancies between existing charging technologies and the burgeoning demands of the EV sector, thus making strides toward enhanced energy independence and environmental stewardship.

1.1. OCPP protocol and Off Grid Electric Vehicle Charging Infrastructure

The Open Charging Point Protocol (OCPP) is a universally accepted standard designed to enable communication among electric vehicles (EVs), charging stations (CSs), and central management systems, irrespective of variations in factory features (Chaudhari *et al.*, 2023; Kamal *et al.*, 2023; Orcioni and Conti, 2020; Rojas-Hernandez, 2022; Du *et al.*, 2021; Galkin, 2024). This protocol ensures the management of all aspects involved in the charging process, creating a thorough openness and accessibility in the electric vehicle network. Consequently, end users have the freedom and flexibility to select a network or charging station that aligns with their preferences and requirements (Savargaonkar *et al.*, 2023; Vailoces *et al.*, 2023). As a result, this promotes greater competition between network suppliers and manufacturers with regard to features, cost, and innovation potential.

From 2009 onward, the OCPP protocol has been continuously improved, resulting in several versions including as OCPP 2.0, 1.6, 1.5, and 1.2 versions. Widespread adoption has been primarily observed in the last three mentioned versions. Each new iteration is developed based on previous versions, bringing in the addition of features, documentation improvements, and other function enhancements to meet the growing demands of the industry (Du *et al.*, 2021; Perez, 2020; Saredidine *et al.*, 2023). This process includes the integration of experience and learning gained from implementation in the field. Figure 1 shows the network infrastructure that was employed for this investigation. Three entities and one tool are utilized in network infrastructure to collect data. The electric car being charged is the first entity, and the charging station for electric vehicle is second. Some data recorded by the charging station includes energy, power, current, and voltage data used when the electric vehicle is being charged, which occurs after the authorization process and transaction from the electric vehicle user is validated. The charging station for electric vehicles uses servers (Charging Station Management System) and a specialized network protocol to handle authorization and verification.

Open Charge Alliance is referred to as OCA. It is a global alliance made up of top producers of infrastructure for electric vehicles. Collaboratively, they created the OCPP (Open Charge Point Protocol), an open-source protocol. (Pruthvi *et al.*, 2019; Zaidi *et al.*, 2024). Globally, electric cars are starting to become the standard for mobility. (Das *et al.*, 2020; Karki *et al.*, 2020; Abo-Khalil *et al.*, 2022). These developments are only possible in conjunction with the expansion of CS in a wide geographical area, which gives end users confidence when traveling far out of town. Interoperability between devices made by different manufacturers is made possible by communication standards and protocols, and this is essential for promoting the creation, deployment, and growth of the infrastructure needed for charging. (Noura *et al.*, 2019; Bansal and Kumar, 2020; Burns *et al.*, 2019; Naqvi *et al.*, 2020). Implementing the OCPP standard enables cost-effective and seamless updates, facilitating the introduction of new features that prioritize high-level communication protocols on the application side (Pruthvi *et al.*, 2019; Mattepu *et al.*, 2022).

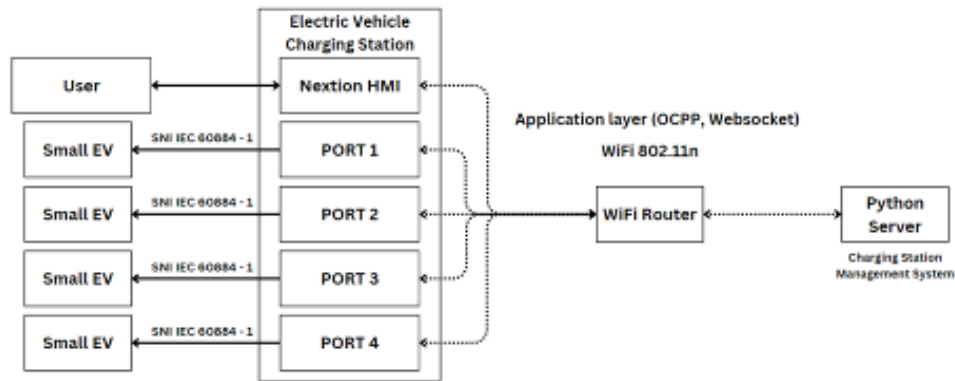


Figure 1. Block Network System Infrastructure Diagram

The integration of the Electric Vehicle Charging Infrastructure with the electric grid creates a dynamic system that requires communication protocols to enable real-time information sharing exchange across different devices. This promotes the advancement of eMobility concepts. A common communication protocol between the charging station and the CSMS is made possible via the OCPP protocol, as depicted in Figure 2. Typically, this communication takes place over the Internet using our proposed infrastructure, which is a fundamental part of our EVCS research infrastructure. (Vailoces *et al.*, 2023). The specification of OCPP defines charging station as a physical entity where EV charging occurs, which might include one or more EVSE (Supply Equipment for Electric Vehicle). C S has the ability to provide energy to electric vehicles as needed. EVSE can accommodate various types of connectors, managed as separate systems, and can refer to a single physical connector such as a charger socket. In certain scenarios, EVSE might feature specific physical outlet or cable arrangements to accommodate a range of vehicles or electric equipment.

1.2. OCPP Protocol Design and Implementation

This section focuses on the design of the OCPP application, which incorporates the latest protocol specifications. It specifically highlights the communication exchange depicted in OCPP image 4 between the charging point and the central system (server). The WebSocket protocol is utilized for network communication, enabling bidirectional message exchange over a TCP connection via IP (Reihs *et al.*, 2023; Fanti *et al.*, 2023; Gainulenko, 2021; Engel *et al.*, 2022; Velychko and Gordiyenko, n.d.; Sayed *et al.*, 2022). When charging station communicates via OCPP-J protocol with the management system, central system functions as a server, while the charging point operates as a client. (Elmo *et al.*, 2023). Figure 3 explains visually the mechanism of this websocket communication.

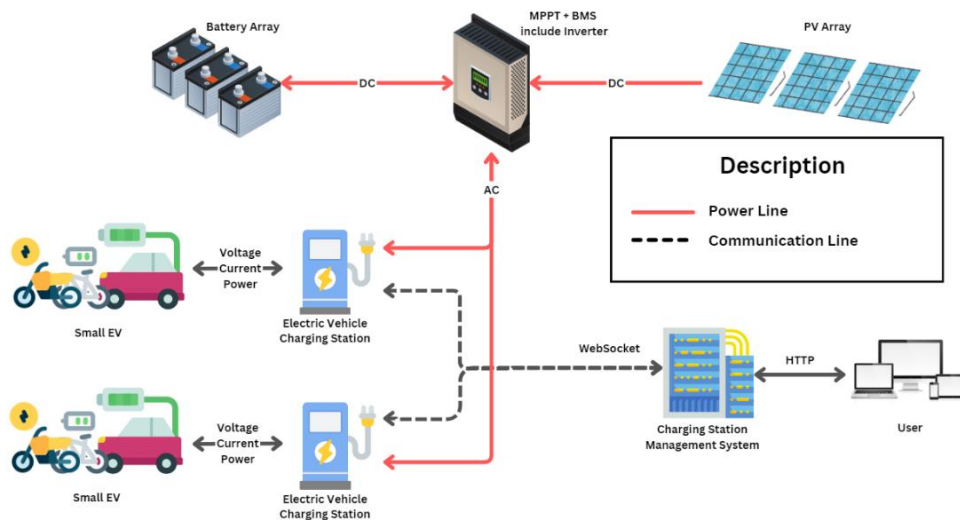


Figure 2. Off-Grid Electric Vehicle Charging Station Infrastructure Components

The OCPP protocol will be used to establish connections with the central system. These connections will be controlled through a fixed server address, specifically "ws://csms.ip.com/ChargingStation1". Profiles are a systematic way for this protocol to organize related features and messages. We may use one or several profiles, depending on the task we intend to finish. To obtain information regarding the status of the charging station (CS) or to arrange necessary activities, the central management system sends out a message. Instead, the charging point sends a notification message both at the initiation and the completion of the transaction, in addition to a heartbeat message for monitoring the stability of the connection. Figures 3 and 4 demonstrate the WebSocket and its communication diagram, respectively.

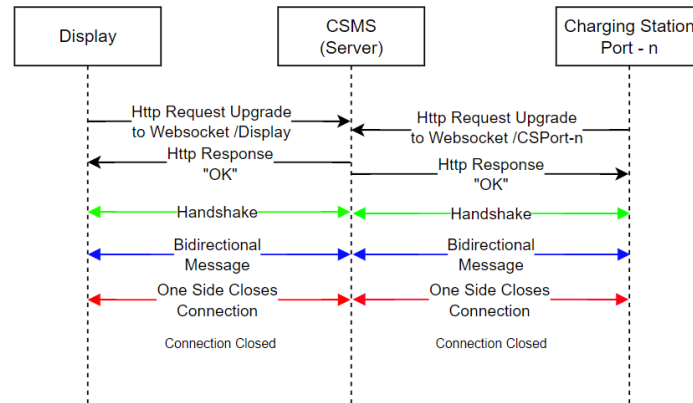


Figure 3. Websocket Communication

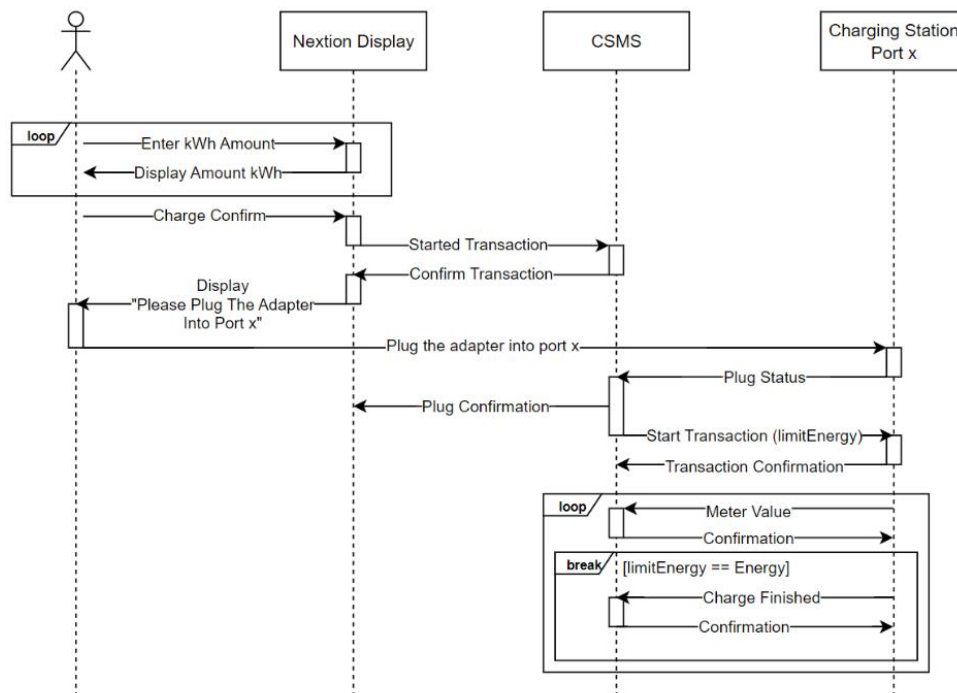


Figure 4. Websocket Communication Diagram for Electric Vehicle Charging Station

1.3. Operations of Electric Vehicle Charging Station

1.3.1. Use Case Diagram

Then the use case diagram for the planned infrastructure of electric vehicle (EV) charging stations, as illustrated in Figure 5. Within this system, three distinct roles are identified: the EV owner who interacts with the station, the EV charging station itself, and charging server which communicates with the station via a WiFi network. The operations of the management system are elucidated, detailing the processes by which it handles data from each actor.

The EV owner has the capability to initiate and terminate the charging process and to monitor the status of their vehicle's charge. A requisite for starting the charge is the specification of the desired energy quantity to be transferred to the EV (Velychko *et al.*, 2020). The EV charging station then processes the request, managing the charging operations such as activation, cessation, and ongoing monitoring. Upon activation, the EV charging station sends an authentication request to the server, confirming its identity and operational status. The server plays a pivotal role, validating the charging activities and maintaining a database that stores both the identity of the charging station and the transactional data associated with EV charging. This ensures that the system operates efficiently and that all data related to charging sessions are accurately logged and retrievable.

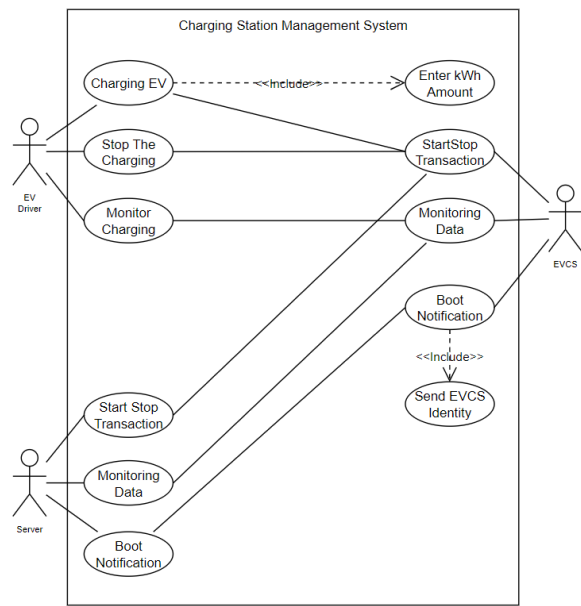


Figure 5. Use Case Diagram of The Proposed Electric Vehicle Charging System

1.3.2. Early Initiation (Boot Notification)

Upon activation, when the Electric Vehicle (EV) Charging Station transitions from an idle state (without voltage) to an active state, it communicates with the server, specifically the Charging Station Management System (CSMS), by sending a notification. This study investigates how the Human Machine Interface (HMI) and each individual port on the EV charging station signal their activation to the CSMS. The transmitted data include details of the activation trigger and the unique identity of the EV charging station. A more detailed explanation and the corresponding data flow are depicted in Figure 6.

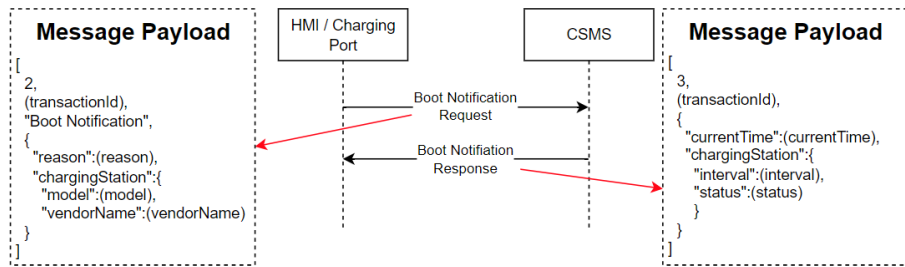


Figure 6. Sequence Diagram for the Initial Activation of the Charging Station

As previously stated, the initial activation phase of an electric vehicle charging station represents the preliminary state at power-up in this study. The data communication protocol employed follows the specifications outlined in the 2.0.1 version of Open Charge Point Protocol (OCPP). According to this standard, the information dispatched by the electric vehicle charging stations encompasses several

compulsory fields: the transaction id, transaction type, the reason for power initiation, and details about the charging station model and vendor. Following the initiation request, the server's response encompasses a timestamp, a check of the time interval for connectivity, and the current status. Specifically, the timestamp communicates the server's real-time clock, detailed to the date, hour, and second. The time interval metric measures communication latency between the server and the charging station. In addition, the status update verifies that the charging station was successfully registered with the server.

1.3.3. Charging Station Transaction System

The transactional process for charging at the station occurs when an electric vehicle (EV) owner initiates or concludes the charging of their vehicle. This process begins with the user interfacing with the display screen provided on the EV charging station, which facilitates communication with the server for transaction handling.

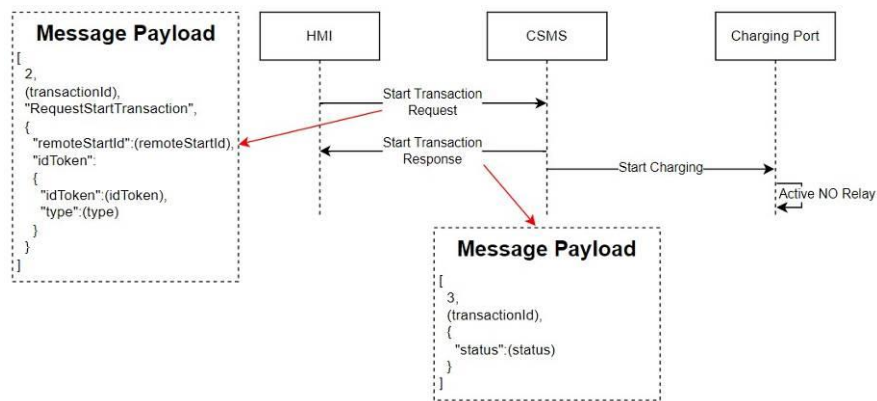


Figure 7. Sequence Diagram of Early Transaction System Charging Station

As previously explained in figure 7, the electric vehicle charging transaction system in this study is the process of payment made by an electric vehicle owner to be able to start charging his electric vehicle. This data communication system is used also based on documentation from OCPP 2.0.1 where data sent from electric vehicle charging stations contains some mandatory data including transaction id, transaction type, remote start id, id token and also type. Then from the request data sent, the server responds, which shows transaction id data and status. Transaction Id is an identifier of charging identity that will go on. The status contains reply information from the request to begin the charging transaction. The server will then send an instruction to the charging station of the electric car to initiate charging and activate the charging relay on the designated port.

1.3.4. Charging Monitor System

Monitoring on electric vehicle charging system can be done when an electric vehicle charger is charging his electric vehicle. Monitoring of charging electric vehicle is done on charging station with server.

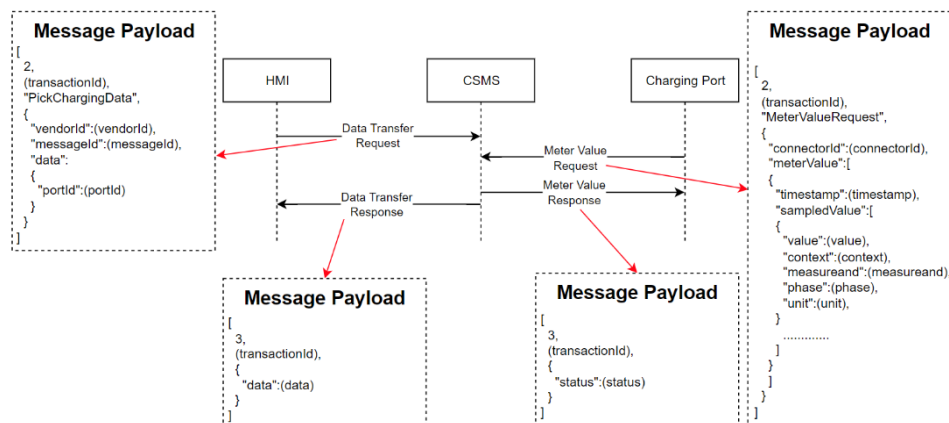


Figure 8. Diagram Sequence Monitor Charging Station System

As previously explained in figure 8, the electric vehicle charging monitor system in this study is a condition in which an electric vehicle owner monitors the charging process of his electric vehicle. This data communication system is used also based on documentation from OCPP 2.0.1 where data sent from electric vehicle charging stations contain some mandatory data including transaction id, transaction type, seller id, message id, socket id, current time data, value readings.

1.3.5. Transaction System to Stop Charging

Power stop transaction system at the charging station is the condition when an electric vehicle owner who will either disconnect his electric vehicle or complete the charging of his electric vehicle. The transaction of the power stop of the electric vehicle begins with the person interacting with the display (display) available on the charging station of the electric vehicle and communicating with the server.

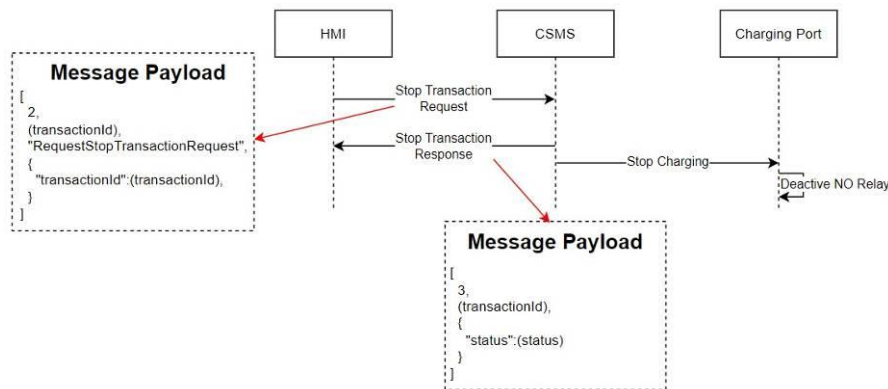


Figure 9. Diagram Sequence Stop Charging Station Transaction System

As previously explained in Figure 9, the electric vehicle power stop transaction system in this study is the process of disconnecting power by an electric vehicle owner to be able to stop charging on his electric vehicle. This data communication system is used also based on documentation from OCPP 2.0.1 where data sent from electric vehicle charging stations contains some mandatory data including transaction id and also the type of transaction done.

Then from the request to the server, the client obtained a response that indicates transaction id and status. Transaction Id is an identifier for the identity of the charging that will stop. Status provides reply information from the request to stop charging transactions. Afterward, the server will issue a directive to the electric vehicle charging station to initiate the charging process and activate the charging relay at the designated port.

1.4. PV Off Grid System

This study investigates an off-grid solar panel system as a renewable energy source of charging stations for electric vehicle (EV). The system architecture is designed to operate on a 24VDC and 220VAC voltage scheme, catering to the control units of EV charging mechanisms. The off-grid system comprises a solar panel array employing Maximum Power Point Tracking (MPPT) technology to optimize the charging process of the battery array. The stored DC power is then converted to AC through an inverter, aligning the output with the common requirements of small EV charging systems. Subsequently, the electrical power is regulated via an EV charger adapter and converted back to DC to replenish the EV's battery (Sikarwar *et al.*, 2023; Sufyan *et al.*, 2020). The block diagram detailing this system configuration is presented in Figure 10.

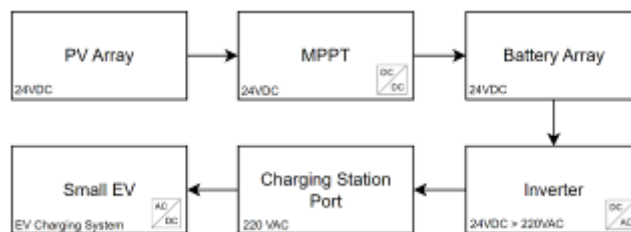


Figure 10. Off Grid System of The Proposed Electric Vehicle Charging Station

2. Result and Discussion

The results presented are derived from tests on an autonomous electric vehicle (EV) charging station utilizing the OCPP (Open Charge Point Protocol). The evaluation incorporated three varieties of compact EVs: electric bikes, scooters, and motorcycles. The assessment protocol involved initiating a charging session at the charging station via the user interface, which necessitated the EV owner to select an accessible port and define the required energy quantity in watt-hours (Wh) for charging. The station then instructed the user to connect their charging adapter to the selected port.

A pivotal aspect of the system is its capability for real-time monitoring, allowing for the observation of voltage, current, power, and energy use for each port. EV owners have the ability to track these metrics live and have the option to discontinue charging at their discretion. The station further enhances user experience by providing informational and promotional content accessible through barcodes, the complexities of which are detailed in Figure 11.

Moreover, the communication between the Human-Machine Interface (HMI) on the EV charging station and the individual charging ports is managed via a centralized server. This server maintains a comprehensive log displaying various metrics such as voltage, current, power, energy, intended charging duration, and the status of each port. The live recording of these parameters throughout the charging process is exhibited in Figure 11, and Figure 12 provides a visualization of the server's database interface, where the aggregated data is presented.

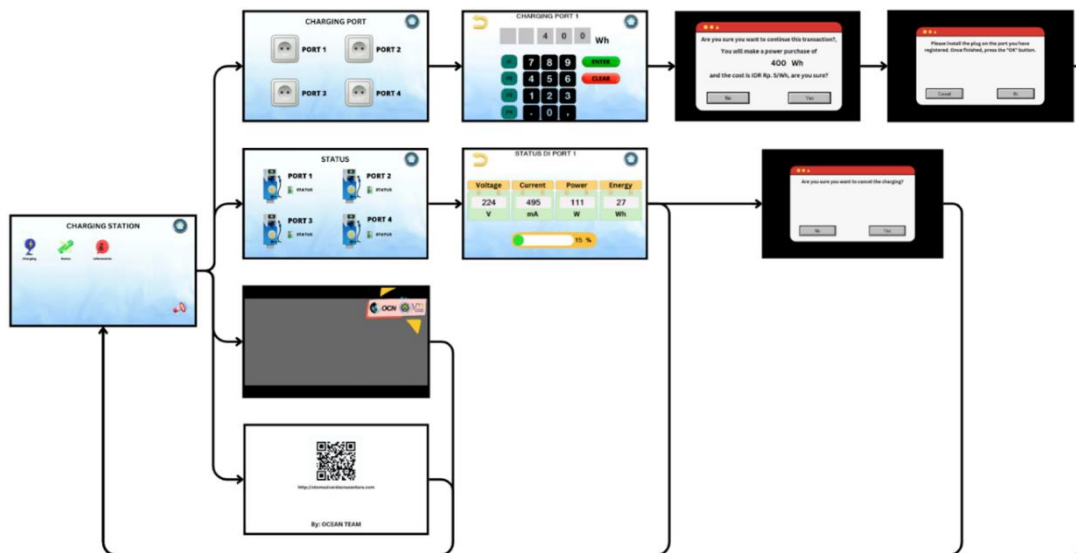


Figure 11. User Interface of the Monitor Display for the Proposed Electric Vehicle Charging Station

evse_id	voltage	current	power	energy	target_charge	status
1	220	446	97	24	500	Available
4	220	424	92	23	500	Available
2	220	483	105	17	500	Available
3	220	2040	449	19	500	Available

Figure 12. Server database interface display



Figure 13. Illustrates the procedure for charging tests conducted on electric motorcycles

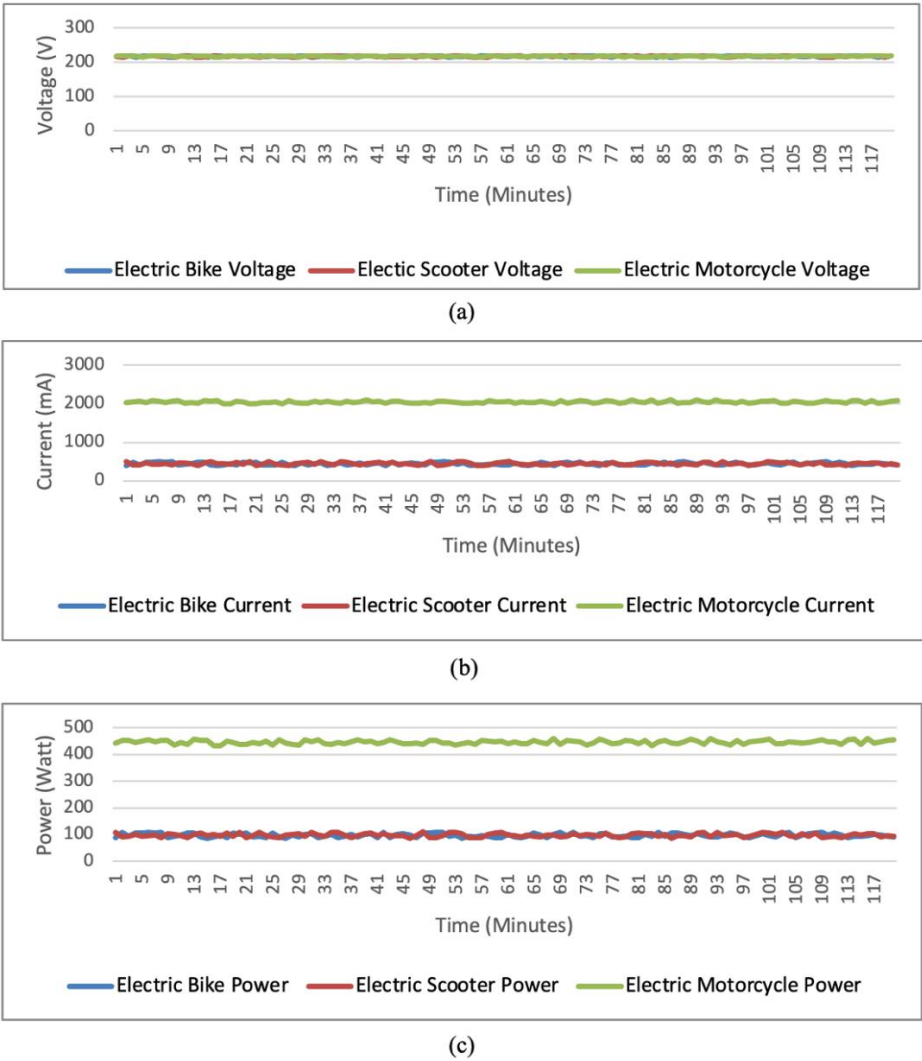


Figure 14. Testing Chart (a) Voltage (b) Current (c) Power

The Electric Vehicle (EV) Charging Testing initiative was expanded to include three distinct vehicle categories, each with unique electrical requirements: an electric scooter and an electric bicycle, both of which utilize a 220 Volt, 500 mA charging adapter, as well as an electric motorbike outfitted with a

220 Volt, 2 A charging adapter. The data acquisition process, illustrated in Figure 14, spanned a continuous two-hour session starting from the onset of charging. This examination produced several illustrative outcomes, including the Wireshark communication flow chart and a graph depicting the mean data throughput for each port at the test charging station, as shown in Figures 15 and 16, respectively. A notable trend was observed in which the server's data handling increased with the activation of additional ports. However, upon engaging more than four ports, a marked decline in transactional data was recorded, indicating an operational threshold and implicating potential data loss as a contributing factor to this limitation.

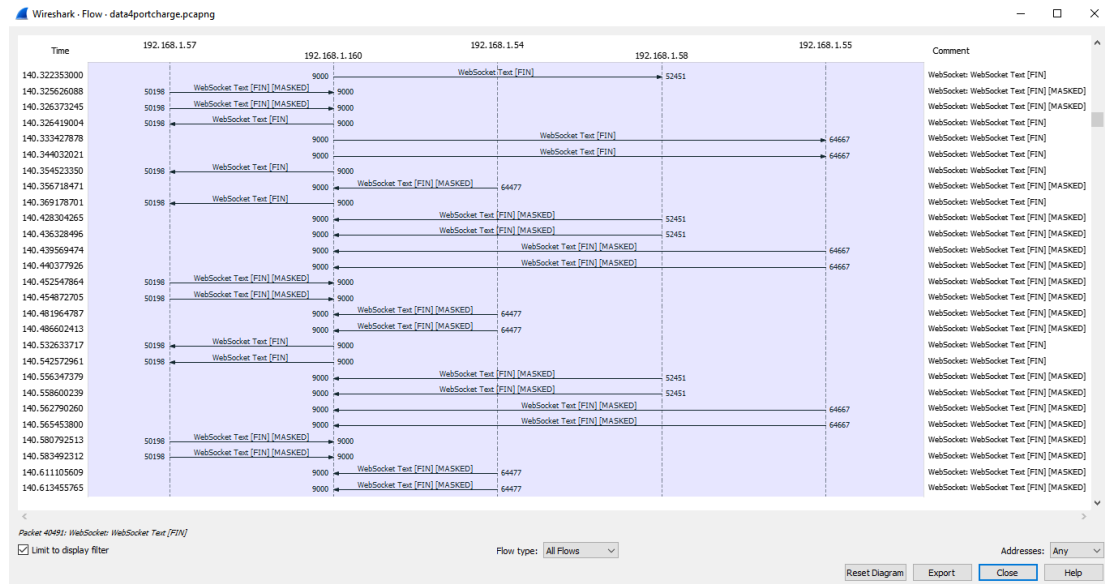


Figure 15. Wireshark Communication Flow of The Proposed Charging Station

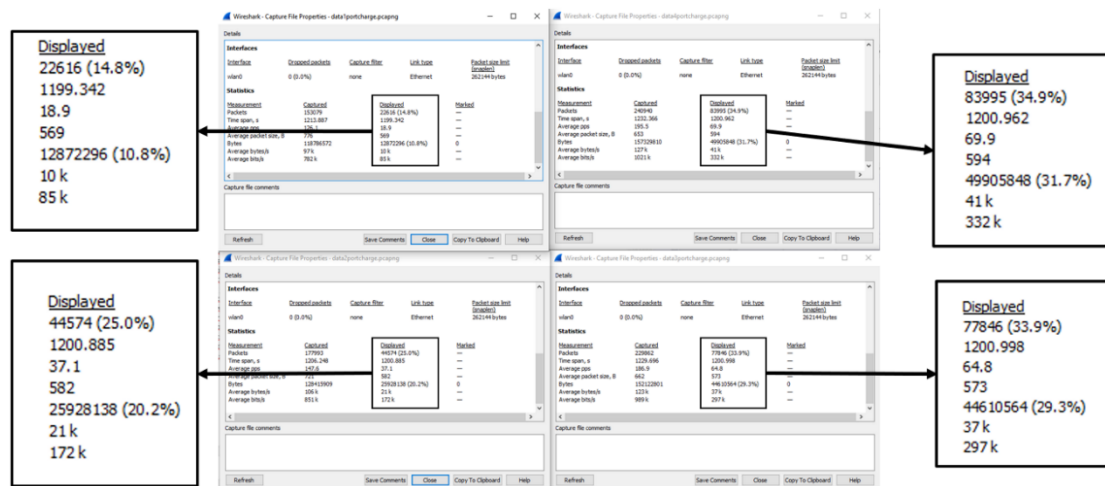


Figure 16. Average throughput of each charging port

The current study conducts an in-depth assessment of Electric Vehicle (EV) charging efficiencies across various vehicle types with differing electrical requirements. The approach adopted enabled a detailed examination of the charging system's capacity to adapt to various power demands. For example, vehicles such as an electric scooter and bicycle, both employing a charging adapter of 220 Volts and 500 mA, in addition to an electric motorcycle with a 220 Volt and 2 A adapter, were evaluated. The real-time data collection, depicted in Figure 14, provides a foundation for an extensive analysis of the system's performance over a typical charging period of two hours. Furthermore, the deployment of analytical instruments like Wireshark for network traffic analysis and port throughput evaluation, as shown in Figures 15 and 16, demonstrates the use of advanced methodologies in data gathering and examination.

The investigation, however, faced certain limitations. The traffic log in Figure 16 reveals a discernible decline in data interactions when more than four ports are active, indicating a probable shortfall in the system's capacity to manage data effectively, which may stem from limitations in server processing power or network bandwidth. This observation identifies a clear operational threshold for the system and highlights the necessity for further research to determine the precise causes of data transmission loss. Such studies are crucial to improving the expandability of EV charging frameworks.

Future research should prioritize enhancing the server's data handling efficiency, perhaps by employing more sophisticated data communication standards or by augmenting the hardware to accommodate increased simultaneous transactions. Additionally, an extended testing timeframe and the integration of a broader spectrum of vehicle types would provide a more comprehensive evaluation of the system's long-term reliability and its adaptability to meet a wide range of EV charging needs.

3. Conclusion

In conclusion, this research proves that off-grid electric vehicle charging systems can be used to charge small electric vehicles, including motorbikes, scooters and bicycles. The implementation of Open Charge Point Protocol (OCPP) facilitates efficient data communication between charging stations and the central server management system (CSMS), ensuring a reliable interface for transaction handling. The integration of Human-Machine Interface (HMI) technology improves user interaction, offering functionalities such as starting a charging session with specific power requirements, real-time monitoring of the charging process, and accessing additional information and advertising provided by the station operator. The system's capabilities extend to the display of charging data on both the server and HMI, enriching the user experience. Empirical testing has shown that the charging station can produce stable voltage, current and power output for a duration of 2 hours, in line with standard electric vehicle inverter output specifications and meeting the demands of electric vehicle charging adapters. Apart from output parameters such as power, voltage and the like, research also proves that the increase in the volume of data packets sent from charging stations is directly proportional to the number of electric vehicle charging ports used with the OCPP data communication format because when using 1 charging port there are 22 thousand data packets, when using 2 charging ports there are 44 thousand data packets, when using 3 charging ports there are 77 thousand data packets and when using 4 charging ports there are 84 thousand data packets sent. So the more ports you want to provide, the network bandwidth must also be increased. Because of this, the server and charging station's communication mechanism is at its best (does not cause data communication delays). It also shows promising opportunities for the development of user-friendly and efficient off-grid charging infrastructure for electric vehicles. Future research could explore scalability, integration of renewable energy sources, and optimization of HMIs to increase user engagement.

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