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Communication Protocols for Electric Vehicles: A Comprehensive Analysis

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Abstract*—Electric vehicles (EVs) Significantly contribute to sustainable development goals (SDGs) by mitigating emissions, enhancing air quality, fostering renewable energy use, generating green employment, and facilitating access to sustainable transportation. In electric vehicles (EVs), multiple components require communication protocols to enable synchronization of subsystems such as battery management and charging infrastructure and ensure optimal efficiency and interoperability. There is a wide adoption of Electric vehicles (EVs) worldwide to create a sustainable environment. Based upon the above aspects, this article presents a thorough literature review of the communication protocols for EVs, where the key technical components of the EV ecosystem are summarized in detail. Further, this study presented an overview of communication protocols for EVs, covering front-end and back-end protocols. The significance of protocols in EV charging is discussed, including aspects like interoperability, communication and data exchange, plug-and-charge capability, monitoring, and smart charging. The findings of the study conclude that this communication protocol is used to integrate electric vehicles (EVs) into transportation networks. Front-end and back-end protocols govern the communication between electric vehicles (EVs) and charging stations, as well as between the infrastructure and third-party operators. Protocols like ISO 15118, OCPP, IEC 61850, and others are used for different purposes. Protocols are based on their openness, compatibility, maturity, and market adoption to determine their adequacy for adoption in the EV business. The review's novelty comes from its comprehensive analysis of communication protocols for electric vehicles (EVs), which encompasses both detailed elements and performing outcomes.

Keywords*— Electric Vehicle, Battery Electric Vehicles, Hybrid Electric Vehicles, Plug-In Electric Vehicles, Fuel Cell Electric Vehicles, International Organization for Standardization 15118, International Electrotechnical Commission 61850, Open Charge Point Protocol, OPEN Automated Demand Response, CHAdeMO, IEEE 2030.5, Open Charge Point Interface, Open Intercharge Protocol, Open Smart Charging Point.

I. INTRODUCTION

Change from conventional internal combustion to a sustainable alternative has considerably affected transportation systems due to reduced exhaustion of fossil fuels and environmental contamination [1]. With the help of Sustainable technology, Electric vehicles have led to the reduction of carbon emissions, and fossil fuels, and EV use is highly appreciated [2]. To mitigate impurities like CO2 and greenhouse gases, the authorities of developed nations are supporting the practice of Electric vehicles (EVs). Authorities encourage sustainable and efficient transportation through initiatives, such as free public parking, toll-free access to motorways, and tax benefits [3]. Various incentives have been announced by the Government of India under the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme for promoting the purchase of EVs [4]. Compared with traditional petrol or diesel fuel, Electric vehicles (EVs) are automobiles that run on electricity. Figure 1 illustrates the different types of Electric vehicles (EVs) classified based on their propulsion technology as shown.

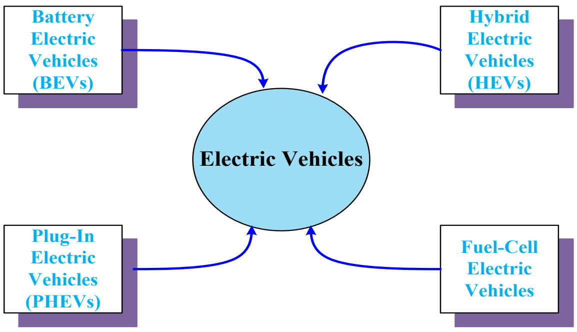

Fig.1. Types of Electric Vehicles

Battery Electric Vehicles (BEVs) are exclusively powered by rechargeable. These vehicles are without a petrol engine or backup generator, resulting in their friendliness and absence of exhaust emissions. However, their driving range is restricted as they need recharging [5].

Hybrid Electric Vehicles (HEVs) are automobiles that combine the use of both electric motors and petrol engines. Plug-in Hybrid Electric Vehicles (PHEVs) are moved by a conventional combustible engine and an electric engine charged by a plug-able external electric source. Fuel cell electric vehicles (FCEVs) utilize the reaction between hydrogen gas and oxygen in the air to generate power. These devices lack a battery and just produce water vapor as trash [6]. The electric vehicle has a limited energy storage capacity, so due to this, it should be charged again and again so it requires a charging infrastructure. According to charging practice, they are classified into three methods i.e., Conductive charging, Inductive or wireless charging, and swapping of battery. In conductive charging the electric vehicle and charging station are connected directly electrically. Inductive or wireless charging, instead of being joined electrically, EVs and charging stations are linked by a magnetic field. This solves the safety and plug-in issues. For the swapping battery charging method, the discharged battery is replaced by the charged battery within five minutes [7]. According to voltage and power levels, the electric vehicle charging is classified as Level 1, Level 2, and Level 3 as shown in TABLE I.

TABLE I. Type of charging Level

Charging Method	**Voltage (Volts)**	**Power (Kw)**	**Current (Ampere)**
Level1/home charging	120	Up to 2	12 or 16 AC supply
Level 2	240	4-20	Up to 80, AC supply
Level 3	480	50-100	Up to 80, AC supply
DC Fast charging	500 v dc	62-100	125-100, AC supply

Level 1/Home charging: In this scheme, charging is very slow and works on 120 V AC. This kind of charging is mostly used at home.

Level 2 charging: This charging scheme is mostly the preferred scheme and works on 240 V AC. This kind of charging is used in charging stations, shopping malls, and parks.

Level 3 / DC Fast Charging: It is a fast-charging scheme and works up to 150 KW. This kind of charging is used in Commercial charging stations.

II. COMMUNICATION IN EV CHARGING STATION

The integration of Battery Electric Vehicles (BEVs) into energy grids and the prompt establishment of communication links to ease the management of BEV charging schemes Maintaining the Integrity of the Specifications. The components of the EV charging system are shown below in Figure 2.

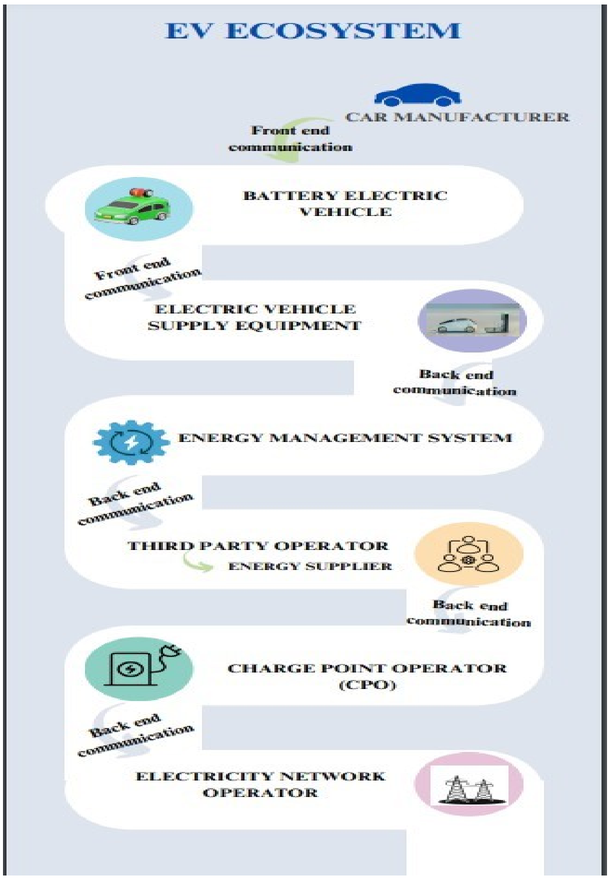

Fig. 2 Entities of the EV Ecosystem

The management of battery electric vehicle (BEV) charging at home and working sites necessitates a growing demand for coordination and communication among different entities involved in mobility and energy. BEV chargers and entities must share informative and control objects to facilitate electrical system assistance, including the elimination of electricity demand peaks. Data such as car identity, battery status of charge (SoC), battery size, and energy required for the next trip would be transmitted between entities. Using the provided data as well as data gathered from the energy system infrastructure, such as frequency, current, and voltage data [8].

The description of EV ecosystem entities is illustrated in TABLE II.

TABLE II: Entities of the EV Ecosystem

Entity	**Description**
Car manufacturer	Following the guidelines for electric mobility (e-mobility).
Battery Electric Vehicle (BEV)	Working on incorporating various e-mobility protocols.
Electric Vehicle Supply Equipment (EVSE)	An electronic device equipped with a microcomputer is being incorporated to facilitate e-mobility protocols. A charging station typically comprises single or multiple Electric Vehicle Supply Equipment (EVSE) units.
Energy Management System (EMS)	Supervising, regulating, and maximizing energy usage and production at a residential site.
Third-party operator	Container of various mobility and energy entities
Electric Mobility Service Provider (eMSP)	An organization or entity that enters into a contract with a BEV user for all services related to charging electric vehicles.
ChargePoint Operator (CPO)	Central system entity which operates and manages charge points.
Energy Supplier	An organization that sells electricity to consumers by the regulations of the electricity market.
Electricity (distribution and/or transmission) Network Operator	An organization that operates, maintains, and invests in electricity networks, ensuring compliance with regulations and standards for electricity supply quality and security.

The power set points of the chargers are determined and transmitted to regulate the charging process, providing the seamless integration of automobiles into the electrical grid. The control should be adaptable, allowing for rapid execution of changes in set points, and ultimately providing a reaction within a fraction of a second, as needed for certain grid services [9].

III. PROTOCOLS FOR EVs

Protocols are defined as a collection of regulations that establish the guidelines for the communication between interconnected devices inside a network, facilitating the secure and efficient transmission of information. Establishing regulations and principles, known as protocols and standards, enables effective communication among various organizations such as plug-in electric vehicles, smart grids, and charging point stations. Multiple international organizations and research institutes have created and formulated open-source and proprietary protocols to fulfill the growing expectations and needs of electric vehicles [10].

A. *Importance of Protocols in EV Charging*

a) Interoperability:

They ensure compatibility between multiple EV infrastructure providers, enabling a diverse variety of EVs to utilize the same charging stations and smoothly integrate various hardware and software systems.

b) Communication and Exchange :

They improve cooperation among participants by organizing communication and facilitating secure and efficient sharing of vital information, such as invoicing details, user credentials, and technical directives.

c) Plug & Charge Capability :

They possess characteristics that initiate the charging process immediately when the car is connected to a charger, enhancing user convenience and minimizing time inefficiency.

d) Monitoring :

They oversee crucial variables while the EV is being charged to minimize potential hazards, enabling the transmission of information and data between the EV, charging station, and central or energy management systems.

Real-time monitoring in EV infrastructure is managed through communication protocols like IEC 61850 and OCPP, which enable continuous data exchange on charging station status, battery levels, and grid load. These protocols facilitate efficient coordination, ensuring optimal charging performance and preventing overloads.

e) Smart Charging :

To improve the charging process of electric vehicles by active adaptations based on the electricity rates and capacity of the grid.

This action relates to smart charging where power consumption can be regulated depending on the supply demand of the grid through smart charging of electric cars. Standards such as ISO 15118 and OpenADR minimize energy losses by charging at off-peak hours and also general management of load sharing for optimal utilization.

B. PROTOCOLS

To link the communication protocols to entities of the EV Ecosystem they are classified into front-end and back-end protocols.

Front-end protocol manages communication between electric vehicles and electric vehicle supply equipment and back-end protocol manages communication between EVSE and third-party operators such as charge point operator (CPO). Using either an E-domain-specific protocol or a generic protocol embracing distributed energy resources, including electric vehicles (EVs) for back-end protocols [11].

The protocols are assessed using properties of Transparency, compatibility, maturity, and market adoption. Transparency indicates that a protocol has been established by a recognized standards organization, whether it is eligible for intellectual property (IP) protection, and whether it is freely or cheaply available to the public [12]. Compatibility refers to the ability of many systems to operate together without any obstacle or disruption [13]. The amount of effort required to replace one of the entities (such as a charging station) in a communication channel can be measured. Maturity is determined by the number of releases, the period the product has been in use, the potential for certification at an official test laboratory, and the availability of a testing tool. Therefore, the level of market acceptance of an EV communication protocol cannot be compared to the market acceptance and development of other protocols like Wi-Fi. Figure 3 illustrates the types of Communication protocols for EV.

Some of the Communication Protocols are discussed below,

1. ISO 15118 (Front-end protocol)

ISO 15118-2 specifically outlines the digital communication protocol used in the exchange of information between EVs and the EVSE which may include Battery Electric Vehicles and Plug-In Hybrid Electric Vehicles [14]. ISO 15118-2 defines the data exchange between the Electric Vehicle Communication Controller (EVCC) and Supply Equipment Communication Controller (SECC), which are the sections that manage the communication of this type of general equipment [15]. This Communication protocol is a higher-level protocol compared to IEC ward 61851 for the exchanging of information between the EV and the charging station. ISO 15118 is applied to charging load management, metering, and billing [16]. Scheduling charging for sessions, authorization for charging, and managing certificates.

2. ***OPEN CHARGE POINT PROTOCOL (OCPP)*** **(Back-end Protocol)**

The Open Charge Point Protocol (OCPP) is an international standard that defines the message exchange between the Electric Vehicle Supply Equipment (EVSE) and a central management system [17]. The protocol is further enriched by a reservation function that enhances all-around charging reservations from verification to charger selection/charge supervision and payment for the user [18]. The general aim of OCPP is to achieve an internationally recognized open communication protocol between Charging Points (CPs), which are situated within public areas like gas stations, supermarkets, and parking lots, and vendor's Central Systems (CSs)[19].

3. ***IEC 61850 (Front-end protocol)***

In the power utility automation systems, the standard that is most widely used and recommended for creating, testing, and deploying automation systems is IEC 61850. It entails protocols that ensure protection, automation, and control systems work without reliance on certain vendors making it affordable to implement while making them interoperable. [20].This standard entails the aspect of modeling the communication characteristics, defining the message forms as well as ensuring modularity of the applications being used in various interfaces such as those of virtual power plants and cooperation between the charging station and EV [21].

4. OPEN ADR (Back-end protocol, generic)

The Open ADR (Automated Demand Response) communication standard provides a secure fully bi-directional relationship between the power suppliers and customers. This makes it possible to control the demand for electric power in real-time and its efficient and cost-effective use, integration of renewable sources, and increasing the reliability of the power grid [22]. Open ADR allows demand response service providers to directly send signals to their already subscribed consumers utilizing a common language and communication media in the form of the Internet [11].

5. CHAdeMO (Front end protocol)

The CHAdeMO has its protocol and this is worked under the organization named CHAdeMO to provide *a* direct current charging system for electric *automobiles*. The v2.0 specification includes bi-directional power transfer functionalities and the functionality of *power-sharing* of the status of the battery [23]. This fast charging standard is widely implemented in Asia*,* especially in Japan and China. The rate of DC charging is faster than that of AC charging since it can transmit electricity to the battery of the EV directly. The CHAdeMO system for instance enables an electric vehicle to extend its range by a wide range of 100 miles within twenty minutes [24].

6. IEEE2030.5(Front-end,Back-end, generic protocol)

The Institute of Electrical and Electronics Engineers (IEEE) is dedicated to electronic and electrical engineering. IEEE 2030.5 is a communication standard facilitating interactions between smart grids and consumers, based on IoT principles. It allows users to control and monitor energy consumption and production, enabling transmission of pricing, demand response, and energy usage data. This technology also facilitates information exchange between electric vehicles (EVs) and electric vehicle supply equipment (EVSE) in certain U.S. research and development (R&D) programs [13].

7. OPEN CHARGE POINT INTERFACE (OCPI)

OCPI is an open standard for roaming that enables communication between the Mobility Service Providers and the Energy Service Providers.

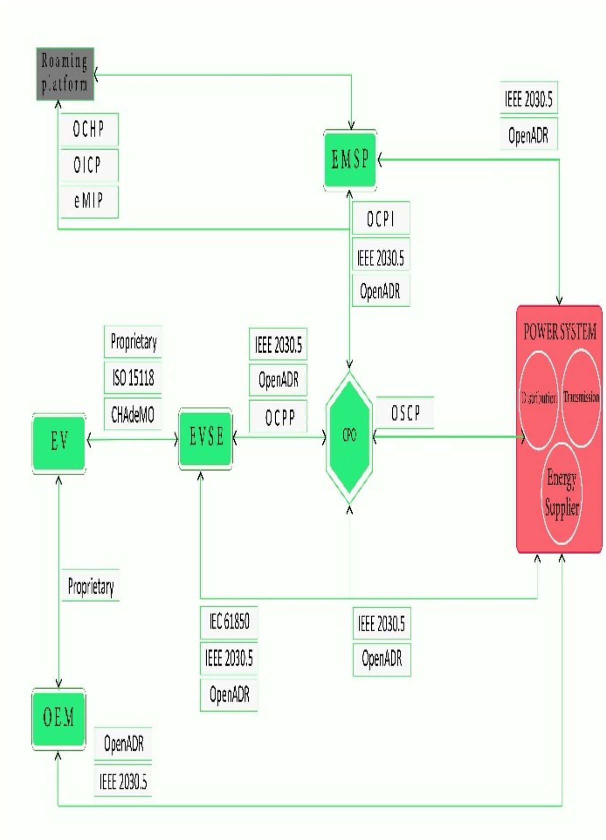

Fig.3 Types of Communication Protocols for EV

This protocol enhances the compatibility and the communication flow which is crucial in the electric vehicle charging system. Currently, most Navigation Service Providers (NSPs) cooperate with Charge Point Operators (CPOs) to conceal the complexity of changing charging networks. This helps the users of electric vehicles to reach different charging stations without the need to have many accounts which helps the users in a way to get the best charging solutions [25].

8. OPEN INTERCHARGE PROTOCOL (OICP):

Indeed, in 2012 Hubject most recently developed the Open Intercharge Protocol (OICP) which has become the predominant common communication interface between European eMSP and CPO systems. The OICP majorly consists of two primary areas: Charge Point Operators and eMobility Service Providers [26].

As indicated earlier, the use of engagement and OICP protocols can be applied in different settings such as

1) Roaming through the Hubject hub.
2) Spontaneous payments
3) Permission
4) Transmission of data about the Charging station, information of the charging station at a very fast rate.
5) Accounting and booking

OICP is a roaming protocol used so that the meter data can be exchanged with data that has to be signed. Original meter data confirms the exact amount of energy delivered to an EV during charging and hence helps the charge point operators [27].

9. OPEN CLEARING HOUSE PROTOCOL (OCHP) :

A German company Smart Lab Innovations Gesellschaft GmbH in partnership with the Netherlands-based ElaadNL designed the Open Clearing House Protocol (OCHP) under which the roaming hub e-clearing. net overseas. Open Clearing House Protocol enables unconstrained charging through electric vehicles of the several charging stations. OCHP helps EV charging service providers build connections with infrastructure providers so they can provide their network access. OCHP enables hub-based roaming by incorporating functionalities such as:

1. Authorization Invoicing
2. Provide information on charging stations and Further details of the session
3. Remote initiation and termination

The OCHP-Direct extension also allows CPOs and EMSPs to apply the same ability over a direct point-to-point connection [28].

10. OPEN SMART CHARGING PROTOCOL (OSCP):

The Open Smart Charging Protocol (OSCP) is an interface standard that enables communication between charge point management systems (CPMS) and energy management systems (EMS) owned by site owners or distribution system operators (DSO). OSCP then allows the charge station operator to receive real-time predictions of the local power grid capacity and hence allows for capacity-based smart charging of Evict and charging points to be able to vary their power output to minimize energy costs and manage peak loads. To ensure control and even to address the aspects of remote connection of EVSEs to optimally plan and manage their operations, it is important to offer optimum visibility to the operators [29].

Thus, standards such as ISO 15118 together with OCPP establish system integrity with the data encrypted and their transmission protected by authentication. These protocols facilitate standard interaction of EVs and charging systems based on any defined operations state. There is also Fault Tolerance, and Error Handling facilities so that the above systems are quite stable.

OCPP and OpenADR make visibility better by providing information on the charging point availability and energy consumption as well as the grid status. OCPP allows operators of charging stations to view the status of charge points, monitor energy consumption, and schedule charge point reservations. Lastly, OpenADR helps the grid operators by containing real-time information on the energy demand along with supply and facilitating advanced change in load control. Collectively, these protocols enable decision-support to the operators, to determine, for example, the end locations of charging connectors and the resource demands for an EV charging network to run efficiently.

Table III draws attention to the need to establish common communication interfaces and interfaces for electric vehicle (EV) charging. The procedures guarantee the harmonized integration with the grid, as well as enhance the charge schedule. The electric vehicle must oversee the solution of problems like maximum energy usage time, construction of infrastructure, and load distribution.

TABLE III: Literature Review of Protocols for EV

Ref	Objective	Protocol Used	Contributions	Advantages
[29]	Develop standards for electric vehicle (EV) charging, incorporate them into intelligent power grids, and optimize the timing of charging sessions. This will allow EVs to function as adaptable energy storage devices and offer additional benefits.	ISO/IEC 15118, Open Charge Point Protocol (OCPP), Hubject's Open Intercharge Protocol	The study presents communication interface standards for V2G for EV charging and a model for reducing charging schedule.	For ease of communication and compatibility protocols like ISO/IEC 15118 protocol are established and used to improve the efficiency of EV charging
[30]	Designing smart grid communication solutions is crucial for effective information sharing and addressing communication gaps in smart electric vehicle (EV) management.	IEC 61850 for communication models in smart grid components.	The study focuses on proposing solutions for smart grid communication and information exchange.	The study showcases the mapping of exact data for information exchange.
[31]	Develop and implement an electric vehicle charging communication testbed following CHAdeMO.Provide software and hardware framework for CHAdeMO-based data exchange	CHAdeMO, ISO 15118-2, GBT is the main protocol used.	The study focuses on CHAdeMO for developing a test bed for electric vehicle communication charging and uses MATLAB and ARDUNIO for programming.	CHAdeMO exchanges messages for charging communication and also shares data from EVSE and EV.
[32]	The technological limitations of SOAP-over-HTTP for charge stations in EV charging infrastructure create obstacles to interoperability, preventing smooth integration and performance optimization.	OCPP is for open back-end protocol for charge spots, and IEC 61850 is for grid automation to enhance OCPP capabilities.	The paper examines the ISO/IEC standardization for the Vehicle-to-Grid (V2G) Interface, investigating its consequences and uses in electric vehicle integration.	SOAP-over-HTTP has strong tool support for charge points, although OCPP could gain advantages by utilizing standardization efforts from IEC 61850.

[33]	By adopting the OpenADR protocol and DPMP, smart grids may effectively support flexibility services. This allows for the implementation of a capacity bidding program to limit energy consumption, as well as the creation of a congestion management tool that offers incentives to flexible service providers.	The OpenADR protocol enables communication between stakeholders and monitoring services, complying with IEC standards and guaranteeing interoperability with IEEE 2030.	The OpenADR protocol enables communication between stakeholders and monitoring services, complying with IEC standards and guaranteeing interoperability with IEEE 2030.	The OpenADR protocol facilitates communication among participants involved in grid operations.
[34]	OpenADR accreditation ensures effective control of electric vehicles by establishing standardized communication protocols for grid interaction. However, the integration of electric vehicles into grid management poses challenges such as balancing the load, managing peak demand, and planning infrastructure.	FleetCarma incorporates the OpenADR standard into their Smart Charge Rewards and Smart Charge Manager platforms, as it is widely embraced.	Electric vehicles provide difficulties for transformers and the administration of the electrical grid. Fleet Carma's platforms, which are certified by OpenADR, effectively control the loads of electric vehicles. A demonstration project demonstrated successful compatibility with Siemens DEMS to manage the power grid.	OpenADR enables efficient grid management by integrating electric vehicles (EVs), providing comprehensive load management solutions, and assisting in stabilizing the system during periods of high demand.

The merits and demerits of existing communication protocols for electric vehicles (EVs) include :

Merits:

- ISO 15118: Offers higher security in the EV-to-charging station communication with added encryption, comes with plug-and-charge provisions, and has stronger and comprehensive measurements and billing components. This guarantees proper charging control and compatibility with Smart grids/.

- OCPP (Open Charge Point Protocol): They allow compatibility of charging networks based on being an open standard where it supports reservation functions through integrating multiple EV charging systems with central management systems.

- IEC 61850: This standard ensures a common network interface for grid automation systems, and charging stations for EVs hence ensuring dependable communication between EVs and the power grid.

- OpenADR: Allows real-time two-way control of the power grids and the EVs on the loads of demand-response service at peak hours.

- **Demerits:**

- ISO 15118: Still, its full implementation needs significant infrastructure, and the cost of certification may be considerably high for the small charging equipment owners.

- OCPP: Although open and accessible to everyone, it does not possess some of the top-shelf options of proprietary systems, for example, real-time load balancing.

- CHAdeMO: However, CHAdeMO though very fast is available in few countries across the globe specifically in the Asia region hence limiting its influence.

This way one can illustrate the benefits and drawbacks of different protocols that is in line with what the reviewers requested – to discuss feature strengths and weaknesses.

Standardized communication protocols like ISO/IEC 15118, OCPP, and Hubjects OICP used for EV charging communication and correspondence between EV charging stations and the power grid are more significant. The study investigates several communication interfaces for electric vehicles (EVs) that are used to enhance charging schedules and smart grid requirements. The open back-end protocols, such as OCPP, are executed for charging stations and coordinated voltage control. Challenges such as load balancing, managing peak electricity demand, and planning infrastructure expansion. Automated demand is implemented during the combination of EVs with the smart grid. For energy consumption management Open ADR protocol is used to know the demand response and demand side management. uniformity and compatibility gain wholesale energy suppliers and operators allowed to manage demand at the grid.

IV. Conclusion

The present study deals with communication protocols for electric vehicles (EVs) to attain sustainable transportation. The importance of protocols in supporting compatibility, monitoring, and smart charging. The purpose is to highlight Protocols like ISO 15118, OCPP, IEC 61850, and others, each fulfilling certain objectives. Integration of EVs and smart grid is analyzed for aiding in the distribution of electrical loads, control of high-demand periods, and infrastructure development. Automated demand response (ADR) and demand-side management (DSM) depend on protocols such as OpenADR to efficiently manage energy use. The Protocols are implemented to provide smooth integration and demand management to support both customers and suppliers. Communication protocols like ISO 15118 and OCPP ensure reliable data exchange between EVs and charging stations by enabling secure, real-time communication, which reduces downtime, ensures consistent power supply and supports predictive maintenance through continuous monitoring.

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