A Study On Electric Vehicle Charging Methods And Suggesting Optimally Best For Kolkata

A THESIS SUBMITTED TOWARDS PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF TECHNOLOGY

IN

ENERGY SCIENCE AND TECHNOLOGY

FACULTY OF INTERDISCIPLINARY STUDIES, LAW AND MANAGEMENT

COURSES ARE AFFILIATED TO

FACULTY OF ENGINEERING AND TECHNOLOGY JADAVPUR UNIVERSITY

SUBMMITTED BY

ASHUTOSH KUMAR SAW

EXAM ROLL NO: M4ENR23004B

REGISTRATION NUMBER: 160449 OF 2021-2022

UNDER SUPERVISION

OF

Dr. TUSHAR JASH

JADAVPUR UNIVERSITY

SCHOOL OF ENERGY STUDIES

JADAVPUR UNIVERSITY

KOLKATA 700032

CERTIFICATE FOR RECOMMENDATION

This is to certify that the thesis Entitled **A Study On Electric Vehicle Charging Methods And Suggesting Optimally Best For Kolkata,** which is being submitted by Ashutosh Kumar Saw in partial fulfilment of the requirements for the award of the degree of **Master of Energy Studies** at the School of Energy Studies and Application, Jadavpur University, Kolkata-700032, during the academic year 2021-2023, is the record of the student's own work carried out by him under our supervision.

____

Thesis Guide Dr.
Tushar Jash
Professor, School of Energy Studies
Jadavpur University
Kolkata

____

Dr. Ratan Mandal
Director
Professor, School of Energy Studies
Jadavpur University
Kolkata

____

Dean
Faculty of Interdisciplinary Studies, Law and Management

Jadavpur University Kolkata

CERTIFICATE FOR APPROVAL

The foregoing thesis entitled, **A Study On Electric Vehicle Charging Methods And Suggesting Optimally Best For Kolkata,** is hereby approved as a creditable study of an engineering subject carried out and presented in a satisfactory manner to warrant its acceptance as a prerequisite for the degree of **Master of Energy Studies** at the School of Energy Studies and Application, Jadavpur University, Kolkata 700032, for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed, or conclusion drawn there in but approve the thesis only for the purpose for which it is submitted.

COMMITTEE ON FINAL EXAMINATION

FOR EVALUATION OF THESIS

____

____

____

DECLARATION OF ORIGINALITY & COMPLIANCE OF ACADEMIC ETHICS

It is hereby declared that the thesis entitled, **A Study On Electric Vehicle Charging Methods And Suggesting Optimally Best For Kolkata,** contains literature survey and original research work by the undersigned candidate, as part of his degree of **Master of Energy Studies** at the School of Energy Studies and Application, Jadavpur University, Kolkata700032.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

It is also declared that all materials and results, not original to this work have been fully cited and referred throughout this thesis, according to rules of ethical conduct.

Name: ASHUTOSH KUMAR SAW

Registration Number: 160449 of 2021-2022

Examination Roll Number: M4ENR23004B

Dated:

____

(Signature)

ACKNOWLEDGEMENT

I have immense pleasure in expressing my profound gratitude and sincere thanks to my respected thesis advisors **Prof. Tushar Jash** for his valuable guidance, constant encouragement, useful suggestions, keen interest and timely help in completing this thesis successfully. It has been an excellent opportunity for me to work under his supervision.

I am also expressing my gratitude towards **Prof. Ratan Mandal** for his guidance.

I also expressing my thankfulness to Mohammad Ramim Mullick for sharing his collected data during his thesis work.

I also want to express my thankfulness to Atanu Dutta, Research Scholar, Department of Energy Studies, Jadavpur University for helping me throughout the course of this project work and also for his untiring efforts for improvement of the work.

I also thankfully acknowledge the assistance received from all the research scholar as well as lab assistants of Department of Energy Studies for their sincere, spontaneous and active support during the preparation of this work.

Further, I also take this opportunity to thank all the teachers who taught me and shared their knowledge with me. I must express my heartiest thanks to my friends and seniors at Jadavpur University.

ABSTRACT

The widespread adoption of electric vehicles (EVs) necessitates a diverse and efficient charging infrastructure to meet the diverse needs of users in urban environments. This abstract explores various electric vehicle charging methods and their potential contributions to sustainable urban mobility. Charging methods, including home and workplace charging, public AC charging stations, fast-charging stations, smart charging infrastructure, incentives for off-peak charging, battery swapping stations, and integrated public transportation charging, are discussed. The integration of these methods, supported by smart grid technologies and community engagement, offers a holistic solution to address the evolving demands of urban populations. The abstract emphasizes the importance of a comprehensive approach to create a resilient and user-friendly EV charging network, contributing to the transition towards greener and more sustainable urban transportation. Developed nations like USA, UK, EU has already made this possible to some extent by actively adopting EVs into their lifestyle and commercial purpose. However, many upfront challenges arisen during the adoption and so after adoption and they managed to tackle many of them. However, when it comes to developing nation like India, Upfront challenges might become more challenging due factors like huge population, diverse economic and educational disparity and may more. So, for example, if one EV adoption strategy which is successful in Delhi might not be successful in Kolkata because of their different localized behavioural and administrative differences. So, it is very important to analyze and implement EV adoption strategies and their consecutive sectors like power sector, transport sector separately according to their locality. To address the demand for electric vehicle (EV) charging in a city like Kolkata with a population of 15 million people, a comprehensive and strategic approach is needed. The key is to deploy a mix of charging methods that cater to various needs and scenarios. By strategically combining these charging methods and incorporating smart grid technologies, Kolkata can create a robust and flexible EV charging infrastructure that caters to the diverse needs of its population. This approach helps ensure accessibility, convenience, and efficiency in the adoption of electric vehicles while managing the increased demand on the power grid.

CONTENTS

List of Tables

List of figures

Chapter 1

Introduction

1.1 Overview

As electric vehicles (EVs) gain prominence in the transportation landscape, the development of an effective and scalable charging methodology is paramount. This overview delves into the diverse electric vehicle charging methods and the methodologies that underpin their deployment. The charging landscape encompasses various approaches, including home and workplace charging, public AC charging stations, fast-charging stations, smart charging infrastructure, incentives for off-peak charging, battery swapping stations, and integrated public transportation charging. These methodologies aim to address the multifaceted requirements of urban mobility, offering accessibility, convenience, and efficiency for EV users.

The strategic integration of these charging methods involves considerations such as infrastructure costs, charging speeds, efficiency, and their impact on the overall power grid. Smart charging technologies play a pivotal role in optimizing energy consumption, managing peak loads, and enhancing user experiences. Additionally, the methodology extends beyond technological aspects to include community engagement initiatives, awareness campaigns, and policy frameworks that foster a supportive environment for EV adoption.

This overview highlights the need for a comprehensive charging methodology that aligns with the unique characteristics of urban environments, addresses the evolving demands of users, and contributes to the sustainable evolution of transportation. By embracing a multifaceted approach, cities can develop resilient, user-centric, and environmentally conscious electric vehicle charging methodologies, paving the way for a cleaner and more efficient urban mobility landscape.

1.2 Literature Review

In these days, Electric Vehicles (EVs) are becoming more essential due to various factors, in the aspect of less price as well as natural environmental awareness. Also, they are reducing dependency on fossil fuels and greenhouse gas emissions. In this paper, we are going to study different types of charging methods with their advantages and limitations. The charging methods of EVs are classified into portable and nonportable charging. As we know automobile industry has become one of the most important worldwide. There is a wide range of increase in vehicles in various sectors of transportation, to this, there is a drastic situation of fossil fuels as these vehicles run on fossil fuels, this not only decreases fossil fuels but also effecting nature by pollution and economic damage as well. To overcome such a major issue, we are moving towards the electrical system that is an electric vehicle. The introduction of electric vehicles has several economic and environmental benefits, including job creation in R&D, manufacturing, and deployment, a reduction in fossil fuel dependency, the ability to better integrate renewable energy sources and thus achieve higher energy efficiency, and improved energy supply security with associated reductions in GHG emissions, localized air, and noise pollution [1]. A comprehensive review of the current electric vehicle scenario, the impact of EVs on grid integration, and Electric Vehicle optimal allocation provisioning are presented. In particular, this paper analyzes research and developments related to charging station infrastructure, challenges, and efforts to standardize the infrastructure to enhance future research work. In addition, the optimal placement of rapid charging stations is based on economic benefits and grid impacts. It also describes the challenges of adoption. On the other hand, future trends in the field, such as energy procurement from renewable sources and cars' benefits to grid technology, are also presented and discussed. A study analyzing recent EV developments and charging infrastructure challenges is presented in this work. Detailed findings from the study are presented below. Optimal charging scheduling techniques can take advantage of EVs' flexibility as a load while minimizing solar and wind systems' impact on the grid. Current research indicates that using metaheuristic techniques coupled with optimization software can significantly affect the efficient use of available resources. EV charging infrastructure can be planned and managed using these tools, including locating the optimal location for charging stations and determining the optimal charging station location. EV owners are reassured by mobile charging stations that they will have access to a charging facility if they cannot find an adjacent charger as part of planning infrastructure for EV charging. Using V2G technology, energy can be bi-directionally exchanged, and ancillary services are provided to the grid. Charging infrastructure available with minimal charging times is critical for adopting EVs. In order to minimize the impact on the primary power grid, battery swap stations regulated the charging schedule of EV battery packs. Furthermore, it can serve as a backup unit and provide power for the primary grid in peak demand periods. As EVs and their charging infrastructure are developed, and renewable energy sources are utilized, harmful emissions can be drastically reduced in the transportation sector. Unfortunately, any damage to the environment this new infrastructure might cause has not been assessed. In future electric vehicles, hydrogen energy and fuel cells will replace the batteries currently used in battery energy storage systems [2]. This paper proposes a general procedure to compute the load profile of a bus rapid transit station where a fleet of full electric buses is charged. Such procedure is divided in two stages. At first, in order to determine if the flash charging is feasible given a certain travel route, the state of charge of a bus during its operation is modeled, based on Geneva's all-electric articulated bus and its flash battery charger. Then, assuming that buses are autonomous and can complete their routes without running out of energy, the point of view of a charging station is taken into account. The objective of the model is to compute the load profile for a station, according to its charging policy and demand. The models are tested with the bus rapid transit system implemented in Bogotá, Colombia. Through the implementation of Monte Carlo simulations, different charging scenarios are considered for this study. The Bus Rapid Transit (BRT) has become a popular transportation system in many countries, especially in Latin America. As evidence of this, cities such as Curitiba (Brazil), Bogotá, Cali, Barranquilla (Colombia), and Santiago (Chile) have implemented this system. The main BRT fleet operates within a fully dedicated bus lane aligned in the center of the road. Stations leveled with the bus floor are placed along these corridors, where passengers can board the buses. In this paper, a fleet of full-electric BRT buses is assumed. As developed and tested by the TOSA Project in Geneva, Switzerland [3], these buses use low capacity and reduced weight batteries. A "flash charging" system transfers energy to buses during a few seconds at each station. Several numbers of feeding stations are installed along the bus route, in order to guarantee that the state of charge (SOC) remains high enough to complete its tour [4]. An adequate infrastructure allowing customers to recharge their electric vehicles would make it easier to adopt electric vehicles (Miller et al., 2012). Fast, reliable, and convenient technology will make it easier for consumers to adopt electric vehicles. Adopting electric vehicles promotes environmentally-friendly transportation and reduces our dependence on fossil fuels. In addition to electric vehicles, conventional power plants and other power generation units will also produce more emissions. The increasing energy demand should be met by a large-scale deployment of renewable energy sources, and the deployment of REG should be coordinated with the increasing number of EVs [2]. Different standards for EVs charging systems have been explored by several organizations around the world. For defining the standards, organizations consider the safety, the reliability, the durability, the rated power, and the cost of the different charging methods. At the same time the charging equipment for EVs plays a critical role in their development, grid integration and daily use: the configuration of the charging station can vary from Country to Country depending on frequency, voltage, electrical grid connection and standards. In any case, charging time must match with EV's battery characteristics in order to guarantee an optimal charging and a long lifetime of EV's battery. Then a charger should be efficient and reliable, with high power density, low cost and low volume and weight. From the grid side an EV charger has also to ensure a low harmonic distortion, so that minimizing power quality impact, and a high power factor to maximize the real power available from a utility outlet. Generally conventional EVs battery chargers contain a boost converter for power factor correction (PFC) for this purpose. From battery side, high frequency PWM converter has bee proposed to reduce inductor size used as current filter to decrease the battery current ripple. Various topologies and schemes are available on the market with these aims. Essential tasks for EVs charging equipment are the ability to quickly charge the EVs battery, to detect the state of charge (SOC) of the battery and to adapt to various battery types and car models. Additional functions can be required, for instance to modulate the charging curve in function of the electricity price in the time of day, automatically bill for the electricity delivered, etc. The charger power level is the main parameter that has an influence on charging time, cost, equipment and effect on the grid. For these reasons the international standards in Europe are referred to this parameter for the EVs charging equipment classification. Besides, the EVs charging systems can be categorized in offboard and on-board types with unidirectional or bidirectional power flow:

- an unidirectional charging limits hardware requirements and simplifies interconnection issues;
- a bidirectional charging supports battery energy injection back to the grid [5].

Moving to another charging method of electric vehicle, which is battery swapping, let's discuss it.

The EV owner would like to replace his discharged battery with a fully charged one in the shortest time possible and move on while the BSS owner considers the most favorable electricity price for him to recharge the discharged battery and minimize the associated costs. Also important is the inherent interdependence between the BSS and the power system. The behavior of EVs owners is unpredictable, and there are limited options for coordinated charging and discharging of grid-connected EV batteries at this time [6]. Uncontrolled charging of plug-in EVs might have a significant impact on the power system as they can contribute to load growth during peak demand. A battery swap solution offers a controlled charging strategy in terms of scheduling battery charging time without plugging in and immobilizing an entire EV for more than 20 minutes. Charging stations for the batteries themselves or battery swap stations that are also charging stations are able to defer charging to off-peak demand hours, which can solve the grid overload problem [7, 8]. From the power system's point of view, BSSs are a large flexible load. The energy storage capability of EV batteries provides an excellent opportunity for the owner of the BSS to offer grid services. By controlling the charging and discharging times of the batteries, the potential peak demand or overload caused by the increasing penetration of electric vehicles can be flattened. This can be achieved by setting an intelligent charging schedule without having to upgrade the current grid infrastructure. EV batteries can also help regulate frequency of a grid. With a rapidly growing market for EVs, the need for fast chargers could become a major concern for consumers. To keep up with technological advances, infrastructure will need to be upgraded on the household side as well as at public charging stations. In this respect, battery swap stations are superior 38 IAPGOŚ 2/2021 p-ISSN 2083-0157, e-ISSN 2391-6761 to traditional charging infrastructure because upgrades are only needed at the swap station location.

Coming to another charging method that is fast charging method. Normally, batteries have low energy density, makes them weighty, costly. bulky. In addition slow in charging and provides shorter lifetime. Now a days lithium ion batteries are mostly used in EVs. Battery capacity restricts the cruise range. Adding the batteries will increase the cruise range, which further increase the weight and cost of the vehicle. Some authors presented fast battery charging methods to minimize the full charging time less than 30 min [9,10]. However, available fast charging systems are costly and complex in control. Still, the charging time of battery more than time that needs to refuel a car based on fossil fuel.

1.3 Aims and Objectives

- To identify and analyse the different types of charging methods available for electric vehicles.
- To assess the suitability of different charging methods for electric bus.
- To conduct a case study of electric bus charging infrastructure in high density urban areas and to suggest better method for e-bus charging method.

2. METHODOLOGY

Now coming to the charging point of view, these vehicles can be charged in various places, unlike fuel vehicles which need to fill only in filling stations. An EV can be charged at home with a charger. nowadays charging points are provided at parking at commercial buildings so that they get charged and also by using solar panels at home or on parking sheds we can utilize non-conventional sources to charge an EV. And also, by using plug-in electric vehicle charging algorithms we can charge an EV because of its high fuel economy and low emissions.

EV CHARGING TECHNOLOGIES

Electric vehicle charging system required to circumstance and switch power from a steady voltage, steady frequency delivers community to direct current for charging the battery or operating it while connected. There are 3 methods of charging: Battery replacement, Conductive, and Induction charging. The battery is connected to the power supply via cable and plugged directly into it when using conductive charging. In battery swapping battery is replaced with a charged battery. and in induction charging electrical energy is transferred through electromagnetic transmission.

Generally, EVs that need to be charged from the power grid can be divided into two categories: battery EVs (BEVs) and plug-in hybrid vehicles (PHEVs) [11]. BEVs use only the electrical energy stored in the battery for propulsion, while PHEVs can also use fossil fuels. Hence, BEVs have batteries with a higher capacity than PHEVs [11, 12]. In this article, ‘EV’ refers to these two types of EVs. In general, EV battery charging methods can be divided into conductive, inductive, and battery swapping methods [13]. In this section, these three charging methods are introduced, but since conductive charging is used to charge EV batteries in most practical applications, the characteristics and effects of this type of charging are considered from different perspectives in this article. Types of EV charging which are available are following:

2.1 Conductive Charging

Conductive charging refers to how a direct physical connection charges the EV from the power grid. In conductive charging, two types of chargers can be used to charge EVs: on-board and off-board chargers. An on-board charger is mounted on the EV itself and does not require additional equipment to connect to the grid, so the EV can be charged anywhere by plugging in an electrical outlet. However, this type of charger has a low power transfer capability, and, therefore, in this method, the EV charging operation takes longer. However, off-board chargers are not part of the EV formation and are usually installed in commercial parking lots, highways, or fast-charging stations [14,15]. Since off-board chargers charge EVs with a higher power, the waiting time for charging is reduced. However, these chargers are not available in all places and are more expensive and complex [13,14].

The Society for Automatic Engineers (SAE) has defined a standard for different EV charging levels [16]. This standard defines three charge levels for each AC and DC charge. A summary of these charge levels is given in Table 1.1.

Table 1: The SAE standard for AC and DC charging of EVs in a power grid [15].

Different Power Levels	Charger Location	Typical Implementation Place	The Expected Power Level (KW)
Level 1: Convenient Vac: 230 (EU) Vac: 120 (US)	1 phase on-board	Office and Home	Power: 1.4 (12A) Power: 1.9 (20A)
Level 2: Main Vac: 400 (EU) Vac: 240 (US)	1 phase/3 phase on-board	Public and Private	Power: 4 (17A) Power: 8 (32A) Power: 19.2 (80A)
Level 3: Fast Vac: 208–600	3 phase off-board	Commercial	Power: 50 Power: 100
DC Power Level 1: Vdc: 200–450	Off-board	Private	Power: 40 (80A)
DC Power Level 2: Vdc: 200–450	Off-board	Private	Power: 90 (200A)
DC Power Level 3: Vdc: 200–600	Off-board	Private	Power: 240 (400A)

2.1.1 Plug-in Charging: There are three levels of charging an EV in this method.

Level 1 EV charging (standard 120v):

Level one charging is the easiest and very commonly used charging. but it is the slowest one in EV charging. At this level of charging, we can use wall sockets for charging. It takes around twenty hours to fully charge a vehicle. But unfortunately, it is not suitable for busy people so they shift towards the next level of charging. Although charging times differ per vehicle and are dependent on other factors such as weather conditions, driving style, and the onboard current converter, charging at Level 1 will replenish your EV's battery with about 4 to 5 miles of range per hour (6 to 8 kilometers).

So, if you've driven 100 miles (160 kilometers), it will take you between 20 to 25 hours to recharge your vehicle.

Due to its slow charging speeds and lack of specific protection other than your home's circuit breakers, Level 1 charging is discouraged for everyday EV charging and is only recommended as a last resort.

Level 2 EV charging (240 v):

Level 2 charging stations are dedicated pieces of hardware wired directly into your home's electrical circuit by a qualified professional. They offer relatively fast charging speeds and can have a variety of additional smart functionalities. This level of charging speed is increased to twice when compared to level 1. So, it is suitable for most people who drive vehicles every day. So, an increase in voltage reduces the charging time to 3 to 5 times less than level 1 charging. This level of charging is often found in public charging stations. EV users can install this level 2 charger in their homes. Roughly speaking, Level 2 charging is about 5 to 15 times faster than Level 1 charging, depending on the power output and the vehicle you're charging.

Charging for an hour with a 7.4 kW power output will add about 25 miles (40 kilometres) of range, 11 kW will add 37 miles (60 kilometres) of range, and 22 kW will add up to 75 miles (120 kilometres) of range. These calculations are approximations based on the average battery consumption of 18 kWh per 62 miles (100 kilometres). Actual power consumption depends on the vehicle, battery size, and vehicle conditions.

Level 3 EV charging (DC fast charging):

Level 3 charging (DC) is significantly faster than Level 2 charging. Depending on the vehicle and charging station's power output, it can take between 15 minutes to an hour to charge most electric cars—making it quick and easy to charge on the go. Because the power output needed for Level 3 charging stations is much higher than for Level 2 charging stations, level 3 charging stations are far more suited for commercial businesses like gas stations or service stops. You typically don't see Level 3 charging stations installed at public parking locations or office spaces. This level of charging delivers 480 volts which makes the battery reach 80% in half an hour. Unlike other levels of charging this level of the charger of only found at public locations like Tesla superchargers. Unfortunately, not all vehicles are equipped with this level of charging. And also, this level of charging requires specialized chargers. A Level 3 charging station is typically quite large. This is because it needs to house powerful converters to be able to convert AC power a lot faster than regular onboard converters inside electric cars. Some Level 3 charging stations can deliver up to 400 kW of power, capable of charging up to 100 km in 3 minutes.

From the above mentioned plug-in charging method DC fast charging is being used for charging the electric buses.

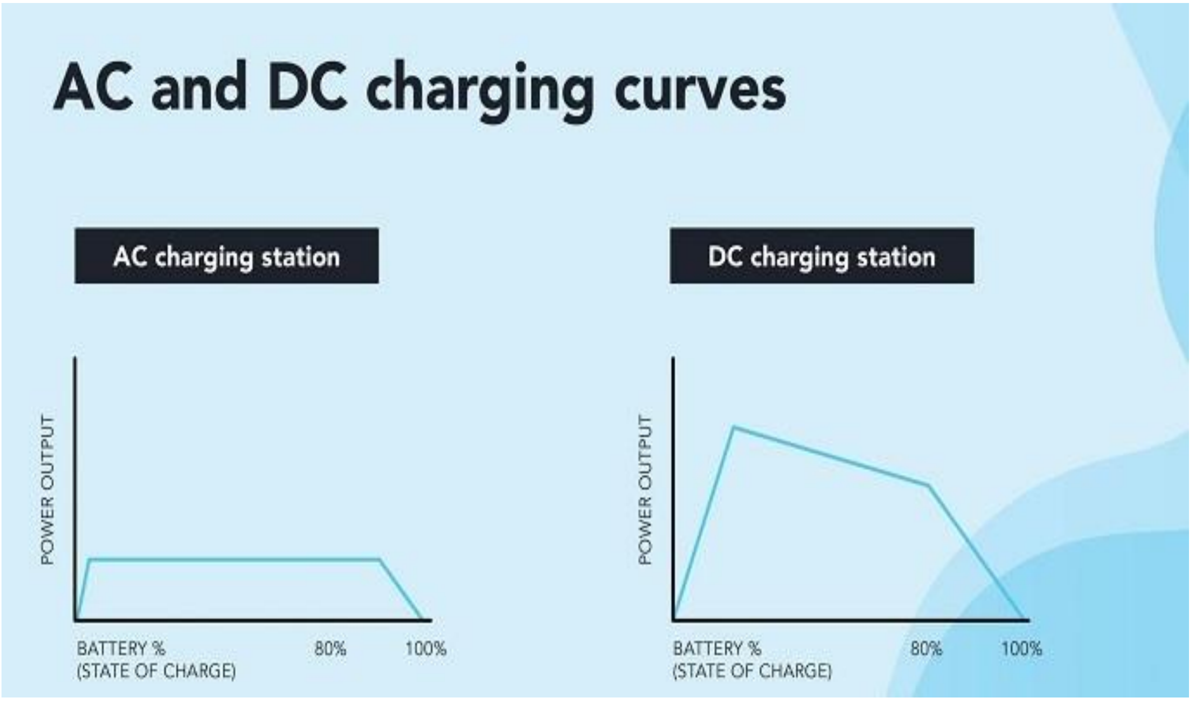

Figure 1: *AC and DC charging station*

2.1.2 Pantograph Charging:

With this charging method, various charging options are available. Typically, this charging infrastructure is used for applications requiring higher battery capacity and more power, such as buses and trucks. As a result of this charging technique, bus batteries require less investment, so the investment costs are reduced, but charging infrastructure costs rise (Meishner et al., 2017). Pantograph charging can be further categorized as follows:

The charging setup is located on top of the bus stop, so it is commonly referred to as an off-board top-down pantograph. This method uses direct current to produce high power (Carrilero et al., 2018), which has already been demonstrated in Germany, Singapore, and the U.S.
Another case is buses have already been equipped with charging equipment, so this charging method is appropriate where the bus already has charging equipment. Alternatively, the bottom-up pantograph is called the onboard pantograph.
There are four main types of pantograph chargers, as shown in Figure 3: downward, upward, horizontal and underbody.

The upward(a) (roof-mounted or bottom-up) pantograph is the easiest to implement. There is no need for a Wi-Fi connection, as the charging process is controlled by the driver. Its communication is performed using the IEC 61851 and ISO 15118 protocol. The downward(b) (infrastructure-mounted or top-down or inverted) pantograph, on the other hand, requires a Wi-Fi connection and uses the OppCharge standard to communicate with the bus. The buses that use downward pantographs usually have reduced weight and reduced height, which enables them to go under low-clearance bridges. The side insertion, or the horizontal(c) pantograph, consists of a moving part on the charging infrastructure and is plugged into the side of the bus. The communication is done using either the ISO 15118 standard without Wi-Fi or the OppCharge that uses Wi-Fi. Lastly, the underbody(d) pantograph is either attached to the bus and moves downward like the roof-mounted pantograph or placed on the ground and moves upward like the inverted pantograph.

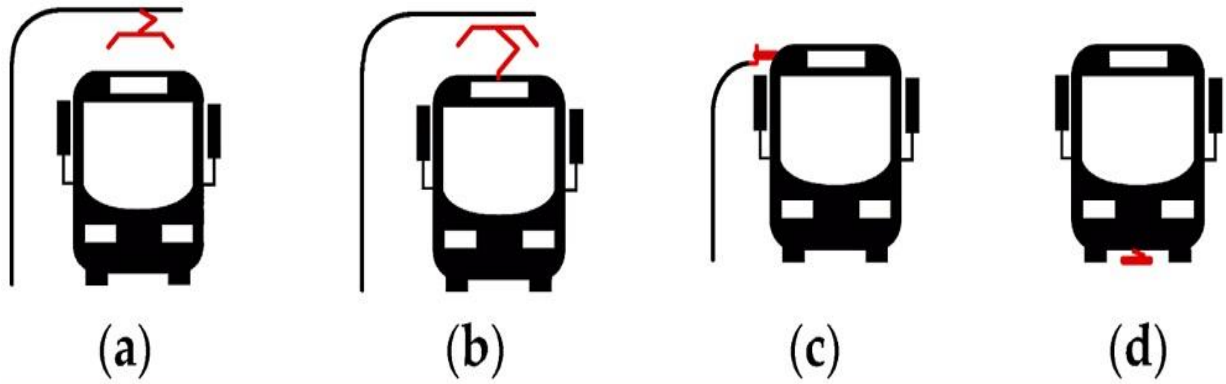

Figure 2: Different types of Pantograph charging

2.2 Inductive Charging

In the inductive charging method, which is also called wireless charging, there is no need for a physical connection between the EV and the power grid, and the power transmission is done using an electromagnetic field. One of the advantages of inductive charging is reducing the risk of electric shocks and related damages due to the power transmission through the air gap; but, on the other hand, due to the relatively large air gap and non-compliance of the windings, the charging efficiency decreases in this case [17,13]. In general, inductive charging can be implemented in both static and dynamic ways. As shown in Figure 1, the EV remains stationary during the charging process in the static mode. However, the EV can also be charged while moving in dynamic charging mode. Therefore, according to Figure 2, by creating special paths for inductive charging from the road floor on highways, the EV driving range could be increased, and the size of the EV's battery may be reduced due to the ability to charge it while moving. Additionally, since a significant portion of an EV's price is due to its battery, dynamic inductive charging will help reduce the initial EV price [13,14]. As a result, dynamic inductive charging will balance many of the barriers seen by users, such as a limited driving range, a long charging time, and higher EV prices compared with conventional internal combustion engine vehicles [18,19]. Hence, the benefits of this charging method have attracted the attention of many researchers. However, high investment costs are one of the main challenges in developing the dynamic inductive charging method [13].

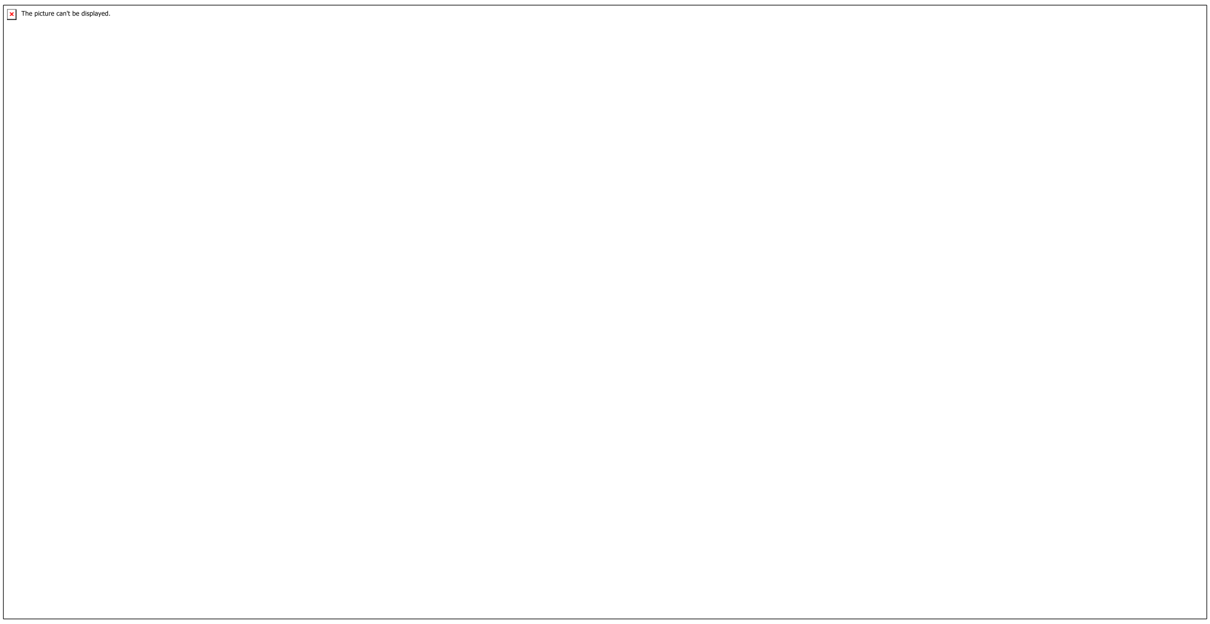

Figure 3: *Static inductive charging of an EV.*

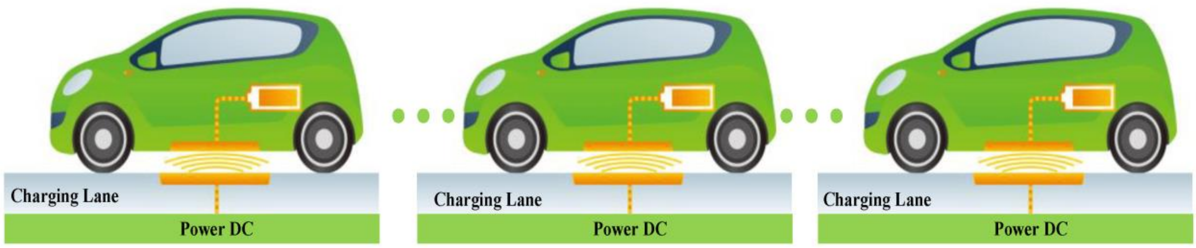

Figure 4: *Dynamic inductive charging of an EV*

2.3 Battery Swapping:

In order to establish and successfully implement battery swapping technology for electric vehicles such as cars, vans, and buses, extensive planning must be carried out, covering all necessary requirements, from the availability of batteries and chargers to the storage and management of data via the cloud and communication between components so as to ensure interoperability. BSSs can only operate successfully if there is continuous communication between the different components of the system (a vehicle, the BSS and information system). The information system is used to communicate with both the vehicle and the station [20]. The vehicle communicates with the information system using the WAVE communication system (integration of several communication networks into one), while the station uses local Internet access. When the battery charge of the vehicle is low, the information system receives a notification from the vehicle requesting a battery swapping service. The information system informs the station of the location of the vehicle and the estimated time of arrival so as to prepare an available battery until the vehicle arrives at the station. When the vehicle arrives at the station, the driver swipes one's membership card and the information system verifies all relevant data contained therein. This data includes information about the vehicle, battery, swapping history, completed transactions and other relevant information. All data must then be archived in the cloud and be accessible to the station owner and customer to ensure full transparency of procedures. Once the swapping is completed, the discharged battery is monitored for state of charge, degradation level, battery age, or number of charge and discharge cycles completed [21, 20].

The main components of the charging station include:

- a control room (controlling and monitoring the overall operation of the BSS),
- charging racks coupled with battery racks,
- a swapping track (the zone where the batteries are located during the swap),
- a swapping lane (the road where the vehicle is during the swap),
- a swapping robot,
- battery and charger service room,
- a service room for other BSS components.

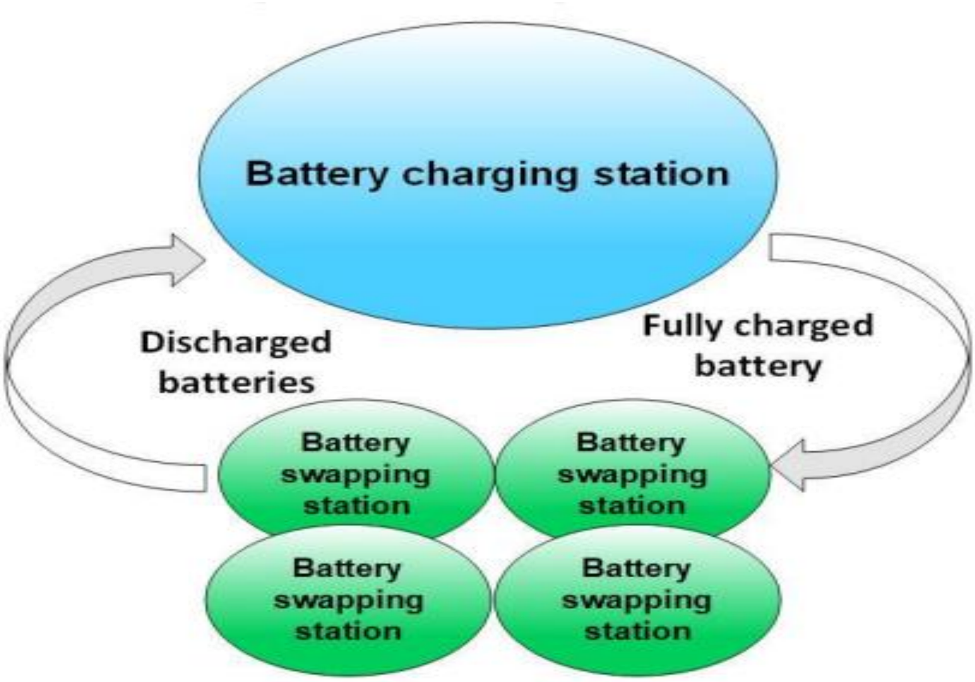

Figure 5: *An approach of battery swapping with the use of an independent battery charging station*

2.4 Collected Data:

To give a brief idea of the methodology and calculations, consumption data of currently operating conventional and electric vehicles are collected from questionnaire-based survey. Then newly registered vehicle numbers have been projected till year 2030 using historical data of Road transport year books and every year certain percentage of them converted to EV. This data is collected to insure the need of best charging method for electric buses in Kolkata.

2.4.1 Electric bus sp. energy consumption data:

One week data of currently operating electric bus has been collected from WBTC Howrah depo near Howrah station shown in annexure *Table A4*. From the data we calculated average sp. energy consumption of 0.997 kwh/km and Sp. energy consumption per passenger stands at 0.032 kwh/pkm shown in annexure *Table A6*. All the electric buses are TATA ultra-urban 9 meter with seating capacity of 31 and battery capacity of 125 kwh.

2.4.2 Considered vehicle information for scheduling:

E4w = Tata Nexon EV with battery capacity of 30.2 kWh, taking 8.5 hours to charge 10% to 90%, with a company claimed range of 300+ kilometre.[22]

In the above-mentioned vehicle Li-ion battery with 80% depth of discharge is considered.

2.4.3 Daily average travelled kilometre:

From [23] daily average travelled kilometre is found to be 160 km for the bus.

2.4.4 Electric Bus charging station infrastructure:

WBTC Howrah depot has total 7 DC chargers, one of them is fast DC charger with dual charging plug with 3-phase AC input voltage of 415 V +/-15% & frequency of 50Hz+/-10% with DC output voltage of (200-750) V & DC output current of (0-160) A and rated power of 120 kW shown in *fig. 2.2.* Rest of the 6 are slow DC charger with single charging plug with 3-phase AC input voltage of 415 V +/-15% & frequency of 50Hz+/-10% with DC output voltage of (200-750) V & DC output current of (0-80) A and rated power of 60 kW shown in *fig. 2.3*. And from the video graphed data a fast-charging plug can serve 1.04333 kWh of energy per minute and a slow charger plug can serve 0.87333 kwh of energy per minute with a load of 62.6 kW & 52.4 kW respectively in *fig. 2.5, fig. 2.6 and fig.*

2.7, fig. 2.8. However, we have considered these calculated charging rate and load is assumed to be non-fluctuating throughout whole charging, irrespective of time & SOC level for all chargers according to their type for simplicity which might not be constant in real case.

Figure 6: Image of charger

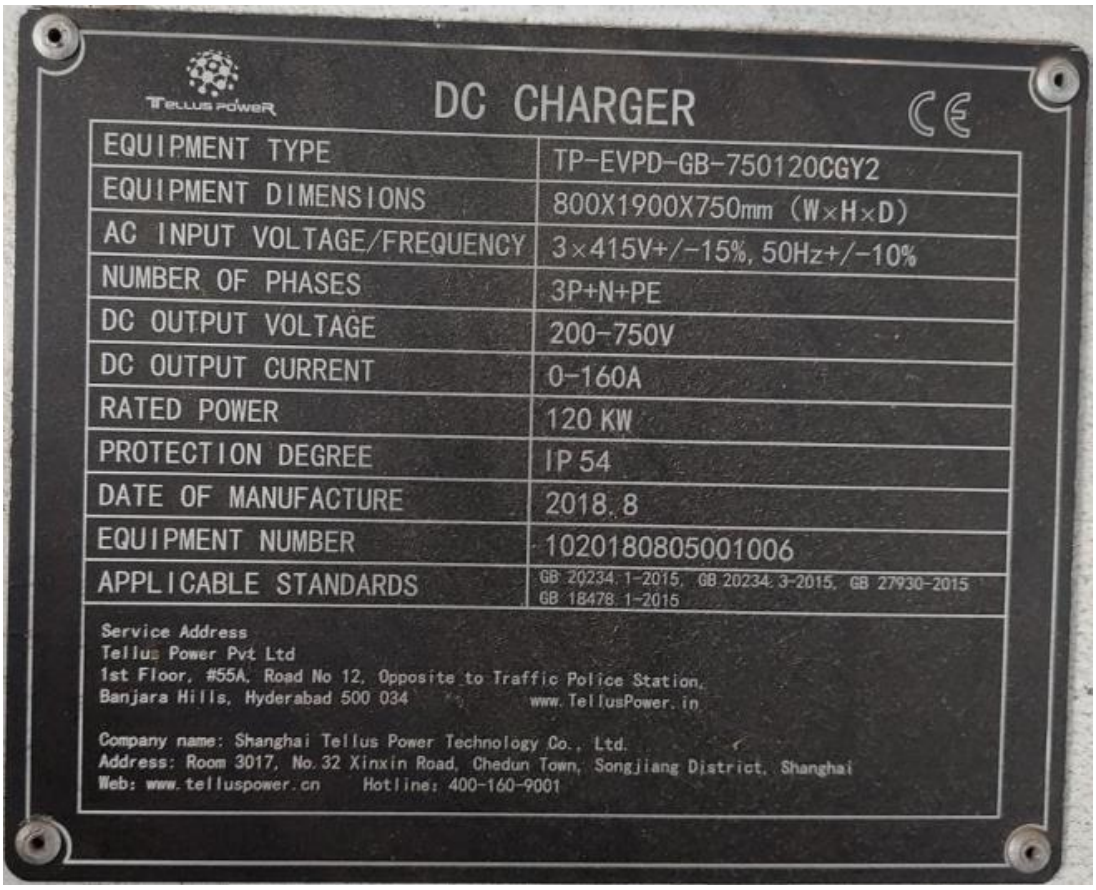

Figure 7: Specification of DC fast charger

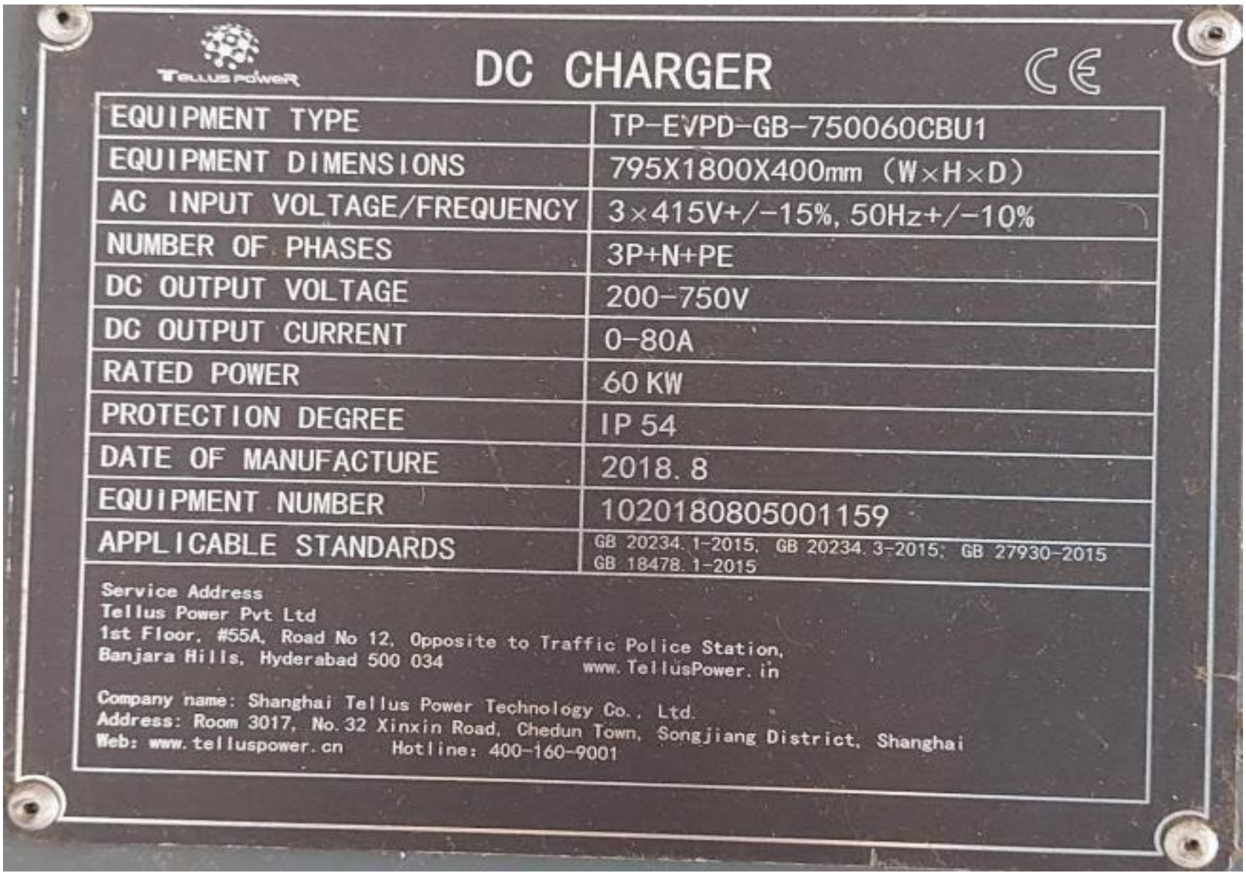

Figure 8: Specification of DC slow charger

Figure 9: Images of DC fast charger plug on left and DC slow charger plug on right

Figure 10: Screen of DC fast charger while charging 1

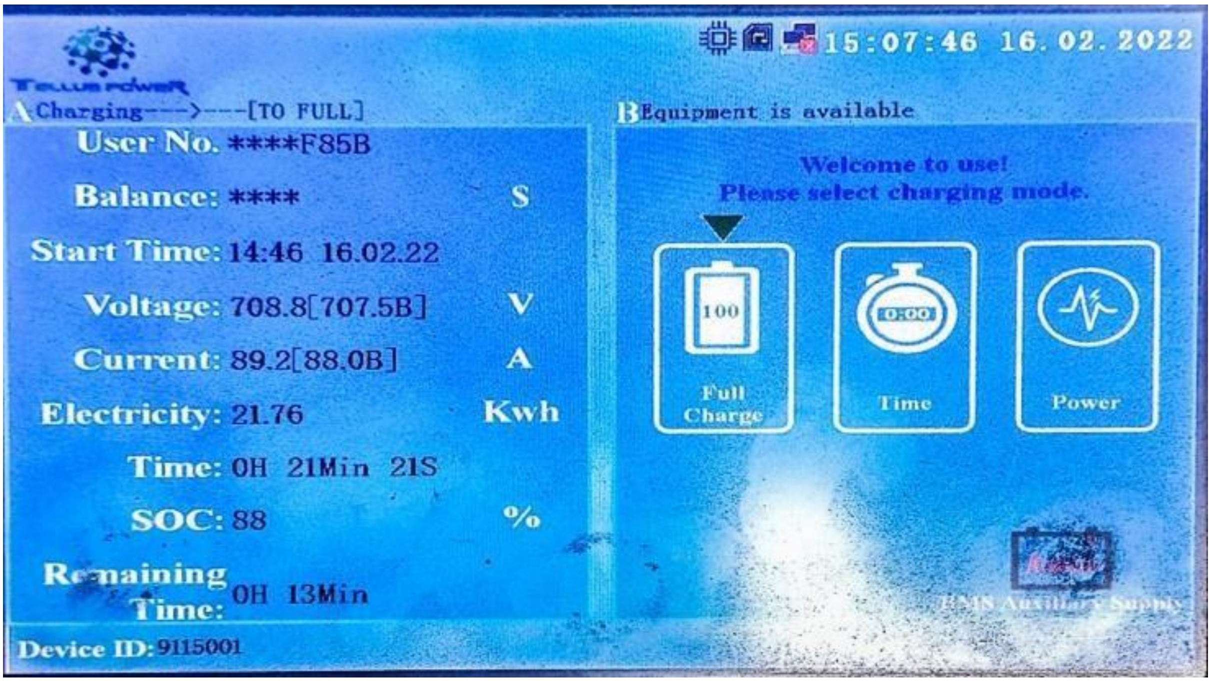

Figure 11: Screen of DC fast charger while charging 2

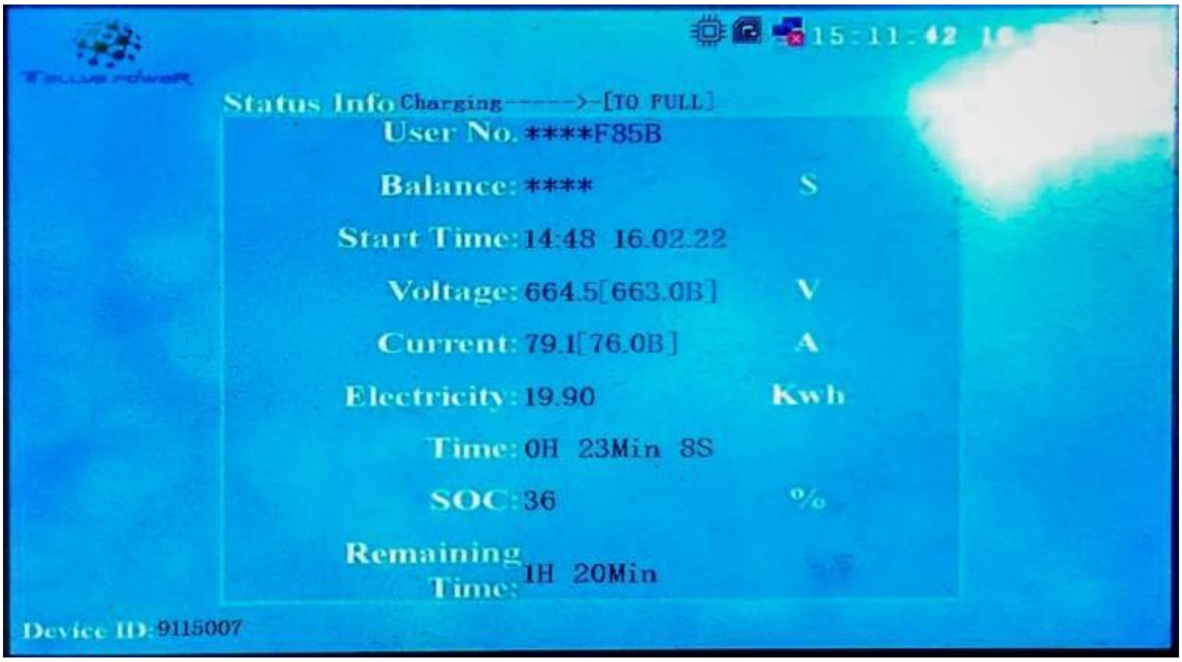

Figure 12: Screen of DC slow charger while charging 1

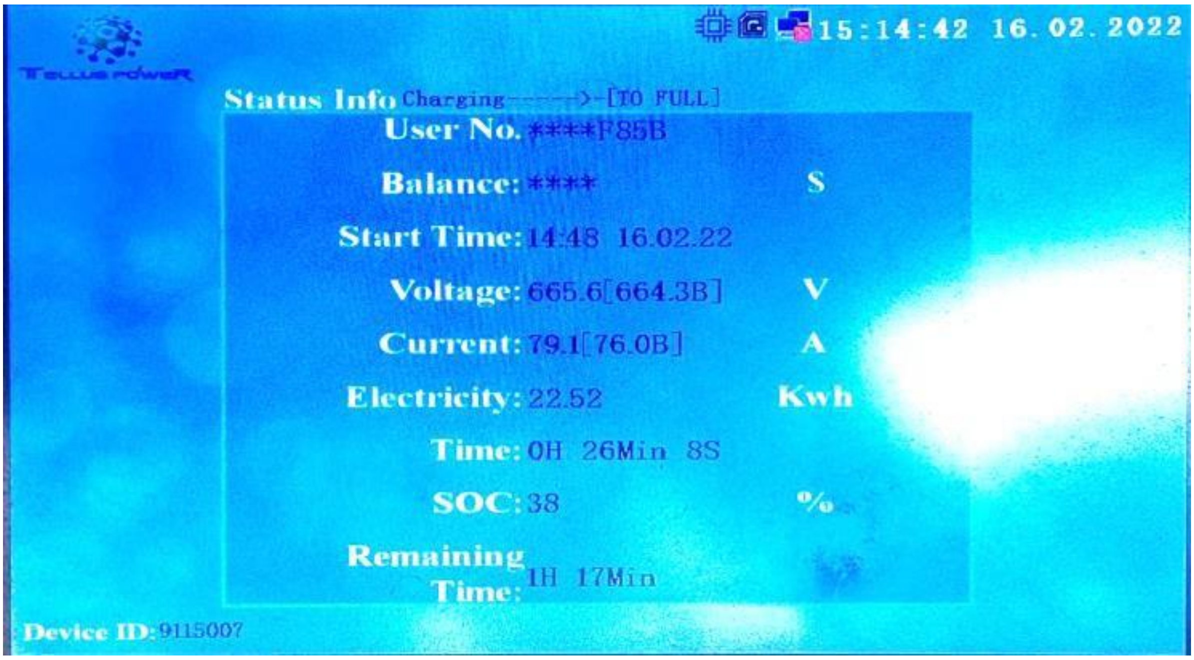

Figure 13: Screen of DC slow charger while charging 2

2.4.5 Power industry in Kolkata:

2.4.5.1 Load curve :

Year wise load curve of West Bengal for 2008 to 2015 has been collected for the month of May in *fig. 2.9.* from electricity demand pattern analysis POSOCO 2016 release , to forecast the demand for 2021 to 2030. For Kolkata it is nearly one fifth of the total energy demand.

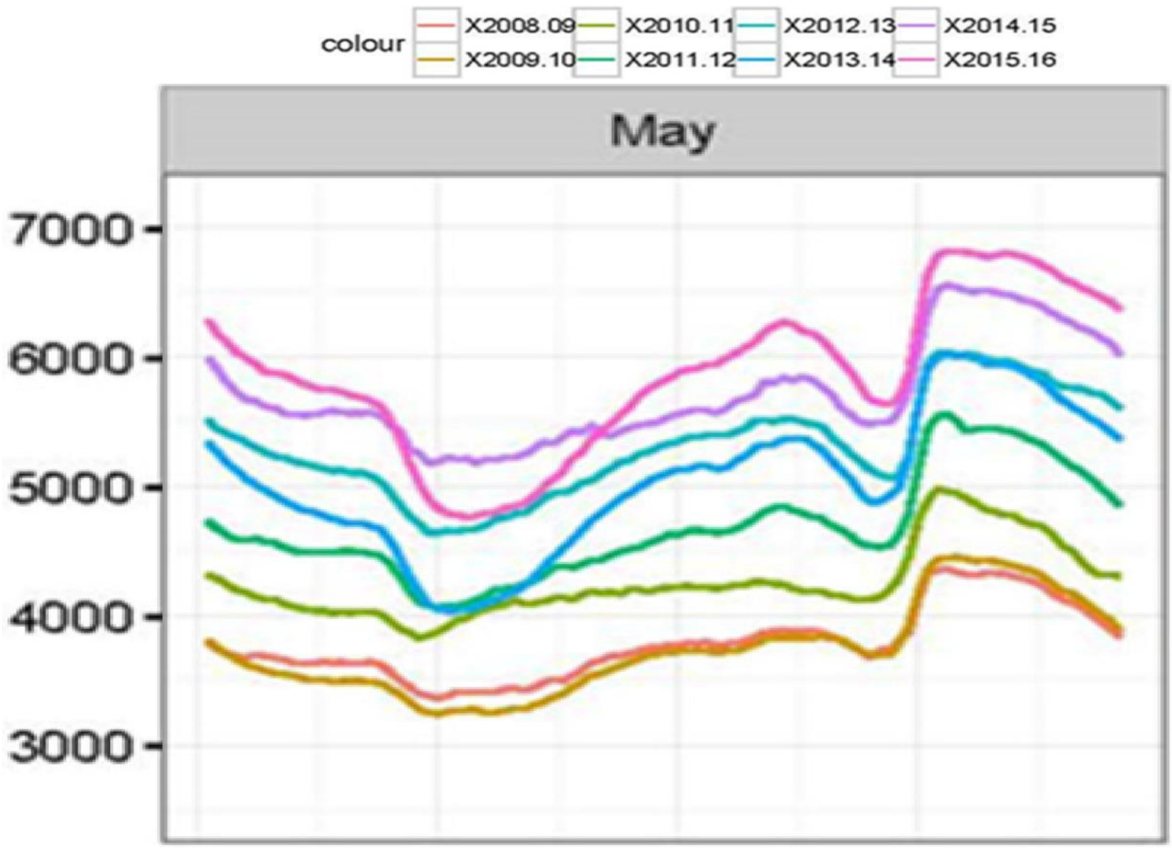

Figure 14: *Year wise load curve of West Bengal*

2.4.5.2 Vehicle number prediction:

In this study we want to determine the upcoming demand due to EV in Kolkata only. For that we need to know how many fleets will convert into EV every year. But we don't have sufficient source of data except the road transport year book of every year. However, in Road transport year books we get vehicle sales & production data for India as a whole. So, we have used category wise number of registered vehicle data from road transport year books, Kolkata as a million plus city. There is no data available for year 2020,2021 and 2018,2019 data are ignored because of being exactly same with 2017. Here data of road transport year books have been used from 2007 to 2017 as historical data and newly registered vehicle in every vehicle category (except bus) are predicted from 2021 to 2030 using forecast sheet in MS Excel, which gives a linear predictive result

, equal growth for every year. For bus we calculated total number of bus fleet of nearly 21009 considering 17,507,500 population [24] of Kolkata in 2030 and 1.2 number of buses needed for every 1000 population [25] and distributed increment equally for every year (2021-2030). However, those historical data are yearly cumulative of (existing+newly registered-old curbed), which we considered as yearly cumulative of (existing+ newly registered) vehicle, as we did not find any source to remove curbed vehicle data. Due to lack of categorized data, Scooters, mopeds, motor cycles are merged under two-wheeler. Stage carriage, contract carriage, private service, others buses are merged under Buses. Motor cab, maxi cab & other taxi are merged under taxis. Three seaters & 4-6 seaters are merged under light motor vehicles passenger auto. However, passenger transport vehicles are only considered, no goods vehicle is considered. So, every year number of newly registered two-wheeler, bus, four-wheeler & three-wheeler will be 23113, 1140, 2681& 819 respectively, which are shown in *Table A3* of annexure.

Here we have considered all the existing EV before 2021 included inside 2021 conversion percentage. For E2w, E3w, E4w the starting & incremental conversion rate are same 3% which touches 30% of newly registered vehicle till 2030. However, we have considered 10% increment every year for e-bus touching 100% of newly registered bus to be EV till 2030 as West Bengal government promises for all WBTC fleet to be electrified till 2030.

Table 2: *Daily SOC requirement*

Vehicle type	Daily avg. travelled km	Daily required SOC (rounded off)	Daytime SOC charging	Night time SOC charging	Leftover SOC before night time charging
E2w	24	32%	0	64%	36%
E3w	100	128%	48%	80%	20%
E4w	150	102%	22%	80%	20%

2.4.5.3 Load Calculation:

Here we have calculated load based on their charging time and battery capacity,

means load = (battery capacity or electricity consumption)/time taken.

For electric bus video footage has been taken for both slow and fast chargers, from there load has been calculated. For electric two wheeler, three wheeler and four wheeler same approach has been taken based on the data available by the company with consideration of 80% depth of discharge, shown in *Table 3.*

Table 3: Load calculation of different EVs

Charger	Battery capacity / energy consumed	Time taken	Load(kW)
e-bus DC fast charger	3.13 kWh consumed	3 min	62.6
e-bus DC slow charger	2.62 kWh consumed	3 min	52.4
E2w home charger	3.176 kWh battery @80% DOD	6 hr. 30 min	0.4886
E3w home charger	5.896 kWh battery @80% DOD	3 hr. 50 min	1.538
E4w home charger	80% of 24.16kWh battery @80% DOD	8 hr. 30 min	2.2738

2.4.5.4 Load curve:

As demand curve of Kolkata is almost 1/5th of total West Bengal's demand. So, data of West Bengal demand curve obtained from POSOCO is divided with 5 to make it equivalent Kolkata demand. A linear forecasted growth in demand is projected till 2030 in MS EXCEL referred in *Table A31* of annexure, using historical demand data from 2008 to 2016 in the month of May shown in *fig. 2.9*, as it is the hottest month having high demand. Then total demand from e2w, e3w, e4w, e-bus combined is aligned with daily demand curve from 2021 to 2030 for the month of May in MS EXCEL shown in *fig. 3.6.*

3. CALCULATION AND RESULTS

Using previously described methodology, the results have been represented graphically, followed by their respective calculations and tables in annexure.

Figure 3.1. Represents how the load due to electric two-wheeler will increase every year with increasing market share. So, during night, when half of the fleet will be charging, the peak load will be 169.23 kW in 2021, all the way up to 9316.86 kW in 2030. However, there is no daytime charging.

In *fig. 3.2*. load due to electric three-wheeler have been showing that two times charging are scheduled one is daytime, another is night time. In both cases the whole vehicle fleet is charging with the peak load of 38.39 kW in 2021, all the way up to 2076.57 kW in 2030.

In *fig 3.3*. Charging of electric four-wheeler scheduled thrice a day, one in night time with whole fleet with the peak load of 181.90 kW in 2021, all the way up to 10057.01 kW in 2030 and another two with half of the fleet at the beginning of first half and second half with the peak load of 90.95 kW in 2021, all the way up to 5028.50 kW in 2030.

In *fig 3.4*. load due to electric bus keep increasing every year with increasing market share has been represented. Charging is scheduled for all over the day except 6 a.m. to 9 p.m. which giving output like a trapezoidal waveform with the peak load of 931.6 kW in 2021, all the way up to 56938.4 kW in 2030.

Whereas in *fig 3.5*. Total load due to all types of EV have been shown which also looks like a trapezoidal waveform, reflecting high influence of e-bus load. So, all types of EV combined, the peak load in 2021 is 1.3206 MW, all the way up to 78.3581 MW in 2030.

Year wise demand of Kolkata excluding EV demand has been projected from year 2021 to year 2030 in *fig 3.6*.

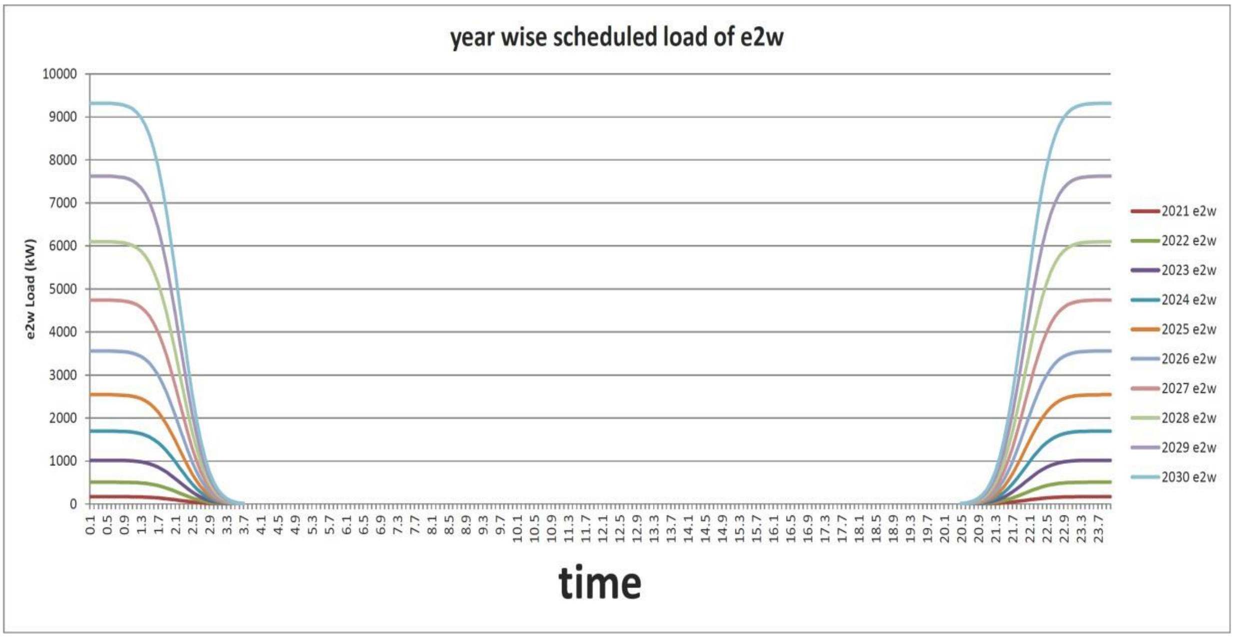

Figure 15: Year wise 24 hour load scheduling of e2w

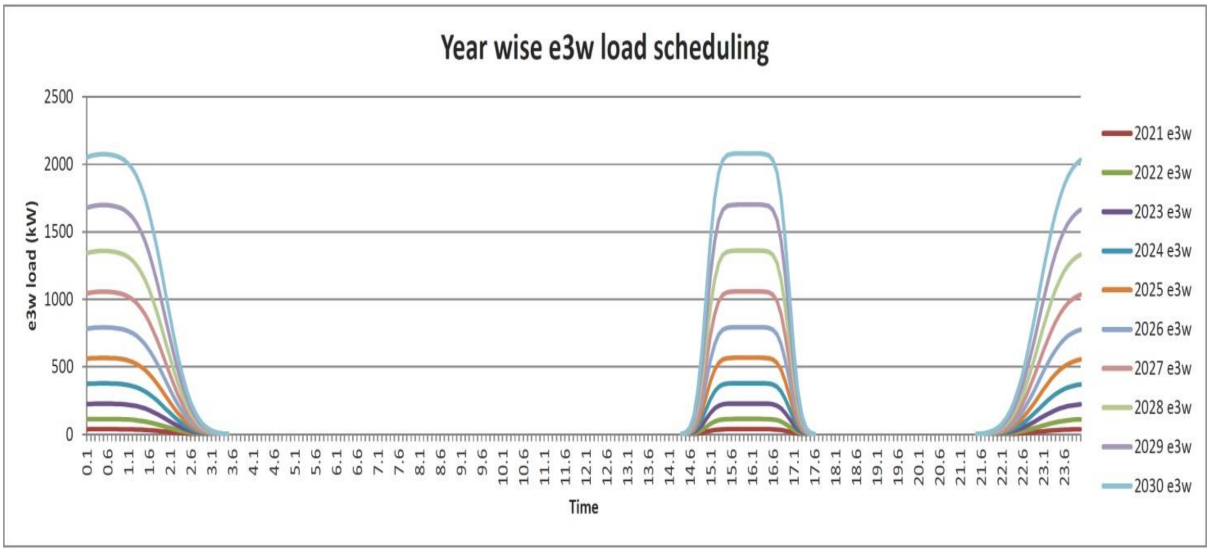

Figure 16: Year wise 24 hour load scheduling of e3w

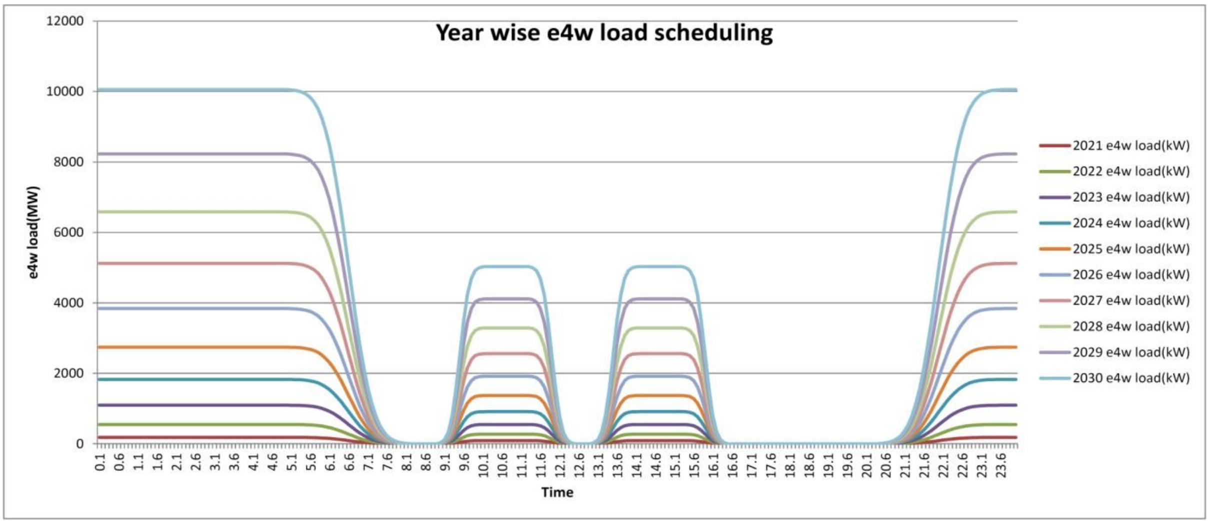

Figure 17: Year wise 24 hour load scheduling of e4w

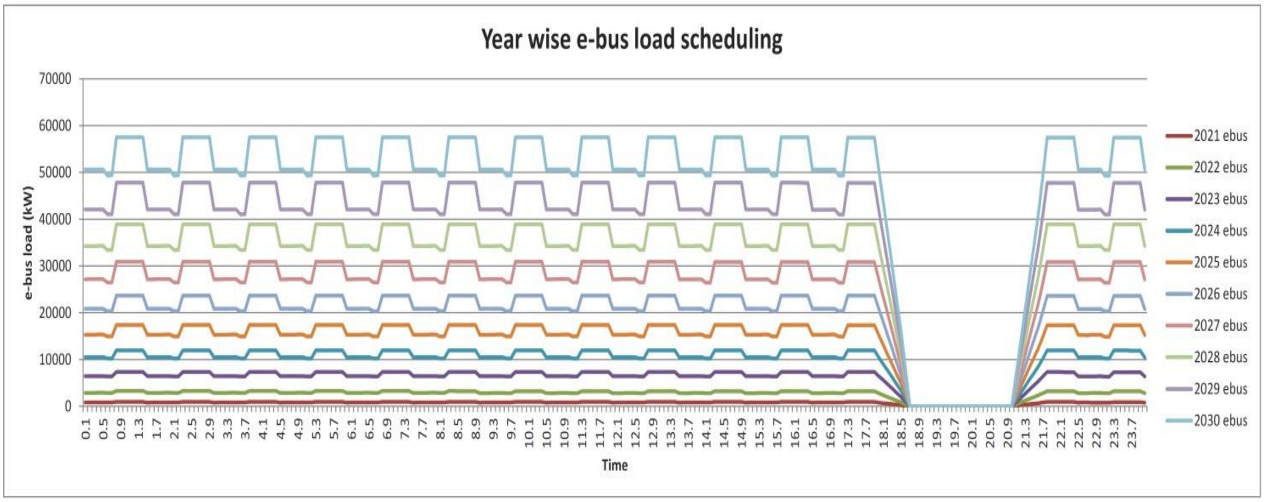

Figure 18: Year wise 24 hour load scheduling of e-bus

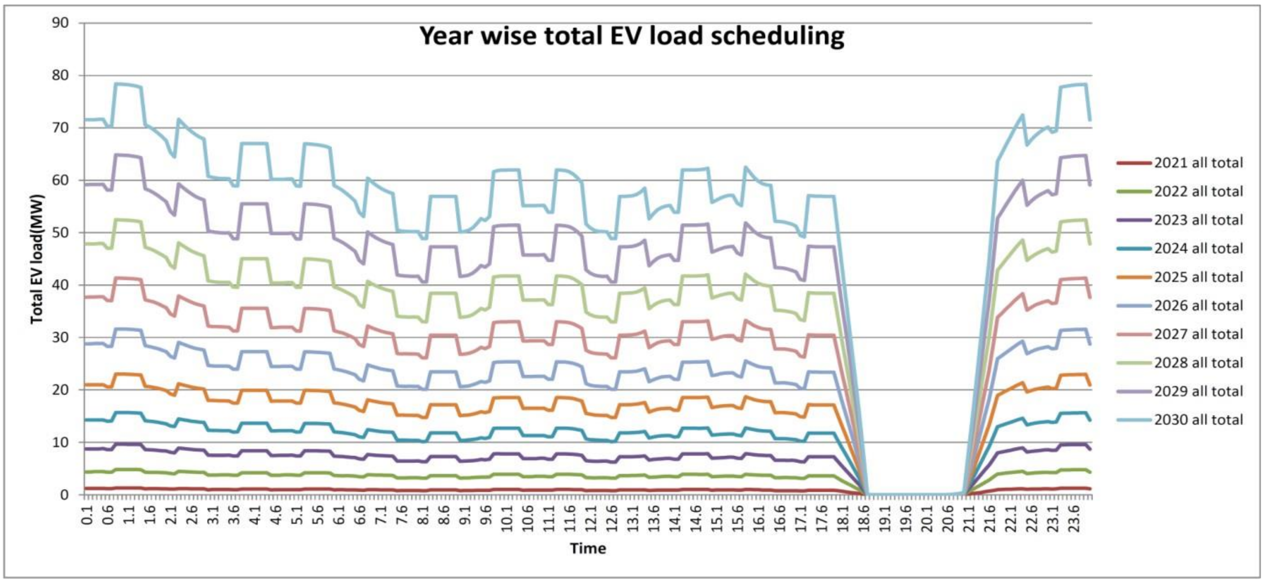

Figure 19: Year wise 24 hour load scheduling of all EV combined

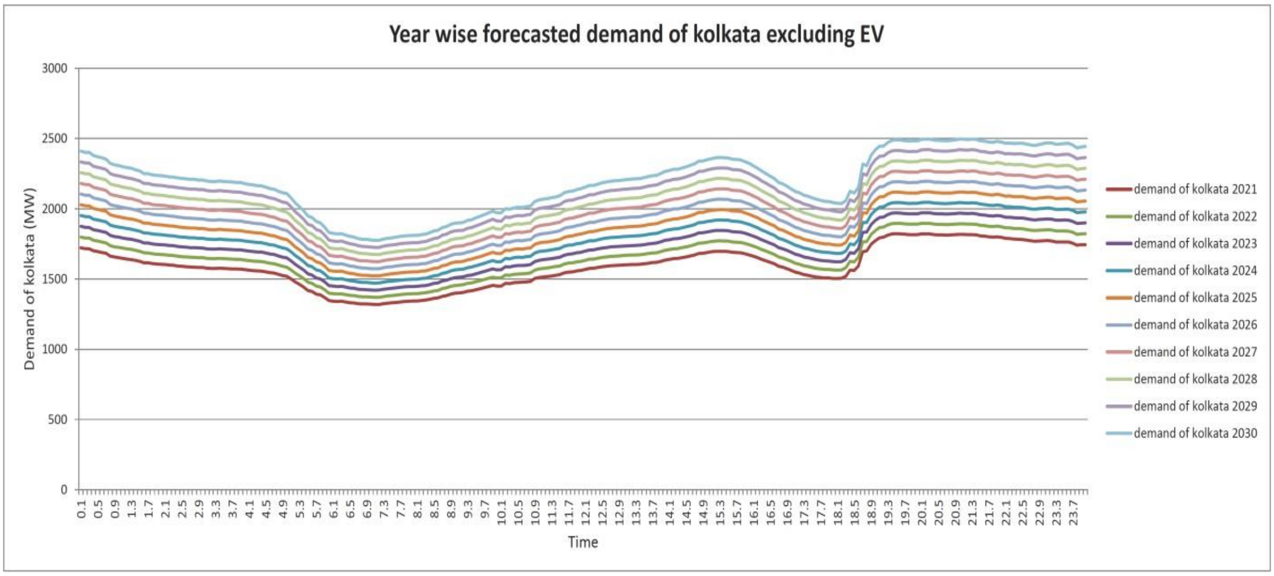

Figure 20: Forecasted demand of Kolkata excluding EV, using historical data

Year wise EV demand with comparison of total load of Kolkata are shown in *Table*

3.1. In year 2021 EV energy demand was only 21.08 MWh in a day which later sought up to 1281.45 MWh in day in 2030.

Table 3.1: Comparison of year wise EV demand

year	calculated demand from all EV				projected demand of kolkata excluding EV (MWh)	Total demand of kolkata+EV (MWh)
	before scheduling(MWh)	after schedule(MWh)	accuracy %	error %		
2021	21.08182197	20.92773714	99.26911047	0.730889533	38195.39669	38216.32443
2022	81.06441007	80.42687862	99.21354951	0.786450492	39792.47565	39872.90253
2023	161.5255533	160.3103972	99.24770042	0.752299582	41389.55461	41549.865
2024	262.2781565	260.4100402	99.28773468	0.712265316	42986.63356	43247.0436
2025	383.1018273	380.5518603	99.33438923	0.665610772	44583.71252	44964.26438
2026	523.8122118	520.5488187	99.37699178	0.62300822	46180.79148	46701.3403
2027	684.1952563	678.5050603	99.1683374	0.831662601	47777.87044	48456.3755
2028	864.0532895	858.538639	99.36176963	0.638230375	49374.94939	50233.48803
2029	1063.208385	1058.063182	99.51606825	0.483931747	50972.02835	52030.09153
2030	1281.450951	1276.143342	99.58581259	0.414187408	52569.10731	53845.25065

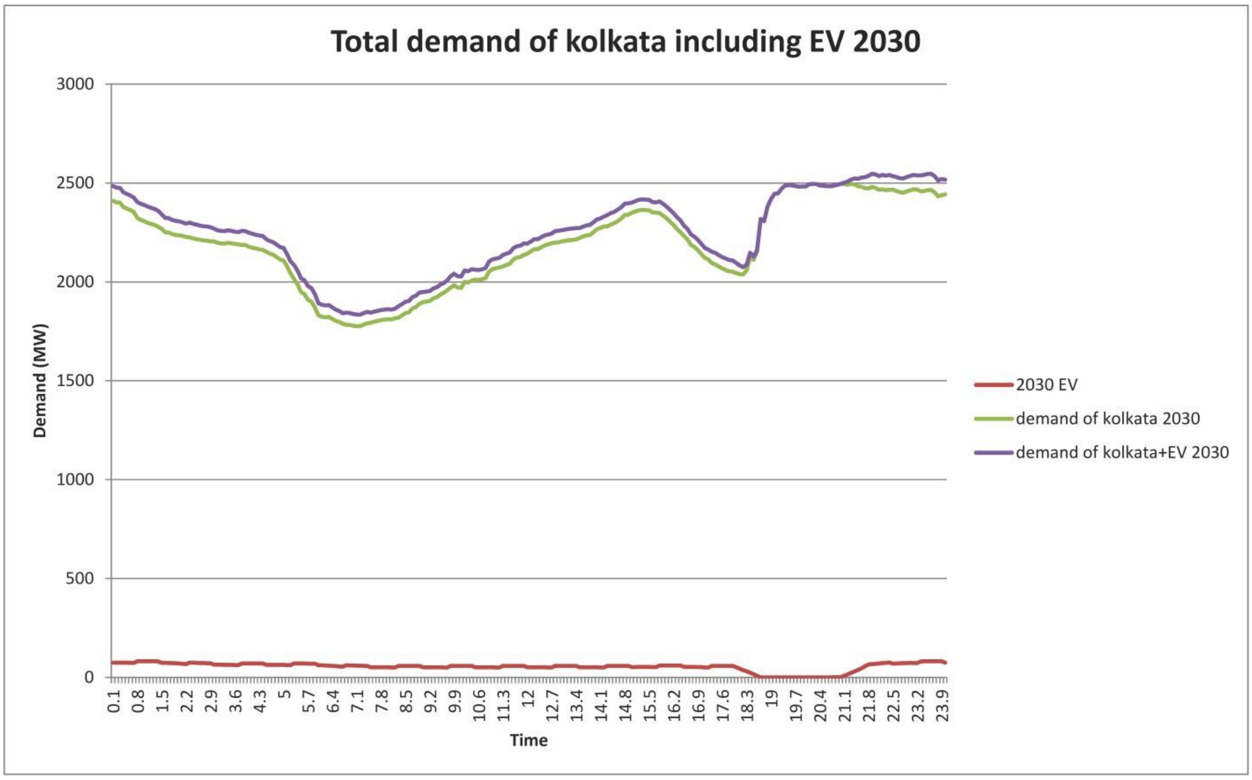

Figure 21: Total demand of Kolkata including EV in 2030

4. Discussion

This study solely describes the situation of intra-city urban traffic condition which in this case is Kolkata . Rural and long route traffic condition is ignored.

For the data of number of registered vehicle of Kolkata , Road transport year books are considered which in this case , has the data upto 2017.

All the data collected is given in annexures. So my conclusion will be based on that data.

Here we have considered EV conversion percentage equally incrementing every year for every type of vehicle which in real scenario might be very slow at the beginning years and exponentially later on. All the electrically converted vehicles are considered to be battery electric vehicle. Hybrid plug-in electric vehicle , hydrogen fuel electric vehicle is ignored.

All the considered vehicles for load scheduling are the current best options available on market. Specific energy consumption of e-bus is calculated based on current consumption which operates with very less passengers now , that consumption might be getting an increase as e-bus becomes mainstream later on which is not considered. However every year reduction in sp. energy consumption due to technological improvement & less T&D loss is considered, also increase in sp. energy consumption due to battery degradation is considered for every type of EV.

However , for charge scheduling we don't have any idea about upcoming EV driving cycles and charging infrastructural advancement in Kolkata. So, scenarios of quick charging or battery swapping are totally ignored for charging. E-bus charging considered for 21x7 on current charging infrastructure, 6 p.m. to 9 p.m. is no charging period because of very high gradient in load curve. Rest of vehicles type are considered for night time charging and day time charging if required. But the on clock timing of e2w, e3w & e4w charging schedule is considered based on general behavioral observation.

By looking on the options available for EV Charging, I think fast EV Charger is optimally viable but at very busiest route I would also recommend Pantograph Charging. So I would recommend fast EV Charging station with 1 to 2 Pantograph charging station at busiest route for Kolkata city, keeping its efficiency, cost and burden on budget in mind.

5. Conclusion

The exploration of electric bus charging methods within the context of Kolkata's 1.5 million population has culminated in a strategic recommendation tailored to the city's unique characteristics. The suggested combination of en-route and depot charging methods aligns with the challenges posed by high population density, traffic congestion, and the need for a reliable and sustainable mass transit system.

En-route charging addresses the immediate operational needs of electric buses, ensuring quick top-ups at key points without significantly disrupting daily routes. Meanwhile, depot charging provides a comprehensive solution, allowing buses to recharge during non-operational hours, thereby optimizing the utilization of charging infrastructure and minimizing the impact on the city's power grid.

The incorporation of smart charging technologies further enhances the adaptability and efficiency of the proposed charging methodology. By leveraging real-time data and optimizing charging schedules, the city can manage peak loads effectively, reduce energy wastage, and enhance the overall reliability of the electric bus fleet.

In conclusion, the recommended charging methodology not only addresses the technical aspects of electric bus charging but also considers the practicalities of implementation within the dynamic urban environment of Kolkata. As the city continues to evolve, embracing sustainable transportation practices is not just a necessity but a transformative step towards a greener, more efficient, and livable urban future for its 1.5 million residents.

6. Reference

[1] M. Faiyaz, D. Pranay, R. K. Gatla and S. Chatterjee, "A Study on Various Electric Vehicle Charging Technologies," 2023 International Conference on Sustainable Computing and Smart Systems (ICSCSS), Coimbatore, India, 2023, pp. 1210-1214, doi: 10.1109/ICSCSS57650.2023.10169328.

[2] Muhammad Shahid Mastoi, Shenxian Zhuang, Hafiz Mudassir Munir, Malik Haris, Mannan Hassan, Muhammad Usman, Syed Sabir Hussain Bukhari, Jong-Suk Ro, “An in-depth analysis of electric vehicle charging station infrastructure, policy implications, and future trends,” Energy Reports, Volume 8, 2022, Pages 11504-11529, ISSN 2352-4847, doi.org/10.1016/j.egyr.2022.09.011.

[3] OPI. (2014, March 18) “TOSA 2013 - Trolleybus optimisation system alimentation”. [Internet]. Available: http://www.tosa2013.com

[4] J. Chen, B. Atasoy, T. Robenek, M. Bierlaire and M. Themans, “Planning of feeding station installment for electric urban public mass-transportation system,” in 13th Swiss Transport Research Conference, Ascona, Switzerland, 2013.

[5] D. Sbordone, I. Bertini, B. Di Pietra, M.C. Falvo, A. Genovese, L. Martirano, “EV fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm,” Electric Power Systems Research, Volume 120, 2015, Pages 96-108, ISSN 0378-7796, doi.org/10.1016/j.epsr.2014.07.033.

[6] Chudy A.: Zarządzanie flotą pojazdów elektrycznych w sieciach inteligentnych – sterowanie ładowaniem oraz zagadnienia optymalizacyjne. Interdyscyplinarność w badaniach naukowych prace doktorantów Politechniki Lubelskiej. Wydawnictwo Politechniki Lubelskiej, Lublin 2020.

[7] Banerjee A., Murali V., Venkoparao V. G.: Measuring Performance Impact of Battery Swapping on Mobility Behavior. 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall), 2018, 1–5.

[8] Zeng B., Luo Y., Zhang C., Liu Y.: Assessing the Impact of an EV Battery Swapping Station on the Reliability of Distribution Systems. Applied Sciences 10(22), 2020, 8023 [http://doi.org/10.3390/app10228023].

[9] H.-Y. Mak, Y. Rong, and Z.-J. M. Shen, "Infrastructure planning for electric vehicles with battery swapping," Manage. Sci., vol. 59, no. 7, pp. 1557–1575, 2013.

[10] M. Yilmaz and P. T. Krein, "Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles," IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2151–2169, May 2013.

[11] Yanchong, Z.; Niu, S.; Shang, Y.; Shao, Z.; Jian, L. Integrating plug-in electric vehicles into power grids: A comprehensive review on power interaction mode, scheduling methodology and mathematical founda-tion. *Renew. Sustain. Energy Rev.* **2019**, *112*, 424–439.

[12] Saldaña, G.; San Martín, J.I.; Zamora, I.; Asensio, F.J.; Oñederra, O. Electric Vehicle into the Grid: Charging Methodologies Aimed at Providing Ancillary Services Considering Battery Degradation. *Energies* **2019**, *12*, 2443.

[13] Ahmad, A.; Khan, Z.A.; Alam, M.; Khateeb, S. A Review of the Electric Vehicle Charging Techniques, Standards, Progression and Evolution of EV Technologies in Germany. *Smart Sci.* **2017**, *6*, 36–53.

[14] Khalid, M.R.; Alam, M.S.; Sarwar, A.; Asghar, M.J. A Comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid. *eTransportation* **2019**, *1*, 100006.

[15] Habib, S.; Khan, M.M.; Huawei, J.; Hashmi, K.; Faiz, M.T.; Tang, H. A study of implemented international standards and infrastructural system for electric vehicles. In Proceedings of the 2018 IEEE International Conference on Industrial Technology (ICIT), Lyon, France, 20–22 February 2018; pp. 1783–1788.

[16] *SAE Standard J1772*; SAE Electric Vehicle and Plug-In Hybrid Electric Vehicle Conductive Charge Coupler. Society of Automotive Engineers (SAE): Warrendale, PA, USA, 2010.

[17] Kumar, R.R.; Alok, K. Adoption of electric vehicle: A literature review and prospects for sustainability. *J. Clean. Prod.* **2020**, *253*, 119911.

[18] Mou, X.; Zhang, Y.; Jiang, J.; Sun, H. Achieving Low Carbon Emission for Dynamically Charging Electric Vehicles Through Renewable Energy Integration. *IEEE Access* **2019**, *7*, 118876–118888.

[19] Chirag, P.; Stegen, S.; Lu, J. Review of static and dynamic wireless electric vehicle charging system. *Eng. Sci. Technol. Int. J.* **2018**, *21*, 922–937.

[20] Ahmad F., Saad Alam M., Saad Alsaidan I., Shariff S. M.: Battery swapping station for electric vehicles: oppor-tunities and challenges. IET Smart Grid 3(3), 2020, 280–286 [http://doi.org/10.1049/iet-stg.2019.0059].

[21] Adegbohun F., Jouanne A. von, Lee K.: Autonomous Battery Swapping System and Methodologies of Electric Vehicles. Energies 12(4), 2019, 667 [http://doi.org/10.3390/en12040667].

[22] https://nexonev.tatamotors.com/nexon-ev/

[23] Deepanjan Majumdar, Bijoy Kumar Majhi, Atanu Dutta, Ratan Mandal, and Tushar Jash. Study on possible economic and environmental impacts of electric vehicle infrastructure in public road transport in kolkata. *Clean Technologies and Environmental Policy, 17(4):1093 1101, 2015.*

[24] Kolkata population data. https://worldpopulationreview.com/world- cities/kolkata-population

[25] https://olaelectric.com/#

7. Annexure:

Table A1: Yearwise Kolkata non-transport vehicle count as per Road transport year books

Kolkata as on year	Non-Transport									
	two wheelers			Cars	Jeeps	Omni buses	Tractors	Trailers	other vehicles not covered	Total Non-Transport
	Scooter	mopeds	motor cycles							
31st march,2019	342119	not available	not available	353373	included in cars	included in cars	94	included in tractors	1401	696987
31st march,2018	342119	not available	not available	353373	included in cars	included in cars	94	included in tractors	1401	696987
31st march,2017	342119	not available	not available	353373	included in cars	included in cars	94	included in tractors	1401	696987
31st march,2016	313508			327388	0	0	94		1209	642199
31st march,2015	76718	10774	512664	541432	514	41144	4610	260	21981	1210097
31st march,2014	68566	10619	492114	514842	512	40497	4610	259	21870	1153889
31st march,2013	62137	10493	470722	489377	512	39689	4607	259	21789	1099585
31st march,2012	202602			222069	included in cars	not available	included in trailers	46	802	425519
31st march,2011	182087			194178	included in cars	not available	included in trailers	82	701	377048
31st march,2010	165799			180644	included in cars	not available	included in trailers	81	628	347152
31st march,2009	173891			313900	Included in cars			609	983	489383
31st march,2008	162753			302821	Included in cars			662	755	466991
31st march,2007	435413			383047	Included in cars			4854	21168	844482

Table A2: Yearwise Kolkata transport vehicle count as per Road transport year books

Kolkata as on year	Transport														
	Multi-Axled/ Articulated vehicles	Truck & Lorries	Light motor vehicles(goods)		Buses				Taxies			Light motor vehicles(passenger auto)		Motor cycles on hire	Total Transport
			Four Wheeler	Three Wheeler	Stage carriage	Contract carriage	Private service	other buses	Motor cab	Maxi cab	Other taxis	Three seaters	four to six seaters		
31st march,2019	not available	not available	12683	11190	2250	1688	563	1688	27315	13658	11381	13840	6920	30	103205
31st march,2018	not available	not available	12683	11190	2250	1688	563	1688	27315	13658	11381	13840	6920	30	103205
31st march,2017	not available	not available	12683	11190	2250	1688	563	1688	27315	13658	11381	13840	6920	30	103205
31st march,2016			22878		6020				49098			20684			98680
31st march,2015	3329	5891	58956	18781	13124	1272	15	4	60941	1611	12	27605	included in three seaters	0	191541
31st march,2014	3310	5736	57724	18781	12498	1036	12	2	57526	1316	10	27354	included in three seaters	0	185305
31st march,2013	3285	5062	56006	18780	12204	1034	12	1	54410	1046	9	26924	not available	0	178773
31st march,2012	15235	included in multi-axled	not available	not available	4316				31807			19429		0	70787
31st march,2011	13773	included in multi-axled	not available	not available	4249				30840			18808		0	67670
31st march,2010	14210	included in multi-axled	not available	not available	4009				27914			17740		0	63873
31st march,2009	35356	Included in Multiaxled	not available	not available	6938				32826			16745		0	91865
31st march,2008	48700	Included in Multiaxled	not available	not available	7310				33524			16258		0	105792
31st march,2007	72576	Included in Multiaxled	not available	not available	11118				40555			18083		0	142332

Table A3: Vehicle number prediction using historical data of road transport year books

Kolkata as on year(31st march)	Two wheeler (scooters,mopeds,motor cycles)	newly registered 2W	Buses(stage carriage,contract carriage,private service,other buses)	newly registered bus	Taxi(mot cabmaxi cab other taxies)	newly registerd taxi	Light motor vehicle(passenger auto)(3seater4-6seater)	newly registered light motor vehicle
2007	435413		11118		40555		18083	
2008	162753	-272660	7310	-3808	33524	-7031	16258	-1825
2009	173891	11138	6938	-372	32826	-698	16745	487
2010	165799	-8092	4009	-2929	27914	-4912	17740	995
2011	182087	16288	4249	240	30840	2926	18808	1068
2012	202602	20515	4316	67	31807	967	19429	621
2013	543352	340750	13251	8935	55465	23658	26924	7495
2014	571299	27947	13548	297	58852	3387	27354	430
2015	600156	28857	14415	867	62564	3712	27605	251
2016	313508	-286648	6020	-8395	49098	-13466	20684	-6921
2017	342119	28611	6189	169	52354	3256	20760	76
2018	382847.5432	40728.5432	7329	1140	55864.01005	3510.01005	26082.85574	5322.85574
2019	405960.2087	23112.6655	8469	1140	58545.07726	2681.06721	26901.91415	819.05841
2020	429072.8742	23112.6655	9609	1140	61226.14447	2681.06721	27720.97257	819.05842
2021	452185.5397	23112.6655	10749	1140	63907.21168	2681.06721	28540.03099	819.05842
2022	475298.2053	23112.6656	11889	1140	66588.27889	2681.06721	29359.08941	819.05842
2023	498410.8708	23112.6655	13029	1140	69269.3461	2681.06721	30178.14783	819.05842
2024	521523.5363	23112.6655	14169	1140	71950.41331	2681.06721	30997.20624	819.05841
2025	544636.2018	23112.6655	15309	1140	74631.48052	2681.06721	31816.26	819.05376
2026	567748.8673	23112.6655	16449	1140	77312.54773	2681.06721	32635.32308	819.06308
2027	590861.5328	23112.6655	17589	1140	79993.61495	2681.06722	33454.3815	819.05842
2028	613974.1983	23112.6655	18729	1140	82674.68216	2681.06721	34273.43991	819.05841
2029	637086.8638	23112.6655	19869	1140	85355.74937	2681.06721	35092.49833	819.05842
2030	660199.5293	23112.6655	21009	1140	88036.81658	2681.06721	35911.55675	819.05842

Table A4: Surveyed data of e-bus charging from charging station

Date	Vehicle no.	Charger no.	Before charging: Km reading	SOC%	Time	After charging: SOC%	Time	Electricity(kWh)	1% in kWh
11.02.22	7132	1B	23995	36	10:30	100	12:50	53.6	0.8375
11.02.22	7178	2	72411	35	11:58	97	13:10	52.11	0.8404839
11.02.22	7191	1A	74496	25	13:15	100	13:31	63.09	0.8412
11.02.22	7140	2	75781	16	13:26	98	14:49	68.61	0.8367073
11.02.22	6903	7	88550	25	13:30	100	15:35	63.91	0.8521333
11.02.22	7132	7	24047	27	16:50	98	18:01	59.35	0.8359155
11.02.22	7178	7	72460	31	23:43	98	01:20	56.73	0.8467164
11.02.22	6903	6	88618	26	23:44	100	01:34	62.84	0.8491892
11.02.22	7128	3	25657	55	23:43	100	02:30	39.51	0.878
11.02.22	7132	2	24077	67	23:51	100	01:21	29.26	0.8866667
11.02.22	7140	1A	75845	17	23:48	100	01:37	68.33	0.823253
11.02.22	7191	1B	74564	26	23:50	100	01:35	64.36	0.8697297
12.02.22	7128	1A	25707	51	10:00	98	11:35	41.08	0.8740426
12.02.22	7178	1A	72522	24	12:45	95	14:02	61.51	0.866338
12.02.22	7128	1A	25758	32	16:20	96	17:15	52.87	0.8260938
12.02.22	7128	1A	25789	67	19:42	98	20:23	26.94	0.8690323
12.02.22	7178	2	72581	20	23:00	98	00:53	65.52	0.84
12.02.22	7140	1A	75933	26	23:01	100	00:48	64.65	0.8736486
12.02.22	7128	6	25858	33	23:06	100	00:40	59.66	0.8904478
12.02.22	6903	2	88644	76	10:28	100	11:32	20.93	0.8720833
12.02.22	7132	7	24102	75	10:29	100	11:33	21.89	0.8756
12.02.22	7191	3	74589	80	10:30	100	11:34	17.35	0.8675
12.02.22	7140	1A	75996	26	11:40	100	13:35	60.43	0.8166216
12.02.22	6903	7	88706	42	23:00	100	00:31	48.98	0.8444828
12.02.22	7178	5	72773	29	23:01	98	00:46	58.3	0.8449275
12.02.22	7128	3	25988	30	23:02	100	00:49	60.31	0.8615714
12.02.22	7191	1A	74651	48	23:03	100	00:12	45.11	0.8675
12.02.22	7140	1B	76060	23	23:04	100	00:20	63.34	0.8225974
12.02.22	7132	2	24137	63	23:05	100	00:16	32.5	0.8783784
13.02.22	7178	1A	72630	49	09:45	100	10:43	43.46	0.8521569
13.02.22	7140	1A	75996	26	11:40	100	13:35	60.43	0.8166216
13.02.22	6903	2	88644	76	10:28	100	11:32	20.93	0.8720833
13.02.22	7132	7	24102	75	10:29	100	11:32	21.89	0.8756
13.02.22	7191	3	74589	80	10:30	100	11:34	17.35	0.8675
13.02.22	6903	7	88706	42	23:00	100	00:31	48.98	0.8444828
13.02.22	7178	5	72773	29	23:01	98	00:46	58.3	0.8449275
13.02.22	7128	3	25988	30	23:02	100	00:49	60.31	0.8615714
13.02.22	7191	1A	74651	48	23:03	100	00:12	45.11	0.8675
13.02.22	7140	1B	76060	23	23:04	100	00:20	63.34	0.8225974
13.02.22	7132	2	24137	63	23:05	100	00:16	32.05	0.8662162
14.02.22	7178	1A	72822	33	10:10	96	12:28	51.72	0.8209524

Continuation of *Table A4:*

14.02.22	7132	2	24189	40	11:56	98	12:53	48.17	0.8305172
14.02.22	7191	1A	74720	34	12:32	100	13:53	64.5	0.9772727
14.02.22	7140	2	76124	15	13:00	98	14:18	69.47	0.836988
14.02.22	6903	7	88775	17	13:20	100	14:49	70.04	0.8438554
14.02.22	7128	1A	26066	47	14:19	100	14:35	43.04	0.8120755
14.02.22	6903	7	88844	20	23:00	100	00:45	68.85	0.860625
14.02.22	7191	6	74789	23	23:01	100	00:50	65.3	0.8480519
14.02.22	7128	5	26167	27	23:02	100	00:52	60.12	0.8235616
14.02.22	7140	3	76188	14	23:03	100	00:55	71.68	0.8334884
14.02.22	7132	2	24242	32	23:04	100	00:59	59.02	0.8679412
14.02.22	7178	1B	72871	24	23:05	100	00:47	62.69	0.8248684
15.02.22	7178	1A	72920	34	11:36	95	12:29	49.98	0.8193443
15.02.22	7140	2	76237	39	12:18	98	13:13	48.59	0.8235593
15.02.22	6903	1A	88913	19	12:52	88	13:49	56.73	0.8221739
15.02.22	7191	2	74858	24	13:24	100	14:39	63.97	0.8417105
15.02.22	7128	1B	26277	28	15:23	96	16:02	56.24	0.8270588
15.02.22	7128	1B	26345	27	23:00	100	01:40	62.58	0.8572603
15.02.22	7178	1A	72969	32	23:01	100	01:40	55.77	0.8201471
15.02.22	7140	2	76286	33	23:02	100	01:43	60.31	0.9001493
15.02.22	7191	3	74926	25	23:03	100	01:36	65.92	0.8789333
15.02.22	6903	6	88999	29	23:04	100	01:38	63.45	0.893662
15.02.22	7132	7	24343	30	23:05	100	01:36	63.19	0.9027143
16.02.22	7132	1A	24395	30	11:39	100	12:49	58.34	0.8334286
16.02.22	7178	7	73018	29	12.21	95	13:26	55.5	0.8409091
16.02.22	7191	1A	74993	24	13:24	100	14:36	63.38	0.8339474
16.02.22	7128	1B	26455	54	16.58	98	17.53	37.54	0.8531818
16.02.22	7140	7	76379	27	23:00	100	00:41	61.01	0.8357534
16.02.22	7191	5	75059	25	23:00	100	01:00	63.96	0.8528
16.02.22	6903	3	89151	23	23:00	100	01:01	65.79	0.8544156
16.02.22	7178	2	73067	32	23:00	100	00:09	65.6	0.9647059
16.02.22	7132	1A	24447	30	23:05	100	00:10	58.64	0.8377143
16.02.22	7128	1B	26523	22	23:15	79	00:20	48.85	0.8570175
								Average=	0.8537903

Table A5: Surveyed data of conventional government and private buses

Bus org. type	Bus route	Bus type	no. of trips in a day / vehicle	Km traveled / trip/vehicle	Seat capacity (avg. passenger count)	Total energy consumption / trip (In kWh)(1lit diesel=10 kWh	Sp.energy (KWh/kilometer) / trip	Sp.energy (kWh/kilometer * passenger) / trip	Time of operation
Govt.	Howrah to Patuli	(AC24)(JAN AC)(Ashok Leyland)-ALFBV 8/1	3	34	40	190	5.588235294	0.139705882	
Govt.	Howrah to Newtown	(S-12)(JAN NON-AC)(Ashok Leyland)-ALFBV8/2	3	60	40	283.3	4.721666667	0.118041667	
Govt.	Howrah to Sapurji	(AC-12)(JAN AC)(Ashok Leyland)-ALFBV 8/1	3	54	40	300	5.555555556	0.138888889	
Govt.	Howrah to Baranagar	(S-57)(JAN NON-AC)(Ashok Leyland)-ALFBV8/2	2	30	40	150	5	0.125	
Govt.	Howrah to Barrackpur	(E-32)(NON-AC)(TATA)-1512TC	2	54	50	210	3.888888889	0.077777778	
Govt.	Howrah to Garia	(AC-5)- Volvo 8400	3	40	40	306.6	7.665	0.191625	
Govt.	Howrah to Amtala	AC-52 (JAN AC)(Ashok Leyland)-ALFBV 8/1	2	60	40	335	5.583333333	0.139583333	
Govt.	Howrah to Ballygaung	(S10-A)(JAN NON-AC)(Ashok Leyland)-ALFBV8/2	3	24	40	113	4.708333333	0.117708333	
Govt.	Howrah to Sarsuna	(7A) (Eicher) -10.90L	3	32	34	53.3	1.665625	0.048988971	
Govt.	Howrah to Joka	S-12D (JAN NON-AC)(Ashok Leyland)-ALFBV8/2	3	40	40	200	5	0.125	5:30 AM to 8:00 PM
Govt.	Howrah to Jadavpur	(E-1)(Tata 1512TC/1613 marcopolo)	3	26	40	103.3	3.973076923	0.099326923	5:30 AM to 8:30 PM
Govt.	Howrah to Jadavpur	(AC-1) (Volvo 8400)	4	24	40	246.6	10.275	0.256875	6:00 AM to 8:30 PM
Pvt.	Dakshineswar to Esplanade	43 (Local Blue bus)	4-5	32	40	95	2.96875	0.07421875	6 AM to 9 PM
Pvt.	Dakshineswar to Sapurji	Dn2/1 (Local blue bus)	3-4	56	40	110	1.964285714	0.049107143	6:30 AM to 8:30 AM
Pvt.	Santoshpur to BBD Bag	mini bus	3-4	38	27	90	2.368421053	0.087719298	
Pvt.	Esplanade to Airport	46 (Local blue Bus)	4	30	40	75	2.5	0.0625	
Pvt.	Esplanade to Batanagar via Birlapur	77A (Local Blue Bus)	3	64	40	300	4.6875	0.1171875	5 AM to 8 PM
Pvt.	Sapurji to Bangur	KB16 (Local Blue Bus)	3	50	40	55	1.1	0.0275	6 AM to 8 PM

Continuation of *Table A5:*

Pvt.	Alampur to Sapurji	SSBTC(deep blue bus)	2.5	128	40	180	1.40625	0.03515625	6.30 AM to 7 PM
Pvt.	Mondirtola to Newtown	white bus	2	46	40	170	3.695652174	0.092391304	
Pvt.	Sapurji to Babughat	239 (Local Blue bus)	3	56	40	110	1.964285714	0.049107143	5:30 AM to 7 PM
Pvt.	Sapurji to Kolkata stn.	K22 (Local blue bus)	3	50	40	90	1.8	0.045	
Pvt.	Dhulagor to Newtown	white bus	3	100	40	170	1.7	0.0425	4 AM to 9 PM
Pvt.	Newtown to Garia stn.	AS-3 (white bus)	5-6	45	40	80	1.777777778	0.044444444	6 AM to 10 PM
Pvt.	Dsk lane to Newtown	42 (white bus)	3	66	40	150	2.272727273	0.056818182	6 AM to 11 PM
Pvt.	Dhulagor to Newtown	white bus	3	98	40	200	2.040816327	0.051020408	5 AM to 7 PM
Pvt.	Dhulagor to sealdah	white bus	4	35	40	125	3.571428571	0.089285714	5 AM to 7 PM
Pvt.	Howrah to golfgreen	mini bus	3	36	27	80	2.222222222	0.082304527	7:30 AM to 8:45 PM
Pvt.	Howrah to Picnic garden	128 (mini bus)	4-5	30	27	70	2.333333333	0.086419753	7:15 AM to 9:10 PM
Pvt.	Howrah to Nagerbazar	mini bus	3-4	22	27	60	2.727272727	0.101010101	6:30 AM to 8:30 PM
Pvt.	Howrah to tangra	mini bus	4-6	20	27	60	3	0.111111111	6:30 AM to 7:30 PM
		Non-AC government bus average=					**4.041542913**		
		Non-AC pvt. bus average=					**2.426353836**		
		AC government bus average=					**6.933424837**		

Table A6: : Year wise daily demand calculation of e-bus

year	e-bus						
	Avg. daily travelled kilometer	Sp.energy(kwh/km)	Sp.energy(kwh/pkm)	Battery degradation	Newly added vehicle	Newly added demand(kwh)	Daily Total demand(kwh)
2021	160	0.997661407	0.032182626	1%	114	18197.34406	18197.34406
2022	160	0.987684793	0.0318608	2%	228	36030.74123	72421.78988
2023	160	0.977807945	0.031542192	3%	342	53505.65073	144297.714
2024	160	0.968029865	0.03122677	4%	456	70627.45897	233648.6197
2025	160	0.958349567	0.030914502	5%	570	87401.48047	340299.775
2026	160	0.948766071	0.030605357	6%	684	103832.9588	464078.1951
2027	160	0.93927841	0.030299304	7%	798	119927.0674	604812.6247
2028	160	0.929885626	0.029996311	8%	912	135688.9106	762333.521
2029	160	0.92058677	0.029696347	9%	1026	151123.5241	936473.0367
2030	160	0.911380902	0.029399384		1140	166235.8765	1127065.002

Table A7: yearwise required number of charging stations and units

year	Daily total demand(kwh)	Daily output from a single charging station(kwh)	Required charging station	demand due to decimal charging station(kwh)	chargers plug
2021	18197.34406	8704	2.09068751	789.344057	2 chrg stn. + 1 slow
2022	72421.78988	8704	8.32051814	2789.78988	8 chrg stn. + 3 slow
2023	144297.714	8704	16.5783219	5033.71403	16 chrg stn. + 2 fast, 3 slow
2024	233648.6197	8704	26.8438212	7344.61974	26 chrg stn. + 2 fast,5 slow
2025	340299.775	8704	39.0969411	843.775027	39 chrg stn. + 1 slow
2026	464078.1951	8704	53.3178073	2766.19506	53 chrg stn.+ 3 slow
2027	604812.6247	8704	69.4867446	4236.62466	69 chrg stn. + 2 fast,2 slow
2028	762333.521	8704	87.584274	5085.52104	87 chrg stn.+ 5 slow
2029	936473.0367	8704	107.591112	5145.03668	107 chrg stn.+ 5 slow
2030	1127065.002	8704	129.488167	4249.00233	129 chrg stn.+2 fast,2 slow