Development of Vehicle-to-Grid (V2G) Communication and Control System

Submitted as a Course Project in the Course titled

EN 663: Electric Vehicle Grid Integration

By

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Abstract

The integration of greater capacity of renewables and a corresponding increase in renewable energy use is one of the goals of the century. It is only apparent that Electric Vehicles (EVs) are becoming more popular with growing concerns of climate change and local environment pollution. However, due to the charging power requirements of the slowest of chargers being comparable to the total peak load of a typical home, the use of EVs could bring a burden on the grid side, prompting the construction of more power generation units, especially to meet the peak demands. This is a problem because of the heavy cost it brings. A possible solution to this while also meeting the two inevitable requirements of the future grid: greater renewable energy use and greater EV use, is brought about by EVs participating in grid services such as load-balancing, peak shaving, congestion management, voltage and frequency regulation, enabled by the Vehicle-to-Grid (V2G) technology.

Due to the future seeing a very high use of EVs, the time to develop a proper charging infrastructure is now, when the penetration of EVs is still in its nascent stage. This calls for standards and protocols followed for each aspect of the EV charging infrastructure. This paper reviews the standards available in the market for communication infrastructure, their features, limitations, and how usable they are in the future, as being easy and convenient to use for all stake holders. A few uncommon protocols are also mentioned.

An illustration of the typical application of a standard to a communication architecture is given by using the ISO 15118 standard which is bidirectional capable. Detailed guidelines on the physical transfer of communication messages and the messages themselves are shown. To further illustrate how a communication architecture would be applied, a control algorithm used for load balancing of the grid load forecast is detailed, and a simulation environment is created. The simulation is conducted for 100,000 V2G compatible EVs in typical Summer (April 2023) and Winter (January 2023) conditions for Delhi and Maharashtra. Results show a very good fit with the expected requirements of load balancing and with validation papers, while also meeting EV user requirements of State-of-Charge (SOC) of the EV battery.

KEYWORDS: *Communication Architecture, V2G, Load Balancing, Simulation*

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Nomenclature

1. CPO : Charge Point Operator
2. EV : Electric Vehicle
3. EVCC : Electric Vehicle Communication Controller
4. EVSE : Electric Vehicle Supply Equipment
5. OCPP : Open Charge Point Protocol
6. OSI : Open Systems Interconnection
7. P_check : safety check
8. P_ev : EV Power
9. SDP : SECC Discovery Protocol
10. SECC : Supply Equipment Communication Controller
11. SOC : State of Charge
12. T_connectedDure : duration of connection
13. T_disconnection : time of disconnection
14. V2G : Vehicle-to-Grid

Chapter 1

Review of Existing V2G Communication Protocols and Standards

1.1 Introduction

Establishing connectivity is a fundamental aspect of building the V2G infrastructure. The role of protocols and standards comes due to ensure secure, reliable and efficient data flow under the typical challenges encountered in V2G communication, namely: high data volumes, fast vehicular speeds, sporadic connections etc. [1].

An EV with bidirectional capability has to first connect to the charge point properly before the grid services can be offered. The aggregator manages this through a communication methodology which first checks whether the vehicle is capable of providing what the grid requires and if the user is willing to participate provided that the EV battery is charged upto the user's requirement [2].

Communication protocols provide a set of rules and guidelines to achieve this and ensure successful charging demand management and grid integration of EVs. The most crucial challenges currently is the use of several proprietary protocols used by companies which hinders the goals of EV grid integration. [2]

This chapter aims to highlight the protocols and standards used in the market as of today and bring out their features and how good they are for use in an EV ecosystem.

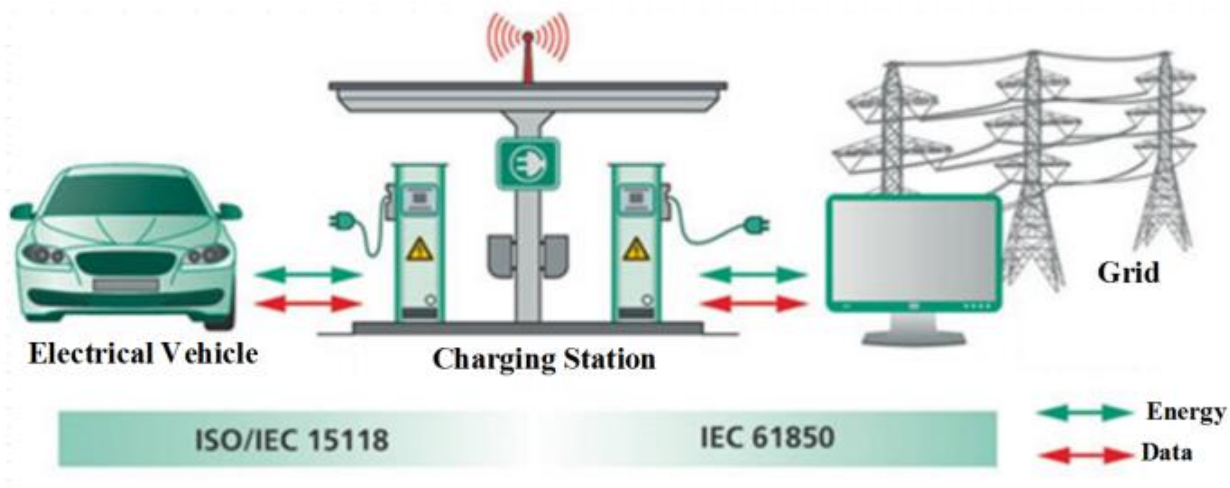

Figure 1: Sample Communication illustrating Fron-End and Back-End Communication [3]

1.2 Classification and General Flow of Communication

1.2.1 Classification

Communication protocols can be divided into front-end and back-end. Front-end dealing with the communication between the charge point and the EVCC (EV Communication Controller). Back-end dealing with the communication between charge point and a third party (like an aggregator/ the grid). [2].

Figure 1 shows an example illustrating this with ISO/IEC 15118 being a front-end protocol and IEC 61850 a back-end. [3].

The reference [2] has tried to further classify a few open protocols based on parameters like: openness, interoperability, maturity and market adoption.

1. **Openness:** judged based on whether an accredited entity has developed the protocol and whether it is easily and publicly accessible. This tells whether other entities can contribute to the development of the protocol.
2. **Interoperability:** can the protocol work with other protocols with ease and whether it is detailed enough to ensure a seamless connection between entities compatible with different protocols. This allows a CPO (charge point operator) to invest in different chargers without worrying about the type of EVs it can expect.
3. **Maturity:** it indicates the number of revisions the protocol has undergone, the time it is used in the market, whether it is certified and whether a testing tool is available.
4. **Market adoption:** based on the current number of users of the protocol.

Table 1: Classification of some Open Protocols based on their usability in V2G applications [2]

Standard	Front-End/ Back-End	Openness	Interoperability	Maturity	Market Adoption
IEC 61851	FE	High	High	High	High
ISO 15118	FE	High	High	Medium	Low
CHAdeMO	FE	Medium	Medium	High	High
OCPP	BE	Medium	High	High	High
IEC 63110	BE	High	Medium	High	Low

Open ADR	BE	High	Medium	High	Medium/ High
IEEE 2030.5	FE/BE	High	Medium	High	Low
EEBUS	BE	Medium/ High	-	Low	Low
Proprietary	FE/BE	Low	Low	Low	Low

1.2.2 Descriptions of Protocols and Standards

This section gives a brief description of the available open protocols and lists the new, under development protocols and their enabling technology. Most of these have detailed descriptions which are named with an added number to their names: for example: ISO 15118-2 provides the description of network and application protocol requirements. These are not included in this report but only the broad description of the protocols.

<u>Open Protocols:</u>

1. **IEC 61851**: IEC 61851-24 and IEC 61851-23 give description for communication in DC charging for conductive charging upto 1000 V AC input / 1500 V DC charging. GAPs: advanced requirements for smart charging strategies like meter readings, tariff information etc. are not mentioned.
2. **ISO 15118**: like IEC 61851 but works on its limitations like smart charging. The main feature is the use of digital certificates to secure communication. It also includes authentication and authorisation methods. ISO 15118 is part of the CCS charging systems.
3. **CHAdeMO**: It is created by the CHAdeMO organisation. It is compliant with IEC 61851-23 and IEC 61851-24. GAPs: The protocol is available on a payment basis, but the code is not updatable by paying member. The protocol does not provide sufficient detail to implement it. It also lacks communication features.
4. **Open Charge Point Protocol (OCPP)**: It is the main protocol for communication between a CPO and charge point. It supports smart charging, enhanced security.
5. **IEC 63110**: It is in the development stage of becoming the successor of OCPP.

6. **OpenADR**: Provides communication for demand response service providers for direct communication to existing customers. GAPs: Description is very generic. Alignment with complementary protocols (OCPP) is required.
7. **IEEE 2030.5**: allows manufacturer independent communication between home energy management systems, solar systems and charge points. It is an IP based protocol. GAPs: Generic description, lacks automatic authentication.
8. **EEBUS**: Similar to IEEE 2030.5 but has authentication features.
9. **IEC 61850**: Used for communication in substations. Enables integration of protection, control, measurement and monitoring functions. It is interoperable between devices from different manufacturers.
10. **DIN SPEC 70121**: DC EV charging communication protocol for use in Combined Charging System (CCS). Uses External Identification Means as an authentication method.
11. **SAE J2847**: Communication between plug-in vehicles and off board DC chargers, in conductive charging. Communication is through the pilot line using Power Line Communications. Used mostly in North America.

Other protocols/ enabling technology:

1. UBAPV2G
2. Efficient XML Interchange (EXI)-based Service
3. Worldwide Interoperability for Microwave Access (WiMAX)
4. Wireless Access in Vehicular Environment (WAVE)
5. Bluetooth and GPS-based V2G Communication
6. Smart Grid Transportation Protocol (SCTP)
7. Low-level Communication Protocol (LLCP)
8. High-level Communication Protocol (HLCP)
9. Reliable Broadcast for EV Charging Assignment (REBECA)
10. Aggregate- Proofs based Privacy-preserving Authentication Scheme (AP3A)
11. Smart Card
12. Portunes and Portunes+
13. Stream Control Transmission Protocol (SCTP)
14. Long-term Evolution (LTE) Protocol
15. LYNX
16. Authentication Protocols
17. Energy Internet

Chapter 2

V2G Architecture compliant with ISO 15118

2.1 General Flow of Communication

The overall flow of communication is detailed in this sub-section.

Management of the flow of communication requires communication between energy (grid operator) and mobility entities (aggregators, charge point operators) [2]. Informational and control objects have to be exchanged to provide grid services like peak reduction, load balancing, voltage regulation, frequency support, etc. The data required from the EVs is: car identification, the battery state of charge (SOC), battery size, maximum charging and discharging power, energy required by the end of the charging session. The data required from the grid is: frequency, current and voltage, load profile. It is required that once a requirement is made it is executed in seconds and response is obtained. This is important because the grid and EV conditions are dynamic [2, 6].

The Figure 2 summarises the general flow of information and required modules. Data storage is required to store information about protocols, customer data (SOC, battery size, customer ID, SOC at end of charging), load forecast, weather forecasts to be used in the optimizer. Trip Forecasting is used to determine how to charge the vehicle. The user can influence this behaviour. Optimization finds the best possible charging schedule, while considering the congestions in the grid and weather forecasts. Customer Relationship Manager keeps billing information and EV IDs [5].

All of this is used in the Communication modules where the communication protocol is executed.

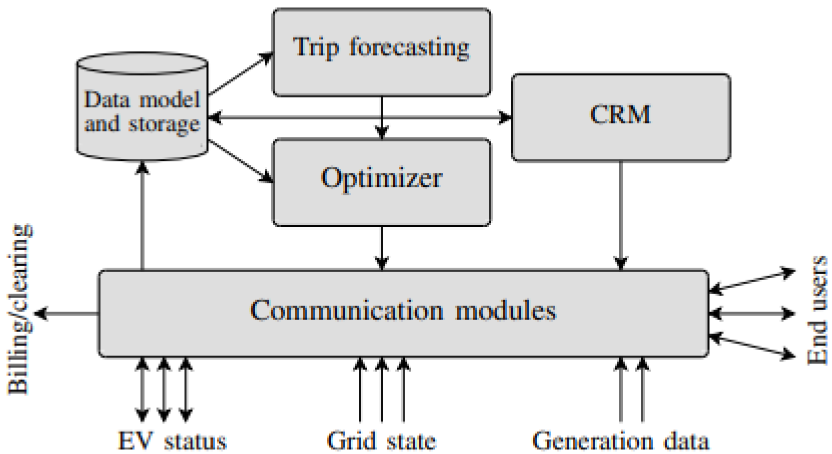

Figure 2: Architecture Modules [5]

The physical connection is done using the following methods [5]:

1. Power line communication
2. GSM and 3G wireless WAN
3. xDSL or cable
4. TCL: it is a connection-oriented transport protocol

Typical pattern for EV communication is [5]:

1. EV registers with the charge point
2. EV uploads its current state and the required state at the end of charging
3. The charger finds the best possible charging plan and sends it to the EV awaiting its approval
4. The EV approves or requests another plan based on user requirements and EV limits.
5. The communication link is maintained and accessed at a periodic time, to communicate the grid conditions, in order to update the set points of power, to participate in the grid services.
6. The EV disconnects and metering information is uploaded to EV before un-registering.

The communication flow is structured according to the **Open Systems Interconnection (OSI)** model which defines how applications communicate in a network, which works on the principle of having 7 distinct groups of related functions or layers between any two endpoints of communication. Further the communication is divided into low level and high level: low level communication handles the current and voltage set points, battery configurations, battery state and PWM required, and other technical aspects; high level communication handles the transfer of data packets across the communication link, message transfer etc. [1].

Figure 3 gives the highlights of this communication structure.

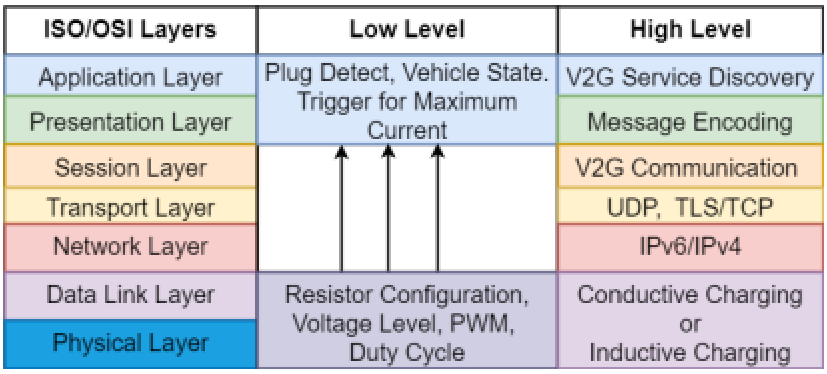

Figure 3: OSI Layers and Low-level & High-level Communication [1]

2.2 Communication Flow in ISO 15118 [7]

The ISO 15118 was created first in 2010 and has undergone many updates since then, adding many capabilities among which bidirectional capability was one. It also follows the OSI flow [7].

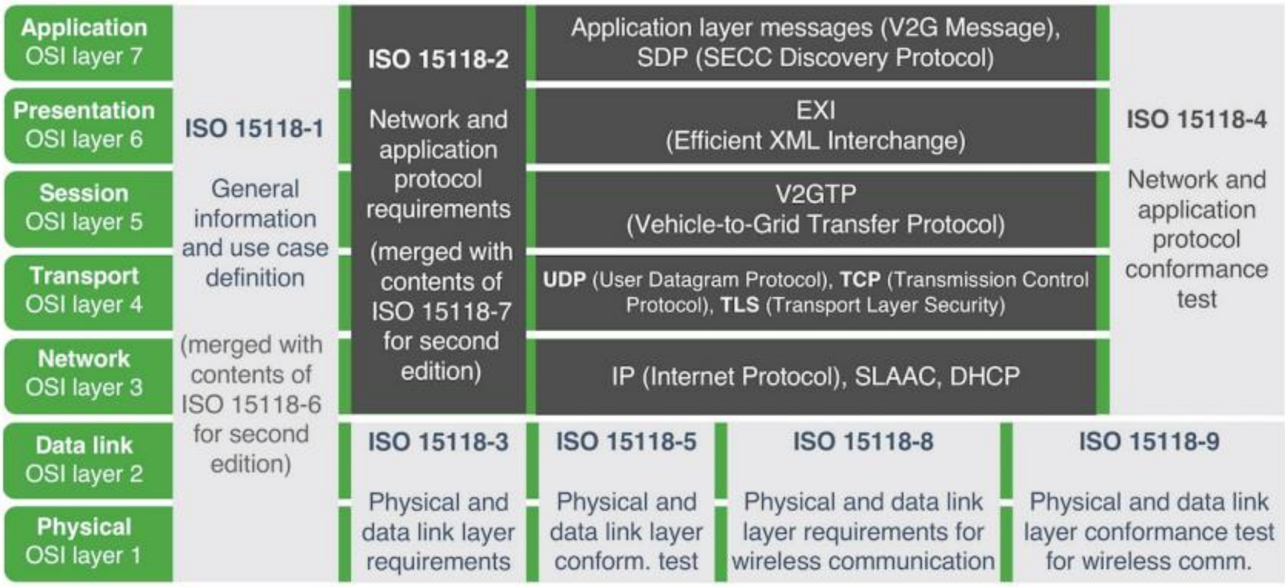

Figure 4: ISO 15118 document parts and their relation to the Open Systems Interconnection (OSI) layers [7]

Figure 4 details all the sub-documents of the ISO 15118 standard.

There are 2 types of messages: SDP (SECC Discovery Protocol) messages (to exchange IP addresses and to know the location where to send data packets) & V2G messages (these are the main messages which handle starting, executing and terminating a session). The layers henceforth will be applicable to the V2G messages. Application layer mentions digital signatures and certifications of the EV to check data authenticity and integrity. The EV messages are in XML format. The presentation layer converts it into the binary EXI format for efficient data transfer. In the session layer, the protocol is executed. The transport layer ensures the security of the messages. The network layer assigns IP addresses to SECC and EVCC [7].

<u>The following points detail the information flow defined in ISO 15118 standard</u> [7]:

1. ISO 15118 information flow is very similar to the flow in IEC 61851, with it being applied between EVCC and SECC, and starts when the PWM signal is set to 5%.
2. Each V2G message has header containing the session ID and an optional digital signature.
3. *supportedAppProtocolRequest*: used to agree on a protocol version

4. *SessionSetupRequest:* used to setup a unique session ID, to start a paused session at the previous parameters.
5. *ServiceDiscoveryRequest*: to recognise the services offered by the charge point (AC (1 phase/ 3 phase)/ DC/ Plug & Charge/ internet access)
6. *ServiceDetailRequest*: for more details on the services provided by charge point
7. *PaymentServiceSelectionRequest*: it is not related to payment, but to the authentication an authorization method. By External Identification Means (RFID required) / by Plug & Charge (no user interaction needed).
8. *CertificateInstallation*: to install a new certificate of authentication
9. *CertificateUpdate*: to update the existing certificate of authentication
10. *PaymentDetailsReques*t: if Plug & Charge is the default authentication, this message is sent
11. *Authorization*: to avoid replay attacks, which is a malicious message sequence sent to access a restricted resource.
12. *ChargeParameterDiscoveryRequest* and Response: here the limits of the EV and charge point are exchanged. The required time of departure and SOC at that time is exchanged by the user, after which a charging schedule is given.
13. *PowerDeliveryRequest*: the charge schedule is sent via this message. The EV can decide to charge right away or at a later time. When it wants to start charging, it will trigger a switch voltage to drop from 9 V (State B) to 6 V (State C).
14. *ChargingStatusRequest*: this allows communication between the charging process, to communicate grid disturbances, so that a new charging schedule can be renegotiated.
15. *MeteringReceiptRequest*: a digital signature which ensures that the user has seen the metering
16. *SessionStopReq/-Res*: to terminate the charging session
17. *CurrentDemandReq/-Res*: for DC charging all other message sequences are similar, with this being added for tighter control.

<u>For bi-directional capability, the only addition that is required</u>:

18. *AC_BidirectionalContolReq/-Res*: contains information about maximum charge and discharge power/ current. The messages below are sent to the EV according to the requirements of the grid.
19. *EVSETargetActivePowe*r
20. *EVSETargetReactivePower*
21. *EVSETargetFrequency*

Figure 5 illustrates the communication flow described above.

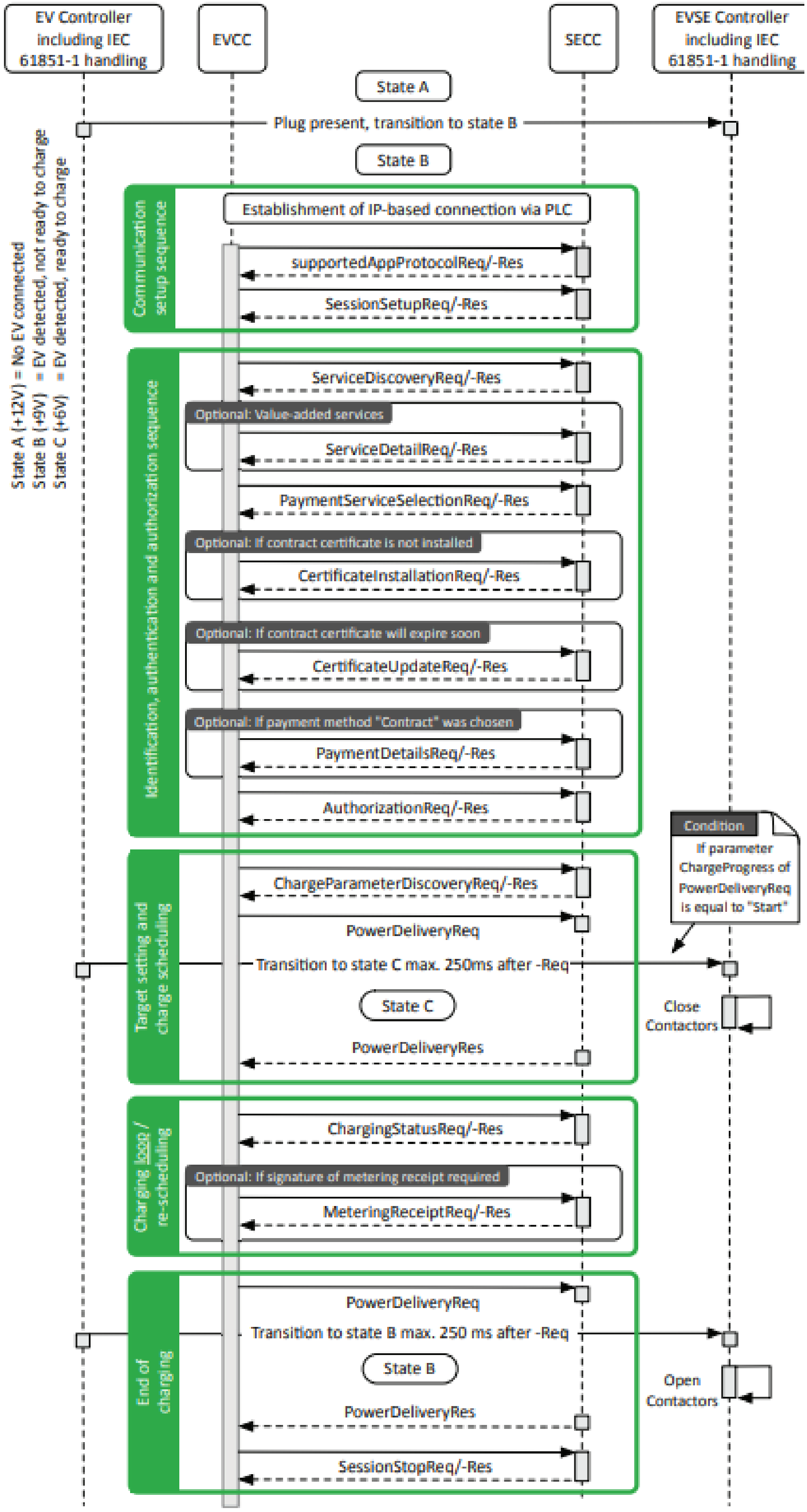

Figure 5: Illustration of message flow in ISO 15118 [7]

Chapter 3

Control Algorithm for Grid Services

3.1 Introduction:

The objective of this chapter is to provide a detailed algorithm to be implemented into a simulation environment which will provide load balancing services to the grid. The grid operator will provide the load forecast data to the charge point operator (CPO). The CPO will then deploy this information to each of the chargers which it controls. The control algorithm will be run and the EV will provide the required power to the grid. There are constraints which have to be followed so that customer requirements are met and the grid services are also satisfied.

3.2 Constraints for EV user satisfaction along with grid efficiency

The EV user will connect the EV with the promise of getting back the vehicle with full charge (80 % SOC) by the time specified by the user. It is the responsibility of the algorithm to ensure this happens. It is also required that the vehicle SOC does not go below 20 % SOC (to ensure battery health is not compromised over time).

The primary logic behind the design of the algorithm is to enhance grid efficiency, i.e. the generation is effectively used while at the same time the high peaks seen by the grid operator are avoided.

One very crucial point to consider is that the EVs are charged only during low load periods. So, the EVs who do not require to be charged during high load periods should not contribute to the grid load and stay idle. Whereas, only those EVs are allowed to charge during high load conditions whose time of disconnection is such that only by using the maximum charging power the EV could reach the 80 % SOC target by the time customer comes back. Such a condition will be called the Critical SOC henceforth in the report.

During low load conditions, all EVs start charging with priority given to those with the least SOC. During high load conditions, all EVs start discharging with priority given to those with the highest SOC. This scheme ensures that an average value of SOC is maintained throughout all the vehicles. It should be noted that the EVs whose time of disconnection is too close will charge no matter at which time of day the EV is in.

Charging of the EV is stopped once it reaches 80 % SOC or if the grid load goes beyond the average of the load forecast. This ensures that there is no unforeseen grid peak.

Discharging of the EV is stopped once it reaches 20 % SOC or if the load goes below the average of the load forecast. This ensures that there is no unforeseen dip in the grid load.

Both charging and discharging set points are decided based on the requirements of the grid. At each hour, the set point will be changed. The algorithm is such that it allows charging the vehicle with critical SOC first. Then the ones with the least SOC. For each vehicle the difference between the average of the load profile and the load after adding the charging loads of the previous EVs is calculated, if this difference is large enough, the step size is increased and the difference is checked again till the EV load increase goes beyond the average of the load profile.

Similar strategy is used during the discharging phase when the load is above the average of the load profile.

3.3 Assumed Parameters

There are (n =) **100,000 EVs** being simulated.

The EV user will connect the EV with a these constraints. Following are the parameters assumed to run the simulation:

SOC: The vehicle state of charge when it is connected

T_connectedDur: Duration of time that the vehicle will stay connected.

Pmax: The maximum charging and discharging power of the EV. They are both assumed to be same in this simulation.

E: The battery capacity

Each of these are produced in the simulation using the random number generator in MATLAB, with either a uniform or a normal distribution.

In order to keep realism, the EV with higher battery capacity is ensured to have higher Pmax values. To ensure this, both E and Pmax are arranged in ascending order and grouped together to create the set of available models of EVs in the simulation.

The description is given in the following table:

Table 2: Assumed Parameters for Simulation

	SOC (%)	**T_connectedDur (hours)**	**Pmax (kW)**	**E (kWh)**
Range of Values	[20, 60]	[6, 10]	[4, 30]	[30, 100]
Distribution Type	Uniform	Uniform	Normal	Normal
Mean	40	8	17	65
Standard Deviation	-	-	8	15

3.4 Control Algorithm for peak shaving and load balancing

The key features of the algorithm and the simulation are as follows:

a. Each charge point will have the data for the load profile without considering the effect of EVs for each day.
b. Initially, at the start of the simulation all vehicles will connect at the same time, which is a reasonable approximation considering the large population of the urban area for which the simulation is being conducted.
c. There are n = 100, 000 vehicles managed by the charge point operator. It is assumed that each customer will be willing to participate in the grid services, for incentives not covered in this report.
d. Each of these vehicles has their own battery capacity, maximum charging rate, maximum discharging rate, time of connection, time of disconnection, vehicle SOC. The time of disconnection is mentioned by the EV user, and it is assumed that the customer requires full charge of the EV (80% SOC) by the time of disconnection.
e. For the simulation, the battery capacity, max charging and discharging rates, time of disconnection, time of disconnection and the vehicle SOC at the time of connection are created in the simulation environment using a random set which will be detailed further in the report.
f. Once the time of disconnection for an EV is met, another EV with a random set of parameters (E, P, SOC, T_disconnection) is created and connected to the charge point.

g. When the load is lesser than the average of the load forecast, the EVs start charging in steps as mentioned in the last paragraph of section 3.2.
h. Similarly, when the load is greater than the average of the load forecast, the EVs start discharging in steps as mentioned in the last paragraph of section 3.2.
i. Charging and discharging rates will be capped by their maximum values.
j. Once a vehicle reaches 80 % SOC, it is assumed that the EV user will disconnect the EV and a new user will connect their EV.
k. Discharging will stop, when the SOC reaches 20 %, in order to maintain battery health.

3.5 Setting up the Simulation and Algorithm Flowchart

The simulation is conducted on MATLAB (Version 9.14.0.2674353 (R2023a) Update 7).

LOAD PROFILE: The load profile was sourced from NITI Aayog's India Climate and Energy Dashboard [10]. It provides the recorded load of an entire state on an hourly basis. The simulation was conducted for Winter and Summer conditions for January 2023 and April 2023 respectively, in Maharashtra and Delhi. I have used this data as a load_forecast for each day to be input into the simulation.

INITIAL CONDITION: As an initial condition, all EVs are assumed to be connected simultaneously. This is a valid assumption for an initial condition considering the population of EVs being simulated (n =100,000) is much lesser than the actual number of EVs as a projection of the future, when V2G would be a mature technology. A random set of assumed parameters, generated from the set created in Table 2 is generated.

PLUGGING IN A NEW EV USER: If the current time step is the same as the time of disconnection (T_disconnection) given by user, and the SOC of the vehicle is 80 %, then a new set of SOC, E, Pmax, and T_disconnection (or, alternately the duration of connection, T_connectedDur) are generated randomly. Otherwise this step is skipped for this EV.

ENSURING THAT SOC = 80 % IS ACHIEVED BY THE T_disconnection TIME: Since it is required by the EV user to get 80 % SOC by the end of the charging session it is necessary to ensure this. A check is done for this. If the following condition is true, then the EV will not participate in grid service and will start charging at its maximum charging rate, until SOC = 80 % is reached.

$$\frac{80 - SOC}{100 * (T_{disconnection} - t)} \geq P_{max} \qquad (1)$$

This guarantees that the EV participates in grid services for as long as it can, and also that the user requirements are met. This is stored as the EV Power (P_ev) for this time iteration and it is added to the load forecast, to be stored in the 'load_new' vector. The variable 'availability' is switched to 0 from its default value of 1, to update its participation in grid services.

DECIDING CHARGING/ DISCHARGING/ IDLE STATE: There are three possible locations the load_new vector profile can be. It can be either in CONDITION 1, 2 or 3:

$CONDITION$ 1: (2)

$$load_{new} > (1 + error) * load_{forecast,mean}$$

$CONDITION$ 2: (3)

$$load_{new} \leq (1 + error) * load_{forecast,mean}$$

&

$$load_{new} \geq (1 - error) * load_{forecast,mean}$$

$CONDITION$ 3: (4)

$$load_{new} < (1 - \ error) * load_{forecast,mean}$$

Here '$load_{forecast,mean}$' is the mean of the load forecast taken every 24 hours. This is chosen such that the simulation complexity is reduced. To comply with requirements of the grid operator preference to keep the load it sees within a certain range, a feature of 'error' is provided.

In condition 1, if the EV 'availability' = 1, then all EVs are arranged in descending order of their SOCs to allow the ones with highest SOC to participate in the grid service first, in DISCHARGING mode. This avoids deep discharge and avoids frequent use of the maximum charging power when it is required. If SOC < 22, it is in IDLE mode.

In condition 2, if the EV 'availability' = 1, then it is in IDLE state.

In condition 3, if EV 'availability' = 1, then all EVs are arranged in ascending order of SOCs, to allow the EVs with least charge to reach a reasonable SOC. EV goes to CHARGE state. If SOC = 80, then it goes in IDLE mode.

DECIDING RATE OF CHARGING/ DISCHARGING: If the EV is in IDLE state, its P_ev is set to 0 W.

If EV is in CHARGE state, then its power (G2V) is increased in steps, with checks at each step ensuring that its contribution to the load profile does not exceed the error threshold of CONDITION 3. P_ev is capped either at the violation of this condition or if the power exceeds the maximum power it can provide. In the simulation step size is 5 for each EV.

If EV is in DISCHARGE state, then its power (V2G) is increased in steps, with checks at each step ensuring that it is not low enough to violate CONDITION 1. The power, P_ev, is capped either at the violation of this condition or if the power is more the maximum discharging power. In the simulation step size is 5 for each EV.

CALCULATION OF SOC AND GOING TO THE NEXT TIME STEP: The vehicle SOC is calculated using the equation: (here Δt = 1 hour)

$$SOC(t+1) = SOC(t) + (\frac{P*1}{E}) * 100 \tag{5}$$

This SOC is fed into the next time step iteration.

When SOC goes beyond 80 %, the SOC is set to 80 % to simulate STOP CHARGING state.

When SOC goes under 20 %, the SOC is set to 20 % to simulate the limit of SOC, and discharging stops.

Figure 6 shows the algorithm flowchart.

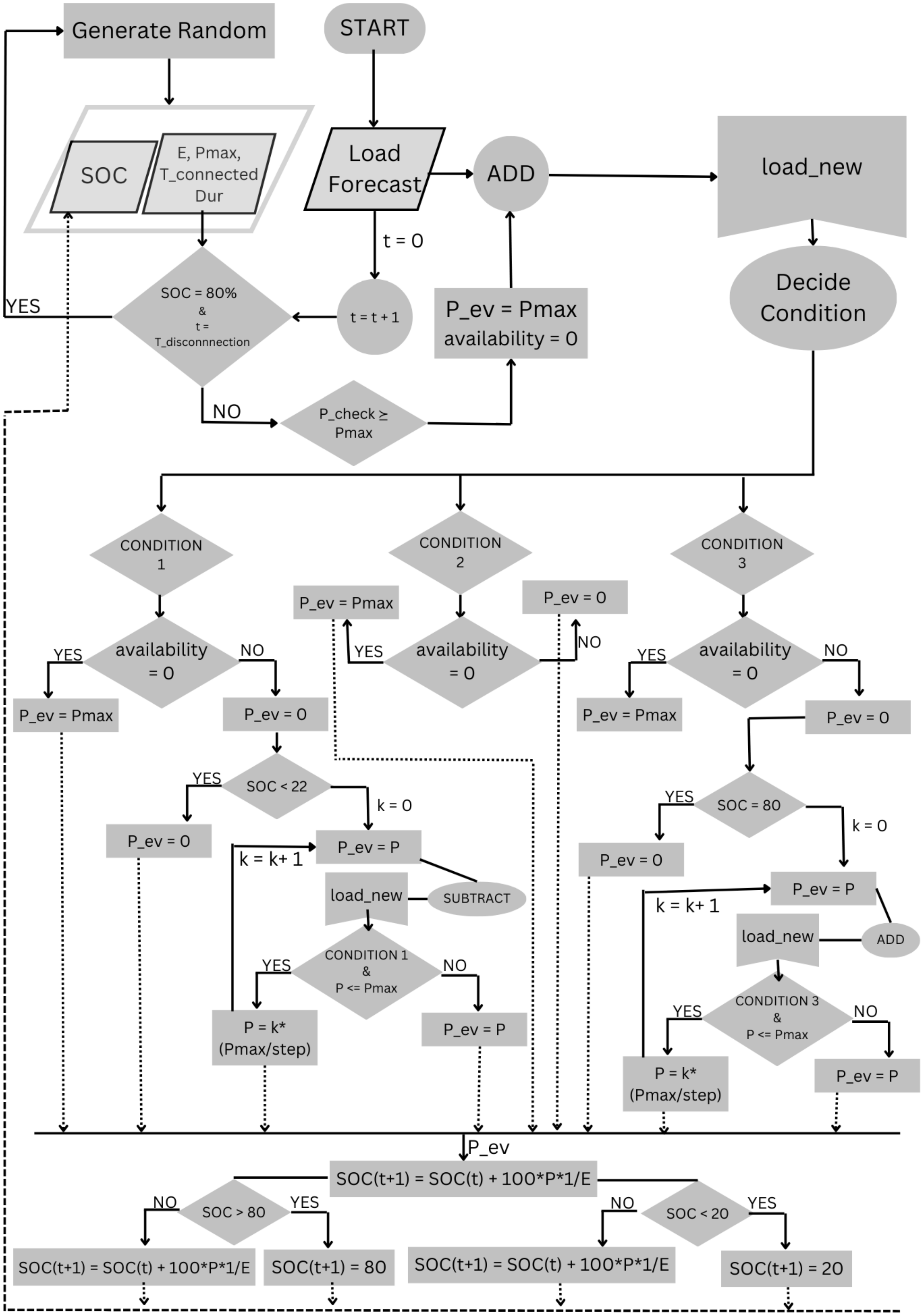

Figure 6: Algorithm Flowchart

3.6 Results of the Simulation

The simulation was run on MATLAB (Version 9.14.0.2674353 (R2023a) Update 7) on an AMD Ryzen 9 5900X laptop with 8 cores and base speed of 3.30 Hz. The simulation took approximately 1 minute to compute for 100,000 vehicles over a simulation of one month. Simulations have ‘error’ = 0.

1. Delhi Summer:

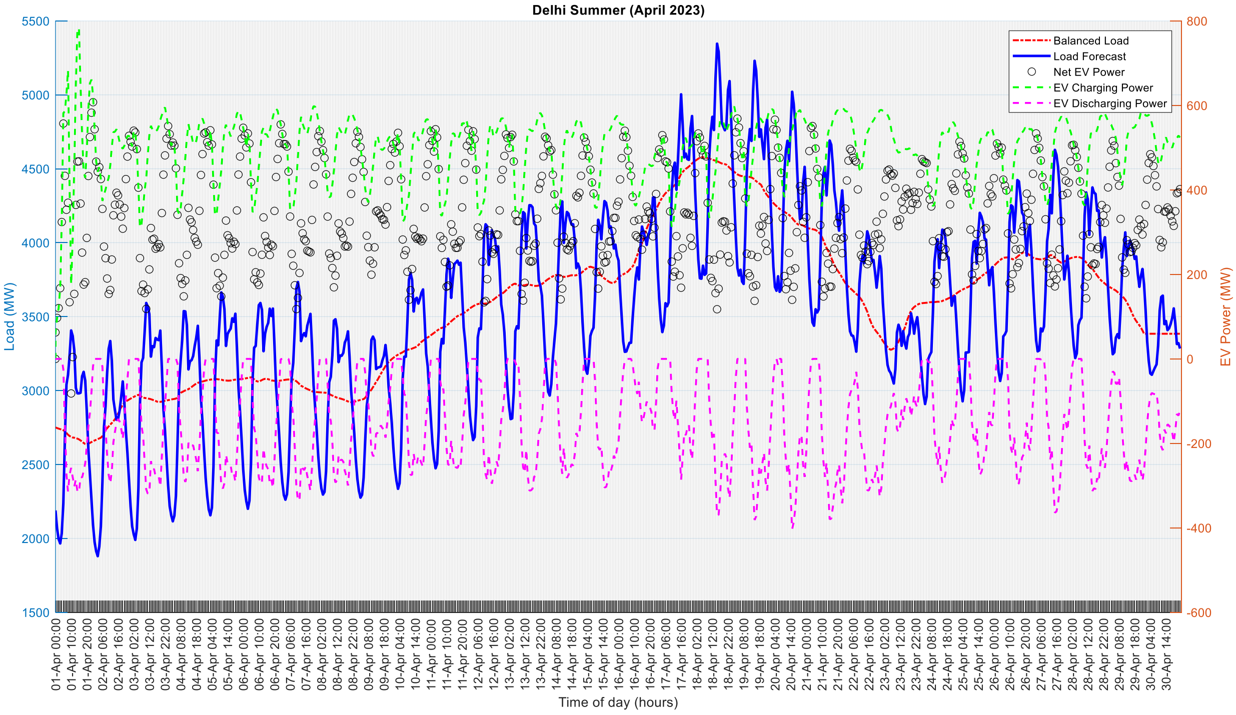

Figure 7: Delhi Summer Simulation Results (Load)

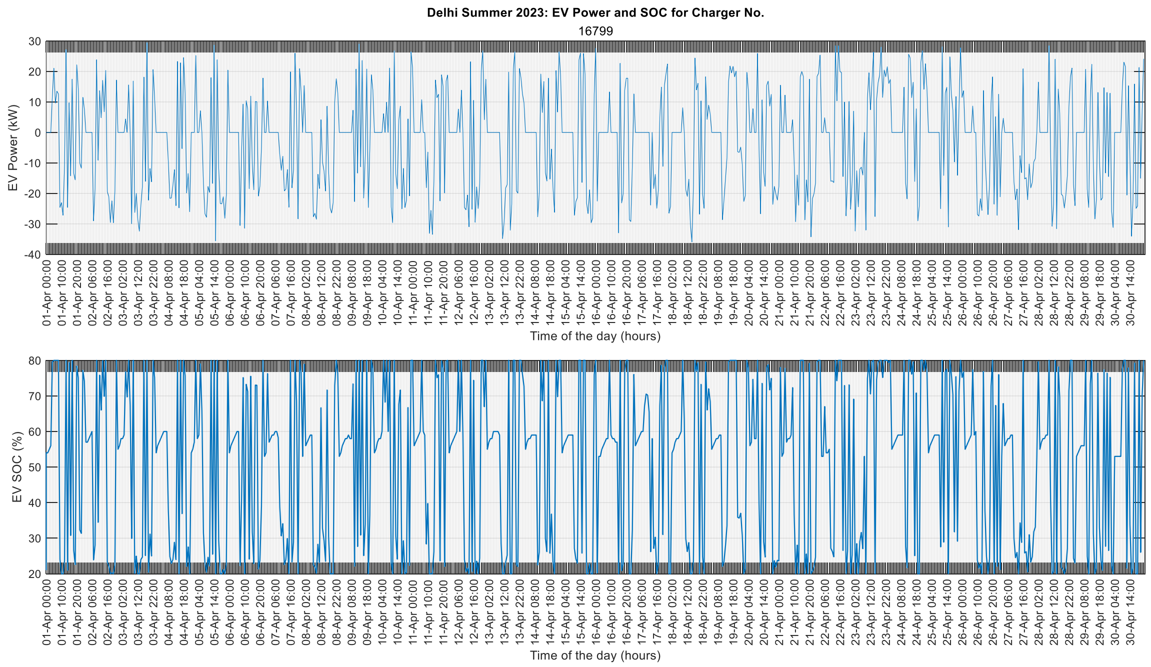

Figure 8: Delhi Summer EV SOC and Power for one random charger

2. Maharashtra Summer

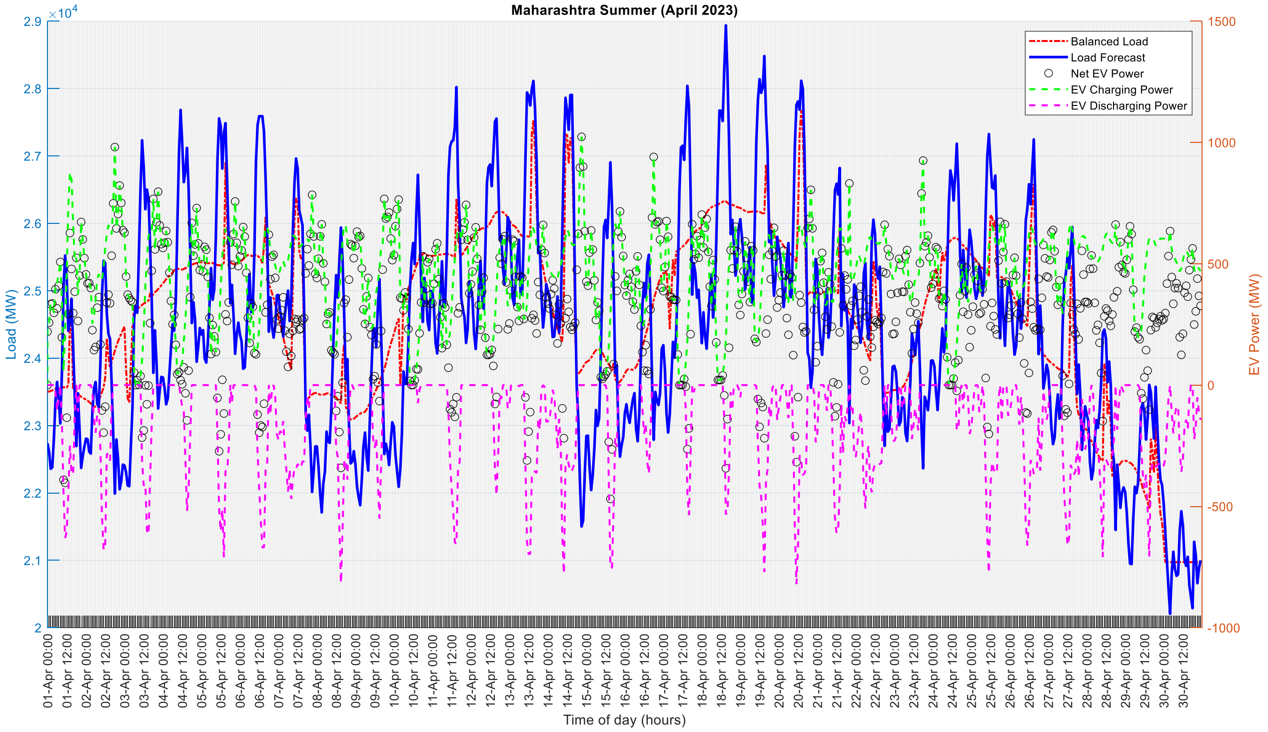

Figure 9: Maharashtra Summer Simulation Results (Load)

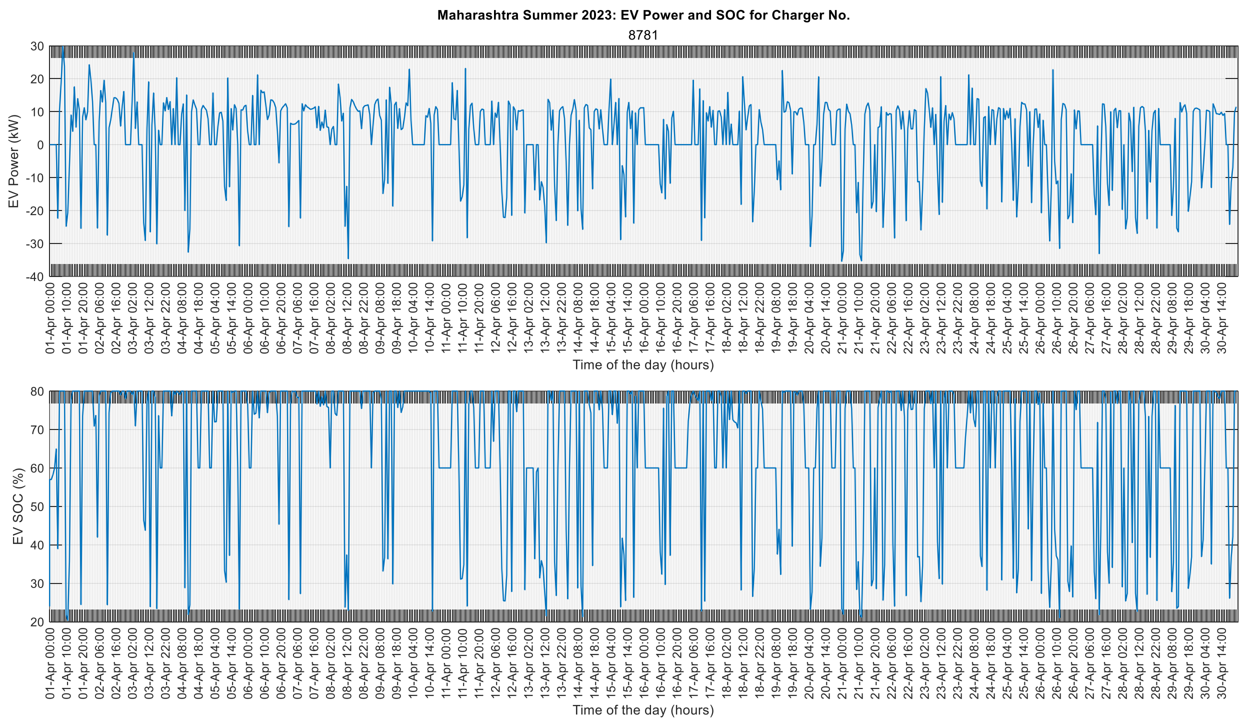

Figure 10: Maharashtra Summer EV SOC and Power for one random charger

3. Delhi Winter

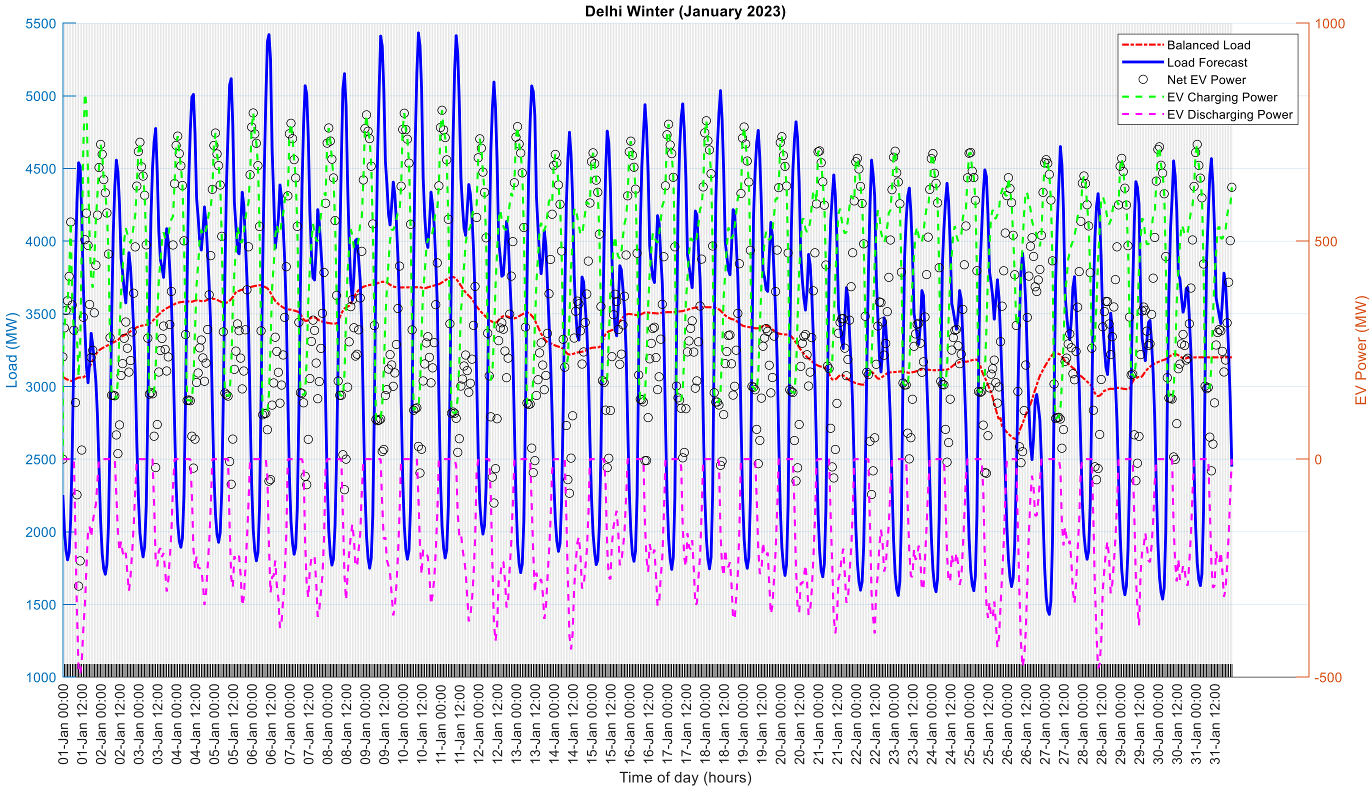

Figure 11: Delhi Winter Simulation Results (Load)

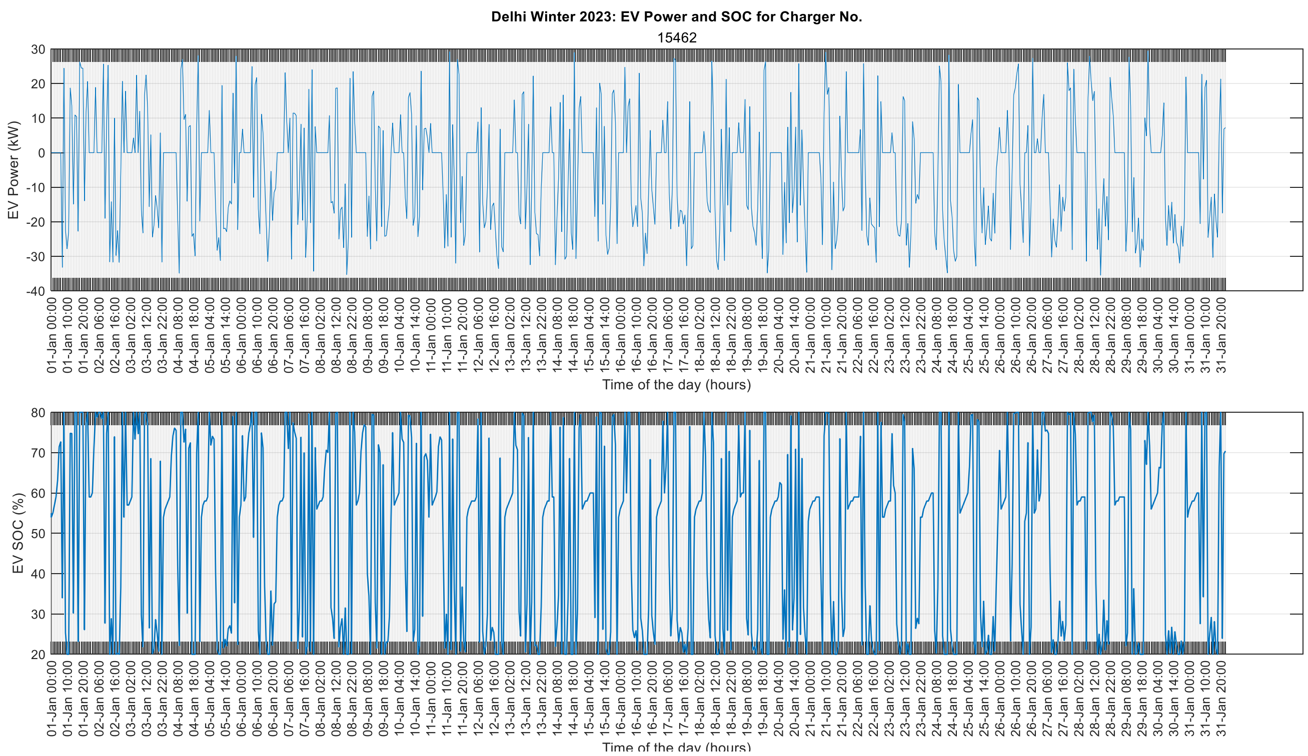

Figure 12: Delhi Winter EV SOC and Power for one random charger

4. Maharashtra Winter:

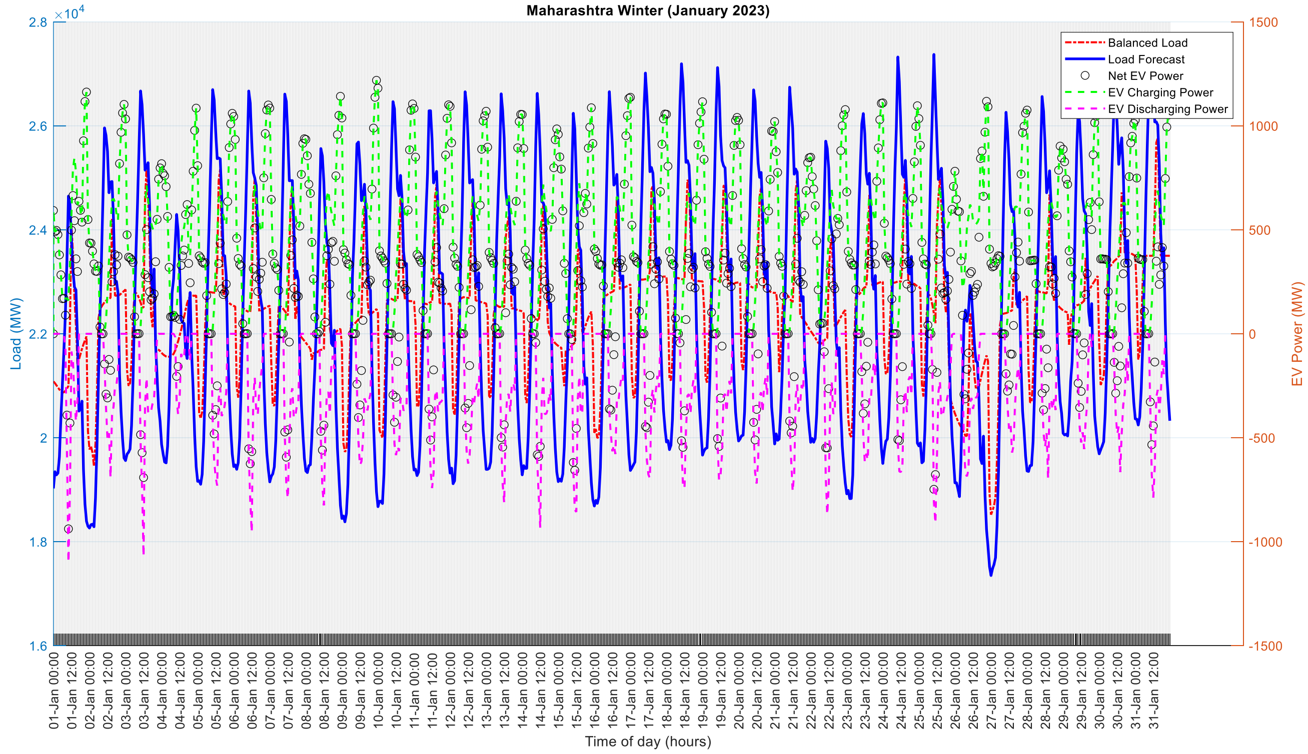

Figure 13: Maharashtra Winter Simulation Results (Load)

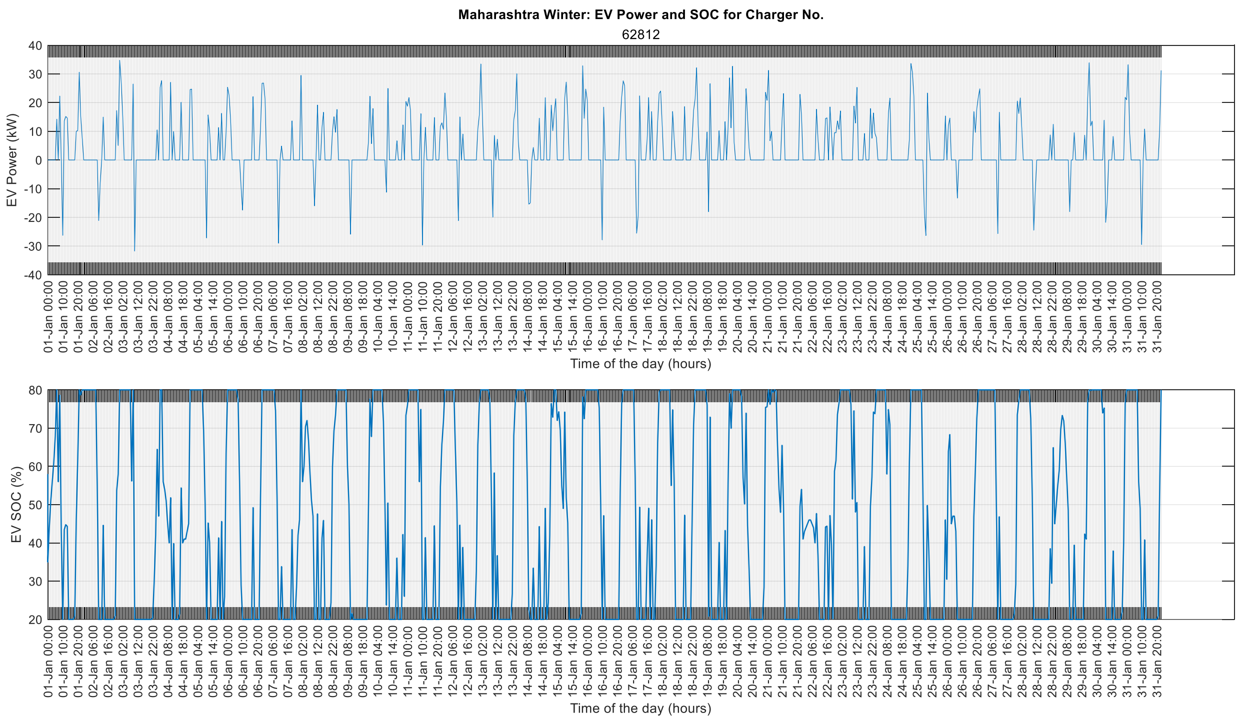

Figure 14: Maharashtra Winter EV SOC and Power for one random charger

3.7 Inferences on the Results:

1. The load balancing achieved in Delhi is much better than in Maharashtra. This is because the total load in Maharashtra is of the order of tens of thousands of MW, whereas in Delhi it is in thousands of MWs. This happened due to applying the same number of EVs in both scenarios (i.e. 100,000). The number of EVs could not be increased further in the simulation of Maharashtra due to computation time constraints.

2. In each of the cases, the EV SOC reaches 80% at regular intervals, closely corresponding to the duration mentioned by the user (in this case, by the vector 'T_connectedDur'. So, the requirements of EV users are fulfilled along with providing grid services.

3. There are peaks in the balanced load curve in case of Delhi's Winter. This is due to the very high peaks observed there due to the temperatures dropping very quickly from afternoons to evenings.

4. These are not observed in the Summer conditions, because the daytime and nighttime temperatures are almost identical (although still not as stable as Mumbai).

5. This comment on peaks can be explained by point 1 in the case of Maharashtra, but cannot be explained by the weather conditions because the weather distribution is variable throughout the landmass of Maharashtra.

6. Although, the load balancing in Maharashtra is not as good as in Delhi, magnitude-wise, the simulation has performed well, and provided a very significant load balancing with the use of only 100,000 V2G compatible vehicles in the entirety of Maharashtra.

3.8 Validation

Two research papers have conducted a similar study [8], [9], both having the same algorithms, both conducting the load balancing through optimisation methods, and both deciding beforehand what the target new load curve should be. They also have done their study only for 24 hours, so they did not require to simulate the input of new customers. They have not considered the requirement of the EV reaching 80% SOC at the end of the required disconnection time, although they have constrained the SOC and Times at a minimum and maximum value. Their study is solely based on evaluating the performance of load balancing using different SOCs of EVs in the ecosystem.

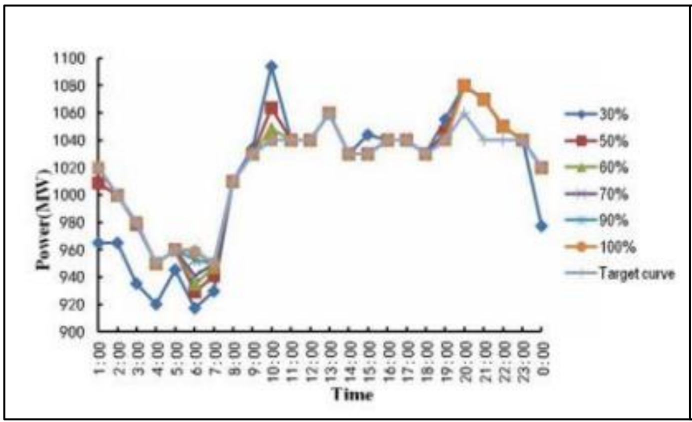

Figure 15: Load Balancing Achieved by [8]

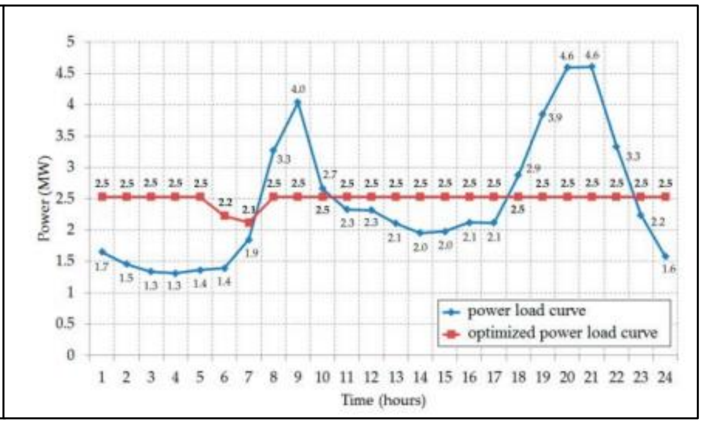

Figure 16: Load Balancing achieved by [9]

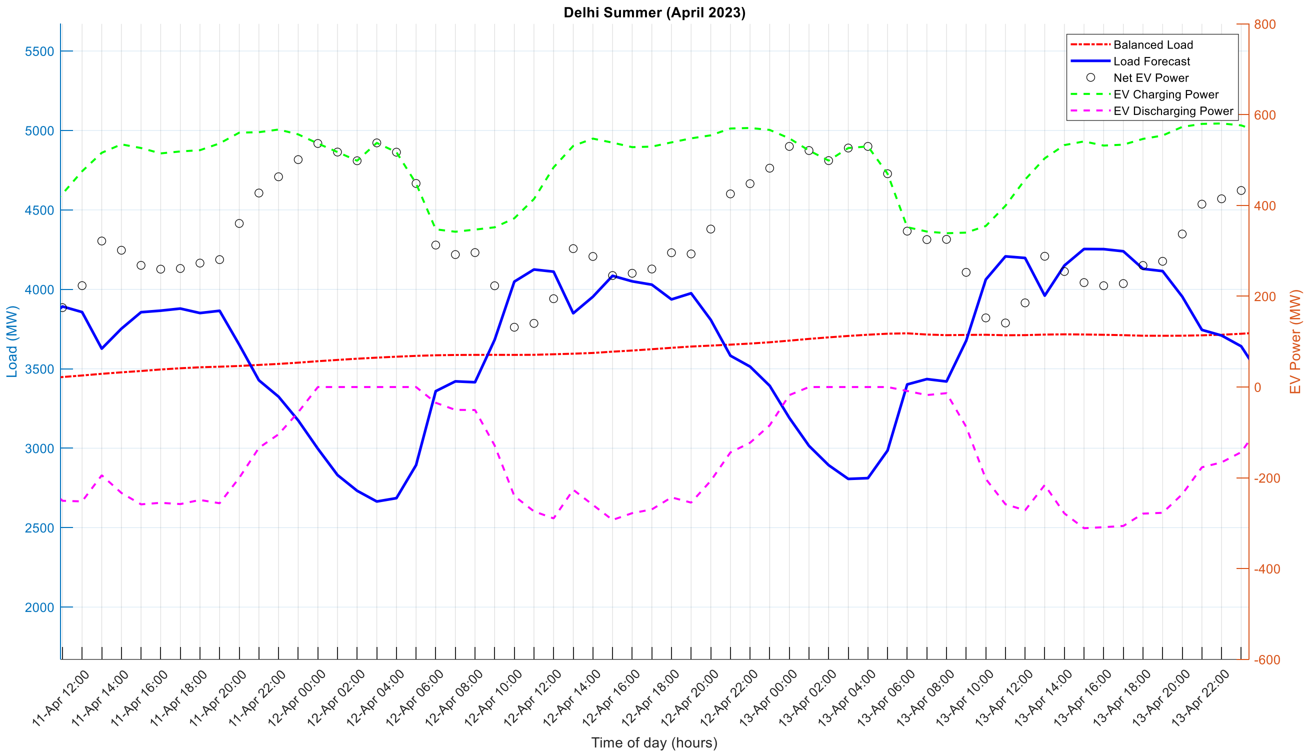

Figure 17: Load Balance Achieved by the Simulation in this Report

The plots obtained in the simulation conducted in this report has a similar behaviour to those conducted in the above-mentioned studies (Figure 15, and Figure 16), while having more features than them. The key features and limitations of the simulation are highlighted below.

3.9 Features and Limitations of the Simulation Conducted in this Report

1. Features:

a. It adheres to the requirements of the user, of getting a fully charged vehicle at the end of the charging session.

b. It achieves load balancing throughout the season, and never going above the original load forecast.

c. Power limits of the EVs are followed.

d. It is a dynamic simulation which updates when the charging session is over and intakes a new user with an updated SOC, power limits and charging duration.

e. Allows maximum participation while respecting the SOC limits of the EVs.

2. Limitations/ Improvements:

a. Some EV charge points do not reach 80% in the simulation. The number of these occurances are very less compared to the number of EVs in the simulation (n = 100,000).

b. Maharashtra's load balancing could have been done using more number of EVs, even though it achieves a good load balance magnitude wise. This was not achieved because of high computation times. It could also be tackled if the data for a smaller area in Maharashtra would be available (like Mumbai).

c. It was assumed that all EV users agree to the grid service participation. This could be included by allowing for a 'participation' parameter, which only allows the CHARGE or IDLE state of the EV.

d. Although the time dynamics of the EV connection times are captured, it could be made more realistic by applying greater connections during the start and end of business hours in the city, when people usually commute to and from their homes to workplace.

e. Capability of other grid services could also be added to the simulation.

f. The number of steps while selecting a power in CHARGE and DISCHARGE state, were assumed to be same for all chargers. This could be different too, for each charger, allowing for greater variability and more realism.

g. The SOC at the end of charging was assumed to be 80 % for each user, but it could be simulated by allowing for a random SOC as a simulation of the SOC input by the user.

Conclusion

This report aimed to provide a review of existing communication architecture. It highlighted the classification based on the application in Front-End or Back-End. A gauge of usability of the protocol was studied with qualitative parameters like: openness, maturity, market adoption and interoperability. A brief description of open protocols was provided along with the gaps in their implementation/ use. Some less-known/ under research protocols were mentioned but not studied.

A complete guideline of how a communication protocol works was detailed using the example of ISO 15118. The physical modes of data transfer and the data packets actually transferred were given in detail. Ultimately, the main messages required for simulation of a communication and control algorithm were the vehicle SOC, the time of departure entered by the EV user, the SOC required at the end of charging session, the maximum charging and discharging powers, and finally whether the EV user wants to participate in the grid services.

A detailed simulation control algorithm for load balancing of grid forecast load was created and simulated for Delhi's & Maharashtra's summer and winter conditions in April and January, respectively. 100,000 vehicles were assumed in both cases, with features such as guaranteed full charge at the end of charge session and simulation of a new user connecting when the old user's time of disconnection has reached. The results of the simulation were validated with two studies which simulated their respective optimization problems for only one day, while lacking the features of the simulation in this report.

Insights into the system's performance under winter and summer conditions were underlined, while providing the reasons of them being observed in the results. The features and limitations of the simulation were provided and possible improvements to the simulations were also given.

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