# A novel Charging Capacity Model (CCM) for electric vehicle charging

by

Shafquat Yasar Aurko (170021106)
Riyad Salehdin (170021109)
Faiaz Allahma Rafi (170021135)

**Bachelor of Science**
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Department of Electrical and Electronic Engineering
Islamic University of Technology (IUT)
Board Bazar, Gazipur-1704, Bangladesh.
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# CERTIFICATE OF APPROVAL

The thesis titled,"**A novel Charging Capacity Model (CCM) for electric vehicle charging**" accepted as partial fulfillment of the requirement for the Degree of BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING of Islamic University of Technology (IUT).

Approved by:


**Dr. Khondokar Habibul Kabir**
(Supervisor)
Professor,
Electrical and Electronic Engineering Department,
Islamic University of Technology (IUT), Gazipur.


This thesis needs to be re-submit.

# Declaration of Candidate

It is hereby declared that this thesis report is only submitted to The Electrical and Electronic Engineering Department. Any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

Shafquat Yasar Aurko

**Shafquat Yasar Aurko**
Student ID: 170021106
Date: 17-05-22

Riyad Salehdin

**Riyad Salehdin**
Student ID: 170021109
Date: 17-05-22

Faiaz Allahma Rafi

**Faiaz Allahma Rafi**
Student ID: 170021135
Date: 17-05-22

*Dedicated to our country*

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| | |
|---|---|
| **EV** | Electric Vehicle |
| **CCM** | Charging Capacity Model |
| **EB** | Easy Bikes |
| **PEV** | Plug-in Electric Vehicles |
| **PHEV** | Plug-in Hybrid Electric Vehicles |
| **PSO** | Particle Swarm Optimization |
| **DSO** | Distribution System Operator |
| **CT** | Charging Time |
| **ICE** | Internal Combustion Engine |
| **GHG** | Green House Gas |
| **SOC** | State of Charge |
| **V2G** | Vehicle to Grid |
| **G2V** | Grid to Vehicle |
| **IoT** | Internet of Things |
| **PV** | Photo-Voltaic |
| **SLM** | Smart Local Moving |
| **BSS** | Battery Swapping Station |
| **DCFC** | DC Fast Charging |
| **BRTA** | Bangladesh Road and Transportation Association |

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# Abstract

On the cusp of the fourth industrial revolution, the worldwide adoption of electric cars (EVs) is likely to cause grid overload. owing to uncoordinated charging of a high number of EVs. As this figure continue to rise, this problem will continue to grow worse. This difficulty is likely to be mitigated by coordinated charging of electric vehicles. Using a modified Particle Swarm Optimization (PSO) method, this research brings forward the Charging Capacity Model (CCM), which limits the number of EVs that may be charged at different times of the day. The CCM is also implemented using IoT, data analytics, communication, and networking. The proposed concept was tested in Bangladesh using an electric vehicle called the Easy-Bike, a popular three-wheeler EV in the nation.

# Chapter 1

## Introduction

The introduction of Electric Vehicles (EVs) as a replacement for ICE (Internal Combustion Engine) vehicles is one of the most prominent examples of modern society as this implementation of EVs will help reduce the usage of fossil fuels. They accomplish this by emitting no exhaust and leaving no carbon footprint. Electric vehicles are rapidly expanding in some of the industry's major vehicle markets. However, the rapid adoption of electric vehicles comes at a price: it necessitates a well-developed power generating and distribution system and a large and sophisticated charging infrastructure. Unfortunately, many countries lack the necessary charging infrastructure and power grid to handle significant numbers of EVs being charged simultaneously. Human civilization has come a long way due to the continuous advancement of technology and science. One of the major factors responsible for the progress of civilization is the advancement of the transportation sector. Fossil fuel-driven vehicles are still in the majority all over the world. However, continuous consumption of fossil fuels is the cause of various problematic scenarios, such as the extinction of fossil fuels, lowering of air quality index, global warming, etc. Though these vehicles have some pros, such as fossil fuels are more comfortable to store, it is easier to refill these vehicles, fossil fuels are cheaper, etc. but the list of cons is heavier, especially because of the impact these vehicles put on the environment. One of the prime reasons for global warming is greenhouse gas. These vehicles have a major contribution in the emission of greenhouse gases, causing air pollution and degradation of the ozone layer. For these reasons, it is time to replace fossil-fuel-driven vehicles. EVs are the answer to this problem. EVs (Electric Vehicles) are the future of the transportation sector. They are gradually replacing the traditional vehicles as they don't emit GHG (Green House Gas). They also have lower running costs and cause less noise etc [2]. The fact that these vehicles don't emit greenhouse gases is of utmost importance. Concerns are rising all over the world about the air quality index and the consequences of GHG. Many countries have set strict rules on emission-free zones and are encouraging lesser usage of fossil fuels. So, these points can be taken care of by using Electric cars, trucks, buses, etc, or in general EVs (Electric Vehicles) as they are beneficial for health, beneficial for energy security, has zero exhaust emissions. [3]. However, some issues are rising and should be taken care of when it comes to the concept of EVs in developing countries. Integration of EVs anywhere in the world causes voltage unbalance, current harmonics, overloading, etc on the power grid. The problems can become severe for the developing countries as most of these countries don't have the optimum charging infrastructure nor do they have the effective management of IoT devices, data samples, and proper incentives regarding EVs. This paper focuses on the grid overloading in developing countries as they lack the proper charging infrastructure to handle the simultaneous charging of the huge number of EVs along with the suitable real-time management system for the charging system. Grid overloading due to unplanned charging can lead to blackouts or load-shedding, hindering the development of the society along with wasting valuable time and energy for the citizens of that locality. A coordinated charging scheme that doesn't require any real-time scheduling, making the scheme more practically implementable, should be introduced in these countries, creating a solid platform for a huge number of EV integration.

## 1.1 Problem Statement

The rapid growth of EVs around the world implies EV integration is one of the main answers to sustainable development since it provides an alternative to ICE-based vehicles, which generate exhaust gases, harm the environment, and contribute to the greenhouse effect. Moreover, it can be said that the transportation industry is evolving and the concern for the load demand due to this is something that should be addressed. For the case of a developing country such as Bangladesh, where the power system is in the process of growing stronger, the integration of EVs will impose a threat on that the basis that uncoordinated charging leads to power outages and blackouts. In a developing country like Bangladesh, where the electricity sector is strengthening, the integration of EVs poses a hazard due to uncoordinated charging, which might result in power shortages and blackouts. Power shortages are one of the key problems in Bangladesh as in this country, sometimes the generation of electricity is not adequate to reach the consumer demand. EV integration necessitates a robust infrastructure to support EV charging operations. The robustness indicates that the grid has the capacity of handling the increased load demand due to the EVs charging simultaneously at random times. The adaptation of real-time scheduling of EVs [4]is somewhat not practical in a third-world country like Bangladesh as there is no sufficient infrastructure to facilitate this process. In this circumstance, involving the user in determining the charge priority can cause havoc. In Bangladesh, charging stations are currently more commonly available for easy bikes and electric three-wheelers. It is more frequent to see them in rural places. However, the problem is complicated by the prohibition of tom-toms and easy cycles in urban areas as the government has banned the usage of easy bikes on the highways of the country. [5]. Due to the currently existing improper infrastructure of the country, the government is not able to earn money from easy bikes and tom-toms for which the government is losing a massive opportunity for earning revenue. Collaboration among governmental bodies focusing on EVs is still lacking, which is a major impediment. The power sector is also suffering due to a lack of income opportunities from these sources related to the shortage of a defined framework for statistical data analysis and a sufficient number of charging stations for electric vehicles. Our proposed charging capacity model will be beneficial for the government, DSO, easy-bike owners and the common people in the following way:

The EV charging percentage pattern found from the survey is given below:

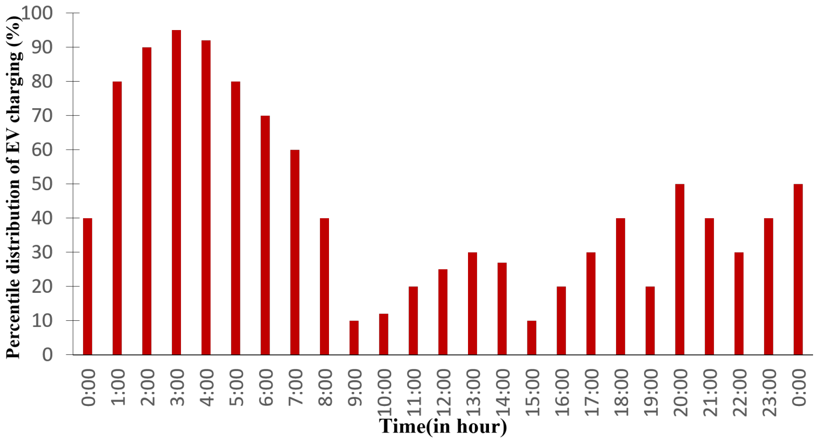


**Figure 1.1:** Percentile distribution of Easy-bike charging patterns in Bangladesh.

In Bangladesh, the majority of battery-powered electric vehicles are easy bikes, autorickshaws, and tom-toms. The drivers charge their vehicles at night, indicating that this is when the peak hour for electric vehicle charging occurs. The figure below indicates the average load curve of eleven months for the year 2021. The figure elucidates that the peak hour for the load curve arises during the nighttime, as a result, there is a high possibility of a power outage if major loads are added to the demand side during that time. For fully charging the batteries, 6-8 hours are required for auto-rickshaws and 3-5 hours are needed for easy bikes. [6].

### 1.1.1 Research Gap

The use of solar energy-based panels for charging electric vehicles has been discussed in [7]. According to the current status, there are roughly 14 EV charging stations deployed in the country that use solar energy. A real-time charging schedule for electric vehicles with a system comprising of PV is discussed in [8]. There are two types of EV charging stations currently deployed in Bangladesh- Public and Private. Currently, there is no centralized process to maintain the charging procedure of EVs nor a constructive decentralized way to process the necessary data to take the parameters related to the arrival time of EVs, the priorities of the drivers in case of charging, etc. Bangladesh's EV charging infrastructure is still in its beginnings as a third-world country. A charging schedule with an SLM algorithm was analyzed with the input parameters such as SOC of batteries, the PEV owner's priority, load variations etc in [9]. However, for a developing country, the input parameters such as prioritizing the electric vehicle charging pattern according to the load variation and EV owner's priority is somewhat impractical due to the unavailability of a proper database and the lacking of a real-time scheduling framework. There has been no research on establishing a coordinated charging system for EVs for underdeveloped countries like Bangladesh, which does not require real-time scheduling but rather limits the charging station's total load so that it does not exceed the generation capacity. In addition, no research has been conducted on what to do with the rejected EVs in the optimal charging scheme. This study establishes a charging schedule to address these concerns.

### 1.1.2 Problem Identification

For large-scale integration of EVs in Bangladesh, the problem that needs to be addressed is that the total load surpassing the generation capacity at peak hours leading to blackouts. Among other types of EVs, easy bikes are responsible for the transporta-

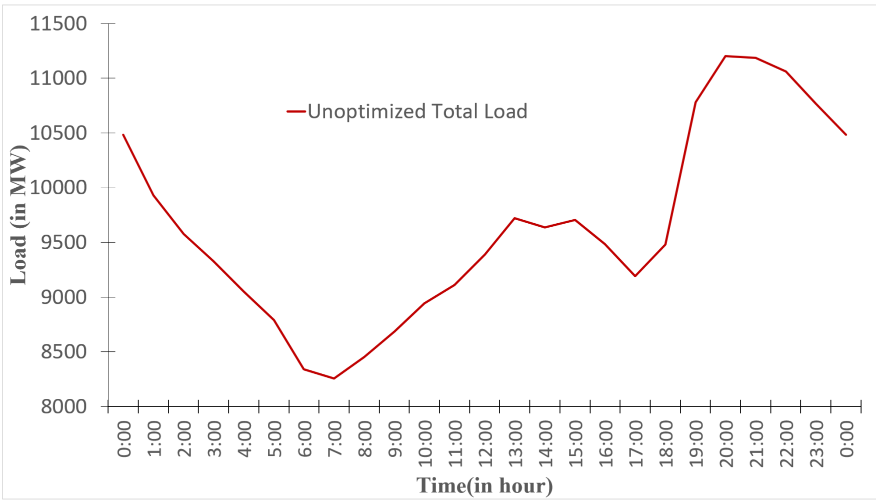


**Figure 1.2:** Total load curve

tion of nearly 250 million people in Bangladesh. [10] So, easy bikes make a great impact on the power sector compared to other types of EVs. During the peak hour owing to the non-coordinated charging of the EVs, there is a greater chance of loadshedding as Bangladesh is a developing country where there is a scarcity of generation of electricity. This problem should be addressed and solved. With a coordinated charging model, the peak load can be shaved and valleys can be filled.

### 1.1.3 Research Motivation

The following factors work as a motivation for the research:

1) The widespread use of EVs will aid in the reduction of global warming through the decreased use of fossil fuels, paving the way for more sustainable living.

2) Reducing the illegal activities regarding the current easy bikes, and tom-toms; putting them under government policies so that the government can generate revenues through them by using the proposed CCM as well as legalizing the whole concept of EVs in Bangladesh. All of these will lead to the total transformation of the transport sector from ICE-based vehicles to electric vehicles.

3) Implementing such a charging scheme so that peak loads can be shaved and valleys can be filled, which will help the operation of DSO.

4) Collaborating the easy bike owners with the government by the implementation of the proposed CCM so that both parties can be benefitted.

5) Availing the opportunity for integrating modern versions of electric cars with proper infrastructure in Bangladesh so that the common people have a pollution-free means of transportation.

### 1.1.4 Scope of the research

With a coordinated charging scheme, there will be a huge potential for implementing heavy electric vehicles such as electric cars, electric buses, trucks, etc in any developing country. The usage of IoT devices and data analytics leaves scope for future data prediction so that the EV load demand is adjusted according to the generation capacity. The concept of V2G (Vehicle to grid) technology has not been used in this research but can find a way to work as an alternative for providing electrical energy during the peak hours in the proposed CCM.

## 1.2 Research Objectives

This paper proposes a Charging Capacity Model (CCM) that considers the entire number of EVs in a country and optimizes the load curve using a modified Particle Swarm Optimization (PSO) algorithm. This algorithm ensures peak reduction and valley increase of the total load curve fortifying the fact that the load demand does not surpass the supplied power from the DSO. In the proposed CCM, at first, the EV load curve is optimized using the modified PSO and an adequate number of EVs to establish the optimization is generated. Using that number, the CCM restraints the load demand from overcoming the supplied power. The number of EVs found from the charging model is defined as the highest number of EVs that can be charged at the same time time instant all over the test zone. This number is calculated throughout the whole day, taking an hour as an interval. Then, the required number of charging stations is estimated that should be deployed all over the test zone to meet the load demand. This model then sets the charging capacity per charging station for every time instant. In the first phase of the proposed CCM, the following are to be found:

- The charging capacity throughout the test zone at each hourly interval
- The number of charging stations needed
- The EV limit allowed at each charging station.

There are two main objectives of this paper-

- To acquire the charging capacities for each time interval throughout 24 hours.
- To acquire the optimized charging station number and utilize it to obtain the number of EVs that can get charged per charging station on an hourly basis.

## 1.3 Research Outcome

The expected outcomes from the research are hereby:

- Finding out the amount of EVs that can be charged at an hourly interval with the condition of not surpassing the generation capacity of the grid by means of reducing peaks and raising valleys.
- Finding out the number of charging stations that can accommodate these EV loads efficiently and with that number, limiting the number of EVs chargeable per hour at each charging station.

Fig. 1.3 shows the whole system envisioned by the CCM.

## 1.4 Novelty of the research

The proposed CCM will ensure that no real-time scheduling is needed so that the coordinated charging is more implementable in third-world countries where the analysis of various parameters such as arrival time of EVs, the priorities of the owners of EVs

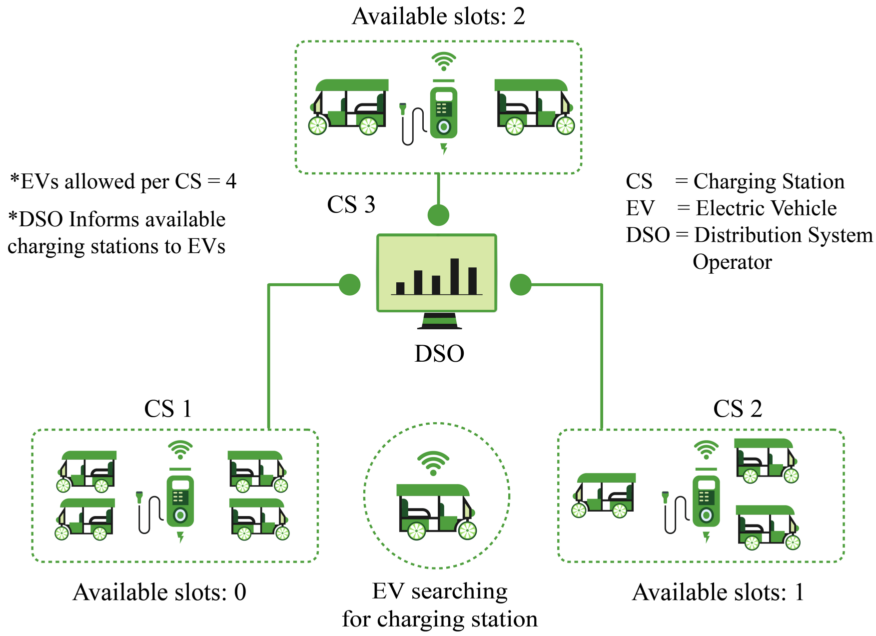


**Figure 1.3:** The system envisioned by the CCM.

in terms of charging their vehicles, the departure time, the state of charge (SOC), etc is hectic and impracticable due to the unavailability of the proper database. The coordinated charging model will be based on modified particle swarm optimization (PSO) which will avail the opportunity to shave off the peak loads and place them on the valley hours but also considering the factor influencing the rush in peak hours and keeping an adequate number of vehicles charging during that period. There hasn't been enough research on developing a charging schedule for EVs that will limit the number of vehicles based on the load demand in developing countries.

# Chapter 2

# Background Study

## 2.1 Current Scenario Worldwide

Though the era of electric vehicles has begun, the usage of these vehicles varies from country to country, depending on the financial and economic standard, availability of resources, availability of proper charging infrastructure and government incentives, customer participation, etc. There are basically two types of EVs- PEVs and PHEVs. The vehicles that run only on battery fall under the category of the first type and the vehicles that use both battery and ICE (Internal Combustion Engine) indicate the latter type. After a decade of tremendous popularity, there were 10 million EVs all over the planet by the closing of 2020 [11]. The manufacturers are becoming extremely ambitious when it comes to the topic of electric vehicles as it has no tailpipe emission which in turn supports decarbonization (lessening the GHG emission due to human activities). In 2020, consumer purchases on electric vehicles reached USD 120 billion [11]. Over the past few years, the government expenditure on the sector of incentives related to electric vehicles has dropped, which indicates that the customers are becoming more interested and are being more appealed towards these vehicles. Considering the positive environmental effect that EVs have, governments are starting to speed up their efforts on marketizing these vehicles, which indicates the active participation in inhibiting climate change. With the goal of sustainable development, it is assumed that the number of EVs (excluding two-three wheelers) will be around 230 million by 2030. [11] Developed countries such as China, Japan, South Korea, France, Norway, etc, continue to lead the way in the usage of these vehicles [12]. Despite the pandemic and its consequences, the year 2020 was promising in terms of electric cars as the sales increased by 43% [13].

## 2.2 Advantages of EVs

Recently the EVs are coming to the mainstream of transportation. They are replacing the ICEs rapidly as days go by. As the EVs are run by induction motors rather than any traditional car engines, there is no space for carbon emission. Moreover the sound and vibration is much less than the ICEs. So the EVs are silent and smooth which gives the riders a pleasant experience. The future of driving is based on clean energy, owing to technological improvements that are enabling the development of even more environmentally friendly batteries, hydrogen advances, and ever more efficient and silent EV motors. Aside from the environmental effect, fuel, tax, and maintenance expenditures can be reduced.

The three basic components that power completely electric vehicles are the on-board charger, inverter, and motor, all of which are designed to be as efficient as possible. Because there will be fewer moving parts to hurt, the car will survive considerably longer and the motor will be less strained. All of this suggests that maintenance and operating costs will be low.

Instant torque will become commonplace all EVs, ensuring the power at fingertips. The car responds quickly and accelerates when the pedal is touched, making these vehicles ideal for city driving. EV batteries are usually found in the car's floor, allowing for optimal weight distribution and balance. As a consequence, turning bends and curves is straightforward and safe.

## 2.3 Disadvantages of EVs

Electric vehicles mainly consist of an induction motor and batteries. The batteries charge up and are used to run the motor. The battery capacity varies with different types of electric vehicles. The 3-wheeler easy bikes, which are the most common type of EVs in Bangladesh, are pulled by an electric motor with a capacity of 650-1400 watts driven by lead acid batteries [14]. There are almost a million of these vehicles deployed which leads to a consumption of 450MW [26, 27, 47]. Though it's 3.6% of the total consumption still with the popularity of the electric vehicles this rate will increase. As the EV penetration increases the chances of overload during peak hours increases which will result in load shedding and sometimes blackout. Blackouts are caused by sudden change of generation or demand. Sudden large amounts of EV penetration may result in blackout. In countries like Bangladesh, EV charging from unregistered distribution lines can also result in transformer failure. Loadshedding will be an everyday problem if the generation is less than the demand which the large amount of EV penetration can create at the peak hours. For a developing country like

Bangladesh, both blackout and load shedding is detrimental for the economy.

## 2.4 EV Charging scenario worldwide

In 2020, the global EV fleet was 8.5M and it is expected to become 116M by 2030 [15]. In the United States, the electric car proportion of new vehicle sales was over 2.4 percent in 2020, up from roughly 2 percent in 2019 [16]. With the increase of demand, the charging infrastructure is also increasing and becoming more efficient. In January 2019 it was reported that among 808,000 EV chargers in China, close to 330,000 were public and 480,000 were residential [17]. Superchargers have become popular now-a-days. There are more than 30,000+ superchargers and over 4,500 destinations charging Tesla motors globally [18].

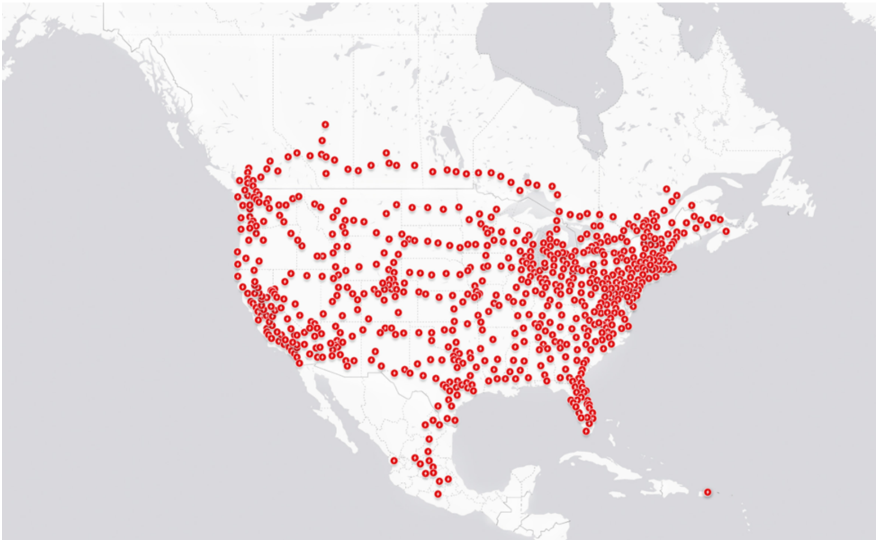

**Figure 2.1:** EV charging stations located all over the US.

There are three different types of charging mechanisms: battery exchange, conductive charging, and wireless charging. The battery swap technique involves paying the BSS owner a monthly payment for the battery. [19]. For 3-wheeler EVs in Bangladesh, this manner of charging is greatly preferred. The BSS's slow charging mechanism extends battery life as well.

Pantograph and overnight depot charging are the two types of conductive charging. Both AC and DC power supply can be used for conductive charging. Depending on our country's power grid, AC charging has various voltage and frequency levels. AC charging mechanisms are classified into three levels: level 1, level 2, and level 3. Slow-charging levels 1 and 2 are used, whereas fast-charging levels 3 are used. Generally, level 1 and level 2 charging stations may be located in private settings, however level 3 charging needs separate wiring and transformers, as well as clearance from utility companies. DC charging is usually quite quick. The new DCFC technology can fully

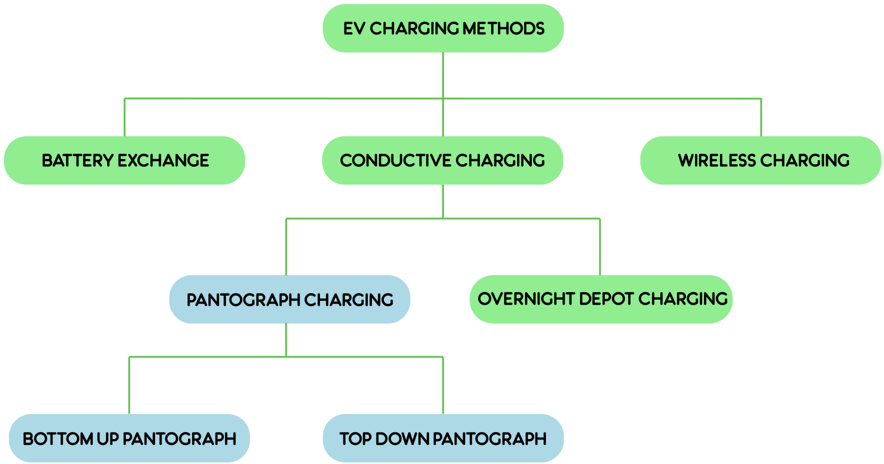


**Figure 2.2:** Various types of EV charging methods [1]

charge an EV in less than 20 minutes approximately [20]. The wireless charging system typically uses WPT technology to charge the battery. Electromagnetic induction is the basis for this technique. The primary coil is installed on the road, while the secondary coil is installed inside the electric car. The WPT system may function at any voltage level (Levels 1, 2, and 3), with a power rating of up to 20 KW and a 90 percent efficiency. [21] [22].

The terms G2V (Grid to Vehicle) and V2G (Vehicle to Grid) refer to both unidirectional and bidirectional power flow (Vehicle to Grid). A bidirectional grid-connected AC-DC converter and a bidirectional DC-DC converter comprise the bidirectional EV charger. [20]. This type of charger can charge or discharge, allowing EVs to perform different grid auxiliary services. However, repeated cycling of discharging electricity back to the grid might shorten the life of an electric vehicle's battery. In addition, the procedure is complicated by metering and grid stability difficulties, which entail selling and purchasing power from utilities [23].

# Chapter 3

## Literature Review

At present, EVs are seeing a rapid increase in deployment all over Bangladesh. There are three broad classes of EVs that are relevant for Bangladesh. The first is the PHEVs, four-wheelers that have seen a 900 % increase in the registered. This can be attributed to its lower operational costs, as for the same amount of fuel, a conventional combustion engine vehicle will run at 7 to 8 km per litre while PHEVs can run to 15 to 16 km. Four wheeler full EVs are very low in numbers, with less than 10 such registered vehicles in the country [24].

Before describing the model, it is necessary to have brief overview of the EV charging infrastructures. Charging an EV requires a number interlinked infrastructures. A charging station with several charging outlets is required. The charging station will use grid electricity to charge the EVs, but can also utilize renewable energy sources. The charging station can be of three basic types, depending on the charging rates. These are Level-1 (120 V), Level-2(240 V) and Level-3(480 V) charging stations. The vast majority of charging stations are of Level-2 [25]. In this paper, it is assumed that the charging rate is that of a Level-2 charging station, as in Bangladesh, almost all EV charging stations for Easy-bikes use household connection.

Easy-bikes (EB) are the most common electric vehicles in Bangladesh, with 1 million now on the road [26, 27]. Their popularity has grown despite little government marketing due to their utility as a low-cost ride-sharing vehicle. Easy-bikes now provide primary mobility for over 250 million people, according to [28]. In comparison to other forms of EVs, their extensive use demonstrates that their grid effects are many times bigger.

While Easy-bikes are widely used, due to legal loopholes, far too many do not have permits or fitness certificates. According to the Ministry of Road Transport and Bridges' [29], easy-bikes are not even considered vehicles. As a result, the BRTA does not provide them with registrations, meaning that these Easy-bikes are exempt from government oversight, resulting in poor design and usage by inexperienced drivers. These are the primary reasons why Easy-bikes have a bad image in Bangladesh for being more accident-prone than ICE-driven auto-rickshaws. As a result, the government may enforce bans from time to time [30].

Only 14 standardized EV charging stations are currently operational in Bangladesh. The overall capacity of these is 278 kW [31]. The charging of the country's 1 million Easy-Bikes, on the other hand, consumes 450 MW every day [28]. The majority of these are charged utilizing residential connections [32] or charging stations [33]. With the problems growing, Bangladeshi officials are finally beginning to take efforts to legalize and regulate Easy-bikes. The BEPRC has begun work on Easy-bikes [34] guidelines. Easy-bike drivers will also be issued licenses to bring them into compliance with rule [35]. The proposed CCM is ideally suited for application and adoption in Bangladesh in this situation.

Non-coordinated charging of electric vehicles has a number of detrimental consequences, including overloading, increased harmonics and worse power quality, increased voltage imbalance, and so on, as outlined in several studies [36]. However, power overloading is certainly the most serious issue, with immediate consequences. The majority of studies on this topic include load shifting using heuristic algorithms and user data and preferences [37,38]. Many of these studies employ machine learning and deep learning algorithms to forecast charging patterns [39–41]. Many more heuristic algorithms use Demand Side Management [42]. Other studies employ approaches like bisection and on/off control to create real-time EV schedules [43]. Controlling and scheduling EVs directly, on the other hand, is difficult to accomplish in nations with large populations and a large number of EVs, especially since many of them take away the EV users' freedom in scheduling, making it a fairly automated procedure.

The planned CCM merely establishes charging capacity restrictions at various times throughout the day. In contrast to the previous works, this model is significantly easier and less expensive to execute since it does not require real-time scheduling or the processing of data from EV users charging. Controlling the charging capacity of charging stations is more practical than controlling the behavior of EV customers. As a result, it is significantly more practicable.

PSO was employed to optimize the EV load curve. This is due to its specific benefits over other optimization algorithms, which include simplicity of operation, fewer variables to work with, faster convergence time, and the ability to improve the global optimum [44]. Similar optimization issues for EVs, such as [44–46], are commonly solved by PSO. The PSO method has been tweaked in this model to optimize the EV load.

The next section describes the proposed CCM model in detail.

# Chapter 4

# Methodology

## 4.1 Basic Workflow

The process of work for the entire thesis is as follows: at first the mathematical model is established. This is done without using any software tools. The theoretical are then used to generate the CCM operational model. This requires the use of a software where an optimization algorithm can be applied. For this, MATLAB is selected as being the most user friendly.

## 4.2 Math Model Formulation

The math model has been formulated based on defining the problem first. The key problem which has to be solved is that charging EVs consume power, and the electric grid can supply only a certain amount of power at any time. So at rush hours, when the peak power consumption is already very high, the introduction of large numbers of EV charging may just cause the demand to exceed the limit, causing grid overload and loadshedding. From that line of thought, the total power consumption has to be formulated, and the power consumption due to EV charging has to be found separately.

## 4.3 MATLAB

MATLAB is used for the optimizing the EV load curve. Matlab works well with optimization algorithms, and plenty of examples have been noted where particle swarm optimization has been carried out in MATLAB. The particle swarm optimization which is used in this thesis is also modified in Matlab. The optimized EV load curve is generated in Matlab.

# Chapter 5

# Charging Capacity Model

## 5.1 Generating the Electric Vehicle load curve

The foremost step of the procedure is the acquisition of the EV load curve. This can be done by either acquiring the load curve data directly if it is available, or by calculating the load curve data using the usage data available from the charging stations. Here, the second method was used.

The average power utilized by an individual EV is first computed [43]. This is shown in Eqn. (5.1),

$$P_{EV_i} = (1 - SOC_i)\frac{E_{max_i}}{CT_i}, \tag{5.1}$$

where $i$ is the identity of the EVs ($i = 1, 2, 3, \ldots, N$), $SOC_i$ is the state of charge , $E_{max_i}$ is the maximum energy that can be stored in the battery of $EV_i$ (depends on the type of EV), and $CT_i$ is the Charging time of $EV_i$. $P_{EV_i}$, the power consumed, is the same for all EVs of a specific value of battery capacity $E_{max_i}$. As the $SOC_i$ for an $EV_i$ decreases, the time $CT_i$ needed for it to charge increases, and vice versa.

The total EV load at a given time $t$ is then calculated. At first, using surveys from different private charging stations, the time, hours, and the number of EVs being charged throughout the day is acquired, which is then used to compute the percentage charging pattern. This percentage of the EVs, $d\%$, being charged at time $t$, is then multiplied by the total number of EVs in Bangladesh, $N$. This is then multiplied by $P_{EV_i}$ to find the total EV load $P_d$ at a given time $t$ as shown in Eqn. (5.2).

$$\begin{aligned} P_d &= P_{EV_i} \times N \times d\% \\ &= (1 - SOC_i)\frac{E_{max_i}}{CT_i} \times N \times d\% \end{aligned} \tag{5.2}$$

## 5.2 Generating the Non Electric Vehicle load curve

The second step is to obtain the Non-Electric vehicle load curve. If the data is specifically available it can be used, but if it is not, it can be calculated separately. First the total load $P_{tot}$ curve is acquired from the data which is widely available in most cases. The EV load is subtracted from this to get the Non-Electric vehicle load $P_n$ curve. This is shown in Eqn. (5.3).

$$P_n = P_{tot} - P_d \tag{5.3}$$

## 5.3 Problem Formulation

In preparation for the optimization of EV load curve, the load limit of the EV loads, $P_{limit}$ is obtained. It is used to denote the maximum value that the total EV load at any time can rise to. In other words, it denotes the upper limit of the EV load values. This is found by subtracting the maximum Non-EV load from the maximum power generation capacity of the power grid $P_s$. This ensures that the value of the EV load never becomes higher than the value of the generation capacity of the EV load at any time, so that no overloading occurs. This is shown in Eqn. (5.4).

$$P_{limit} = P_s - max(P_n) \tag{5.4}$$

Eqn. (5.5) shows the determining function, which represents the power difference of the $P_d$ from the load limit $P_{limit}$. for the objective function ,

$$\begin{aligned} F &= P_{limit} - P_d \\ &= P_{limit} - \sum_{i=1}^{N}((1 - SOC_i)\frac{Emax_i}{CT_i}). \end{aligned} \tag{5.5}$$

There are two objective functions in this optimization, for each of the two principal conditions. Eqn. 5.6 represents the objective function when the Non-EV load is low, also called valley hour. Eqn. 5.7 represents e objective function when the Non-EV load is high, also called the peak hour.

Objective function when Non-EV load is low (valley hour):

$$
\begin{aligned}
& \text{minimize } F && (5.6) \\
\text{subject to} & \\
& P_n < \text{mean}(P_n), \\
& P_d < P_s, \\
& 0 < SOC_i < 1, \\
& P_d > 0.
\end{aligned}
$$

Objective function for the peak hour:

$$
\begin{aligned}
& \text{maximize } F && (5.7) \\
\text{subject to} & \\
& P_n < \text{mean}(P_n), \\
& P_d < P_s, \\
& 0 < SOC_i < 1, \\
& P_d > 0.
\end{aligned}
$$

The above pair of objective functions achieve peak reduction and valley raising of the EV load curve. The constraint $(0 < SOC_i < 1)$ sets the normal limits of the state of charge of an EV. But given the fact that, this is not a control variable, this is not part of the optimization function. Constraint $(P_d > 0)$ denotes that $(P_d)_{opt}$ is never zero.

The problem formulated with the objective function and constraints is then optimized using the modified PSO to obtain the optimized EV load curve, $(P_d)_{opt}$.

## 5.4 Particle Swarm Optimization

The optimization of the EV load curve can be thought of as the principal operation in the entirety of the thesis. It optimizes the EV load curve to the desired characteristics needed for fulfilling the objectives of lowering the peaks and raising the valleys. This optimization is carried out using the modified Particle Swarm Optimization (PSO) algorithm.

The PSO algorithm uses the swarming of particles (or values) by the classification of the particle positions as the best value and worst value. Here, the particles positions are updated in accordance the velocity of the equation.

Here, the algorithm is modified in order to operate in a way that fulfils the objectives of the model. This modification involves some special conditions which are

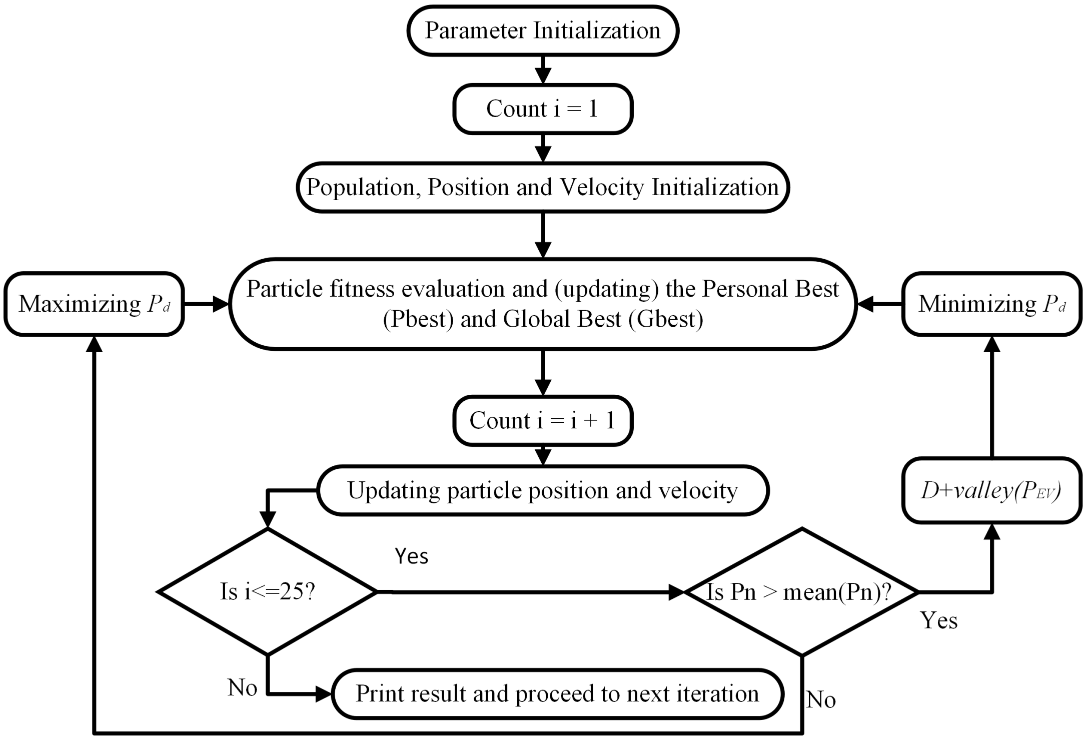


**Figure 5.1:** The Flowchart of the modified PSO algorithm.

introduced in the part where the positions of the particles are updated. This condition entails the position of the particles, that is the new values of the EV load, will be set by keeping the corresponding Non-EV load in consideration. This means for any time $t$, if the value of the Non-EV load is under the value of the mean value of the Non-EV load pattern in the dataset, the EV load $P_d$ is set to the maximizing condition in accordance with the objective function. The value of $P_d$ is minimized if Non-EV load is higher than the mean Non-EV load pattern. Here the condition of the EV load pattern is also taken into consideration. At the Non-EV peak hour, if the EV load is higher than the mean EV load, then the EV load is lowered at that point. The value by which the position is reduced, $D$, is then equally distributed among all the EV load values in the pattern that are below the mean EV load at all times $t$, meaning the valley hours of the EV load curve, $valley(P_{EV})$. From this modified PSO algorithm, the optimized EV load curve is obtained from the unoptimized pattern. This is given by $(P_d)_{opt}$.

## 5.5 Charging Capacity Limit

The final step to the CCM is the acquisition of the charging capacity limit. This means that the number of EVs needed to be charged at a given time at each charging station has to be found. This is the application point of the CCM model and this is how the the peak shaving and valley filling will occur. This is because these limits would be set in accordance with the optimized EV load curve which has been optimized to have peak reduction and valley raising.

After the optimized EV load curve values, $(P_d)_{opt}$, are obtained, the total number of EVs that are allowed to be charged throughout the test zone at different time intervals is calculated. Denoted by $N_{opt}$, these values are calculated by dividing the $(P_d)_{opt}$ at those time intervals by the value of $P_{EV_i}$, shown by Eqn. (5.8).

$$N_{opt} = \frac{(P_d)_{opt}}{P_{EV_i}} \tag{5.8}$$

The next variable to be determined from here is the number of charging stations required throughout the whole test zone. The number of full capacity charging stations, $C$, is calculated for each value of $N_{opt}$. It is acquired by dividing it by the number of EVs that a standard charging station can support. This given by $n$.

$$C = \frac{N_{opt}}{n} \tag{5.9}$$

Using the values of $C$, the maximum number of charging stations, $C_{max}$ is determined. It is considered to be the number of charging stations that should be constructed in the test zone so that it can accommodate the maximum number of EVs that need to be charged.

The optimized number of EVs that can be allowed all over the test zone, $N_{opt}$, is then divided by the maximum number of charging stations, $C_{max}$, to find the number of vehicles that can be charged at each charging station at each hour. This is then denoted by $N_c$.

$$N_c = \frac{N_{opt}}{C_{max}} \tag{5.10}$$

The DSO can observe the number of EVs that are being charged at all times in the charging station. They can ensure that the limits of $N_c$ are being obeyed.

## 5.6 Mathematical model with respect to Easy-bikes in Bangladesh

As mentioned before, Easy-Bikes are the most widely available EV type in Bangladesh. Thus, for the application of the CCM model for the present scenario of Bangladesh, a model with Easy-Bikes has to be considered.

For the present scenario of Bangladesh, there are four primary stakeholders who would be benefited from the application of a coordinated charging scheme on Easy-Bikes. These are the government, the DSO, the Easy-bike owners and the common people. The application of the proposed CCM to the East-Bike charging system will fully bring the Easy-Bike charging infrastructure under government regulation. Peak shaving and valley filling favor the DSO by making their operations easier. The Easy-bike (EB) owners can cut their losses by coming under government regulation and therefore avoid crackdowns and fines. Meanwhile the ordinary people would be the biggest beneficiaries as they would have continued access to an easily affordable means of commutation. Table 5.1 summarizes the ways in which the proposed model is expected to maximize the profits and minimize the losses for all the stakeholders involved.

**Table 5.1:** Advantages of the CCM for Bangladesh

| Stakeholders | Description |
|---|---|
| Government | They can generate revenue through legitimization, can regulate the Easy-bikes through the CCM and can curb illegal activities surrounding these EVs. |
| DSO | The model can reduce chances of overloading through peak-shaving and valley filling, making operations easier for the DSO. |
| Easy-bike owners | The adoption of the model is expected to help cooperation with the government and prevent financial losses. |
| Common people | They are expected to achieve the easy availability of low cost Easy-bikes while ensuring grid stability. |

The values of the different variables for the application of the CCM model in Bangladesh is summarized in Table 5.2.

**Table 5.2:** Summary of values of Mathematical variables for Bangladesh.

| Qualities | Notation | Value |
|---|---|---|
| Total number of Easy-bikes (present estimate) | $N$ | 1 million [26, 27] |
| Power Consumed individual Easy-bikes | $P_{EV_i}$ | 0.0004 MW [47] |
| Generation Capacity | $P_s$ | 21,000 MW [48] |
| Maximum Non-EV load | $max(P_n)$ | 12,500 MW |
| Load limit of EV loads | $P_{limit}$ | 8,500 MW |
| Maximum Number of EBs in a charging station | $n$ | 12 |

Given the fact that the $E_{max}$ value is approximately same for all EVs of the same type, the power consumed by each of the EVs, $P_{EV_i}$, is the same. For Easy-Bikes it is an average of 0.4 kW [47].

While no explicit data is available for the exact EV load pattern that is resulting from the uncontrolled charging of Easy-Bikes in Bangladesh, it can still be acquired through unofficial means, by conducting surveys with the EV charging station owner. This was done for this thesis as well. Based on survey from several Easy-Bike users and the employees in charge of several existing charging stations, the percentile distribution for the charging pattern of Easy-Bikes is generated. This percentage distribution, $d\%$ is shown in Fig. 1.1.

There are over 1 million Easy-Bikes present all over Bangladesh, the value of which is denoted by $N$, [26, 27]. The value of $P_d$ for Bangladesh for each time instant $t$ for 24 hours is then calculated using Eqn. 5.2. The total load curve for 24 hours for a typical day is generated by averaging the total load curve for the 15th of every month of the running year. These data are acquired from the official reports of the Power Grid Company of Bangladesh (PGCB) [49]. The Non-EV load curve is acquired by subtracting the EV load curve from the total load curve, shown in Fig. 5.2.

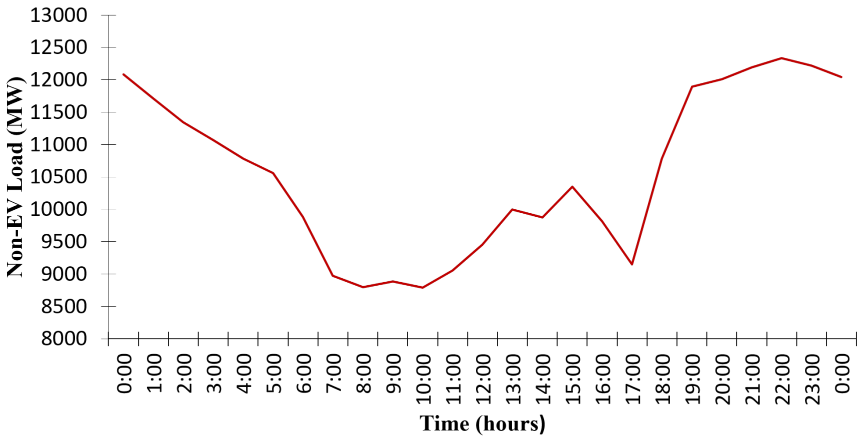


**Figure 5.2:** The Non-EV load curve

At present, the total generation capacity, $P_s$, of Bangladesh is at 21,000 MW [48], with the maximum Non-EV load, $max(P_n)$ being 12,500 MW in accordance with the load curve data used [49]. This puts the value of $P_{limit}$ to be 8,500 MW with respect to the present data. Typical Easy-bike charging stations can charge upto maximum of 12 Easy-bikes at a time, found through survey. So $n$ has a value of 12 in this case. This is the same for all charging stations in this model

With these parameters set, the optimization operation is carried out on the data of Bangladesh, and the results are shown in the following section.

# Chapter 6

# Result Analysis

## 6.1 Main Section 1

The CCM model has been applied for the data of Bangladesh as shown in the previous chapter. The results can be thought of as two sepearte types. First, the results of the charging power capacities are visualized, followed by charging station capacities.

## 6.2 Charging power capacity

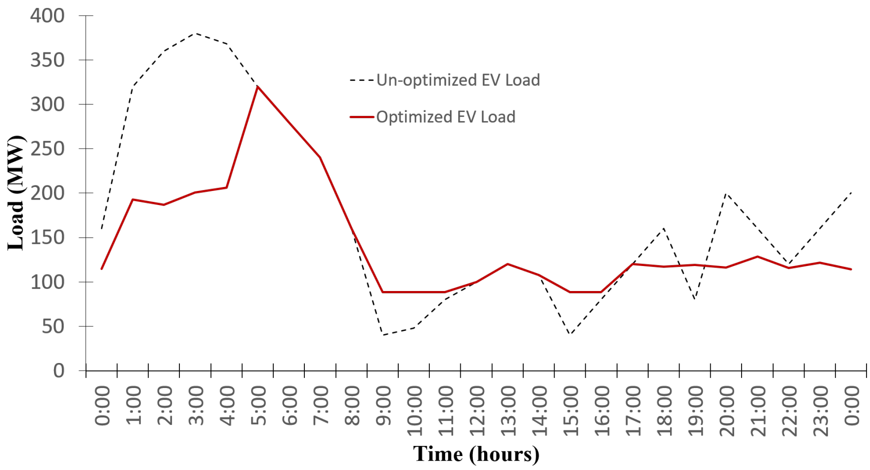


**Figure 6.1:** Comparison of un-optimized and optimized EV load curve

The $P_d$ load curve and $(P_d)_{opt}$ load curve is shown in Fig 6.1 . It can be observed that the peaks have been significantly reduced and the valleys have also increased. While one may question why the change is not very drastic, the most logical answer to that is that its simply not possible to massively change the peaks and valleys just to suit the needs of the power grid. This is because the EVs, although moving randomly are following an approximate pattern that does not usually change. For instance, the vast majority of EVs cannot be moved to charge at a time when most of them are likely to be active and travelling. The main target of this optimization is to lower the number of EVs trying to charge in the same time instance with the sole aim of preventing a power grid overload.The total load curves before and after optimization is shown in Fig. 6.2.


**Figure 6.2:** Comparison of un-optimized and optimized total load curve

As can be seen in Fig.6.2 , as consequence of the EV load being optimized, the optimized total load also had its peaks reduced and valleys raised. While the change appears miniscule at first glance, it should be noted that these results are obtained for the present number of active Easy-Bikes on record in Bangladesh. At the time when this thesis was prepared, the maximum EV load at any point is less than 450 MW. At the same time, maximum total load reaches upto 12,500 MW. When more sophisticated EV types with far greater values of $E_{max}$, such as Electric cars and buses, will be introduced in large numbers, the EV load values will see a sharp rise. It is without a doubt that in that scenario, the proposed model will have a significant effect on the load curve. Table 6.1 summarizes the results of the optimization algorithm for peak shaving and valley filling. It can be observed that the maximum value of the EV load curve is significantly lower, and the minimum value has also seen a significant increase.

**Table 6.1:** Peak shaving and valley filling.

| **Variables** | | **EV Load data** | | **Optimized EV load data** | |
|---|---|---|---|---|---|
| $N$ | 1 million [26, 27] | $min(P_d)$ | 40 MW | $min((P_d)_{opt})$ | 88.3MW |
| $P_{EV_i}$ | 0.0004 MW [47] | $max(P_d)$ | 380 MW | $max((P_d)_{opt})$ | 320MW |
| $P_s$ | 21,000 MW [48] | $mean((P_d))$ | 176.2MW | $mean((P_d)_{opt})$ | 145MW |
| $max(P_n)$ | 12,500 MW | | | | |

## 6.3 Charging station capacities

In the first step, the optimized EV load curve and the optimized total load curve is obtained. The next step consists of finding the total number of EVs permitted at each time instant $t$ throughout the country. This is then followed by obtaining the number of charging stations throughout the country. The charging stations will be under the control of the DSO, and will be capable of coordination with IoT devices.

Fig. 6.3 shows the highest number of EV allowed throughout the test zone in accordance with the optimized EV load curve. Fig. 6.4 shows the maximum number of EVs per charging station..

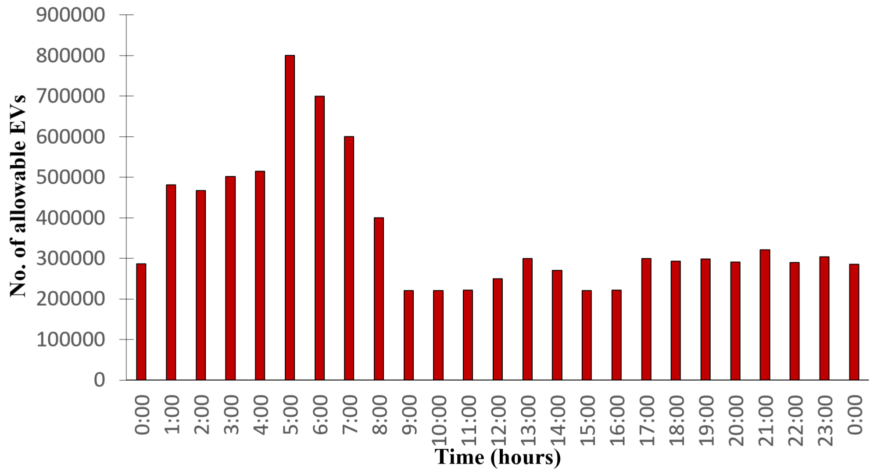


**Figure 6.3:** The Optimized Number of Easy-bikes all over the country.

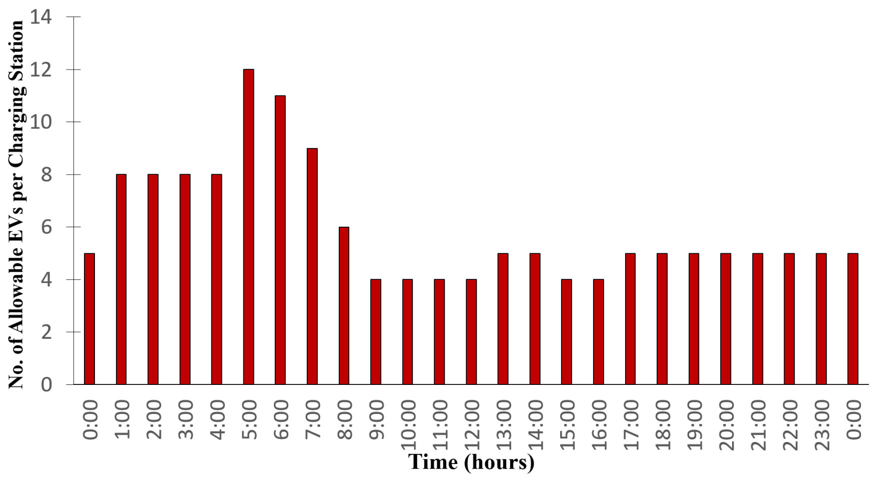


**Figure 6.4:** The Number of Easy-bikes allowed per charging station all over the country.

The results pertaining to the charging station data are summarized in Table 6.2. The number of standard charging stations required to be built for fulfilling the requirements of grid are displayed.

**Table 6.2:** Optimized charging station capacity of Bangladesh

| **Variables** | | | | | **Results** |
|---|---|---|---|---|---|
| $N$ | $P_{EV_i}$ | $P_s$ | $max(P_n)$ | $P$ | $C_{max}$ |
| 1million | 0.0004 MW | 21,000 MW | 12,500 MW | 8,500MW | 66,667 |

## 6.4 Discussion

The results of the thesis elucidates the success of the CCM in fulfilling the objectives of this research. The optimized EV load curve is obtained for EV load curve achieves peak shaving and valley filling, demonstrated by Fig. **??** and Table 6.1, which fulfilled the first objective. The number of charging stations and the number of EVs allowed per charging station per hour is also found, demonstrated by Fig. 6.4 and Table 6.2, fulfilling the second objective. The CCM can be implemented in the real world using IoT devices at the charging stations which would monitor the number of EVs being charged, and would ensure that the limits are being obeyed. Appropriate communication protocols can be used for the transfer of information to and from the DSO control center and the charging stations. The DSO can choose to make the information available online, so that EV drivers may look up which nearby charging stations have free slots and direct themselves to those in accordance.

# Chapter 7

## Conclusion

Countries all around the world have begun to adopt EVs, in some shape or form, in large numbers. EVs therefore, are very likely to replace the conventional fuel driven vehicles as the main mode of transportation in the near future. But with that, the problems of the overloading of the electric grid due to EVs charging is expected to increase by a large margin. The CCM model is designed to be suitable for areas where large number of EVs are expected to be charged. In this work, the CCM model has been implemented on the data for Easy-Bikes considering Bangladesh as a test case. The results of the model demonstrate successfully, that the model can carry out peak shaving and valley filling for the EV load curve. This results in the reduction of the peak of the total load curve and therby eliminates any chance of grid overloading. If this model is adopted as a national project by the Government of Bangladesh with sufficient investments from interested players in the private sector, it can greatly avert the looming threat to the power grid of Bangladesh which may not expand fast enough to accomadate large scale EV adoption without facing overloading issues. On other test cases around the globe it is expected to have a similar positive effect in stablizing the electric grid in the case of high EV penetration. It hinges on the fact that it is relatively easy to implement, offers privacy for EV owners and does not require extensive data management, which is a boon for many developing countries like Bangladesh.

However, while the CCM model can set the charging capacities for each charging station, this model has some limitations, notably in the implementation phase. This model does not yet have any mechanisms to deal with the accepting and rejecting of EVs from the charging station. When implementing the CCM on a practical level, such procedures are required to ensure the smooth operation of the system that the CCM will set up. There is room to expand and improve this model for a practical implementation.

# REFERENCES


[1] S. M. Arif, T. T. Lie, B. C. Seet, S. Ayyadi, and K. Jensen, “Review of electric vehicle technologies, charging methods, standards and optimization techniques,” *Electronics*, vol. 10, no. 16, p. 1910, aug 2021.

[2] “Benefits of electric cars,” edf, (accessed on 16/01/2022). [Online]. Available: https://www.edfenergy.com/electric-cars/benefits

[3] “Benefits of electric vehicles,” ergon, (accessed on 16/01/2022). [Online]. Available: https://www.ergon.com.au/network/smarter-energy/electric-vehicles/benefits-of-electric-vehicles

[4] Z. Wan, H. Li, H. He, and D. Prokhorov, “Model-free real-time EV charging scheduling based on deep reinforcement learning,” pp. 5246–5257, sep 2019.

[5] D. Tribune, “Top court: No battery-run three-wheelers on highways,” 2022. [Online]. Available: https://www.dhakatribune.com/court/2022/04/04/sc-no-battery-run-3-wheelers-on-highways

[6] M. R. Ahmed and A. K. Karmaker, “Challenges for electric vehicle adoption in bangladesh,” in *2019 International Conference on Electrical, Computer and Communication Engineering (ECCE)*. IEEE, feb 2019.

[7] N. Chowdhury, C. Hossain, M. Longo, and W. Yaïci, “Optimization of solar energy system for the electric vehicle at university campus in dhaka, bangladesh,” *Energies*, vol. 11, no. 9, p. 2433, sep 2018.

[8] W. Jiang and Y. Zhen, “A real-time EV charging scheduling for parking lots with PV system and energy store system,” *IEEE Access*, vol. 7, pp. 86 184–86 193, 2019.

[9] A. Masoum, S. Deilami, P. Moses, M. Masoum, and A. Abu-Siada, “Smart load management of plug-in electric vehicles in distribution and residential networks with charging stations for peak shaving and loss minimisation considering voltage regulation,” *IET Generation, Transmission and Distribution*, vol. 5, no. 8, p. 877, 2011.

[10] T. N. Nation, “1m ‘easy-bikes’ in country,” 2017. [Online]. Available: https://thedailynewnation.com/news/149439/1m-easybikes-in-country.html

[11] “Global ev outlook,” IEA, 2021, (accessd on 20/01/2022). [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2021

[12] Richard and Z. Yurnaidi, “Potential impacts of ev on developing countries’ electricity systems and how to mitigate them,” ACCEPT, Oct. 2020, (accessed on 20/01/2022). [Online]. Available: https://accept.aseanenergy.org/potential-impacts-of-ev-on-developing-countries-electricity-systems-and-how-to-mitigate-them/

[13] “The global electric vehicle market overview in 2022 - statistics and forecasts,” VIRTA, 2022, (accessed on 20/01/2022). [Online]. Available: https://www.virta.global/global-electric-vehicle-market

[14] M. J. Al-Hossain and M. Rahman, “Efficient charging system for electric three wheelers thesis 1406061 1406129,” 04 2019.

[15] “Projected size of the global electric vehicle fleet between 2021 and 2025,” Statista, (Accessed on 1 May, 2022). [Online]. Available: https://www.statista.com/statistics/970958/worldwide-number-of-electric-vehicles/

[16] “Evaluating electric vehicle market growth in u.s. cities,” The International Conference on Clean Transportation, Sep. 2021, (Accessed on May 2, 2022). [Online]. Available: https://theicct.org/publication/evaluating-electric-vehicle-market-growth-across-u-s-cities/

[17] A. Hove and D. Sandalow, “Electric vehicle charging in china and the united states,” Columbia - SIPA, Feb. 2019, (Accessed on May 2, 2022). [Online]. Available: https://www.energypolicy.columbia.edu/

[18] “Tesla,” (Accessed on May 3, 2022). [Online]. Available: https://www.tesla.com/

[19] A. Ahmad, Z. A. Khan, M. S. Alam, and S. Khateeb, “A review of the electric vehicle charging techniques, standards, progression and evolution of EV technologies in germany,” *Smart Science*, vol. 6, no. 1, pp. 36–53, dec 2017.

[20] H. Das, M. Rahman, S. Li, and C. Tan, “Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review,” *Renewable and Sustainable Energy Reviews*, vol. 120, p. 109618, mar 2020.

[21] J. A. Sanguesa, V. Torres-Sanz, P. Garrido, F. J. Martinez, and J. M. Marquez-Barja, “A review on electric vehicles: Technologies and challenges,” *Smart Cities*, vol. 4, no. 1, pp. 372–404, mar 2021.

[22] Y. Cao, N. Ahmad, O. Kaiwartya, G. Putrus, and M. Khalid, *Intelligent Transportation Systems Enabled ICT Framework for Electric Vehicle Charging in Smart City*. Germany: Springer, 2018, pp. 311–354.

[23] M. C. Kisacikoglu, M. Kesler, and L. M. Tolbert, “Single-Phase On-Board Bidirectional PEV Charger for V2G Reactive Power Operation,” *IEEE TRANSACTIONS ON SMART GRID*, vol. 6, no. 2, pp. 767–775, Jan. 2015.

[24] “Is bangladesh ready for the adoption of electric vehicles?” LightCastle Partners, Last accessed 11 Oct 2021. [Online]. Available: https://www.lightcastlebd.com/insights/2021/06/the-current-shape-of-ev-and-hybrid-vehicle-ecosystem-in-bangladesh

[25] “Developing infrastructure to charge plug-in electric vehicles,” U.S. Department of Energy, Last accessed 10 Oct 2021. [Online]. Available: https://afdc.energy.gov/fuels/electricity-infrastructure.html

[26] M. R. Awal, M. M. Rahman, A. K. M. N. Islam, J. Al-Hossain, and M. Z. R. Khan, “Energy consumption analysis of electric three wheelers in bangladesh,” in *2019 IEEE International Conference on Power, Electrical, and Electronics and Industrial Applications (PEEIACON)*. Dhaka, Bangladesh: IEEE, 2019.

[27] “Plying of easy bikes on highways needs to be controlled: Tawfiq-e-elahi,” Last accessed 14 Oct 2021. [Online]. Available: https://www.tbsnews.net/bangladesh/transport/plying-easy-bikes-highways-needs-be-controlled-tawfiq-e-elahi-214963

[28] “1m ‘easy-bikes’ in country,” Last accessed 11 Oct 2021. [Online]. Available: https://thedailynewnation.com/news/149439/1m-easy-bikes-in-country.html

[29] *The Project on the Revision and Updating of the Strategic Transport Plan for Dhaka*. Dhaka Transport Coordination Authority (DTCA), 2015.

[30] “Rethinking ban on battery-run vehicles,” Last accessed 11 Oct 2021. [Online]. Available: https://thefinancialexpress.com.bd/views/rethinking-ban-on-battery-run-vehicles-1624640129

[31] “Bangladesh plans to attract ev manufacturers,” PV magazine, Last accessed 13 Oct 2021. [Online]. Available: https://www.pv-magazine.com/2020/12/04/bangladesh-plans-to-attract-ev-manufacturers/

[32] “Pdb for bringing battery-run vehicles under tariff regulations,” Last accessed 13 Oct 2021. [Online]. Available: https://www.dhakatribune.com/bangladesh/power-energy/2017/09/27/pdb-bringing-battery-run-vehicles-tariff-regulations

[33] "Easy bike: a blessing or a curse," Last accessed 13 Oct 2021. [Online]. Available: https://www.newagebd.net/article/58639/easy-bike-a-blessing-or-a-curse

[34] "BEPRC moves to formulate guideline for easy bikes," Last accessed 12 Oct 2021. [Online]. Available: https://www.thefinancialexpress.com.bd/national/beprc-moves-to-formulate-guideline-for-easy-bikes-1615472819

[35] "Quader: Easy bike, 3-wheelers to come under purview of registration," Last accessed 13 Oct 2021. [Online]. Available: https://www.dhakatribune.com/bangladesh/2021/02/18/quader-easy-bike-3-wheelers-to-come-under-purview-of-registration

[36] Y. Wang, H. Su, W. Wang, and Y. Zhu, "The impact of electric vehicle charging on grid reliability," *IOP Conference Series: Earth and Environmental Science*, vol. 199, p. 052033, 2018.

[37] M. Usman, W. U. K. Tareen, A. Amin, H. Ali, I. Bari, M. Sajid, M. Seyedmahmoudian, A. Stojcevski, A. Mahmood, and S. Mekhilef, "A coordinated charging scheduling of electric vehicles considering optimal charging time for network power loss minimization," *Energies*, vol. 14, no. 17, p. 5336, 2021.

[38] A. Masoum, S. Deilami, P. Moses, M. Masoum, and A. Abu-Siada, "Smart load management of plug-in electric vehicles in distribution and residential networks with charging stations for peak shaving and loss minimisation considering voltage regulation," *IET Generation, Transmission and Distribution*, vol. 5, no. 8, p. 877, 2011.

[39] S. Shahriar, A. R. Al-Ali, A. H. Osman, S. Dhou, and M. Nijim, "Machine learning approaches for EV charging behavior: A review," *IEEE Access*, vol. 8, pp. 168 980–168 993, 2020.

[40] M. Straka, P. D. Falco, G. Ferruzzi, D. Proto, G. V. D. Poel, S. Khormali, and L. Buzna, "Predicting popularity of electric vehicle charging infrastructure in urban context," *IEEE Access*, vol. 8, pp. 11 315–11 327, 2020.

[41] J. Zhu, Z. Yang, M. Mourshed, Y. Guo, Y. Zhou, Y. Chang, Y. Wei, and S. Feng, "Electric vehicle charging load forecasting: A comparative study of deep learning approaches," *Energies*, vol. 12, no. 14, p. 2692, 2019.

[42] K. Clement, E. Haesen, and J. Driesen, "Coordinated charging of multiple plug-in hybrid electric vehicles in residential distribution grids," in *2009 IEEE/PES Power Systems Conference and Exposition*. Seattle, WA, USA: IEEE, 2009.

[43] V.-L. Nguyen, T. Tran-Quoc, S. Bacha, and B. Nguyen, “Charging strategies to minimize the peak load for an electric vehicle fleet,” in *IECON 2014 - 40th Annual Conference of the IEEE Industrial Electronics Society*. Dallas, TX, USA: IEEE, 2014.

[44] J. Yang, L. He, and S. Fu, “An improved PSO-based charging strategy of electric vehicles in electrical distribution grid,” *Applied Energy*, vol. 128, pp. 82–92, 2014.

[45] A. Awasthi, K. Venkitusamy, S. Padmanaban, R. Selvamuthukumaran, F. Blaabjerg, and A. K. Singh, “Optimal planning of electric vehicle charging station at the distribution system using hybrid optimization algorithm,” *Energy*, vol. 133, pp. 70–78, 2017.

[46] M. Z. Zeb, K. Imran, A. Khattak, A. K. Janjua, A. Pal, M. Nadeem, J. Zhang, and S. Khan, “Optimal placement of electric vehicle charging stations in the active distribution network,” *IEEE Access*, vol. 8, pp. 68 124–68 134, 2020.

[47] M. R. Md. Zulkefa Rian. A. N. M., “Study on power consumption and social aspects of battery operated auto-rickshaw,” in *International Conference on Mechanical, Industrial and Energy Engineering 2014*. Khulna, Bangladesh: KUET, 2014.

[48] “Power generation in bangladesh: Important facts to look at,” Last accessed 9 Oct 2021. [Online]. Available: https://www.thedailystar.net/opinion/news/power-generation-bangladesh-important-facts-look-2052261

[49] “Daily Operational Report,” Power Grid Company of Bangladesh Limited., Last accessed 15 Oct 2021. [Online]. Available: http://pgcb.gov.bd/site/page/0dd38e19-7c70-4582-95ba-078fccb609a8/-

# List of Publications

## Conference

1. **S. Y. Aurko**, **R. Salehdin**, **F. A. Rafi K. Habibul Kabir** , "Designing of a Charging Capacity Model (CCM) for Electric Vehicles and Easy-Bikes", in International Conference on 4th Industrial Revolution and Beyond (IC4IR) 2021 (IC4IR 2021), 10-11 December, Dhaka, Bangladesh, 2021.