Impact of Plug-in Electric Vehicles on Power Distribution System of Major Cities of India: A Case Study

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ABBREVIATIONS

AC	Alternating Current
BES	Battery Energy Storages
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
DC	Direct Current
DN	Distribution Networks
DT	Distribution Transformer
EPDS	Electric power distribution system
EV	Electric vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
kW	Kilowatt
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
SLDC	State Load Dispatch Centre

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Executive Summary

In India, presently, most of the motorised vehicles used for the transportation purpose are fuelled by petrol, diesel, and natural gas. These vehicles are considered to be the major source of air pollution because of high carbon emission by them. Further, the petroleum products, which are being used in the vehicles, are depleting at a very fast rate. We have petroleum resources available for next few years only. Therefore, there is a need to find an alternate way to run the motorised vehicles. Recently, the National Electric Mobility Mission Plan 2020[1] was notified by the Department of Heavy Industry, Ministry of Heavy Industries and Public Enterprises, Government of India, to address the environmental challenges due to conventional motor vehicles and boost the production of reliable, affordable, and efficient electric vehicles (EVs).

Recent breakthrough in the electric vehicle (EV) technology and affordable battery storage have shown a hope of mass level adoption of EVs. Accordingly, the Government of India has also taken various initiatives, such as FAME (Faster Adoption and Manufacturing of Hybrid& Electric Vehicles) India Scheme [2] to support hybrid/electric vehicles market development and Manufacturing eco-system. However, to the best of authors' knowledge, there is no detailed study carried out to find the impact of large penetration of EVs on the future Indian electric power distribution system (EPDS).

The objective of the present report is to highlight the challenges to be faced by utilities in future due to large penetration of EVs in the Indian EPDS. To forecast the impact of EV penetration on EPDS in years 2025 and 2030, a detailed study has been carried out for six metro cities of India, i.e. Delhi, Mumbai, Kolkata, Chennai, Bengaluru, and Hyderabad. Typical summer load curves of these cities for year 2018 are used to forecast their estimated load demands in summers of years 2025 and 2030, considering steady electric load growth. Subsequently, utilizing the current motorised vehicle growth rate in the cities, penetration of EVs for years 2025 and 2030 is also estimated. Considering consumer behaviours of various vehicle segments, their vehicle charging patterns are also estimated. Accordingly, multiple scenarios of charging the vehicle at home and charging the vehicle at charging stations are considered for carrying out the study. The estimated EV load, obtained from the study, is, then, compared with the estimated conventional electrical load in these cities and the analysis results are documented.

1 Introduction

India does not have adequate petroleum reserves. Therefore, it is heavily dependent on crude oil and natural gas imports. Presently, India is the third biggest oil importer after US and China [3]. The total crude basket of India includes 82.8% import of crude oil and 45.3% import for natural gas. As, the petroleum products consumption contributes to the air pollution, there has been a huge demand to contain the consumption of petroleum products to address the pollution problem. Further, it also causes huge economic burden on the Indian citizens due to large size of crude oil import. Therefore, to reduce the dependence on petroleum products and save the environment, it is required to switch over to alternate clean fuel and clean technology.

A major portion of the petroleum products is being consumed by the motorized vehicles. Hence, running these vehicles is causing major damage to our environment by adding air pollution. As the Indian transport sector is heavily dependent on petroleum products, the technologies like battery powered Plug-in Electric Vehicle (PEV) and Plug-in Hybrid Electric Vehicle (PHEV) are gaining momentum to combat the greenhouse gas emissions and air pollution. The vehicles in which charging takes place from an external source of power supply, such as electric grid, are called plug-in electric vehicles (PEV). The Plug-in Hybrid Electric Vehicle (PHEV), on the other hand, comprises of both plug-in electric vehicle system to charge from an electrical power source and a petrol/diesel engine which acts as a backup power source to charge the battery and run the electric motor of vehicle. To connect EVs to the electric grid, power electronics controllers based Electric Vehicle Supply Equipment (EVSE) is required. The on-board AC to DC converter, with single or three phase connectors are integral part of these controllers [4]-[8]. Recently, a lot of new EV charging technologies are being developed and deployed commercially across the globe [9]. This enables EVs to get charged at very fast rate. In future, there will be further innovations in the development of ultra-fast charging technologies for EVs, which will enable large size of EVs to be charged in few minutes. Although the fast charging technology for the EV makes vehicle owner comfortable in getting his vehicle charged quickly, it may pose a lot of challenges in the smooth functioning of the electrical power distribution system (EPDS). Further, charging a large number of EVs simultaneously from the grid may also cause various power system operational challenges due to higher peak load demands and system harmonics. Therefore, it is required to analyse the impact of large number of EV charging on the EPDS.

In this work, key challenges to be faced by EPDS operators, due to massive EV charging load, are highlighted. For analysis, required parameters for six major cities of India, i.e. Delhi, Mumbai, Kolkata, Chennai, Bengaluru, and Hyderabad, are considered. The required parameters include, existing electrical load curve of a typical summer day of 2018, number and types of existing motorised vehicles, estimated vehicle and load growth for 2025 and 2030, consumer EV charging behaviour, load and vehicle growth rate, EV growth rate, EV charging technologies, EV battery sizing etc. Using existing electrical load curves for the year 2018, electrical load curves for years 2025 and 2030 are forecasted by utilizing historical load growth rates. Further, utilizing the current motorised vehicle growth rate, the forecasted values of motorised vehicles for years 2025 and 2030 are estimated. Considering forecasted penetration of EVs, including charging pattern and EV battery size, EV load for years 2025 and 2030 are also estimated. For various vehicle segments, the vehicle charging behaviours are also estimated. Using multiple scenarios of charging the vehicle at home and at charging stations, the study is carried out. Accordingly, estimated EV load curve is superimposed on the conventional electrical load curve to study the challenges to be faced by EPDS operators. The contribution of the present report can be summarized as follows –

- Estimation of electrical load for six major cities of India in years 2025 and 2030
- Estimation of the numbers of various types of motorized vehicles for six major cities of India in years 2025 and 2030
- Estimation of number of EVs and their equivalent electrical load in six major cities of India in years 2025 and 2030
- Analysis of the impact of large penetration of EVs on the electrical distribution system
- Comparison of EV load with conventional electrical load
- Recommendations for better ways of integration of EVs to the grid

2 Present scenario

With the growth of population in India, the demand for passenger vehicles is also increasing. The growth of vehicles is causing more challenges in addressing the pollution problem. To address the pollution caused by conventional vehicles, EVs can be promoted and utilized to a greater extent. However, there are few challenges in adopting the EV technology. The process of charging EVs is one of the most important concerns, as the charging of uncertain number of Battery Energy Storages (BES) of EVs with uncertain power and energy demand poses an essential predicament of addressing the electrical power demand and supply situation in real time. Further, very high charging current requirement of EV also poses challenges in efficient operation of the power system due to frequent connect/disconnect of the large amount of intermittent BES loads. Further, the implementation of the BES in EVs encounters some challenges, such as battery degradation and reduced life, as frequent charging and discharging of BES leads to battery life and capacity deterioration. For continuous monitoring of various BES parameters, advanced communication infrastructures among EVs, charging stations, and the BES are required. The net electrical energy needed by EVs in a specific area is termed as charging load curve of EVs for that area. The prediction of this load curve is required to analyze the impact of penetration of EVs on EPDS [8]. The EV load curve analysis can help in evaluating various fundamental parameters of the EPDS as a part of impact evaluation such as overloading, impact on domestic transformer, power loss in the distribution system, stability of the grid, fluctuations in the voltage, power quality, and stress on distribution cables or conductors. The current state of the art of BES technologies and EV charging infrastructures are presented as follows.

BATTERY IN EV

The batteries are chosen on the basis of their weight, power density, energy density, and costs. Mopeds (low range) and electric cycles comprise of small units of battery, while electric cars install a huge number of batteries units. Conventionally, the lead-acid batteries were deployed because of their moderate cost, and mature technology. The significant advancement in battery technologies with time, has lead the development of various new kinds of batteries. Nowadays, the battery storage, utilizing various derivatives and combinations of Li-ion, are achieving ubiquitous adoption due to reduced weight, higher power density, quick response time, less charging time, and increased lifetime. The most important advantage associated Li-ion is that, it possess more specific energy with respect to the other types of batteries. The innovation in technology with Li-ion and other batteries is anticipated to result with much higher specific energy and reduced cost [7]. As the cost of Li-ion batteries are reducing, the size of BES used in the EVs is increasing. For example Tesla

Model 3 has BES of 75 kWh while the long range Tesla model S has 100 kWh of BES [10-11]. With the improvement in battery technology, the size of BES will further increase in future.

CHARGING INFRASTRUCTURE

Fast charging is paramount in making electric vehicles a success. The charging infrastructure can be AC (Alternating Current) or DC (Direct Current) charging. In case of AC charging, AC is supplied to an onboard charging device which further charges the BES of EV by converting AC to DC. The DC charging on the other hand, supplies electric power to battery management system of BES directly, which is embedded inside the EV. There is no requirement of additional on-board charging system for DC fast charging. The fast charging can only be accomplished with DC. The charging infrastructure for AC and DC charging is given in the figure below [9]:

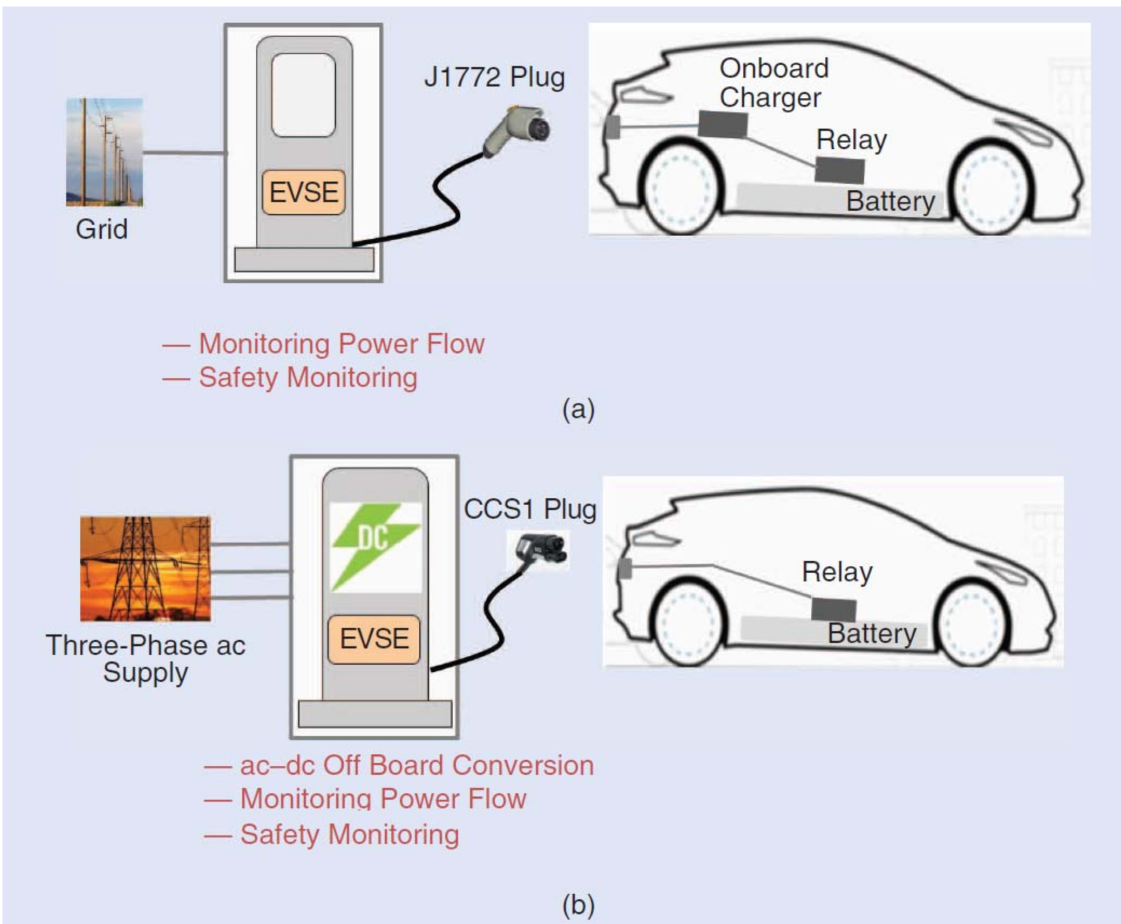

Figure 1: The different types of charging technologies (a) An ac charging station uses an onboard charger inside an EV. (b) A dc charging station directly charges the EV battery [9]

The following table summarises various types of AC and DC chargers available commercially across the globe [9].

Table 1: Various types of AC and DC charges for EVs [9]

AC Chargers	**AC Level 1**	**AC Level 2**	**AC Level 3**
	120-V, single-phase AC up to 16 A for up to 1.9 kW, limited to 12 A. It takes 8–12 hrs to charge a battery completely.	240-V, single-phase AC up to 80 A for up to 19.2 KW, limited to 32 A. It takes 4–6 hrs to charge a battery completely.	More than level 2. A couple of car makers make cars supporting Three-phase AC charging at rates up to 43 kW.
DC Chargers	**Introduced in 2016**	**Introduced in 2018**	**Introduced in 2019**
	CHAdeMO: 500-V DC up to 62.5 kW (125 A) CCS: 400-V DC up to 50 kW	CHAdeMO: 500-V DC up to 150 kW (350 A) CCS: 400-V DC for at least 150 kW	CHAdeMO: 1,000-V DC up to 350 kW (350 A) CCS: 400-V DC for at least 350 kW

Fast-charging standards presently being utilized by electric car manufacturers are summarized in the table below [6], [9].

Table 2: Various charging standards

Standard/Plug Connectors	**Communication Protocol**	**Compatible Manufactures**
CHAdeMo	CAN	Nissan, Mitsubishi, Toyota
SAE-J1772-2009	PLC	GM, Ford, Nissan, Tesla
SAE combined Charging system (CCS)	PLC	Volkswagen, GM, BMW
GB/T	CAN	Chinese manufacturers

3 Objective and Scope of the Study

OBJECTIVE

The pollution level in major cities of India is rising exponentially. According to the data obtained from AirVisual, out of 30 cities in the world with highest pollution levels, 22 cities are from India [12]. To contain the air pollution, EVs can be a good option. However, there are certain challenges from EPDS operations point of view. Therefore, a proper planning for EV roll out and charging infrastructure is required in order to have better operation, monitoring, and control of EPDS. The objective of the report is to highlight the challenges to be faced by electrical power distribution network due to sudden increase in EVs penetration in a geography resulting in increase in the peak electrical load and intermittency of electrical load in the distribution network. The report also suggests measures to address the challenges to be faced by EPDS.

SCOPE

The scope of the report is limited to –

- Provide initial details on forecasted conventional electrical load and penetration of various types of EVs in the EPDS for the years 2025 and 2030 only
- Provide initial analysis outcome for six major cities of India only, i.e. Delhi, Mumbai, Kolkata, Chennai, Bengaluru, and Hyderabad
- Provide initial challenges and suggestions to address the issue of high penetration of EVs on EPDS

OUT OF SCOPE

The report does not cover the following points which can be taken up in future based on research funding availability –

- Detailed EV load modelling and any power system analysis using EV load model
- Detailed analysis on impact of EV integration on power system operations, stability, and control.
- Detailed analysis on the findings of the initial study
- Detailed analysis of EV load for complete one year
- Analysis of the impact of temperature on performance of the BESS of EV

4 Assumptions

The following assumptions are considered while carrying out the study and analysis on the impact of penetration of EVs on Indian distribution grids in major cities-

General Assumptions –

- Lithium-ion is continued to be the preferred battery technology till the duration of analysis, i.e. year 2030.
- As in India summer temperature goes in the range of 40-45 degree centigrade, considering the temperature and ageing effect for the Lithium-ion battery, the average round trip efficiency of the battery during summer period is assumed to be 80%.
- The preferred DC fast charger during the analysis period is considered to be an ABB 350 kW charger [6].
- With the evolution of EV technology and mass production of EV, the cost of ownership of EV will become at par with that of the conventional vehicles well before the year 2025.

FOR YEAR 2025

It is assumed that -

- 15% of total non-commercial 4-wheelers will be EVs and each will be having a capacity of 75 kWh as BES.
- 25% of total 2-wheelers will be EVs and each will be having a capacity of 8 kWh as BES.
- 5% of total commercial 4-wheelers will be EVs. Each taxis and tractor will be having BES capacity of 110 kWh, and buses and trucks will be having BES capacity of 350 kWh.
- All E-Rickshaws are considered as EVs. Further, 15% of total 3 wheelers will be EVs and each will be having a capacity of 8 kWh as BES.
- Total E-rickshaws will be forecasted for year 2025 using their current growth rate and each will have a capacity of 8 kWh as BES

FOR YEAR 2030

It is assumed that –

- 30% of total non-commercial 4-wheelers will be EVs and each will be having a capacity of 75 kWh as BES.
- 50% of total 2-wheelers will be EVs and each will be having a capacity of 8 kWh as BES.

- 10% of total commercial 4-wheelers will be EVs. Each taxis and tractor will be having BES capacity of 110 kWh, and buses and trucks will be having BES capacity of 350 kWh.
- All E-Rickshaws are considered as EVs. Further, 30% of total 3 wheelers will be EVs and each will be having a capacity of 8 kWh as BES.
- Total E-rickshaws will be forecasted for year 2030 using their current growth rate and each will have a capacity of 8 kWh as BES

CHARGER SPECIFICATIONS

- Swiss company ABB has recently launched its Terra High Power DC fast charger [6], which can charge a vehicle with impressive 350 kW power. Considering latest and impressive technology, it is assumed that this technology will be the most preferred charging option at the commercial charging stations in years 2025 and 2030. Therefore, the ABB DC fast charger is considered for the present analysis of the penetration of EVs on Indian distribution grids. Using this charger -
    - Four wheelers of 75 kWh capacity can be charged in around 15 minutes.
    - Four wheelers of 110 kWh capacity can be charged in around 25 minutes.
    - Heavy vehicles of 350 kWh capacity can be charged in around 60 minutes.
- Two-wheelers and three-wheeler EVs will be charged from home with 5 A power socket.
- Four-wheeler EVs will be charged at home with 20 A power socket.

CHARGING SCENARIO

It is assumed that –

- All commercial EV vehicles in a city will be charged at charging station.
- All 2-wheeler EVs in a city will be charged at home.
- 3-wheeler EVs in a city can be charged at home as well as at charging station.
- Non-commercial 4-wheelers EVs in a city will have 4 scenarios of charging -
    - **Case 1:** 90% of total Non-commercial 4-wheelers EVs are charged at home and rest 10% are charged at charging station
    - **Case 2:** 70% of total Non-commercial 4-wheelers EVs are charged at home and rest 30% are charged at charging station
    - **Case 3:** 50% of total Non-commercial 4-wheelers EVs are charged at home and rest 50% are charged at charging station
    - **Case 4:** All Non-commercial 4-wheelers EVs are charged at charging station

- Considering the current plan of the development of EV charging infrastructure, it is assumed that there will be limited charging stations in years 2025 and 2030. The work places, such as offices, shopping malls, industrial establishments, will not be having dedicated charging infrastructure to charge vehicles during the day time. Based on the above assumption, the EV customer will generally try to charge his EV in the morning hours, before going for his work, or in the late evening hours, after coming from his work. For EV charging at home, the EV owner will plug-in the vehicle in the night after returning from his work. Based on the above forecasted EV customer behaviours, it is assumed that –
    - For commercial EVs (4-Wheelers and above) in a city -
        - Most of the commercial EVs charging from charging stations will take place during 6 AM - 9 AM and 9 PM - 12 AM mid-night with assumption of small percentage of 10% of commercial EVs being charged from 9 AM-9 PM.
        - Out of the total commercial EVs, 45% EVs will be charged in the morning hours and 45% EVs will be charged in the evening hours.
        - It is assumed that out of 45% commercial EVs being charged in the morning, 12.5% EVs will come by 6:00 AM, 20% will come at by 7:00 AM, and rest 12.5% will come by 8:00 AM for the charging.
        - It is also assumed that out of 45% commercial EVs being charged in the evening, 12.5% will come by 9:00 PM, 20% will come by10:00 PM, and rest 12.5% will come by11:00 PM for the charging.
        - The remaining 10% of commercial EVs will be charged during 9:00 AM - 9:00 PM.
        - All commercial EVs will be charged on a daily basis.
    - For non-commercial EVs in a city -
        - Non-commercial 4-wheeler EVs will be charged at home in the night during 7 PM – 10 AM using 20 Amp charger.
        - It is assumed that out of total Non-commercial 4-wheeler EVs being charged at home, 25% 4-Wheeler EVs are added every hour for charging, i.e. 25% 4-Wheeler EVs are added at 7 PM, next 25% are added at 8 PM and so on.
        - Most of the non-commercial 4-Wheeler EVs charging from charging stations will take place during 7 AM - 10 AM and 7 PM - 10 PM with assumption of small percentage of 10% of non-commercial 4-Wheeler EVs being charged from 10 AM - 7 PM.
        - Out of the total non-commercial 4-Wheeler EVs, 45% EVs will be charged in the morning hours and 45% EVs will be charged in the evening hours.

    - It is assumed that out of 45% non-commercial 4-Wheeler EVs being charged in the morning, 12.5% EVs will come by 7:00 AM, 20% will come at by 8:00 AM, and rest 12.5% will come by 9:00 AM for the charging.
    - It is also assumed that out of 45% non-commercial 4-Wheeler EVs being charged in the evening, 12.5% will come by 7:00 PM, 20% will come by 8:00 PM, and rest 12.5% will come by 9:00 PM for the charging.
    - The remaining 10% of non-commercial 4-Wheeler EVs will be charged during 10:00 AM - 7:00 PM.
    - All non-commercial 4-Wheeler EVs will be charged in every three days.
  - For 2-Wheeler/3-Wheeler EVs in a city –
    - 2-Wheeler EVs will start charging from home between 8 PM to 11 PM with 5 Amp charger.
    - 25% of 2-Wheeler EVs are added every hour to the grid for the charging at home, i.e. 25% at 8 PM, next 25% at 9 PM and so on.
    - All 2-Wheeler EVs will be charged in every three days.
    - 3-Wheeler EVs (mainly e-rickshaw) will be added to grid for charging from home between 10 PM to 12 AM midnight with 5 Amp charger.
    - 3-Wheeler EVs (mainly Auto) will also be charged from charging stations between 7 AM to 10 PM.
    - 3-Wheeler EVs will be charged daily.
- EVs coming from nearby cities for a transit period are not considered for the analysis.

5 Status of Electrical Distribution Systems of Major Cities

5.1 Delhi

To carry out the analysis, a typical load curve of Delhi for a summer day (peak day) of May, 2018 was considered. The load profile of Delhi was obtained from daily and monthly reports of the State Load Dispatch Centre (SLDC) [13] of Delhi. From the load curves, it can be verified that the peak load demand for Delhi occurs at around 3:45 PM. The maximum and minimum load demands for peak days (May) in years 2016, 2017, and 2018 are obtained and compared as given in table below:

Table 3: Maximum and minimum load demands of Delhi for a summer day in May

YEAR	MAX (MW)	MIN (MW)
2016	6188	4173
2017	6021	3907
2018	6442	4270

Considering the peak load details for previous 10 years, the estimated load demand for years 2025 and 2030 is computed using the load forecasting tool, considering load growth of around 3.5% from previous years. The estimated load demand outputs are shown in the table below.

Table 4: Forecasted Maximum and minimum load demands of Delhi for a summer day in May

YEAR	MAX (MW)	MIN (MW)
2025	8196	5433
2030	9734	6452

Estimated load profiles for years 2025 and 2030 along with load profile of year 2018 of a hot summer day in May for Delhi is shown in the figure below.

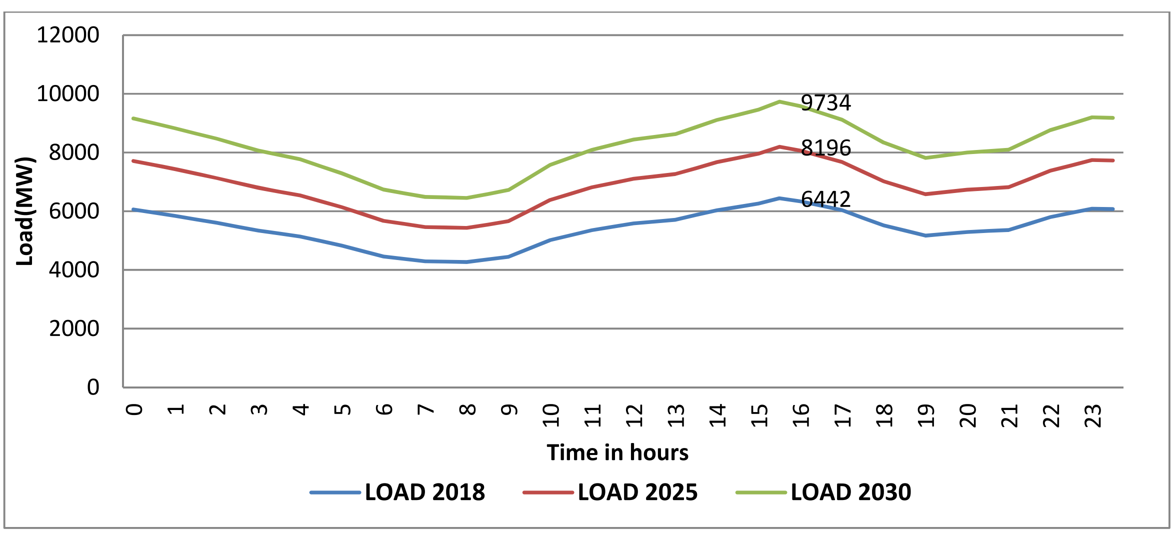

Figure 2: Daily load profile of Delhi (May Month)

5.2 Mumbai

The existing load profile of Mumbai is obtained from Maharashtra State Load Dispatch Centre. The load curves are prepared from the Maharashtra SLDC daily and monthly reports of May 31, 2018 (peak day) [14]-[16]. From the load curve data, it can be verified that the day peak occurs at around 4 PM. The maximum and minimum load demands in years 2016, 2017, and 2018 for the month of May on their specific peak day are as follows:

Table 5: Maximum and minimum load demands of Mumbai for a summer day in May

YEAR	MAX (MW)	MIN (MW)
2016	3552	2051
2017	3561	2206
2018	3670	2202

Using above peak load details of Mumbai, estimated load demand for years 2025 and 2030 is computed using load forecasting tool. The estimated load demand outputs are shown in table below.

Table 6: Forecasted Maximum and minimum load demands of Delhi for a summer day in May

YEAR	MAX (MW)	MIN (MW)
2025	4514	2708
2030	5248	3148

Load forecast for years 2025 and 2030 along with load profile of year 2018 of a hot summer day of Mumbai in May is shown in the figure 3.

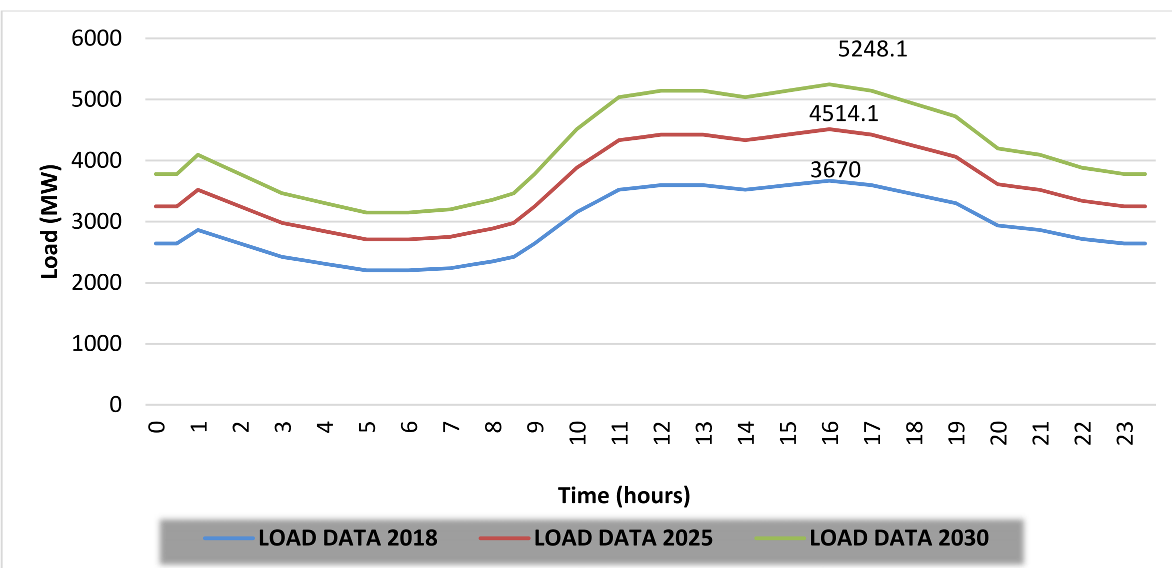

Figure 3: Daily load profile of Mumbai (May Month)

5.3 Kolkata

To generate the load curve of Kolkata during summer, CESC daily reports of May 2018 (23 May) [17] were utilized. Although the data obtained from the reports does not provide total load of Kolkata city, however, this data is sufficiently scaled up to provide an idea about the total load requirement of the city. From the load curve, it can be seen that the Kolkata peak demand occurs during the day at 3:30 PM in summer. The maximum and minimum load demands in years 2016, 2017, and 2018 for the month of May on their specific peak day are as follows:

Table 7: Maximum and minimum load demands of Kolkata for a summer day in May

YEAR	MAX LOAD (MW)	MIN LOAD(MW)
2016	1720	900
2017	2090	1150
2018	2070	1100

Using above peak load details of Kolkata, estimated load demand for years 2025 and 2030 is computed using load forecasting tool. The estimated load demand outputs are shown in table below.

Table 8: Forecasted maximum and minimum load demands of Kolkata for a summer day in May

YEAR	MAX LOAD (MW)	MIN LOAD(MW)
2025	2629	1422
2030	3126	1691

Load forecast for years 2025 and 2030 along with load profile of year 2018 of a hot summer day of Kolkata in May is shown in the figure 4 below.

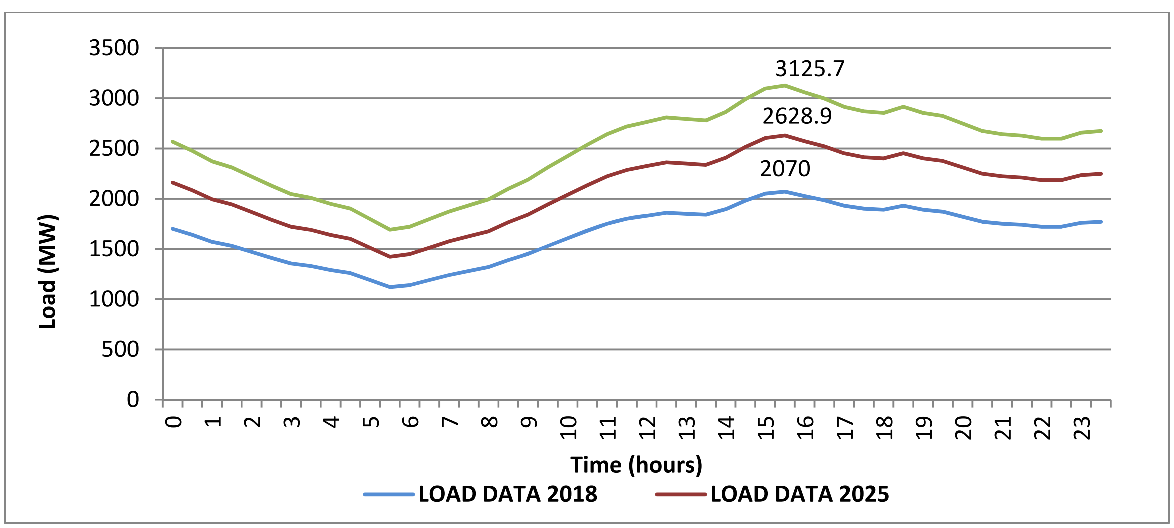

Figure 4: Daily load profile of Kolkata (May Month)

5.4 Chennai

The existing load profile data of Chennai is obtained online from the website of State Load Dispatch Centre, Chennai [18], [19]. Accordingly, the load curves during summer are prepared using SLDC, Chennai daily reports of May 2018 (summer). It can be verified from the load curve that the Chennai peak demand occurs at 2 PM in summer. The maximum and minimum load demands of Chennai in year 2018 for the month of May, along with the estimated load demand computed for years 2025 and 2030, for their specific peak day are as follows:

Table 9: Forecasted maximum and minimum load demands of Chennai for a summer day in May

YEARS	MAX LOAD (MW)	MIN LOAD(MW)
2018	3405	2011
2025	4188	2574
2030	4869	2856

Load forecast for years 2025 and 2030 along with load profile of year 2018 of a hot summer day of Chennai in May is shown in the figure 5 below.

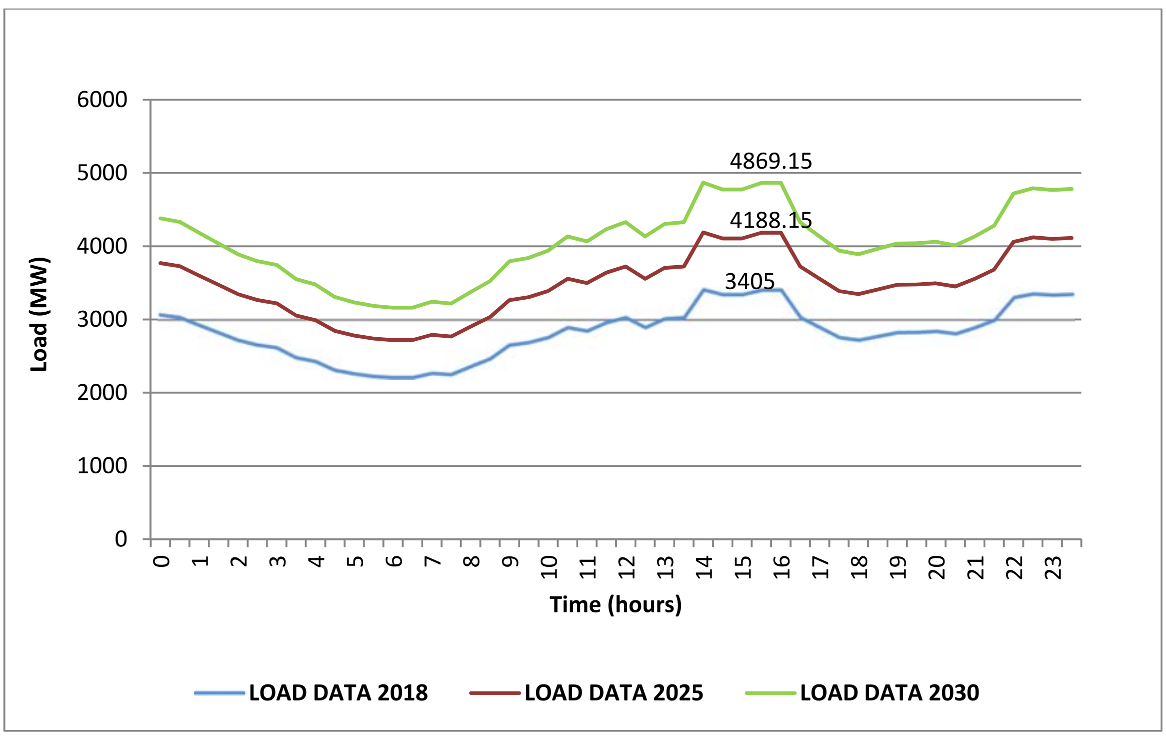

Figure 5: Daily load profile of Chennai (May Month)

5.5 Bengaluru

The existing load profile of Bengaluru is obtained from the website of Bangalore Electricity supply company Ltd. [20]. From the load profile data, it is observed that the peak load of Bengaluru occurs around 8 PM. The maximum and minimum load demands in years 2016, 2017, and 2018 for the month of May on their specific peak day are as follows:

Table 10: Maximum and minimum load demands of Bengaluru for a summer day in May

YEAR	MAX (MW)	MIN (MW)
2016	4122	2911
2017	4007	3169
2018	4073	2869

Using above peak load details of Bengaluru, estimated load demand for years 2025 and 2030 is computed using load forecasting tool. The estimated load demand outputs are shown in table below.

Table 11: Forecasted maximum and minimum load demands of Bengaluru for a summer day in May

YEAR	MAX LOAD (MW)	MIN LOAD(MW)
2025	5009	3528
2030	5824	4102

Load forecast for years 2025 and 2030 along with load profile of year 2018 of a hot summer day of Bengaluru in May is shown in the figure 6 below.

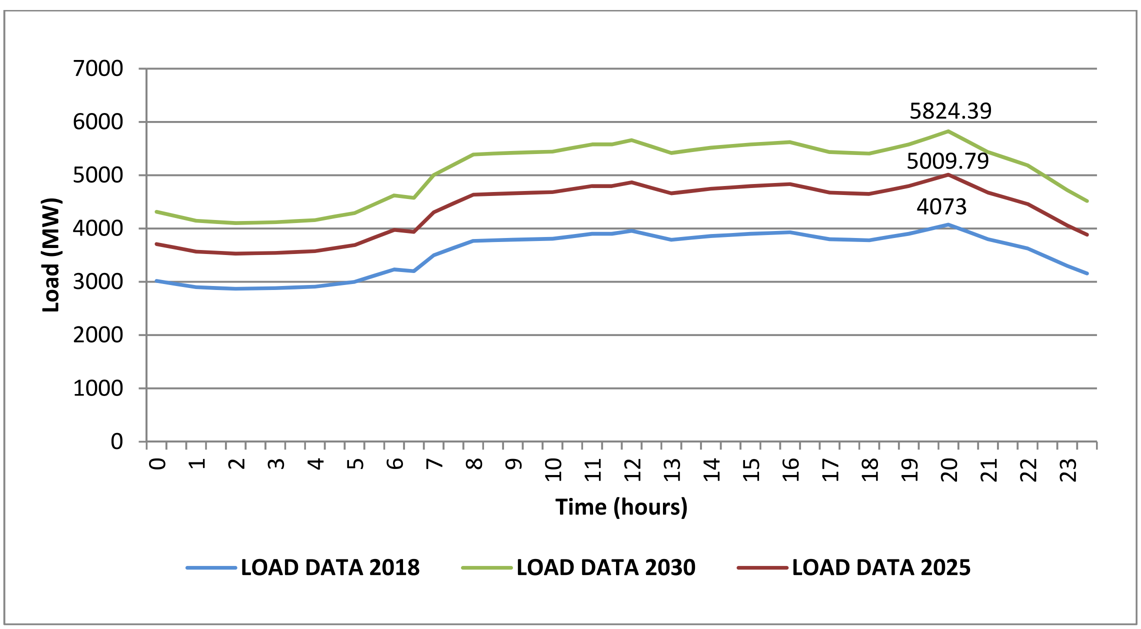

Figure 6: Daily Load Curve for Bengaluru (May Month)

5.6 Hyderabad

The load curve of Hyderabad is obtained from Telangana Southern Power Distribution Company Limited. Form the load curve data, it is observed that the peak of 2950 MW occurs at around 3 PM in the city [21]-[23]. The maximum and minimum demand forecast for years 2025 and 2030 in the city, on the basis of growth rate in previous years (approx. 3%), is estimated and is given as follows:

Table 12: Forecasted maximum and minimum load demands of Hyderabad for a summer day in May

YEARS	MAX LOAD (MW)	MIN LOAD(MW)
2018	2950	1915
2025	3628.5	2355
2030	4218.5	2738

Load forecast for years 2025 and 2030 along with load profile of year 2018 of a hot summer day of Hyderabad in May is shown in the figure 7 below.

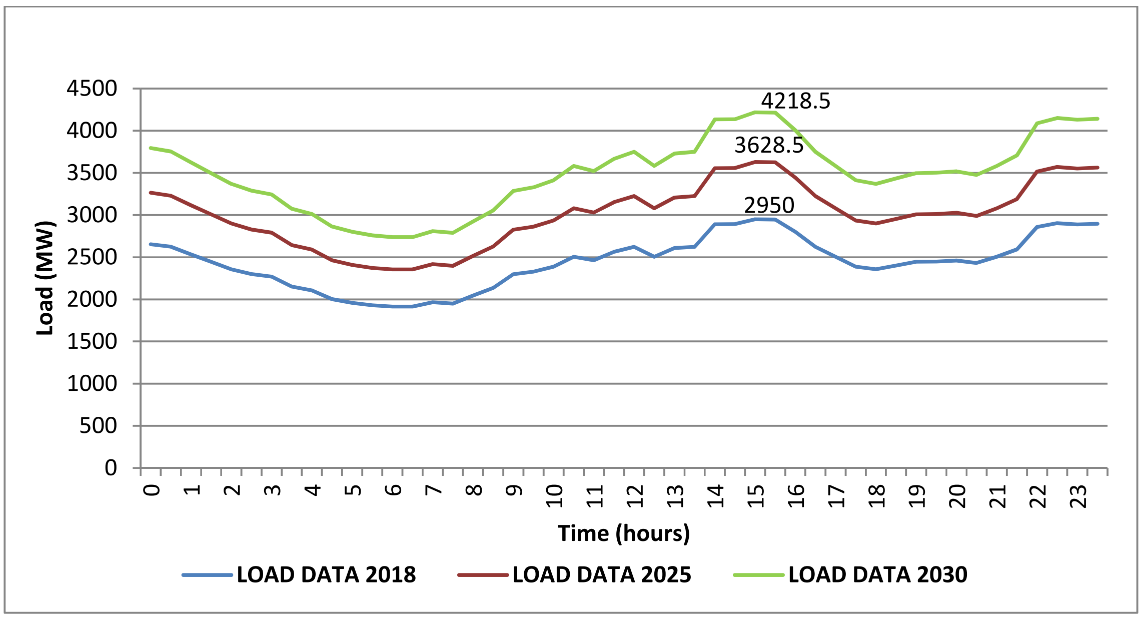

Figure 7: Daily load profile of Hyderabad (May Month)

6 Growth Forecast for Electric Vehicles in Major Cities

The EV market is undergoing development to a large extent, following the progressive plans and initiatives taken by the government. A number of essential steps have been taken to provide incentives, under FAME scheme, in order to accelerate the implementation of EVs and public charging stations to attain notable EV roll outs in India by 2030. The target of the government aims at decreasing the import of crude oil and combat the pollution levels across major cities in near future. To achieve this target, EVs are going to play an essential role. Although the current penetration of EVs in India is very low, considering current conventional vehicles concentration, the government initiatives, upcoming EV technologies, and potential customer interests, the future EV penetrations for years 2025 and 2030 can be estimated. The details about the estimated size of future EV penetrations in major cities of India for years 2025 and 2030 are provided in this section.

6.1 Delhi

To forecast the future EV penetrations in Delhi for years 2025 and 2030, the existing conventional (petrol/diesel/CNG/LPG) vehicle data is utilized. The conventional vehicle data is taken from the Transport Department, Government of NCT of Delhi [24]. The year wise breakup of the conventional vehicles is as follows.

(1) Growth of two wheelers in Delhi in previous years

Year	**No. of two wheelers**
2015	5698242
2016	6129505
2017	6578358

(2) Growth of three wheelers in Delhi in previous years

Year	**No. of three wheelers**
2015	125791
2016	141814
2017	155609

(3) Growth of E-Rickshaw in Delhi in last three years

Year	No. of E-Rickshaw
2016	8557
2017	29123
2018	45965

(4) Growth of non-commercial four wheelers in Delhi in previous years

Year	No. of Non Comm. Four wheelers
2015	2797215
2016	2968735
2017	2984448

(5) Growth of commercial four wheelers in Delhi in previous years

Year	No. of Comm. Four wheelers
2015	287631
2016	314036
2017	341995

(6) Growth of heavy commercial vehicles in Delhi in previous years

Year	No. of Heavy Comm. Vehicle
2015	104195
2016	120086
2017	132626

Using above data of various types of conventional vehicles and their historical growth rates, forecasted number of conventional vehicles in Delhi for the years 2025 and 2030 are as follows:

Year	2025	2030
No of two wheelers	10484903	14031165
No of three wheelers	229905	293423
No of E-Rickshaw	122965	128765
No of commercial Four wheelers	505282	644882
No of heavy commercial Vehicle	195949	250086
No of non-commercial Four wheelers	4409388	5627621

Using the forecasted number of conventional vehicles for the years 2025 and 2030, forecasted EVs in Delhi for the years 2025 and 2030 are computed as follows:

Year	**2025**	**2030**
Number of two wheeler EVs (25% of total two wheeler vehicles in 2025 & 50% of total two wheeler vehicles in 2030)	2621226	7015582
Number of E-Rickshaws	122965	128765
No of three wheelers EVs (15% of total three wheeler vehicles in 2025 & 30% of total three wheeler vehicles in 2030)	34485	88026
Number of commercial four wheelers EVs (5% of commercial four wheelers in 2025 & 10% of commercial four wheelers in 2030)	25264	64488
Number of heavy commercial Vehicle EVs (5% of heavy commercial vehicles in 2025 & 10% of heavy commercial vehicles in 2030)	9797	25008
Number of non-commercial four wheelers EVs (15% of non-commercial four wheelers in 2025 & 30% of non-commercial four wheelers in 2030)	661408	1688286

The above EVs data is utilized to analyse the impact of EVs on EPDS of Delhi.

6.2 Mumbai

To forecast the future EV penetrations in Mumbai for years 2025 and 2030, the existing conventional (petrol/diesel/CNG/LPG) vehicle data is utilized. The conventional vehicle data is taken from the "Vehicles Population as on 31st March, 1998 to 31st March 2017" documents of Motor Vehicles Department, Maharashtra [25]-[28].

(1) Growth of two wheelers in Mumbai in previous years

Year	No. of Two Wheelers
2015	3183268
2016	3536181
2017	3901369

(2) Growth of three wheelers in Mumbai in previous years

Year	No. of Three Wheelers
2015	389206
2016	402559
2017	415783

(3) Growth of Commercial Four Wheelers in Mumbai in previous years

Year	No of Comm. Four wheelers
2015	221330
2016	261778
2017	311954

(4) Growth of Commercial Heavy Vehicles in Mumbai in previous years

Year	No of Heavy Comm. Vehicle
2015	208589
2016	212741
2017	213323

(5) Growth of Non Commercial Four Wheelers in Mumbai in previous years

Year	No. of Non Comm. Four wheelers
2015	1456923
2016	1566986
2017	1684551

Using above data of various types of conventional vehicles and their historical growth rates, forecasted number of conventional vehicles in Mumbai for the years 2025 and 2030 are as follows:

Year	2025	2030
No of two wheelers	5764098	7356613
No. of three wheelers	526701	610591
No of Comm. Four wheelers	460898	588235
No of Heavy Comm. Vehicle	249941	275956
No of Non Comm. Four wheelers	2894372	4059506

Using the forecasted number of conventional vehicles for the years 2025 and 2030, forecasted EVs in Mumbai for the years 2025 and 2030 are as follows:

Year	2025	2030
Number of two wheeler EVs (25% of total two wheeler vehicles in 2025 & 50% of total two wheeler vehicles in 2030)	1441024	3678306
Number of three wheeler EVs (15% of total three wheeler vehicles in 2025 & 30% of total three wheeler vehicles in 2030)	79005	183177
Number of commercial four wheelers EVs (5% of commercial four wheelers in 2025 & 10% of commercial four wheelers in 2030)	23044	58823
Number of heavy commercial Vehicle EVs (5% of heavy commercial vehicles in 2025 & 10% of heavy commercial vehicles in 2030)	12497	27295
Number of non-commercial four wheelers EVs (15% of non-commercial four wheelers in 2025 & 30% of non-commercial four wheelers in 2030)	434155	1217851

The above EVs data is utilized to analyse the impact of EVs on EPDS of Mumbai.

6.3 Kolkata

To forecast the future EV penetrations in Kolkata for years 2025 and 2030 also, the existing conventional (petrol/diesel/CNG/LPG) vehicle data of West Bengal is utilized, because the complete vehicle data of Kolkata city was not readily available. Therefore, the conventional vehicle data of West Bengal is taken from the Open Government Data (OGD) Platform India [29]-[30]. Thereafter, it is assumed that 25% of the West Bengal vehicles are in Kolkata. Accordingly, the growth for various segments of vehicles are estimated as follows:

(1) Growth of two wheelers in Kolkata in previous years

Years	No. of two wheelers
2014	1188681
2015	1320062

(2) Growth of three wheelers in Kolkata in previous years

Years	No of three wheelers
2014	29626
2015	30579

(3) Growth of commercial four wheelers Kolkata in previous years

Years	No of commercial four wheelers
2014	42379
2015	45511

(4) Growth of commercial heavy vehicles in Kolkata in previous years

Years	No. of Heavy vehicles
2014	188571
2015	201689

(5) Growth of non-commercial four wheelers in Kolkata in previous years

Years	Non-commercial 4-wheelers
2014	236994
2015	252974

Using above data of various types of conventional vehicles and their historical growth rates, forecasted number of conventional vehicles in Kolkata for the years 2025 and 2030 are estimated as follows:

Year	2025	2030
No of two wheelers	2633867	3290769
No. of three wheelers	40101	44862
No of Comm. Four wheelers	76823	92479
No of Heavy Comm. Vehicle	332846	398423
No of Non Comm. Four wheelers	412769	492666

Using the forecasted number of conventional vehicles for the years 2025 and 2030, forecasted EVs in Kolkata for the years 2025 and 2030 are as follows:

Year	2025	2030
Number of two wheeler EVs (25% of total two wheeler vehicles in 2025 & 50% of total two wheeler vehicles in 2030)	639110	1579019
Number of three wheeler EVs (15% of total three wheeler vehicles in 2025 & 30% of total three wheeler vehicles in 2030)	6015	13458
Number of commercial four wheelers EVs (5% of commercial four wheelers in 2025 & 10% of commercial four wheelers in 2030)	4094	15172
Number of heavy commercial Vehicle EVs (5% of heavy commercial vehicles in 2025 & 10% of heavy commercial vehicles in 2030)	51012	96333
Number of non-commercial four wheelers EVs (15% of non-commercial four wheelers in 2025 & 30% of non-commercial four wheelers in 2030)	67313	166310

The above EVs data is utilized to analyse the impact of EVs on EPDS of Kolkata.

6.4 Chennai

To forecast the future EV penetrations in Chennai for years 2025 and 2030 also, the existing conventional (petrol/diesel/CNG/LPG) vehicle data of Chennai is utilized. The conventional vehicle data is taken from the Open Government Data (OGD) Platform India [29], [31]. Accordingly, the growth for various segments of vehicles is as follows:

(1) Growth of two wheelers in Chennai in previous years

Year	No of two wheelers
2014	3072813
2015	3516062
2016	3516062

(2) Growth of three wheelers in Chennai in previous years

Year	No of three wheelers
2014	124427
2015	132769
2016	131710

(3) Growth of non commercial four wheelers in Chennai in previous years

Year	No of non comm. Four wheelers
2014	771891
2015	873516
2016	873516

(4) Growth of commercial four wheelers in Chennai in previous years

Year	No of comm. Four wheelers
2014	182928
2015	197948
2016	200752

(5) Growth of commercial heavy vehicles in Chennai in previous years

Year	No of heavy comm. Vehicle
2014	202172
2015	214117
2016	215948

Using above data of various types of conventional vehicles and their historical growth rates, forecasted number of conventional vehicles in Chennai for the years 2025 and 2030 are as follows:

Year	2025	2030
No of two wheelers	5454566	6961562
No. of three wheelers	204325	260776
No of Comm. Four wheelers	285732	347637
No of Heavy Comm. Vehicle	258077	284938
No of Non Comm. Four wheelers	1043932	1152586

Using the forecasted number of conventional vehicles for the years 2025 and 2030, forecasted EVs in Chennai for the years 2025 and 2030 are as follows:

YEAR	2025	2030
Number of two wheeler EVs (25% of total two wheeler vehicles in 2025 & 50% of total two wheeler vehicles in 2030)	1363641	3480781
Number of three wheeler EVs (15% of total three wheeler vehicles in 2025 & 30% of total three wheeler vehicles in 2030)	30648	78232
Number of commercial four wheelers EVs (5% of commercial four wheelers in 2025 & 10% of commercial four wheelers in 2030)	14286	34763
Number of heavy commercial Vehicle EVs (5% of heavy commercial vehicles in 2025 & 10% of heavy commercial vehicles in 2030)	12903	28493
Number of non-commercial four wheelers EVs (15% of non-commercial four wheelers in 2025 & 30% of non-commercial four wheelers in 2030)	156589	345775

The above EVs data is utilized to analyse the impact of EVs on EPDS of Chennai.

6.5 Bengaluru

To forecast the future EV penetrations in Bengaluru for years 2025 and 2030 also, the existing conventional (petrol/diesel/CNG/LPG) vehicle data of Bengaluru is utilized. The conventional vehicle data is taken from the Open Government Data (OGD) Platform India [32]. Accordingly, the growth for various segments of vehicles is as follows:

(1) Growth of two wheelers in Bengaluru in previous years

Year	No of two wheelers
2014	3479208
2015	3841139
2016	4222676

(2) Growth of Three wheelers in Bengaluru in previous years

Year	No of three wheelers
2014	175711
2015	189249
2016	205284

(3) Growth of non-commercial four wheelers in Bengaluru in previous years

Year	No of non comm. Four wheelers
2014	995514
2015	1096030
2016	1199026

(4) Growth of commercial four wheelers in Bengaluru in previous years

Year	No of comm. Four wheelers
2014	196226
2015	219579
2016	257661

(5) Growth of commercial heavy vehicles in Bengaluru in previous years

Year	No of heavy comm. Vehicle
2014	161405
2015	170797
2016	183959

Using above data of various types of conventional vehicles and their historical growth rates, forecasted number of conventional vehicles in Bengaluru for the years 2025 and 2030 are as follows:

Year	2025	2030
No of two wheelers	9171201	14111030
No. of three wheelers	204325	260776
No of Comm. Four wheelers	399716	510151
No of Heavy Comm. Vehicle	285380	364226
No of Non Comm. Four wheelers	1860082	2373989

Using the forecasted number of conventional vehicles for the years 2025 and 2030, forecasted EVs in Bengaluru for the years 2025 and 2030 are as follows:

YEAR	2025	2030
Number of two wheeler EVs (25% of total two wheeler vehicles in 2025 & 50% of total two wheeler vehicles in 2030)	2292800	7055515
Number of three wheeler EVs (15% of total three wheeler vehicles in 2025 & 30% of total three wheeler vehicles in 2030)	30648	78232
Number of commercial four wheelers EVs (5% of commercial four wheelers in 2025 & 10% of commercial four wheelers in 2030)	19986	51015
Number of heavy commercial Vehicle EVs (5% of heavy commercial vehicles in 2025 & 10% of heavy commercial vehicles in 2030)	14269	36422
Number of non-commercial four wheelers EVs (15% of non-commercial four wheelers in 2025 & 30% of non-commercial four wheelers in 2030)	279012	712196

The above EVs data is utilized to analyse the impact of EVs on EPDS of Bengaluru.

6.6 Hyderabad

To forecast the future EV penetrations in Hyderabad for years 2025 and 2030, the existing conventional (petrol/diesel/CNG/LPG) vehicle data is utilized. The conventional vehicle data of Hyderabad is taken from the Open Government Data (OGD) Platform of India [33] and Telangana Transport Department [34]. Accordingly, the year wise breakup for various segments of vehicles in the year 2018 and forecasted number of conventional vehicles for the years 2025 and 2030, using the data of various types of conventional vehicles and their historical growth rates in previous years, for Hyderabad city are as follows:

Year	2018	2025	2030
No of two wheelers	7907083	9082752	10028093
No. of three wheelers	380838	437463	482994
No of Comm. Four wheelers	196805	226067	249596
No of Heavy Comm. Vehicle	892367	1025049	1131737
No of Non Comm. Four wheelers	1269856	1458665	1610484

Using the forecasted number of conventional vehicles for the years 2025 and 2030, forecasted EVs in the Hyderabad city for the years 2025 and 2030 are as follows:

YEAR	2025	2030
Number of two wheeler EVs (25% of total two wheeler vehicles in 2025 & 50% of total two wheeler vehicles in 2030)	2270688	5014046
Number of three wheeler EVs (15% of total three wheeler vehicles in 2025 & 30% of total three wheeler vehicles in 2030)	65619	144898
Number of commercial four wheelers EVs (5% of commercial four wheelers in 2025 & 10% of commercial four wheelers in 2030)	11303	24959
Number of heavy commercial Vehicle EVs (5% of heavy commercial vehicles in 2025 & 10% of heavy commercial vehicles in 2030)	51252	113173
Number of non-commercial four wheelers EVs (15% of non-commercial four wheelers in 2025 & 30% of non-commercial four wheelers in 2030)	218799	483145

The above EVs data is utilized to analyse the impact of EVs on EPDS of Hyderabad.

7 Forecast of future distribution systems of major cities of India

To forecast the load curves of various cities in years 2025 and 2030, which includes EV load as well as conventional load, the conventional load curves and the EV load curves were forecasted separately. The EV loads for various cities in years 2025 and 2030 were forecasted considering following four different scenarios –

- **Case 1:** 90% of total Non-commercial 4-wheelers EVs are charged at home and rest 10% are charged at charging station, keeping other types of vehicle charging same as described in the Assumption section (Section 4).
- **Case 2:** 70% of total Non-commercial 4-wheelers EVs are charged at home and rest 30% are charged at charging station, keeping other types of vehicle charging same as described in the Assumption section (Section 4).
- **Case 3:** 50% of total Non-commercial 4-wheelers EVs are charged at home and rest 50% are charged at charging station, keeping other types of vehicle charging same as described in the Assumption section (Section 4).
- **Case 4:** All Non-commercial 4-wheelers EVs are charged at charging station, keeping other types of vehicle charging same as described in the Assumption section (Section 4).

After getting the EV load curves for the above scenarios, the conventional load curves and the EV load curves were merged together to get the total load curve of the cities under above mentioned scenarios. Accordingly, the total load curves for various cities, including EV load, were computed, as described below.

7.1 Delhi

To analyse the load curve of Delhi in years 2025 and 2030, the load curves of conventional load, as described in Section 5, and the estimated load corresponding to number of EVs, as described in Section 6, were utilised. Accordingly, the total load curves under four different charging scenario were prepared. The results and our observations are summarised as follows -

Case 1:

In this case, 90% of total Non-commercial 4-wheelers EVs are charged at home and rest 10% are charged at the charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional and EV load, obtained from the simulation studies is shown in the figure below.

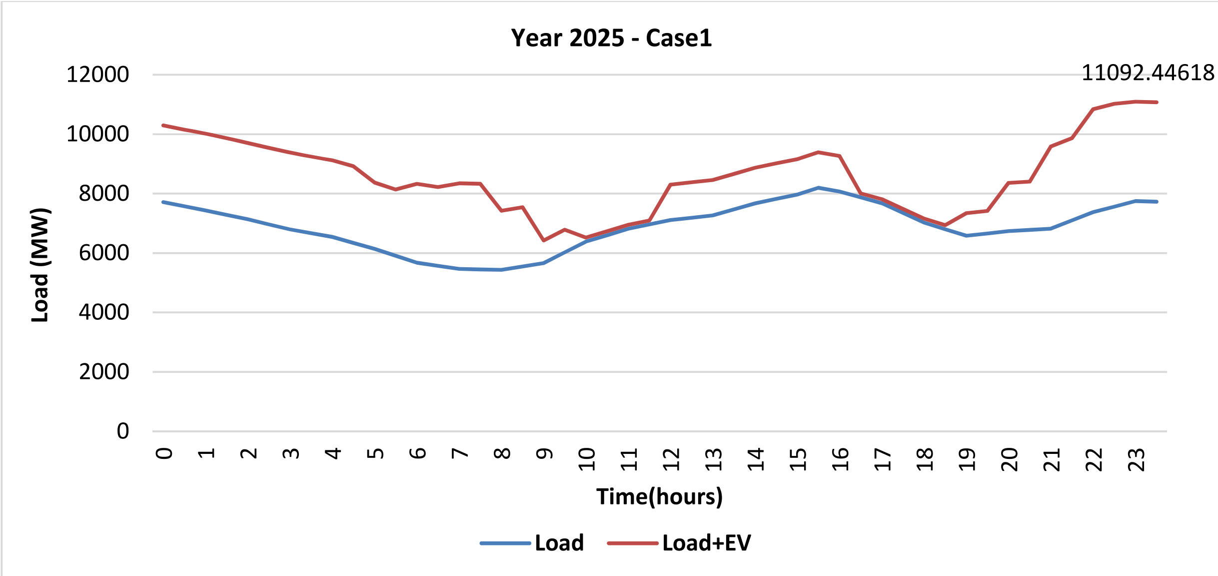

Figure 8: Conventional load curve and total load curve, including EV, for Delhi in year 2025 – Case 1

The forecasted peak loading conditions for the EPDS of Delhi in the year 2025 is shown in Figure 8. From the above Figure, it can be observed that the peak load, which occurs at around 4 PM when EV is not considered, has now shifted to around 11 PM in the night when EV load is considered along with the conventional load. The normal peak load, without EV, in the year 2025 is 8196 MW. While, the peak load after EV penetration (EV+Load) has become 11092 MW in year 2025. This shows that the peak load demand in Delhi due to EV in the year 2025 will increase by 2896 MW, i.e. around 35%. The peak load of the curve is also shifted from 4 PM to 11 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging. Interestingly, the contribution of two wheeler EV load in the total EV load is around 40%.

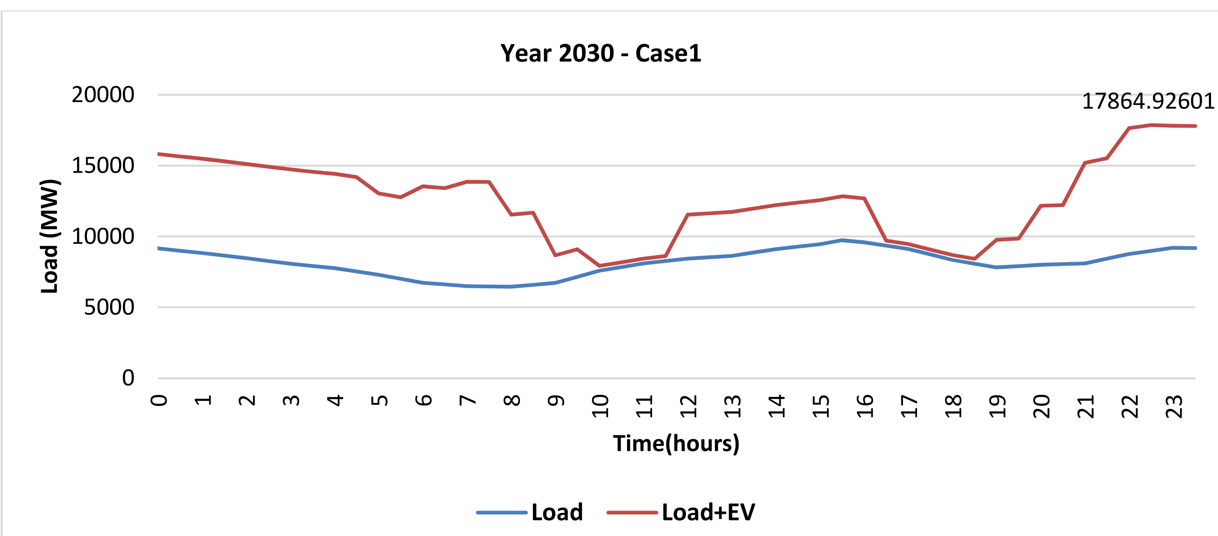

Figure 9: Conventional load curve and total load curve, including EV, for Delhi in year 2030 – Case 1

Figure 9 shows the forecasted peak loading condition for the EPDS of Delhi in the year 2030. From the above figure also, it can be observed that the peak load, which occurs at around 4 PM when EV is not considered, has now shifted to around 10.30 PM in the night when EV load is considered along with the conventional load. The normal peak load, without EV, in the year 2030 is 9734 MW. While, the peak load after EV penetration (EV+Load) has become around 17865 MW in year 2030. This shows that the peak load demand in Delhi due to EV in the year 2030 will increase by 8131 MW, i.e. around 84%. The peak load of the curve is also shifted from 4 PM to 10.30 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging. In this case also, the contribution of two wheeler EV load in the total EV load is around 31%.

Case 2:

In this case, 70% of total Non-commercial 4-wheelers EVs are charged at home and rest 30% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

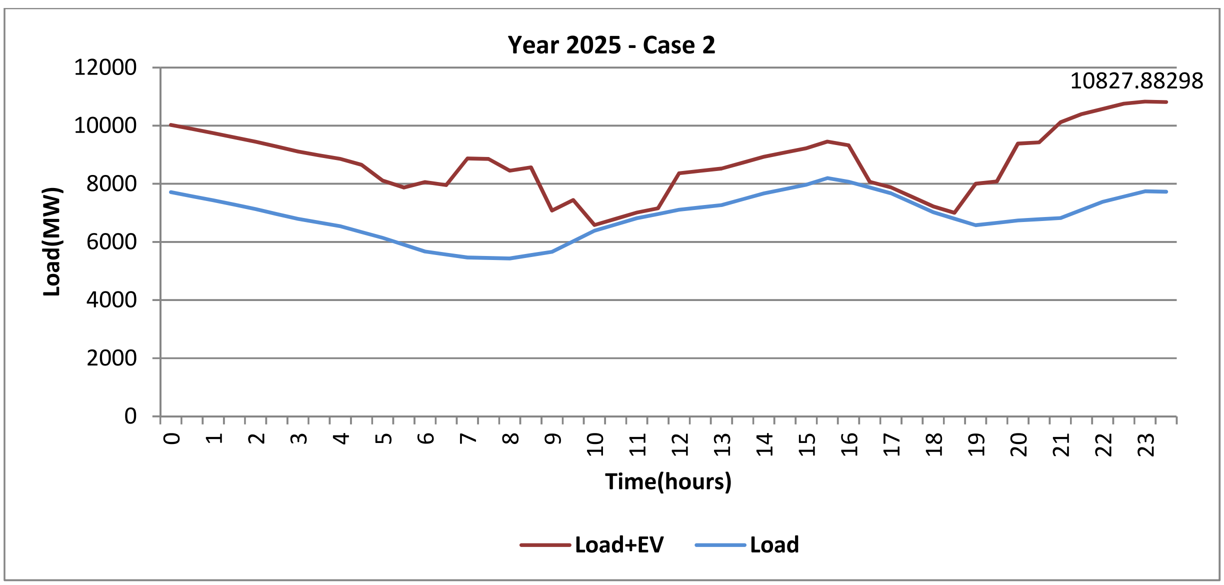

Figure 10: Conventional load curve and total load curve, including EV, for Delhi in year 2025 – Case 2

From the above figure, it can be observed that, compared with the conventional peak of 8196 MW which occurs at around 4 PM, the peak of total load curve, including EV, occurs at 11 PM with the peak load of around 10828 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been reduced by 264 MW. It is so, because in this case 20% more non-commercial vehicles are being charged from the charging stations before the system peak occurs. Therefore, the charging of more vehicles at the charging station before the system peak load condition helps in flattening the load curve. This may be a case of devising a method of deciding the correct timing of the EV charging at home as well as at charging station to reduce stress on the EPDS.

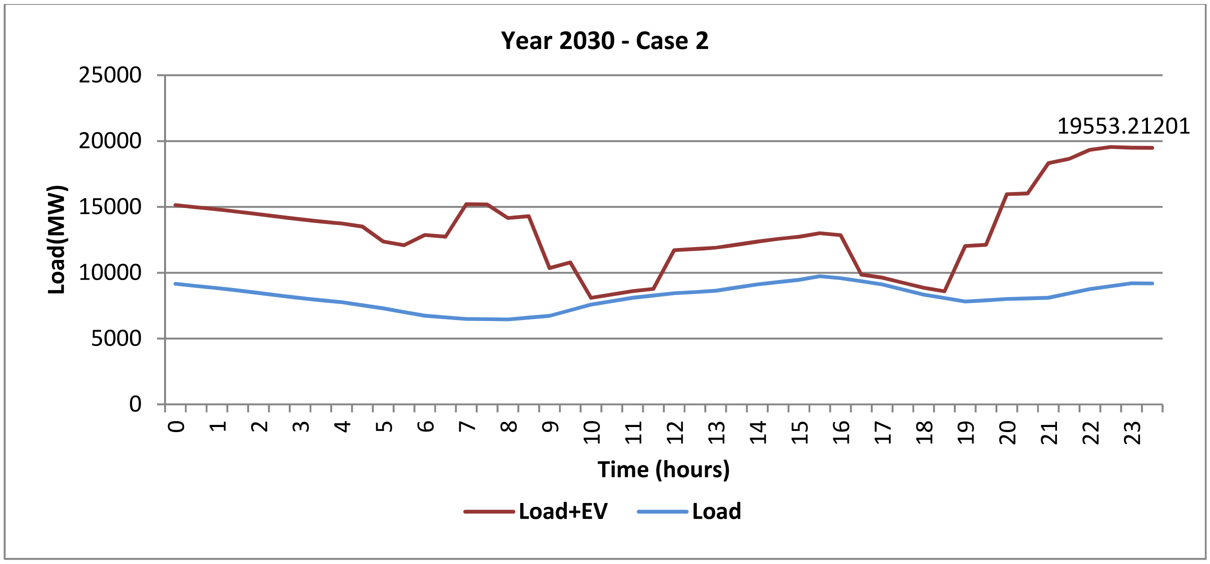

Figure 11: Conventional load curve and total load curve, including EV, for Delhi in year 2030 – Case 2

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 11 that, compared with the conventional peak of 9734 MW which occurs at around 4 PM, the peak of total load curve, including EV, occurs at 10.30 PM with the peak load of around 19553 MW. This shows that the demand of EV load is 101% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required from day 1 to address this scenario. On comparing with the total load curve of case 1 in the year 2030, it also observed that, in this case, the peak load has been increased by 1689 MW. It is so, because, in this case, the number of EVs, being charged from the charging stations as well from the home, have increased significantly when compared with the case 1 in year 2030. Therefore, the charging of more vehicles at the charging stations before the system peak load condition does not help in flattening the load curve.

Case 3:

In this case, 50% of total Non-commercial 4-wheelers EVs are charged at home and rest 50% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

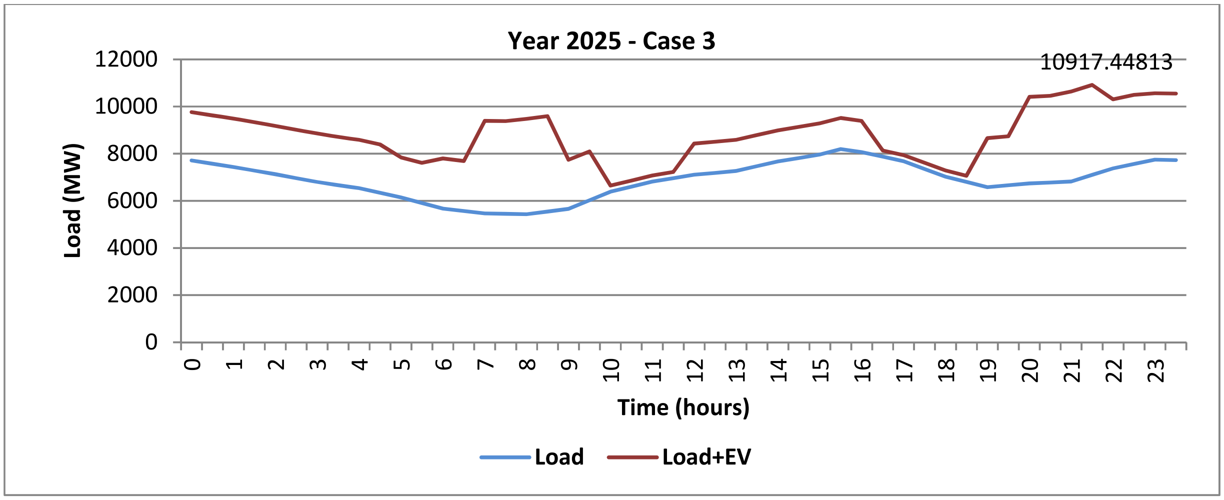

Figure 12: Conventional load curve and total load curve, including EV, for Delhi in year 2025 – Case 3

From the Figure 12, it can be observed that, compared with the conventional peak of 8196 MW which occurs at around 4 PM, the peak of total load curve, including EV, occurs at 9.30 PM with the peak load of around 10917 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been reduced by 175 MW. It is so, because in this case 40% more non-commercial vehicles are being charged from the charging stations. Therefore, the system peak also shifts from 11 PM to 9.30 PM. Accordingly, the charging of more vehicles at the charging stations helps in reducing the system peak load value. As in previous case, in this case also, it may be a case of devising a method of identifying the correct timing and mix of the EV charging at home as well as at charging stations to reduce stress on the EPDS. It is also observed that the case 2 of year 2025, when only 30% non-commercial vehicles are charged from the charging station, is better in reducing the peak load situation on the EPDS.

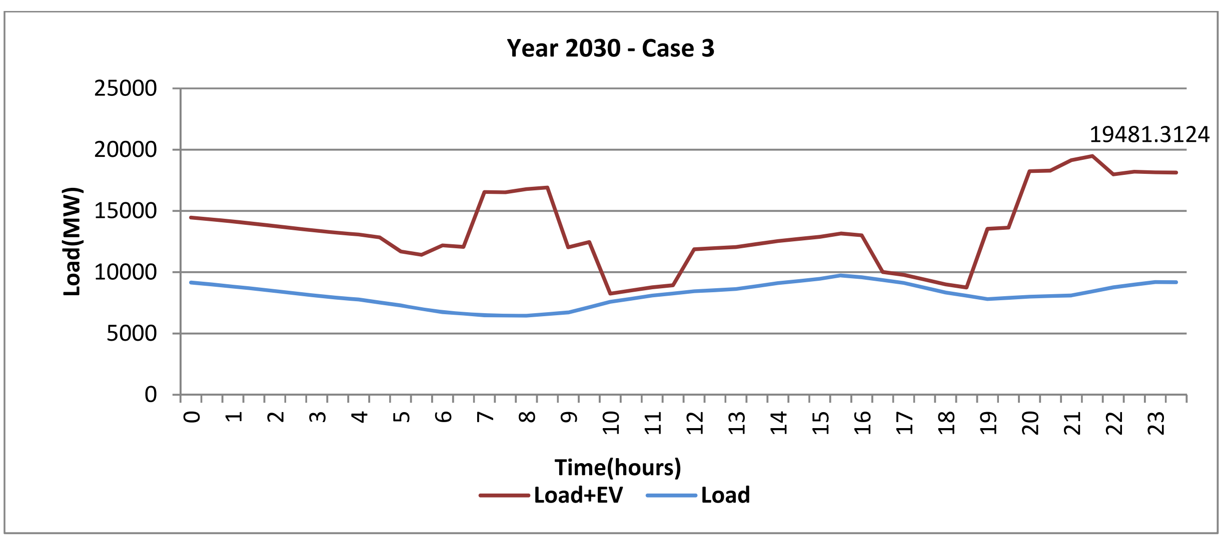

Figure 13: Conventional load curve and total load curve, including EV, for Delhi in year 2030 – Case 3

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 13 that, compared with the conventional peak of 9734 MW which occurs at around 4 PM, the peak of total load curve, including EV, occurs at 9.30 PM with the peak load of around 19481 MW. This shows that the demand of EV load is around 101% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required from day 1 to address this scenario. On comparing with the total load curve of case 2 in the year 2030, it is also observed that, in this case, the peak load has been slightly reduced by 72 MW. It shows that shifting of charging of EVs from home to charging stations does not play major role in year 2030 in reducing the total system load. Therefore, the charging of more vehicles at the charging stations, before the system peak load condition occurs, does not help much in flattening the load curve.

Case 4:

In this case, all non-commercial 4-wheelers EVs are charged at charging station, keeping other types of vehicles charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies under this case is shown in the figure below.

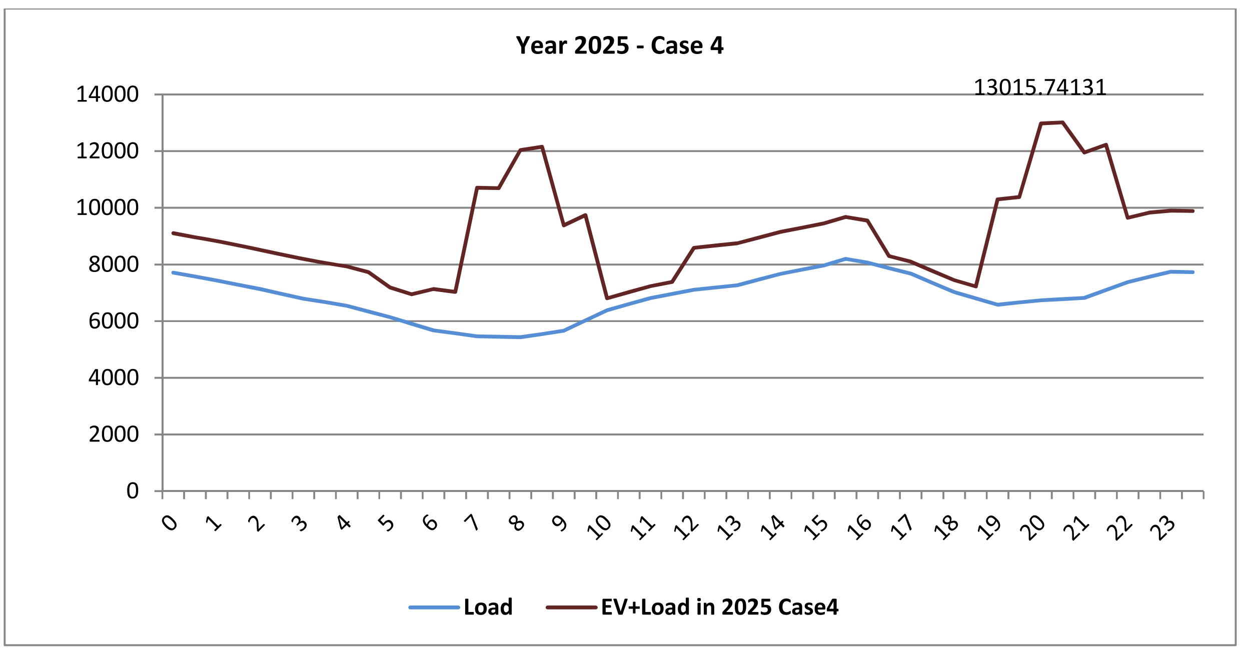

Figure 14: Conventional load curve and total load curve, including EV, for Delhi in year 2025 – Case 4

From the Figure 14, it can be observed that, compared with the conventional peak of 8196 MW which occurs at around 4 PM, the total load curve having EV load included contains two peaks. One peak of 12153 MW occurs at 9.00 AM while the other peak of 13016 MW occurs at 9 PM. These peaks occur due to EV owners' behaviour of charging their vehicles either in the morning time, before going to work, or in the evening time, after coming from the work. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been drastically increased by 1924 MW. It is so, because in this case all non-commercial vehicles are being charged from the charging stations. The system peak also shifts from 11 PM, as in case 1, to 9.00 PM in this case.

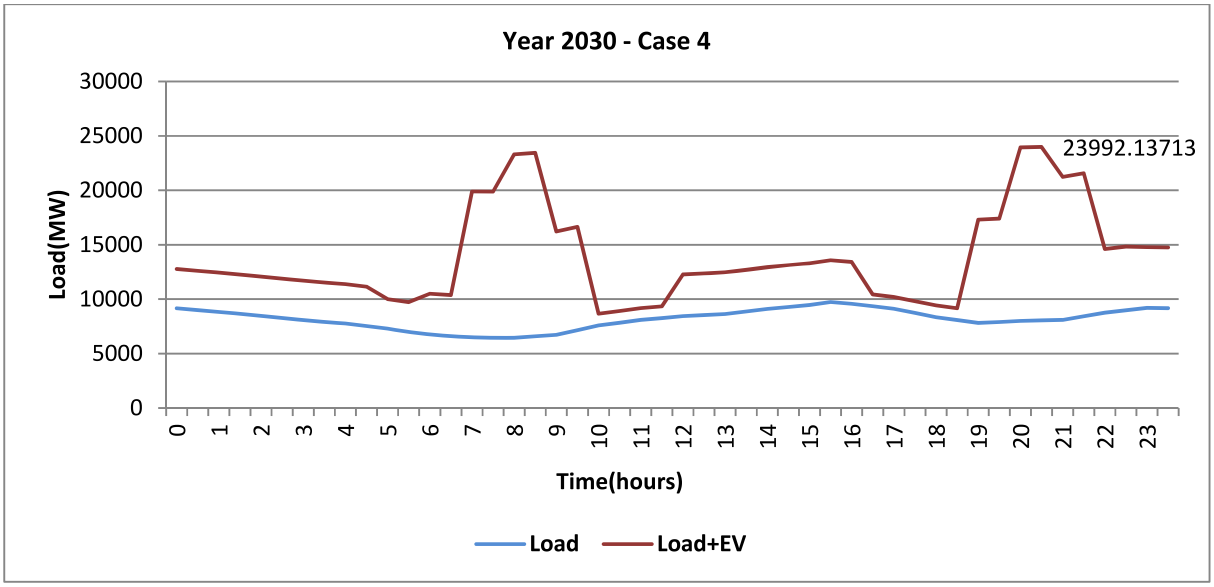

Figure 15: Conventional load curve and total load curve, including EV, for Delhi in year 2030 – Case 4

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 15 that, compared with the conventional peak of 9734 MW which occurs at around 4 PM, the total load curve, having EV load included, contains two peaks. One peak of 23453 MW occurs at 8.30 AM while the other peak of 23992 MW occurs at 8.30 PM. This shows that the demand of EV load is around 146% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. As the EV load requirement is around 1.5 times of the conventional load, proper planning is required in advance to address this scenario. Further, it also shows that shifting of charging of EVs from home to charging stations by 100% will make the EPDS operation very challenging. Therefore, the dual peak load conditions occurring due EV load needs proper operational measures and needs specific technology interventions and capacity augmentations.

7.2 Mumbai

To analyse the load curve of Mumbai in years 2025 and 2030, the load curves of conventional load, as described in Section 5, and the estimated load corresponding to number of EVs, as described in Section 6, were utilised. Accordingly, the total load curves under four different charging scenarios were prepared. The results and our observations are summarised as follows –

Case 1:

In this case, 90% of total Non-commercial 4-wheelers EVs are charged at home and rest 10% are charged at the charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional and EV load, obtained from the simulation studies is shown in the figure below.

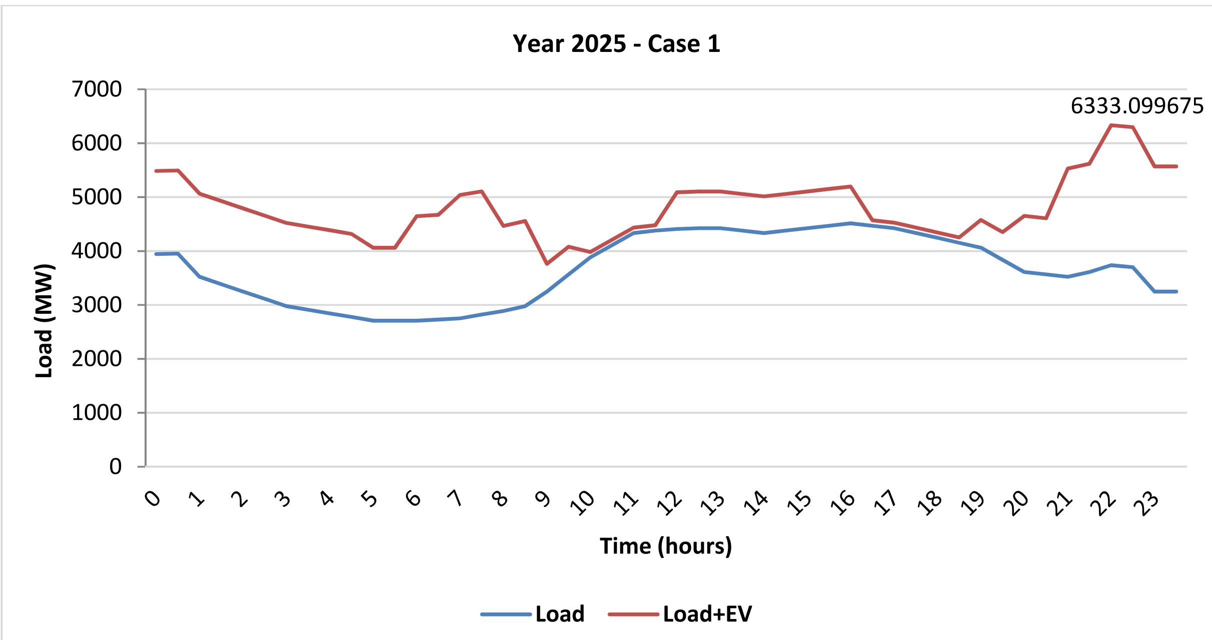

Figure 16: Conventional load curve & total load curve, including EV, for Mumbai in year 2025 – Case 1

The forecasted peak loading conditions for the EPDS of Mumbai in the year 2025 is shown in Figure 16. From the above Figure, it can be observed that the peak load, which occurs at around 4 PM when EV is not considered, has now shifted to around 10 PM in the night when EV load is considered along with the conventional load. The normal peak load, without EV, in the year 2025 is 4514 MW. While, the peak load after EV penetration (EV+Load) has become 6333 MW in year 2025. This shows that the peak load demand in Mumbai due to EV in the year 2025 will increase by 1819 MW, i.e. around 40%. The peak load of the curve is also shifted from 4 PM to 10 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

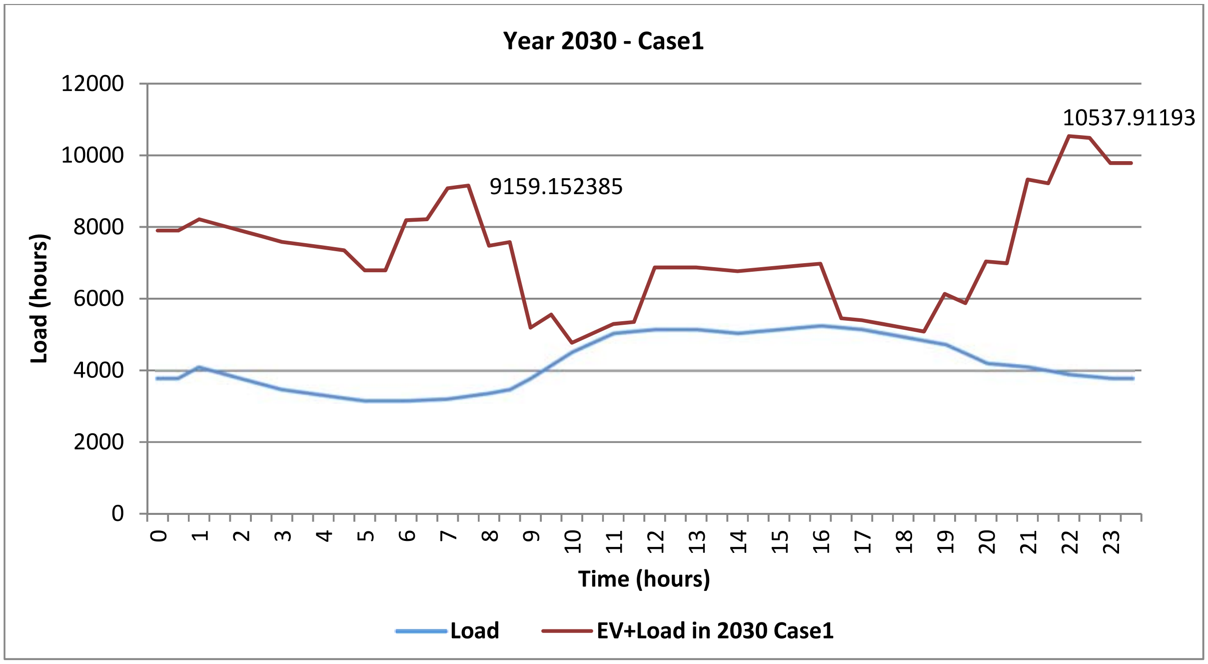

Figure 17: Conventional load curve & total load curve, including EV, for Mumbai in year 2030 – Case 1

Figure 17 shows the forecasted peak loading condition for the EPDS of Mumbai in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 5248 MW which occurs at around 4 PM, the total load curve, having EV load included, contains two peaks. One peak of around 9159 MW occurs at 7:30 AM while the other peak of around 10537 MW occurs at 10 PM. The two peaks in the load curve occurs due to EV owners' behaviour of getting EV charged from the charging stations either in the morning or late in the evening. The load curve shows that the peak load demand in Mumbai due to EV in the year 2030 will increase drastically by 5289 MW, i.e. around 100%. The peak load of the curve is also shifted from 4 PM to 10 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

Case 2:

In this case, 70% of total Non-commercial 4-wheelers EVs are charged at home and rest 30% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

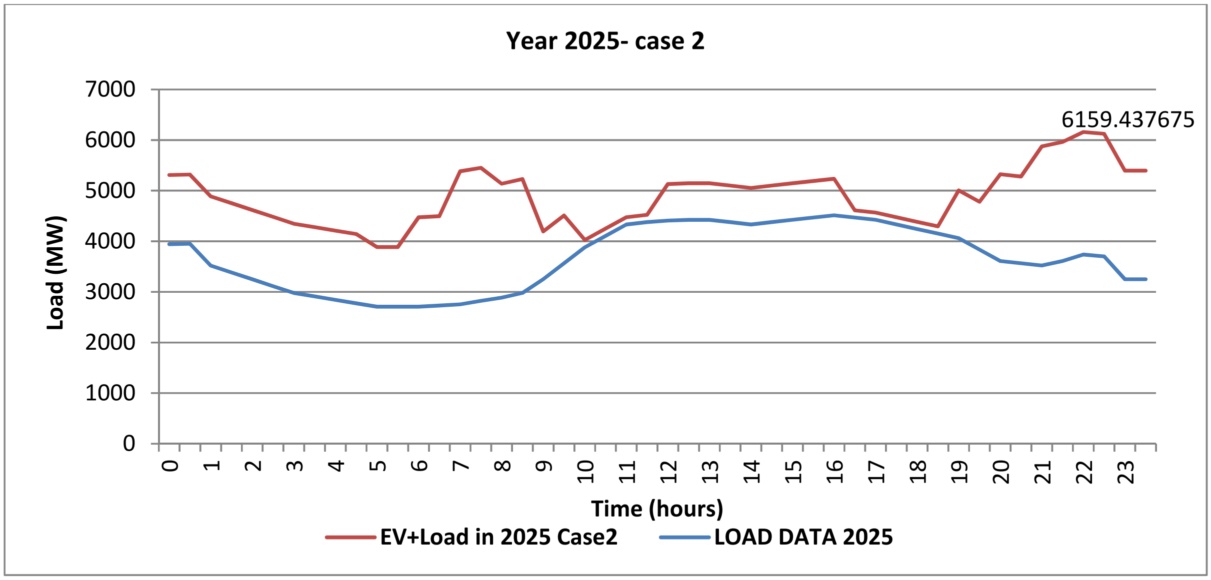

Figure 18: Conventional load curve & total load curve, including EV, for Mumbai in year 2025 – Case 2

From the above figure, it can be observed that, compared with the conventional peak of 4514 MW which occurs at around 4 PM, the peak of total load curve, including EV, occurs at 10 PM with the peak load of around 6159 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been slightly reduced by 174 MW. It is so, because in this case 20% more non-commercial vehicles are being charged from the charging stations before the system peak occurs. Therefore, the charging of more vehicles at the charging station before the system peak load condition helps in flattening the load curve. It also needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 10 PM, is 2422 MW which is 64% more than the conventional load demand at that time.

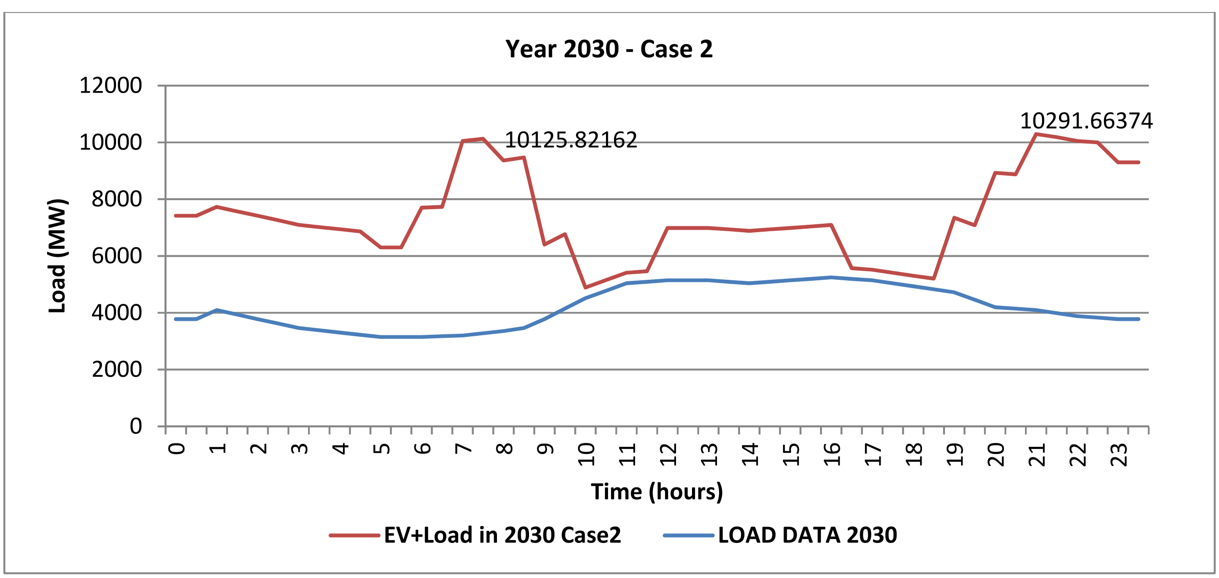

Figure 19: Conventional load curve & total load curve, including EV, for Mumbai in year 2030 – Case 2

Figure 19 shows the conventional load curve and total load curve, including EV, for Mumbai in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 5248 MW which occurs at around 4 PM, the total load curve, having EV load included, contains two peaks. One peak of around 10125 MW occurs at 7.30 AM while the other peak of around 10291MW occurs at 9 PM. This shows that the demand of EV load at peak load condition is 96% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required to address this scenario. As in the case of year 2025, in this case also, it needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 9 PM, is 6303 MW which is around 158% more than the conventional load demand at that time. This shows that, in case of Mumbai, the conventional load is lesser than the EV load. Therefore, the EV integration will pose a huge challenge in addressing the extra power demand required by the EVs.

Case 3:

In this case, 50% of total Non-commercial 4-wheelers EVs are charged at home and rest 50% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

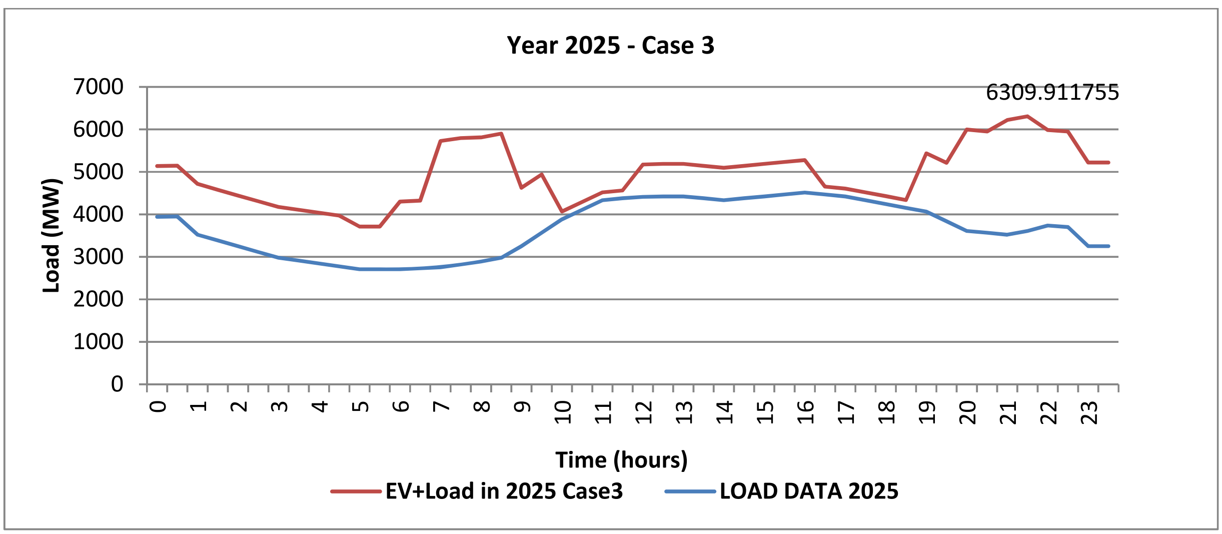

Figure 20: Conventional load curve & total load curve, including EV, for Mumbai in year 2025 – Case 3

From the Figure 20, it can be observed that, compared with the conventional peak of 4514 MW which occurs at around 4 PM, the peak of total load curve, including EV, occurs at 9.30 PM with the peak load of around 6309 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been slightly reduced by 24 MW. It is so, because in this case 40% more non-commercial vehicles are being charged from the charging stations.

Therefore, the system peak also shifts from 10 PM to 9.30 PM. Accordingly, the charging of more vehicles at the charging stations helps in reducing the system peak load value. As in previous case, in this case also, it may be considered a case of devising a method of identifying the correct timing and mix of the EV charging at home as well as at charging stations to reduce stress on the EPDS. It is also observed that the case 2 of year 2025, when only 30% non-commercial vehicles are charged from the charging station, is better in reducing the peak load situation on the EPDS.

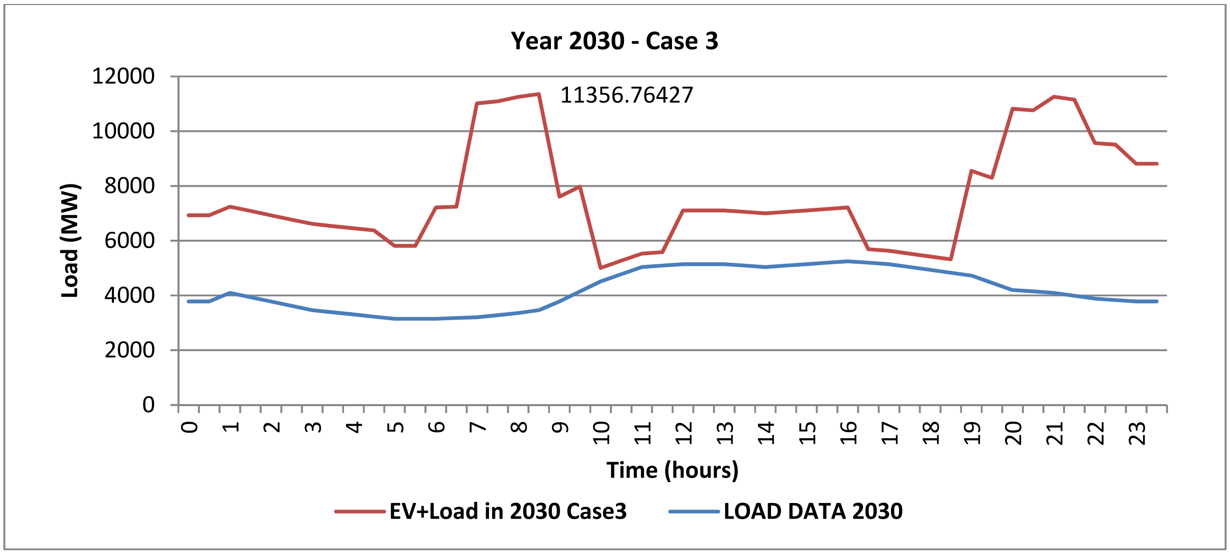

Figure 21: Conventional load curve & total load curve, including EV, for Mumbai in year 2030 – Case 3

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 21 that, compared with the conventional peak of 5248 MW which occurs at around 4 PM, two peaks are observed in the load curve having EV load integrated. First peak of total load curve, including EV, occurs at 8:30 AM with the peak load of around 11356 MW. The second peak of total load curve, including EV, occurs at 9 PM with the peak load of around 11258 MW. This shows that the demand of EV load is around 116% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required from day 1 to address this scenario. On comparing with the total load curve of case 2 in the year 2030, it is also observed that, in this case, the peak load has been increased by 1065 MW. It shows that shifting of charging of EVs from home to charging stations does not play major role in reducing the total system load. Therefore, the charging of more vehicles at the charging stations, before the system peak load condition occurs, will not help in flattening the load curve.

Case 4:

In this case, all non-commercial 4-wheelers EVs are charged at charging station, keeping other types of vehicles charging same as described in the section 4. Total load curve, including conventional as well as EV load, obtained from the simulation studies under this case is shown in the figure below.

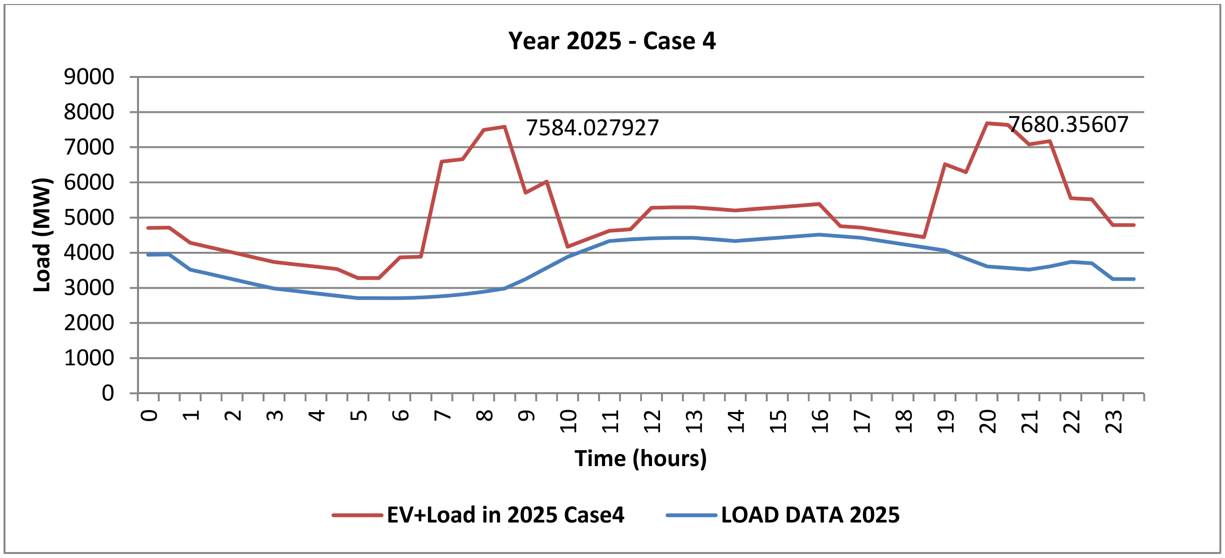

Figure 22: Conventional load curve & total load curve, including EV, for Mumbai in year 2025 – Case 4

From the Figure 22, it can be observed that, compared with the conventional peak of 4514 MW which occurs at around 4 PM, the total load curve having EV load included contains two peaks. One peak of 7584 MW occurs at 8:30 AM while the other peak of 7680 MW occurs at 8 PM. These peaks occur due to EV owners' behaviour of charging their vehicles either in the morning time, before going to work, or in the evening time, after coming from the work. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been increased by 1347 MW. It is so, because in this case all non-commercial vehicles are being charged from the charging stations. The system peak also shifts from 10 PM, as in case 1, to 8.00 PM in this case.

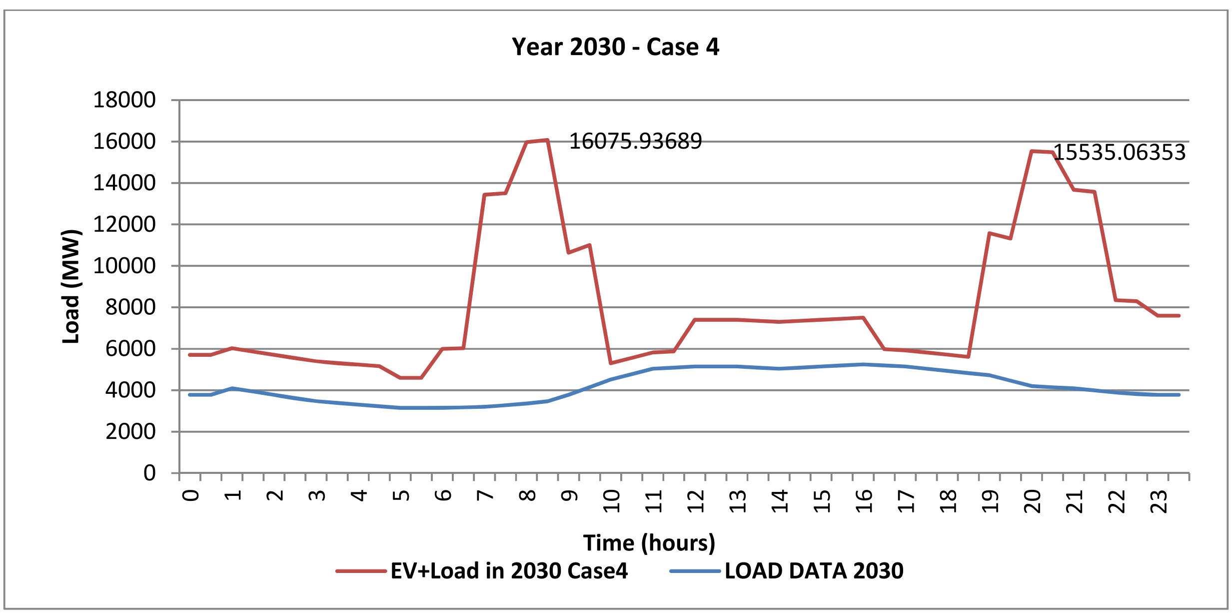

Figure 23: Conventional load curve & total load curve, including EV, for Mumbai in year 2030 – Case 4

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 23 that, compared with the conventional peak of 5248 MW which occurs at around 4 PM, the total load curve, having EV load included, contains two peaks. One peak of 16075 MW occurs at 8.30 AM while the other peak of 15535 MW occurs at 8 PM. This shows that the demand of EV load is around 200% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. As the EV load surpasses conventional load by manifolds, proper planning is required in advance to address this scenario. Further, it also shows that shifting of charging of EVs from home to charging stations by 100% will make the EPDS operation very challenging. Therefore, the dual peak load conditions occurring due EV load needs proper operational measures and needs specific technology interventions and capacity augmentations.

7.3 Kolkata

To analyse the load curve of Kolkata in years 2025 and 2030, the load curves of conventional load, as described in Section 5, and the estimated load corresponding to number of EVs, as described in Section 6, were utilised. Accordingly, the total load curves under four different charging scenarios were prepared. The results and our observations are summarised as follows –

Case 1:

In this case, 90% of total Non-commercial 4-wheelers EVs are charged at home and rest 10% are charged at the charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional and EV load, obtained from the simulation studies is shown in the figure below.

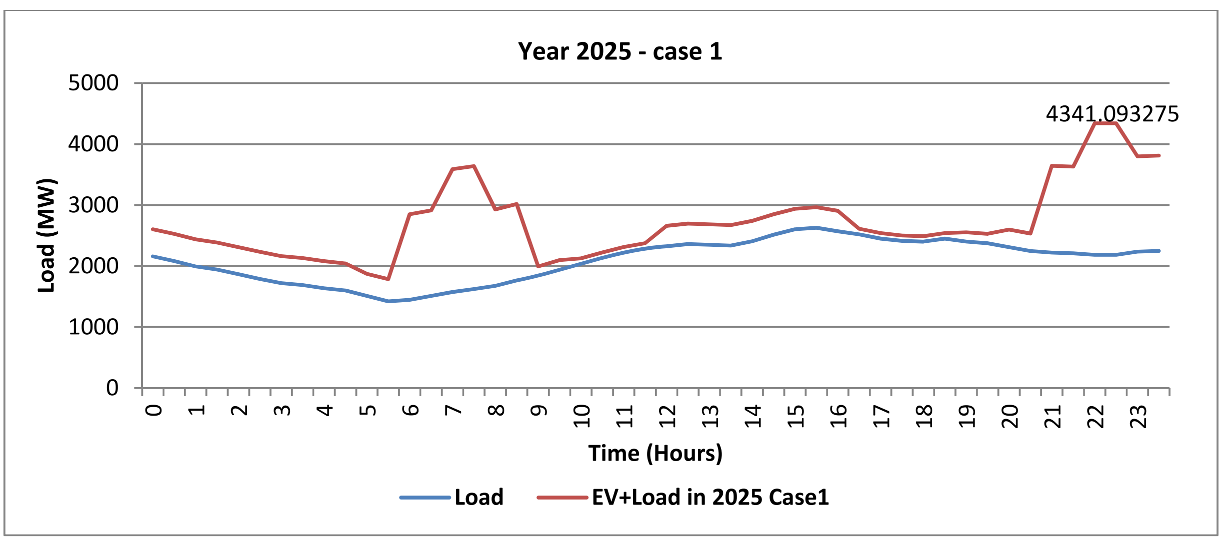

Figure 24: Conventional load curve & total load curve, including EV, for Kolkata in year 2025 – Case 1

The forecasted peak loading conditions for the EPDS of Kolkata in the year 2025 is shown in Figure 24. From the above Figure, it can be observed that the peak load, which occurs at around 3:30 PM when EV is not considered, has now shifted to around 10 PM in the night when EV load is considered along with the conventional load. The normal peak load, without EV, in the year 2025 is 2629 MW. While, the peak load after EV penetration (EV+Load) has become 4341 MW in year 2025. This shows that the peak load demand in Kolkata due to EV in the year 2025 will increase by 1712 MW, i.e. around 65%. The peak load of the curve is also shifted from 3:30 PM to 10 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

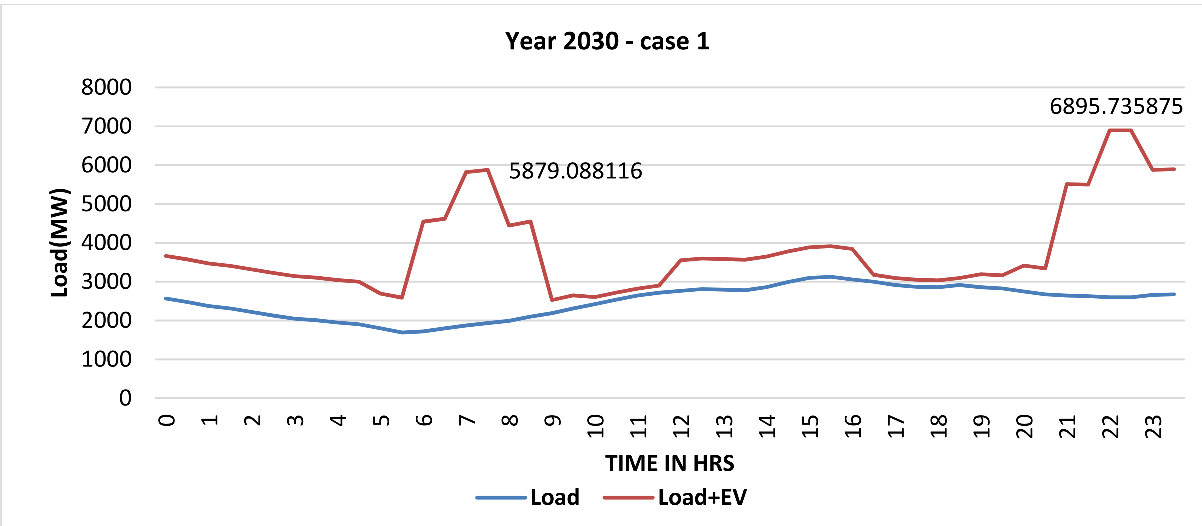

Figure 25: Conventional load curve & total load curve, including EV, for Kolkata in year 2030 – Case 1

Figure 25 shows the forecasted peak loading condition for the EPDS of Kolkata in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 3126 MW which occurs at around 3:30 PM, the total load curve, having EV load included, contains two peaks. One peak of around 5879 MW occurs at 7:30 AM while the other peak of around 6896 MW occurs at 10 PM. The two peaks in the load curve occurs due to EV owners' behaviour of getting EV charged from the charging stations either in the morning or late in the evening. The load curve shows that the peak load demand in Kolkata due to EV in the year 2030 will increase drastically by 3770 MW, i.e. around 120%. The peak load of the curve is also shifted from 3:30 PM to 10 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

Case 2:

In this case, 70% of total Non-commercial 4-wheelers EVs are charged at home and rest 30% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

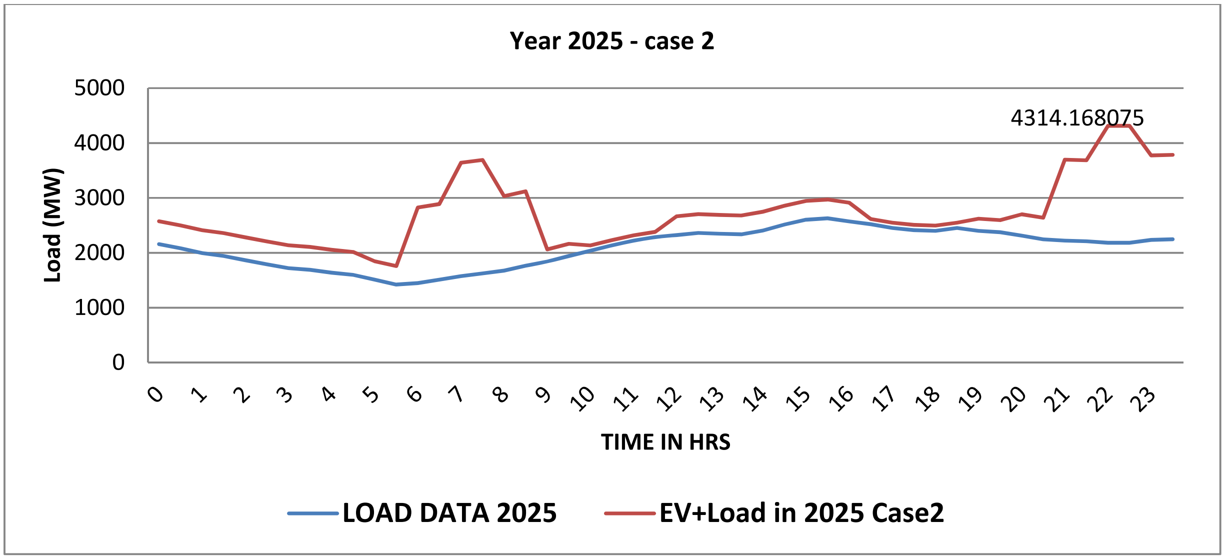

Figure 26: Conventional load curve & total load curve, including EV, for Kolkata in year 2025 – Case 2

From the above figure, it can be observed that, compared with the conventional peak of 2629 MW which occurs at around 3:30 PM, the peak of total load curve, including EV, occurs at 10 PM with the peak load of around 4314 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been slightly reduced by 27 MW. It is so, because in this case 20% more non-commercial vehicles are being charged from the charging stations before the system peak occurs. Therefore, the charging of more vehicles at the charging station before the system peak load condition helps in flattening the load curve. It also needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 10 PM, is 2130 MW which is 98% more than the conventional load demand at that time.

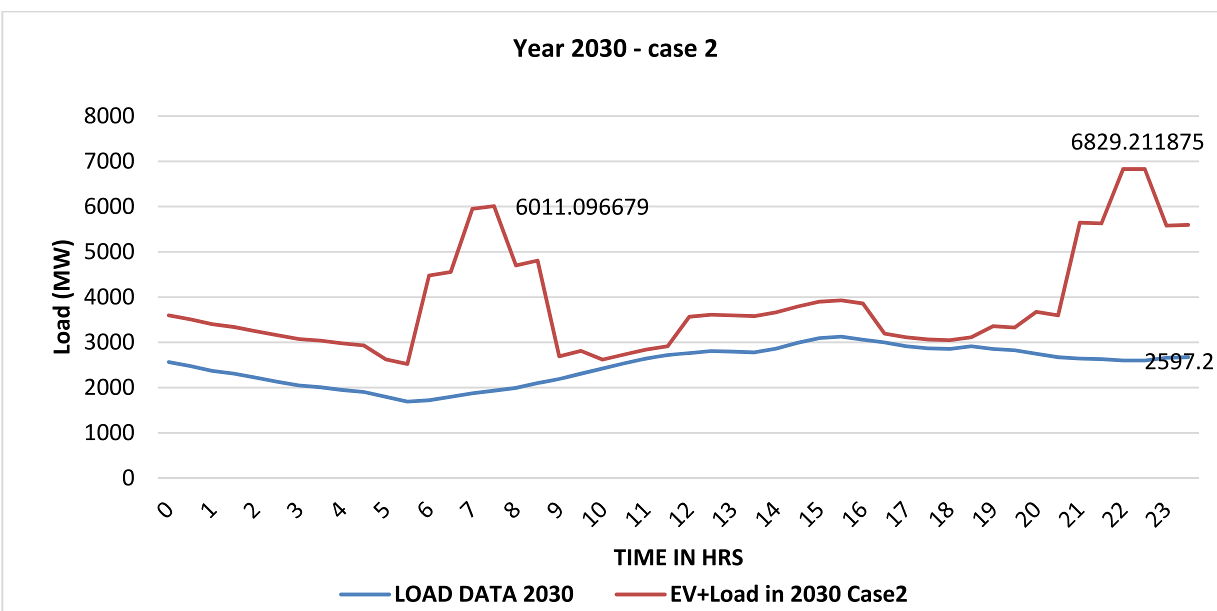

Figure 27: Conventional load curve & total load curve, including EV, for Kolkata in year 2030 – Case 2

Figure 27 shows the conventional load curve and total load curve, including EV, for Kolkata in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 3126 MW which occurs at around 3:30 PM, the total load curve, having EV load included, contains two peaks. One peak of around 6011 MW occurs at 7.30 AM while the other peak of around 6829 MW occurs at 10 PM. This shows that the demand of EV load at peak load condition is 118% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required to address this scenario. As in the case of year 2025, in this case also, it needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 10 PM, is 4232 MW which is around 163% more than the conventional load demand at that time. This shows that, in case of Kolkata, the conventional load is lesser than the EV load. Therefore, the EV integration will pose a huge challenge in addressing the extra power demand required by the EVs.

Case 3:

In this case, 50% of total Non-commercial 4-wheelers EVs are charged at home and rest 50% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

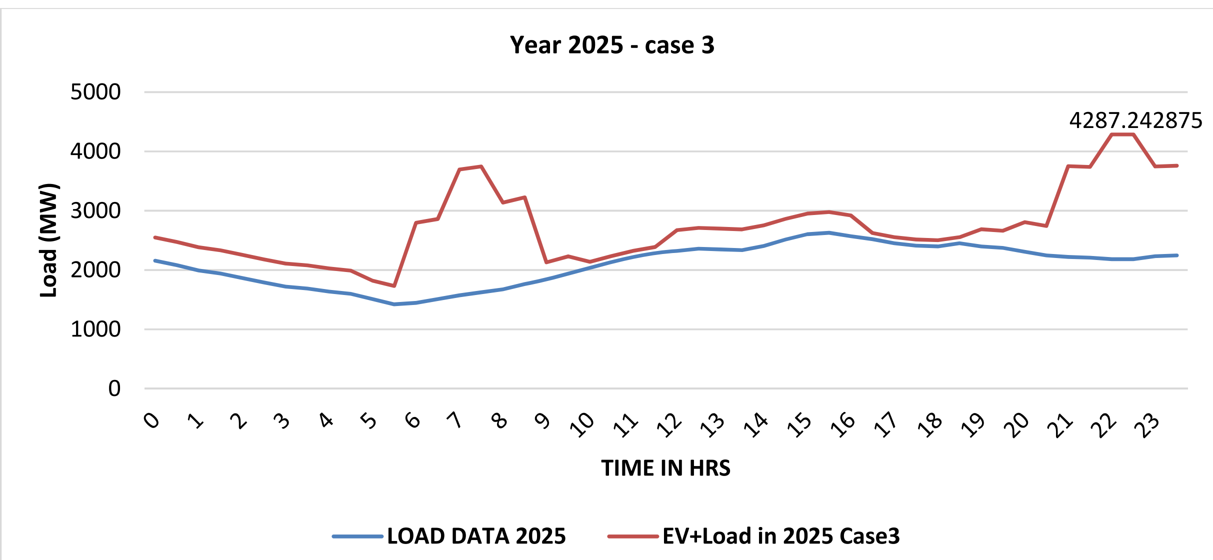

Figure 28: Conventional load curve & total load curve, including EV, for Kolkata in year 2025 – Case 3

From the Figure 28, it can be observed that, compared with the conventional peak of 2629 MW which occurs at around 3:30 PM, the peak of total load curve, including EV, occurs at 10 PM with the peak load of around 4287 MW. On comparing with the total load curve of case 1 in the year

2025, it also observed that, in this case, the peak load has been reduced by 54 MW. It is so, because in this case 20% more non-commercial vehicles are being charged from the charging stations. Accordingly, the charging of more vehicles at the charging stations helps in reducing the system peak load value. As in previous case, in this case also, it may be used as a case of devising a method of identifying the correct timing and mix of the EV charging at home as well as at charging stations to reduce stress on the EPDS. It is also observed that compared with case 2 of year 2025, when only 30% non-commercial vehicles are charged from the charging station, this case is better in reducing the peak load situation on the EPDS.

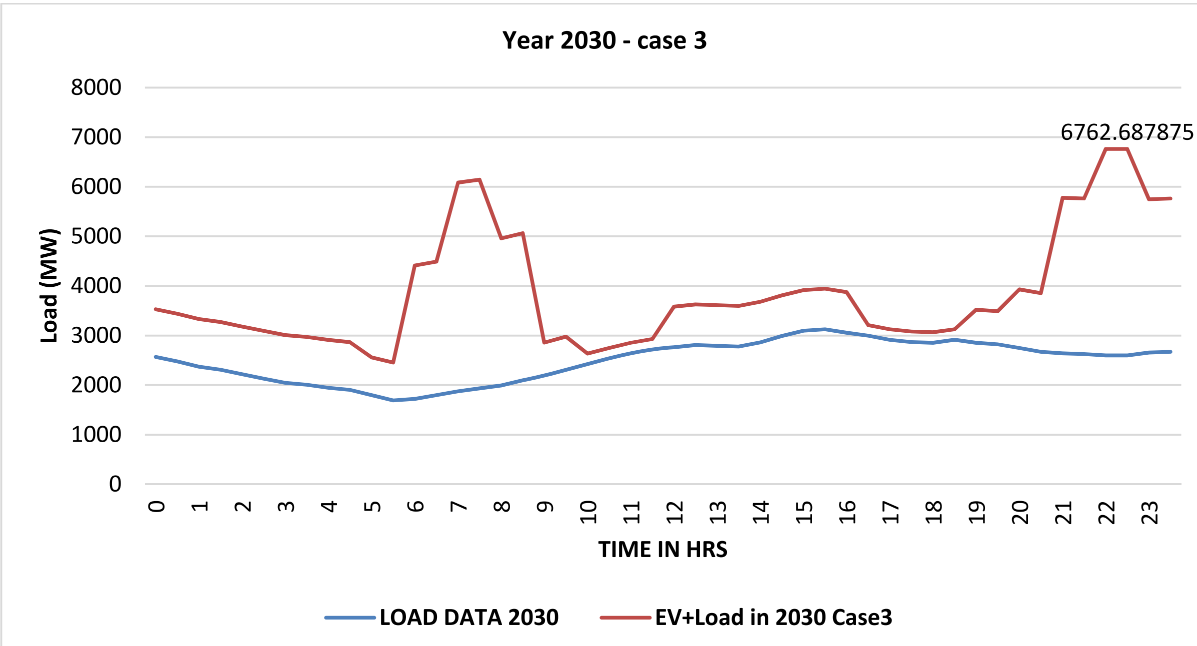

Figure 29: Conventional load curve & total load curve, including EV, for Kolkata in year 2030 – Case 3

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 29 that, compared with the conventional peak of 3126 MW which occurs at around 3:30 PM, the peak of total load curve, including EV, occurs at 10 PM with the peak load of around 6763 MW. This shows that the demand of EV load is around 116% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required from day 1 to address this scenario. On comparing with the total load curve of case 1 in the year 2030, it is also observed that, in this case, the peak load has been reduced by 133 MW. It shows that shifting of charging of EVs from home to charging stations will play a role in reducing the total system load. Therefore, the charging of more vehicles at the charging stations, before the system peak load condition occurs will help in flattening the load curve.

Case 4:

In this case, all non-commercial 4-wheelers EVs are charged at charging station, keeping other types of vehicles charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies under this case is shown in the figure below.

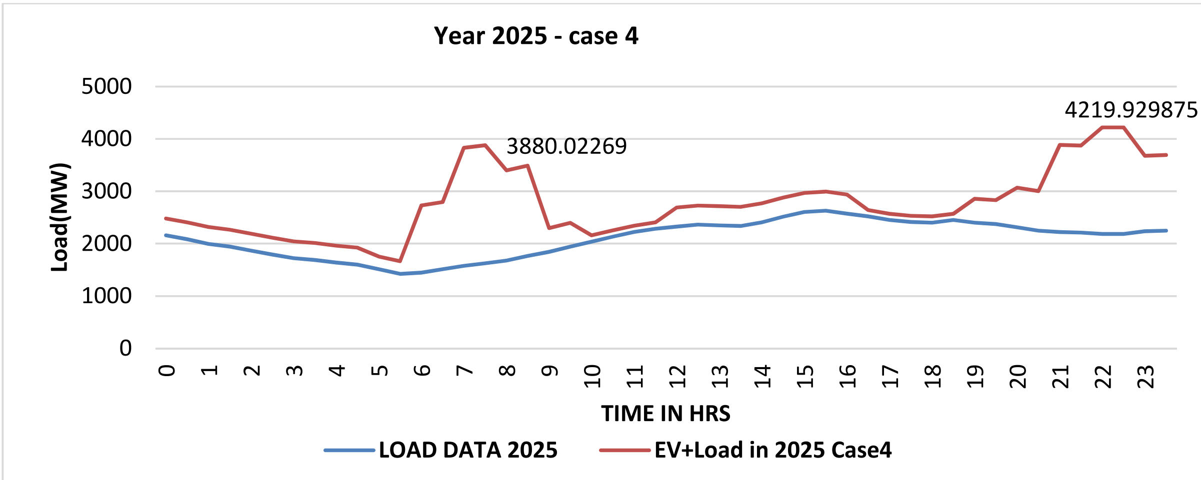

Figure 30: Conventional load curve & total load curve, including EV, for Kolkata in year 2025 – Case 4

From the Figure 30, it can be observed that, compared with the conventional peak of 2629 MW which occurs at around 3:30 PM, the total load curve having EV load included contains two peaks. One peak of 3880 MW occurs at 7:30 AM while the other peak of 4220 MW occurs at 10 PM. These peaks occur due to EV owners' behaviour of charging their vehicles either in the morning time, before going to work, or in the evening time, after coming from the work. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been reduced by 121 MW.

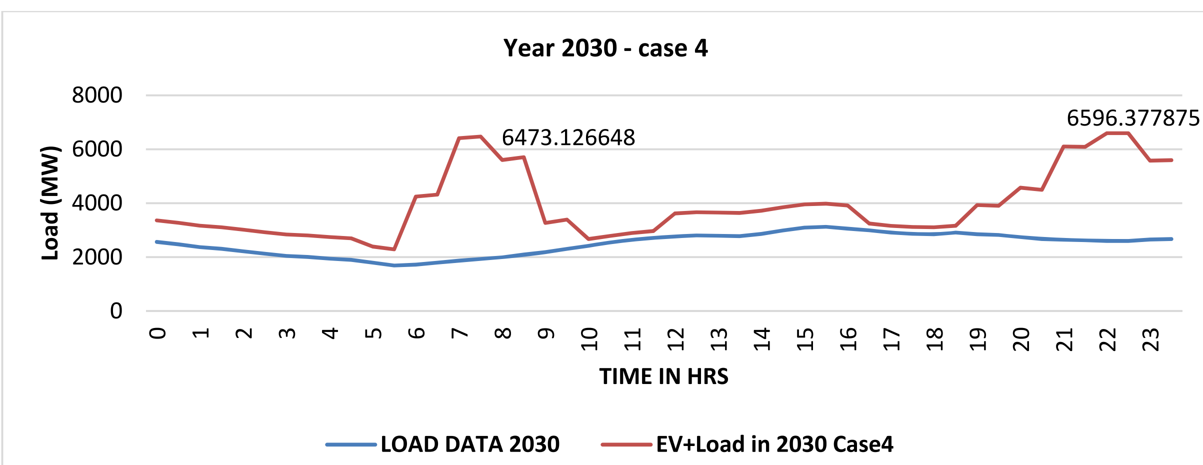

Figure 31: Conventional load curve & total load curve, including EV, for Kolkata in year 2030 – Case 4

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 31 that, compared with the conventional peak of 3126 MW which occurs at around 3:30 PM, the total load curve, having EV load included, contains two peaks. One peak of 6473 MW occurs at 7.30 AM while the other peak of 6596 MW occurs at 10 PM. This shows that the demand of EV load is around 111% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. As the EV load surpasses conventional load by more than 100%, proper planning is required in advance to address this scenario. Further, it also shows that shifting of charging of EVs from home to charging stations by 100% will make the EPDS operation very challenging. Therefore, as in case of other cities, the dual peak load conditions occurring due EV load needs proper operational measures and needs specific technology interventions and capacity augmentations.

7.4 Chennai

To analyse the load curve of Chennai in years 2025 and 2030, the load curves of conventional load, as described in Section 5, and the estimated load corresponding to number of EVs, as described in Section 6, were utilised. Accordingly, the total load curves under four different charging scenarios were prepared. The results and our observations are summarised as follows –

Case 1:

In this case, 90% of total Non-commercial 4-wheelers EVs are charged at home and rest 10% are charged at the charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional and EV load, obtained from the simulation studies is shown in the figure below.

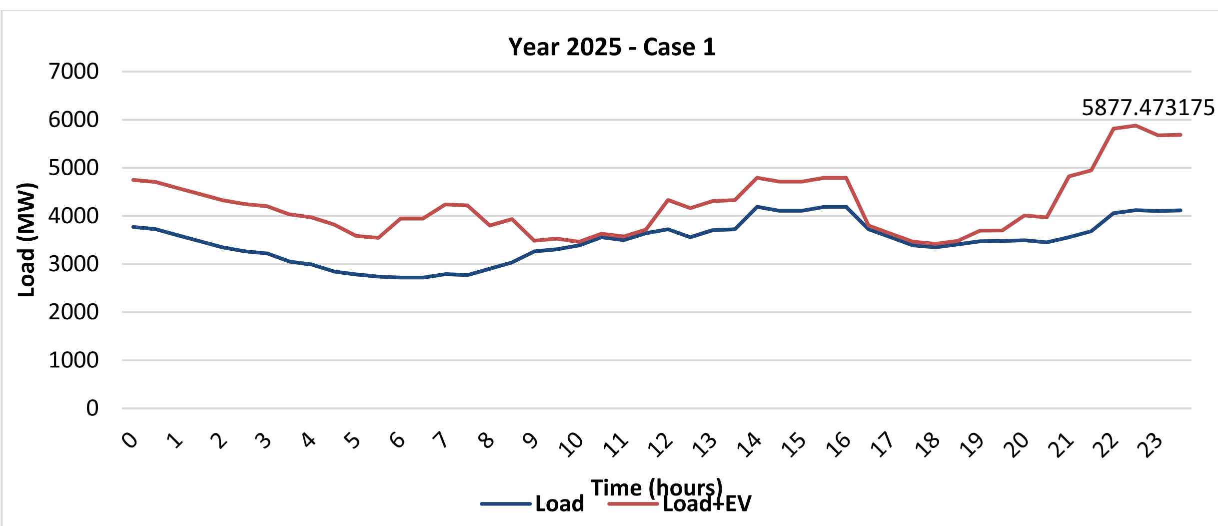

Figure 32: Conventional load curve & total load curve, including EV, for Chennai in year 2025 – Case 1

The forecasted peak loading conditions for the EPDS of Chennai in the year 2025 is shown in Figure 32. From the above Figure, it can be observed that the peak load, which occurs at around 2 PM when EV is not considered, has now shifted to around 10:30 PM in the night when EV load is considered along with the conventional load. The normal peak load, without EV, in the year 2025 is 4188 MW. While, the peak load after EV penetration (EV+Load) has become 5877 MW in year 2025. This shows that the peak load demand in Chennai due to EV in the year 2025 will increase by 1689 MW, i.e. around 40%. The peak load of the curve is also shifted from 2 PM to 10:30 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

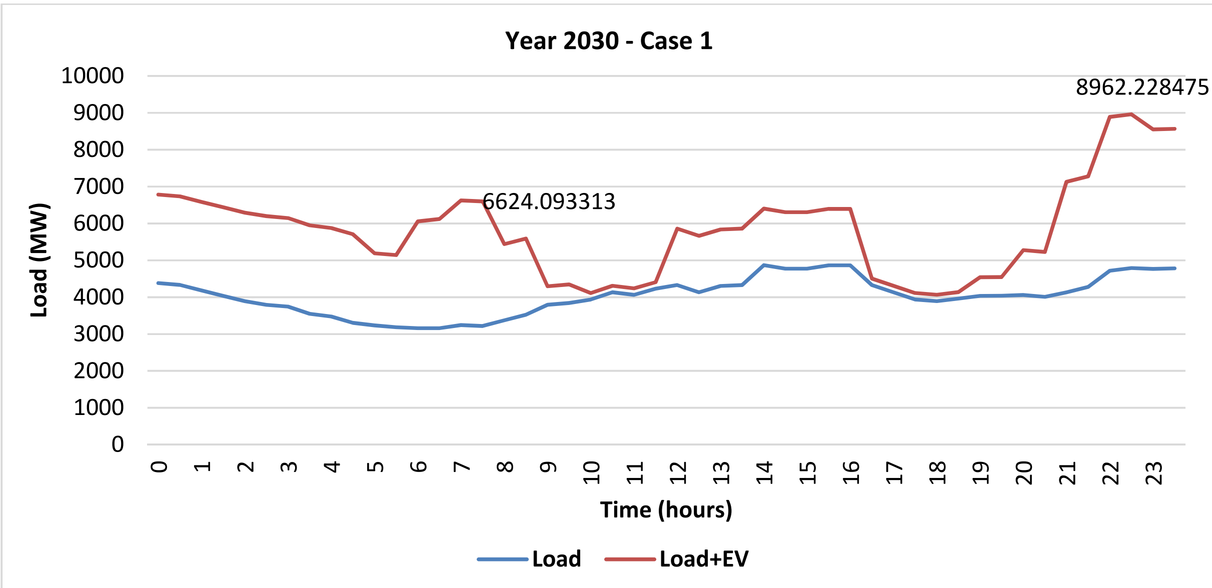

Figure 33: Conventional load curve & total load curve, including EV, for Chennai in year 2030 – Case 1

Figure 33 shows the forecasted peak loading condition for the EPDS of Chennai in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 4869 MW which occurs at around 2 PM, the peak with EV is of around 8962 MW which occurs at 10:30 PM. The load curve shows that the peak load demand in Chennai due to EV in the year 2030 will increase drastically by 4093 MW, i.e. around 84%. The peak load of the curve is also shifted from 2 PM to 10:30 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

Case 2:

In this case, 70% of total Non-commercial 4-wheelers EVs are charged at home and rest 30% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

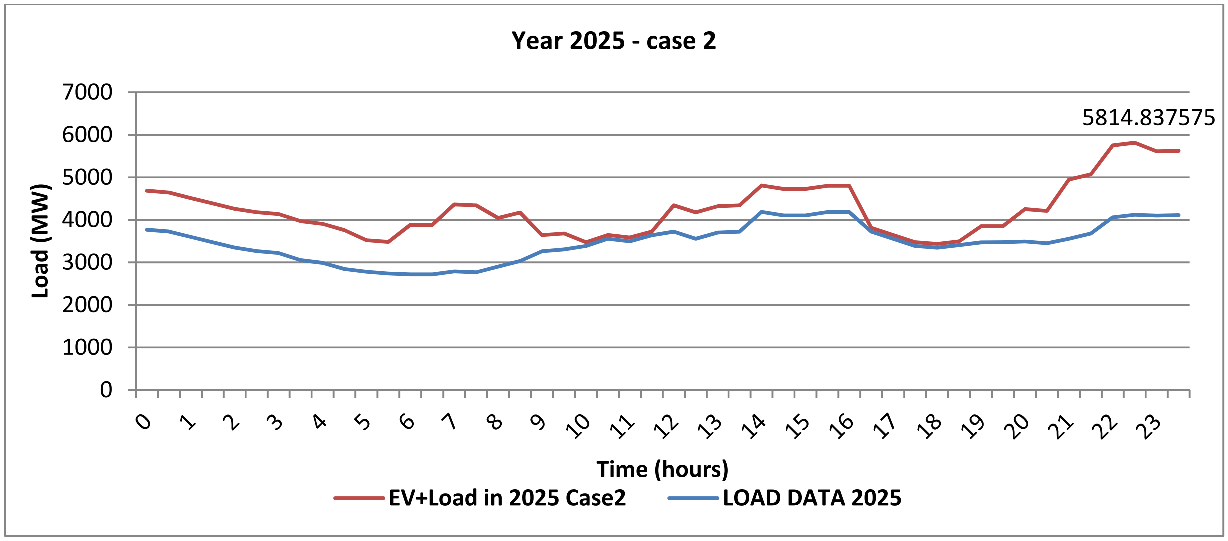

Figure 34: Conventional load curve & total load curve, including EV, for Chennai in year 2025 – Case 2

From the above figure, it can be observed that, compared with the conventional peak of 4188 MW which occurs at around 2 PM, the peak of total load curve, including EV, occurs at 10:30 PM with the peak load of around 5815 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been slightly reduced by 62 MW. It is so, because in this case 20% more non-commercial vehicles are being charged from the charging stations before the system peak occurs. Therefore, the charging of more vehicles at the charging station before the system peak load condition helps in flattening the load curve. It also needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 10:30 PM, is 1694 MW which is 41% more than the conventional load demand at that time.

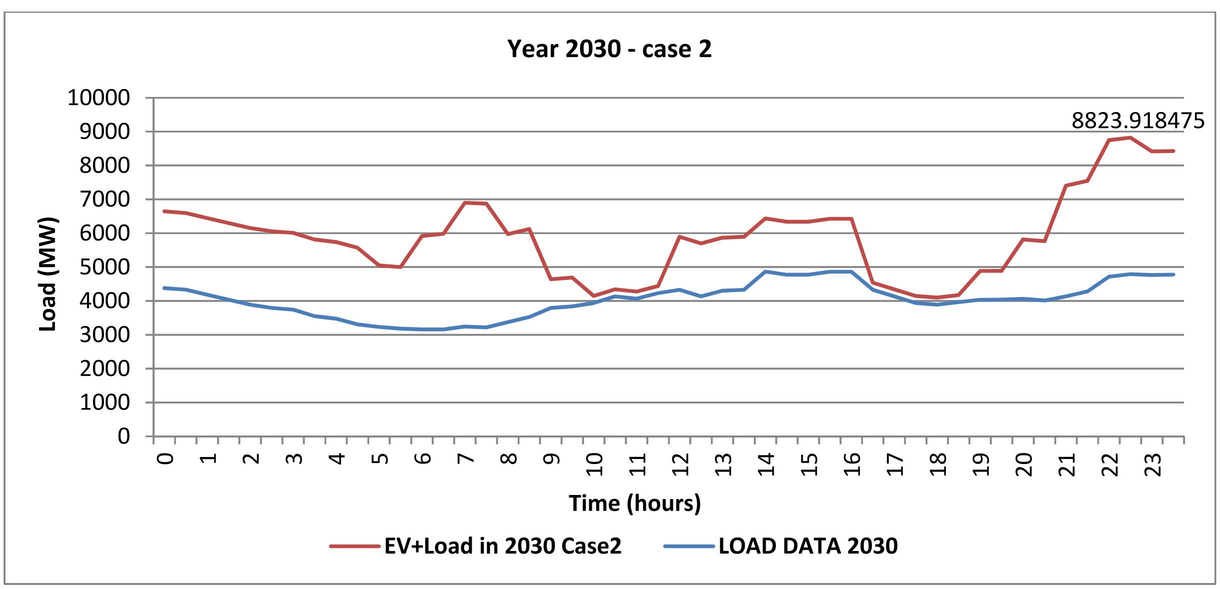

Figure 35: Conventional load curve & total load curve, including EV, for Chennai in year 2030 – Case 2

Figure 35 shows the conventional load curve and total load curve, including EV, for Chennai in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 4869 MW which occurs at around 2 PM, the total load curve, having EV load included, contains peak of around 8824 MW occurs at 10.30 PM. This shows that the demand of EV load at peak load condition is 81% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required to address this scenario. As in the case of year 2025, in this case also, it needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 10:30 PM, is 4032 MW which is around 84% more than the conventional load demand at that time. This shows that, similar to other cities in case of Chennai also, the conventional load is lesser than the EV load. Therefore, the EV integration will pose a huge challenge in addressing the extra power demand required by the EVs.

Case 3:

In this case, 50% of total Non-commercial 4-wheelers EVs are charged at home and rest 50% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

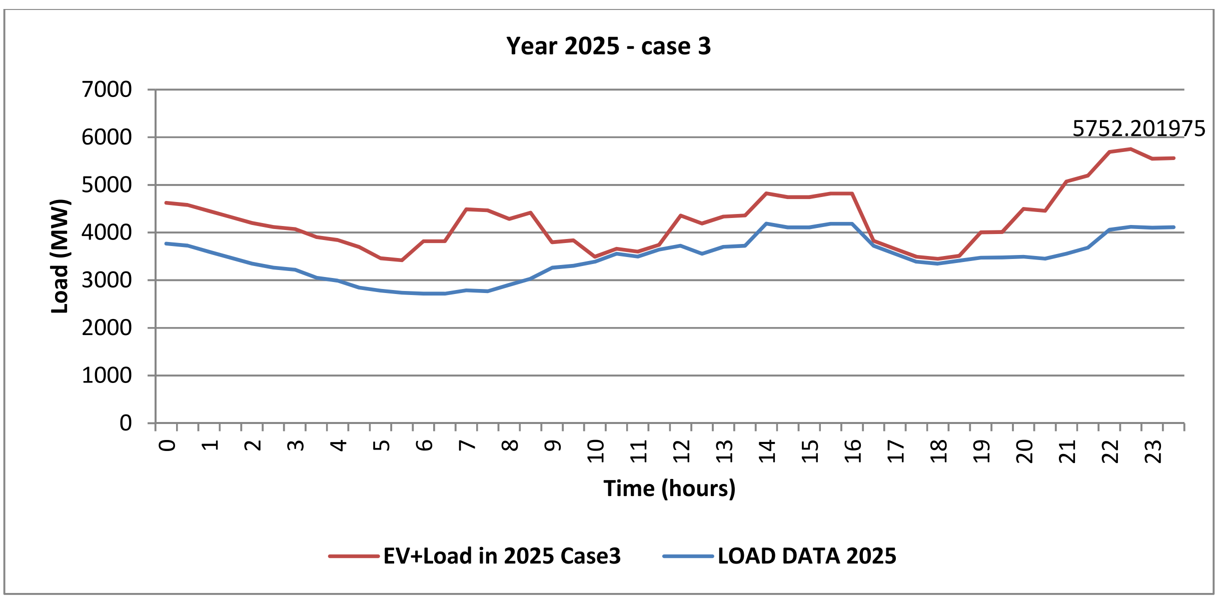

Figure 36: Conventional load curve & total load curve, including EV, for Chennai in year 2025 – Case 3

From the Figure 36, it can be observed that, compared with the conventional peak of 4188 MW which occurs at around 2 PM, the peak of total load curve, including EV, occurs at 10:30 PM with the peak load of around 5752 MW. On comparing with the total load curve of case 1 in the year

2025, it also observed that, in this case, the peak load has been reduced by 125 MW. It is so, because in this case 40% more non-commercial vehicles are being charged from the charging stations. Accordingly, the charging of more vehicles at the charging stations helps in reducing the system peak load value. As in previous case, in this case also, it shows a strong case of devising a method of identifying the correct timing and mix of the EV charging at home as well as at charging stations to reduce stress on the EPDS. It is also observed that compared to case 2 of year 2025, when only 30% non-commercial vehicles are charged from the charging station, this case is better in reducing the peak load situation on the EPDS.

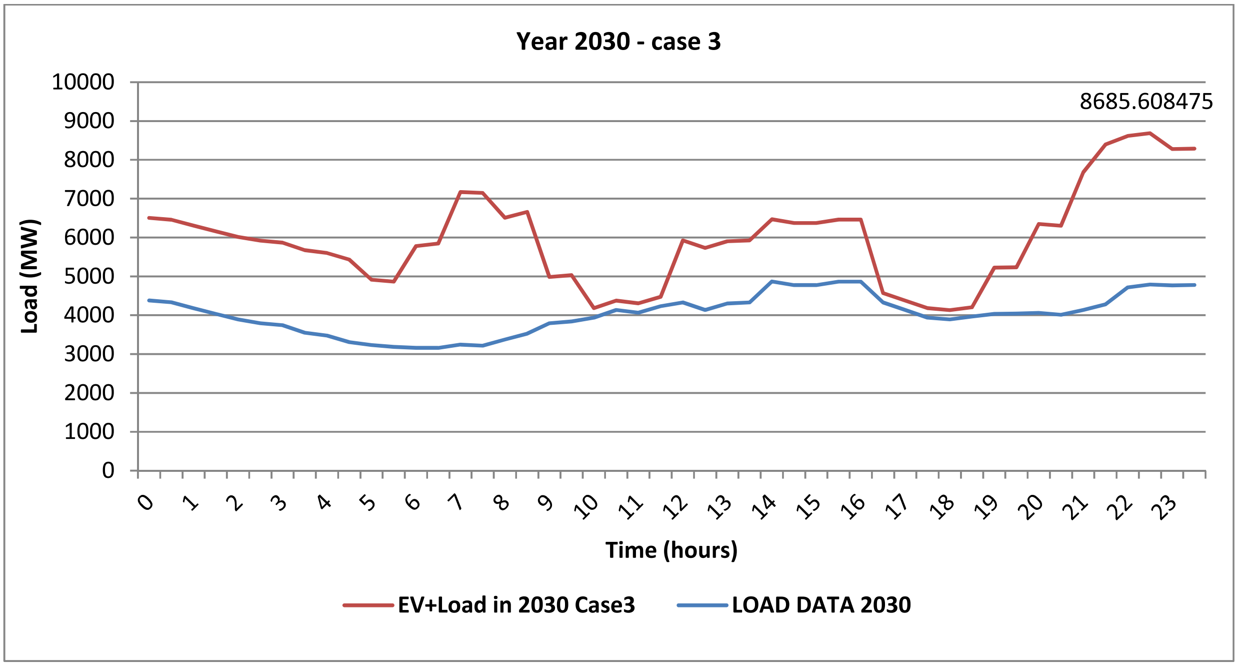

Figure 37: Conventional load curve & total load curve, including EV, for Chennai in year 2030 – Case 3

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 37 that, compared with the conventional peak of 4869 MW which occurs at around 2 PM, the peak of total load curve, including EV, occurs at 10:30 PM with the peak load of around 8686 MW. This shows that the demand of EV load is around 78% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required from day 1 to address this scenario. On comparing with the total load curve of case 2 in the year 2030, it is also observed that, in this case, the peak load has been reduced by 138 MW. It shows that shifting of charging of EVs from home to charging stations will play a role in reducing the total system load. Therefore, in this case, the charging of more vehicles at the charging stations before the system peak load condition occurs, helps in flattening the load curve. Therefore it may be considered a case to identify right time and right mix of charging scenario to address peak load situation.

Case 4:

In this case, all non-commercial 4-wheelers EVs are charged at charging station, keeping other types of vehicles charging same as described in the section 4. Total load curve, including conventional as well as EV load, obtained from the simulation studies under this case is shown in the figure below.

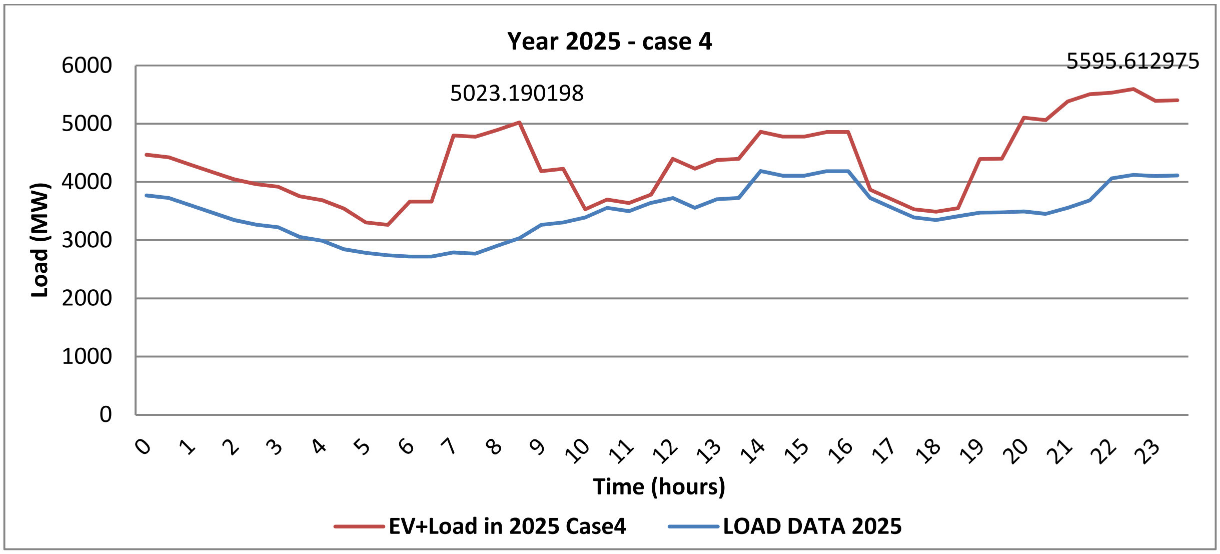

Figure 38: Conventional load curve & total load curve, including EV, for Chennai in year 2025 – Case 4

From the Figure 38, it can be observed that, compared with the conventional peak of 4188 MW which occurs at around 2 PM, the total load curve having EV load included contains two peaks. One peak of 5023 MW occurs at 7:30 AM while the other peak of 5596 MW occurs at 10:30 PM. These peaks occur due to EV owners' behaviour of charging their vehicles either in the morning time, before going to work, or in the evening time, after coming from the work. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been drastically reduced by 281 MW.

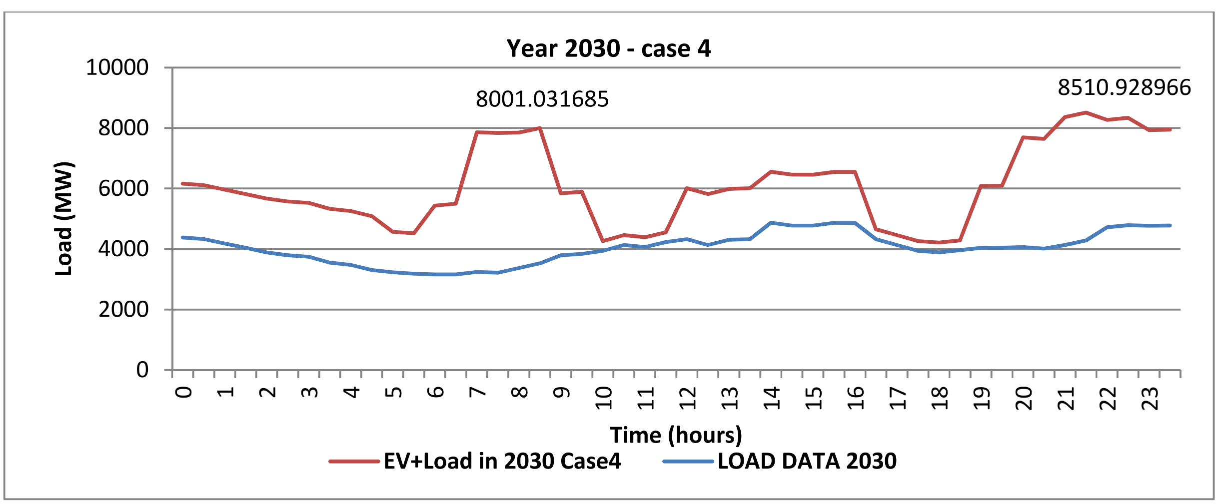

Figure 39: Conventional load curve & total load curve, including EV, for Chennai in year 2030 – Case 4

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 39 that, compared with the conventional peak of 4869 MW which occurs at around 2 PM, the total load curve, having EV load included, contains two peaks. One peak of 8001 MW occurs at 8:30 AM while the other peak of 8511 MW occurs at 9:30 PM. This shows that the demand of EV load is around 75% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. On comparison with the case 1, 2 and 3 of year 2030, it can be observed that, in this case, the size of peak load is minimum. Therefore, charging of more vehicles at the charging stations, before the system peak load condition occurs, helps in flattening the load curve of Chennai. However, the dual peak load conditions occurring due EV load needs proper operational measures and needs specific technology interventions and capacity augmentations.

7.5 Bengaluru

To analyse the load curve of Bengaluru in years 2025 and 2030, the load curves of conventional load, as described in Section 5, and the estimated load corresponding to number of EVs, as described in Section 6, were utilised. Accordingly, the total load curves under four different charging scenarios were prepared. The results and our observations are summarised as follows –

Case 1:

In this case, 90% of total Non-commercial 4-wheelers EVs are charged at home and rest 10% are charged at the charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional and EV load, obtained from the simulation studies is shown in the figure below.

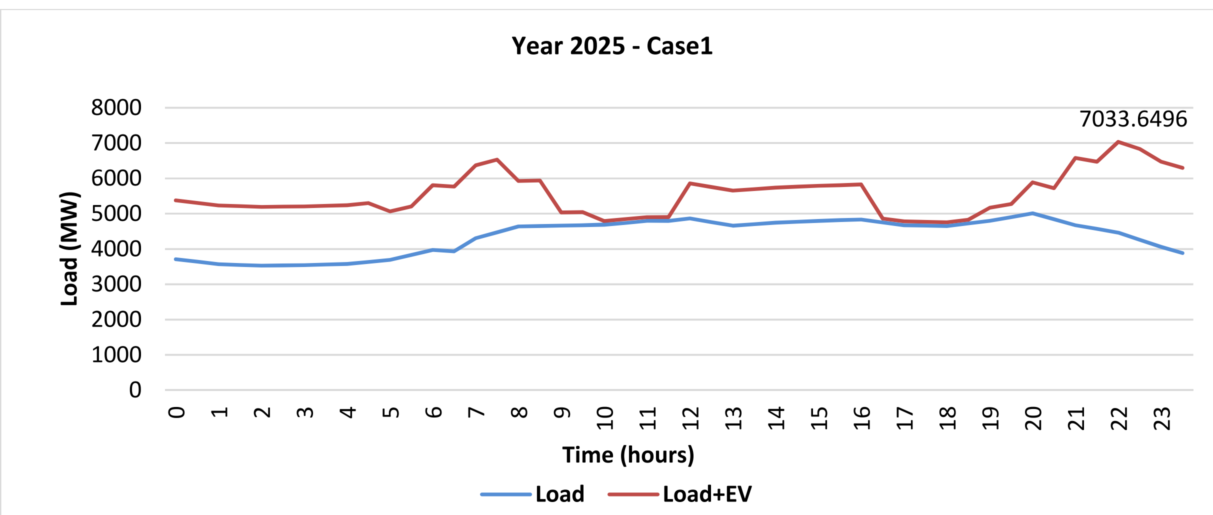

Figure 40: Conventional load curve & total load curve, including EV, for Bengaluru in year 2025 – Case 1

The forecasted peak loading conditions for the EPDS of Bengaluru in the year 2025 is shown in Figure 40. From the above Figure, it can be observed that the peak load, which occurs at around 8 PM when EV is not considered, has now shifted to around 10 PM in the night when EV load is considered along with the conventional load. The normal peak load, without EV, in the year 2025 is 5009 MW. While, the peak load after EV penetration (EV+Load) has become 7034 MW in year 2025. This shows that the peak load demand in Bengaluru due to EV in the year 2025 will increase by 2025 MW, i.e. around 40%. The peak load of the curve is also shifted from 8 PM to 10 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

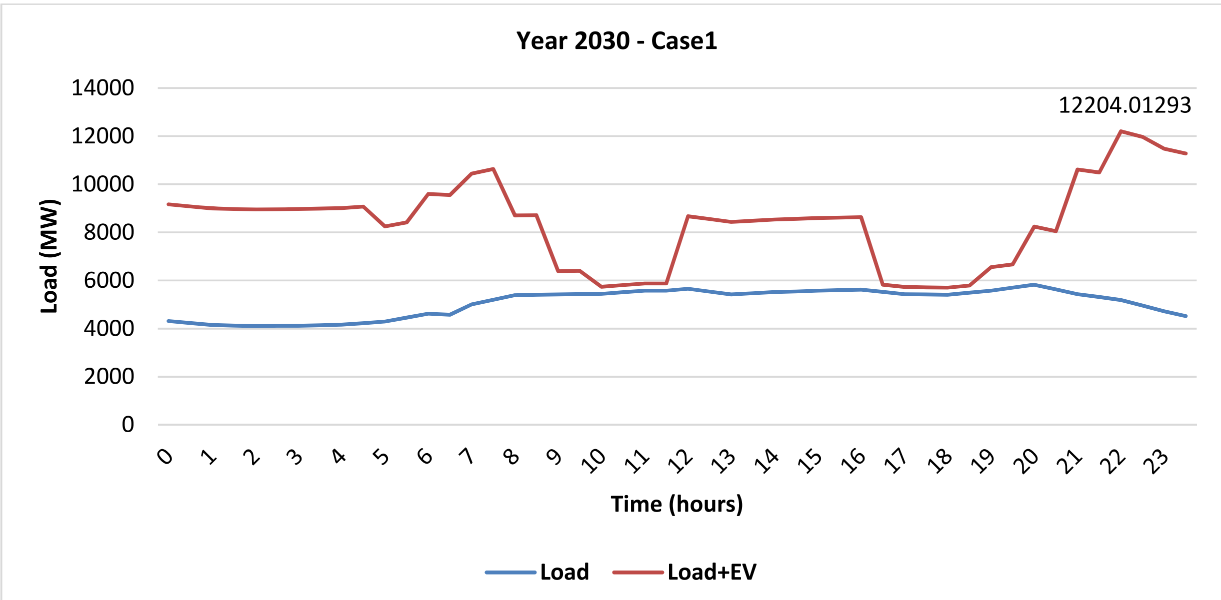

Figure 41: Conventional load curve & total load curve, including EV, for Bengaluru in year 2030 – Case 1

Figure 41 shows the forecasted peak loading condition for the EPDS of Bengaluru in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 5824 MW which occurs at around 8 PM, the peak with EV is of around 12204 MW and occurs at 10PM. The load curve shows that the peak load demand in Bengaluru due to EV in the year 2030 will increase drastically by 6380 MW, i.e. around 110%. The peak load of the curve is also shifted from 8 PM to 10PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

Case 2:

In this case, 70% of total Non-commercial 4-wheelers EVs are charged at home and rest 30% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

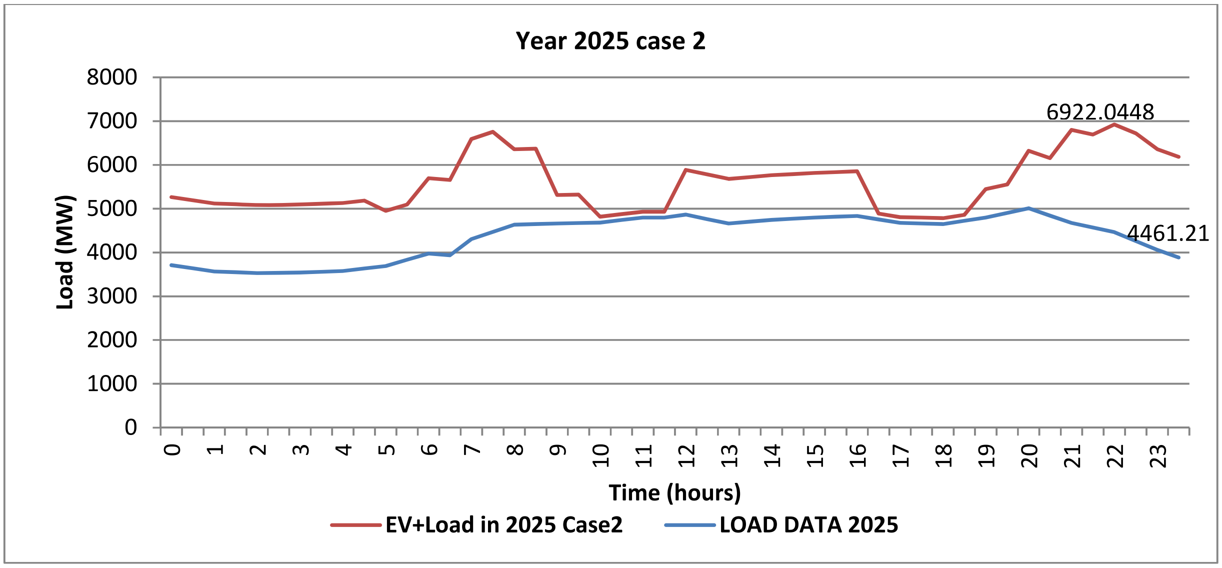

Figure 42: Conventional load curve & total load curve, including EV, for Bengaluru in year 2025 – Case 2

From the above figure, it can be observed that, compared with the conventional peak of 5009 MW which occurs at around 8 PM, the peak of total load curve, including EV, occurs at 10 PM with the peak load of around 6922 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been slightly reduced by 112 MW. It is so, because in this case 20% more non-commercial vehicles are being charged from the charging stations before the system peak occurs. Therefore, the charging of more vehicles at the charging station before the system peak load condition helps in flattening the load curve. It also needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 10 PM, is 2461 MW which is 55% more than the conventional load demand at that time.

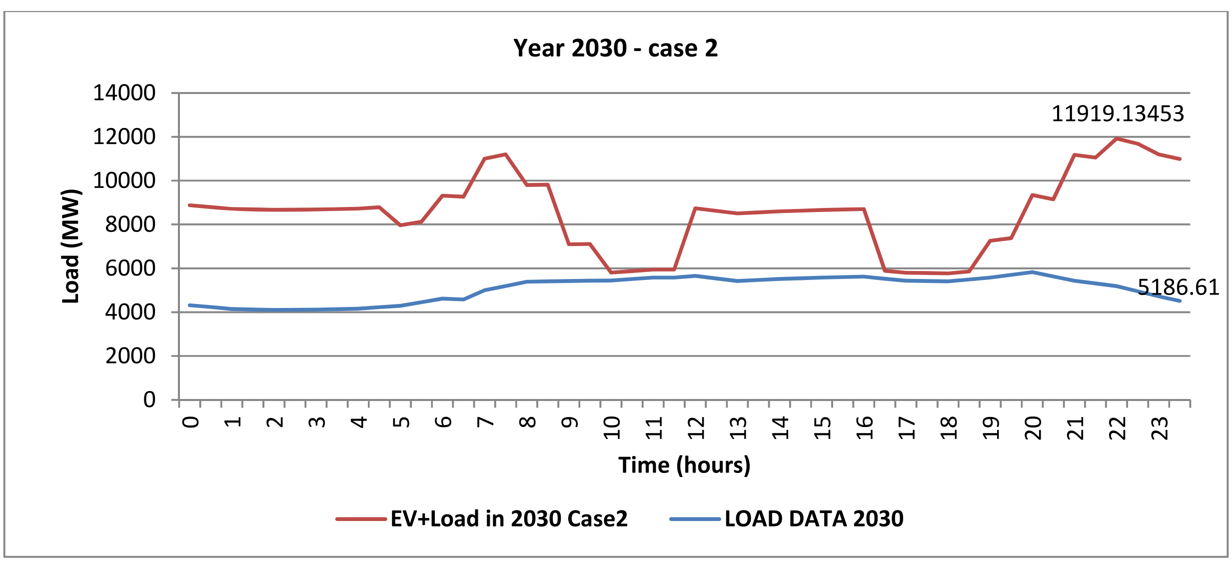

Figure 43: Conventional load curve & total load curve, including EV, for Bengaluru in year 2030-Case 2

Figure 43 shows the conventional load curve and total load curve, including EV, for Bengaluru in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 5824 MW which occurs at around 8 PM, the total load curve, having EV load included, contains peak of around 11919 MW occurs at 10 PM. This shows that the demand of EV load at peak load condition is 104% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required to address this scenario. As in the case of year 2025, in this case also, it needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 10 PM, is 6733 MW which is around 129% more than the conventional load demand at that time. This shows that, in case of Bengaluru, the conventional load is lesser than the EV load. Therefore, the EV integration will pose a huge challenge in addressing the extra power demand required by the EVs.

Case 3:

In this case, 50% of total Non-commercial 4-wheelers EVs are charged at home and rest 50% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

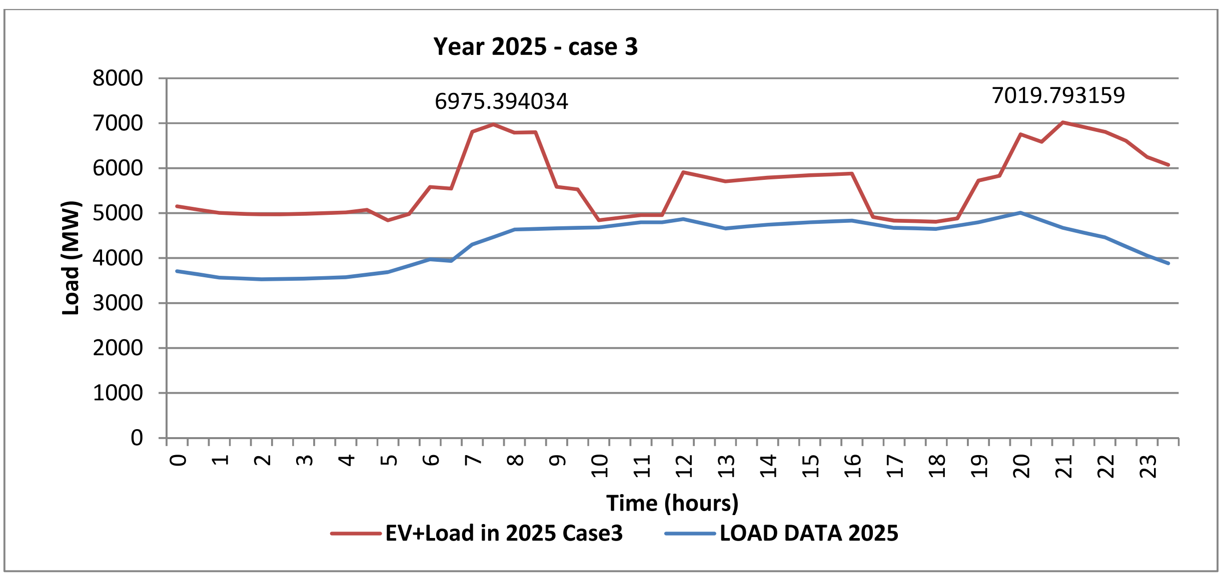

Figure 44: Conventional load curve & total load curve, including EV, for Bengaluru in year 2025 – Case 3

From the Figure 44, it can be observed that, compared with the conventional peak of 5009 MW which occurs at around 8 PM, the peak of total load curve, including EV, has two peaks. One occurs at 7.30 AM with the peak load of around 6975 MW while the second peak occurs at 9 PM with the peak load of around 7020 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been slightly reduced by 14 MW. It is so, because in this case 40% more non-commercial vehicles are being charged from the charging stations. It is also observed that the case 2 of year 2025, when only 30% non-commercial vehicles are charged from the charging station, is better in reducing the peak load situation on the EPDS.

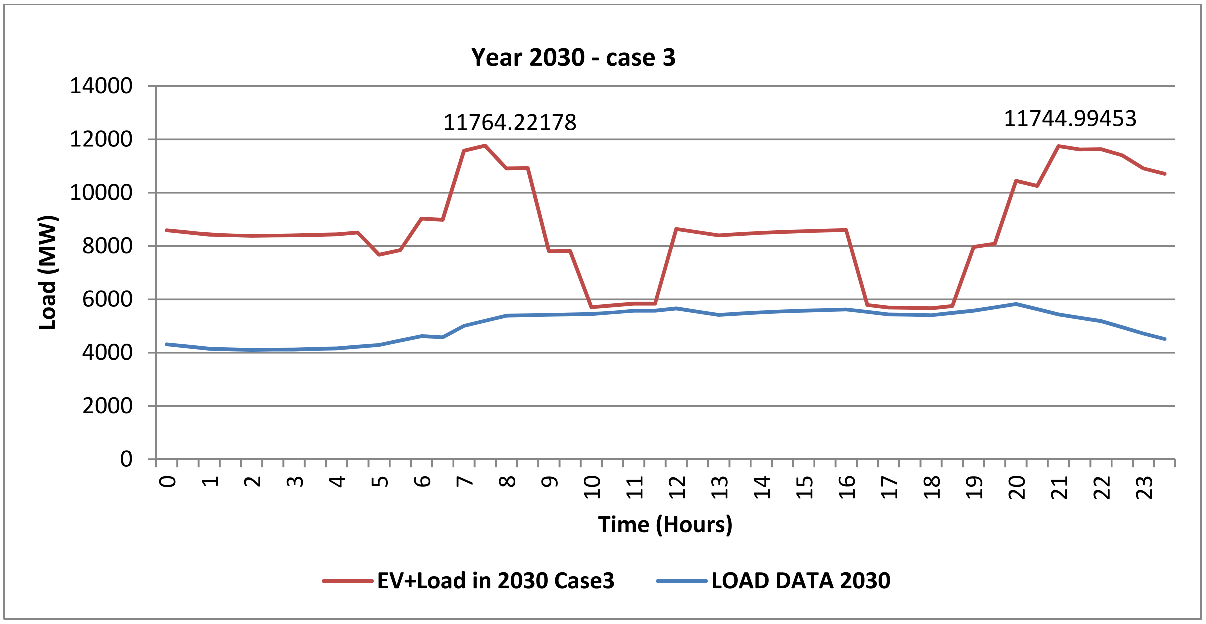

Figure 45: Conventional load curve & total load curve, including EV, for Bengaluru in year 2030 – Case 3

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 45 that, compared with the conventional peak of 5824 MW which occurs at around 8 PM, the peak of total load curve, including EV, occurs at two instances. One peak occurs at 7:30 am with the peak load of around 11764 MW. While the other peak of around 11745 MW occurs at 9 PM. This shows that the demand of EV load is around 100% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required from day 1 to address this scenario. On comparing with the total load curve of case 2 in the year 2030, it is also observed that, in this case, the peak load has been reduced by 155 MW. It shows that shifting of charging of EVs from home to charging stations may play a role in reducing the total system load. Therefore, the charging of more vehicles at the charging stations, before the system peak load condition occurs, can help in flattening the load curve.

Case 4:

In this case, all non-commercial 4-wheelers EVs are charged at charging station, keeping other types of vehicles charging same as described in the section 4. Total load curve, including conventional as well as EV load, obtained from the simulation studies under this case is shown in the figure below.

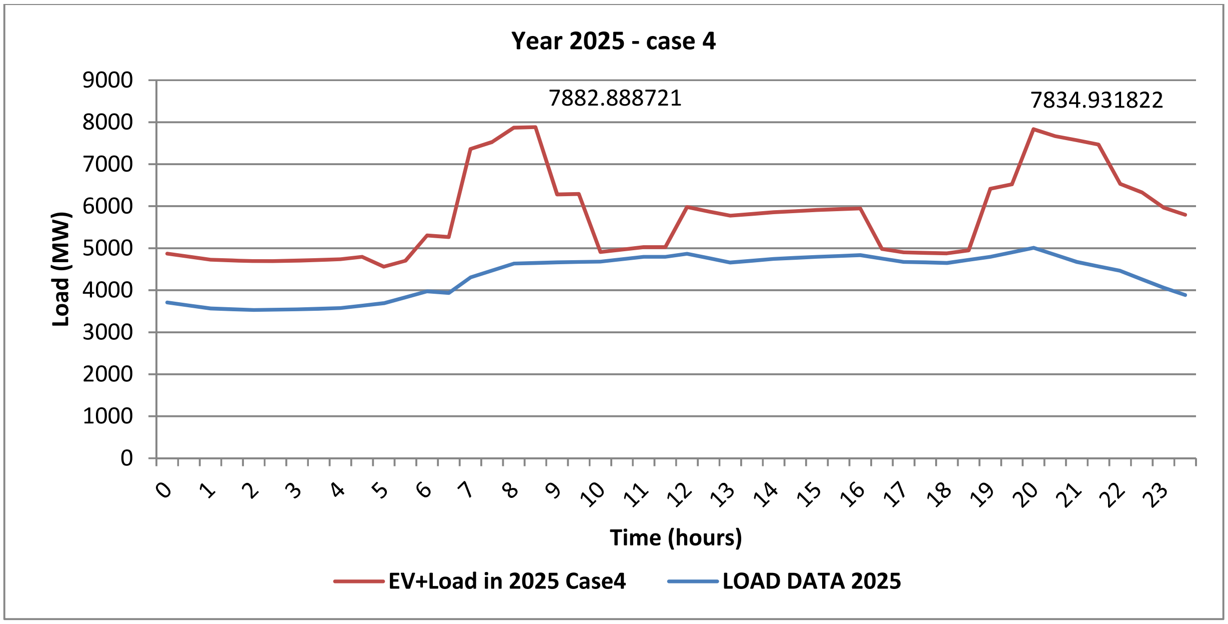

Figure 46: Conventional load curve & total load curve, including EV, for Bengaluru in year 2025 – Case 4

From the Figure 46, it can be observed that, compared with the conventional peak of 5009 MW which occurs at around 8 PM, the total load curve having EV load included contains two peaks. One peak of 7882 MW occurs at 8:30 AM while the other peak of 7834 MW occurs at 8 PM. These peaks occur due to EV owners' behaviour of charging their vehicles either in the morning time, before going to work, or in the evening time, after coming from the work. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been increased by 849 MW.

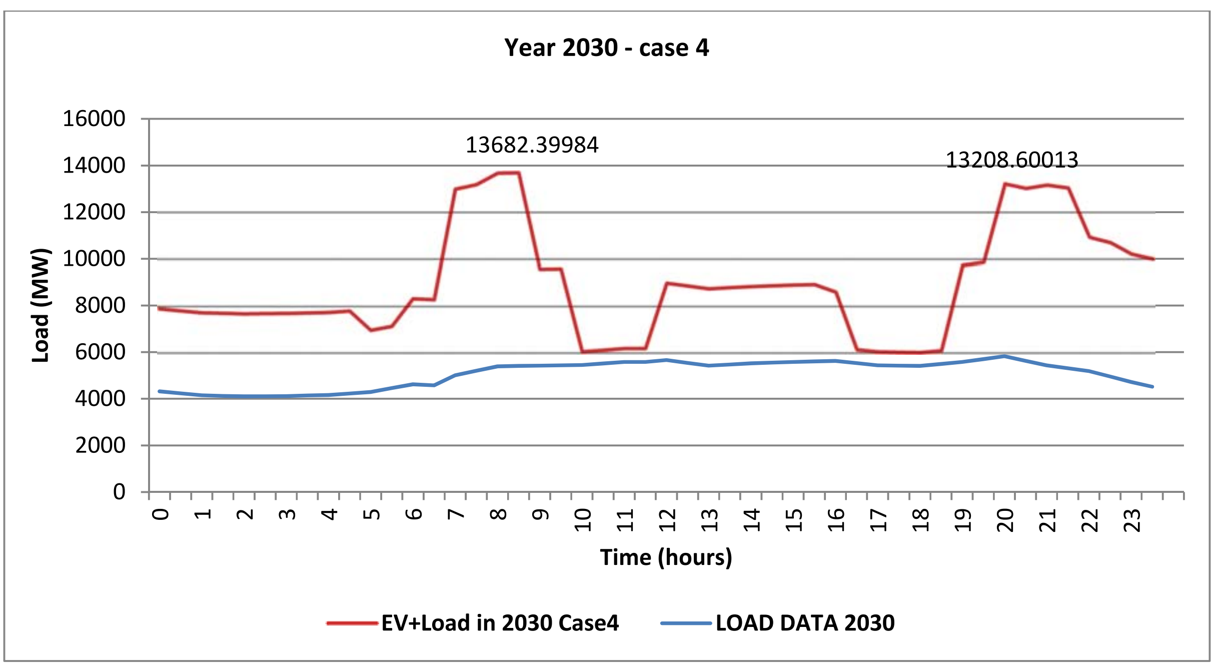

Figure 47: Conventional load curve & total load curve, including EV, for Bengaluru in year 2030 – Case 4

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 47 that, compared with the conventional peak of 5824 MW which occurs at around 8 PM, the total load curve, having EV load included, contains two peaks. One peak of 13682 MW occurs at 8:30 AM while the other peak of 13208 MW occurs at 8 PM. This shows that the demand of EV load is around 135% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. As the EV load surpasses conventional load by manifolds, proper planning is required in advance to address this scenario. Further, it also shows that shifting of charging of EVs from home to charging stations by 100% will make the EPDS operation very challenging. Therefore, the dual peak load conditions occurring due EV load needs proper operational measures and needs specific technology interventions and capacity augmentations.

7.6 Hyderabad

To analyse the load curve of Hyderabad in years 2025 and 2030, the load curves of conventional load, as described in Section 5, and the estimated load corresponding to number of EVs, as described in Section 6, were utilised. Accordingly, the total load curves under four different charging scenarios were prepared. The results and our observations are summarised as follows –

Case 1:

In this case, 90% of total Non-commercial 4-wheelers EVs are charged at home and rest 10% are charged at the charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional and EV load, obtained from the simulation studies is shown in the figure below

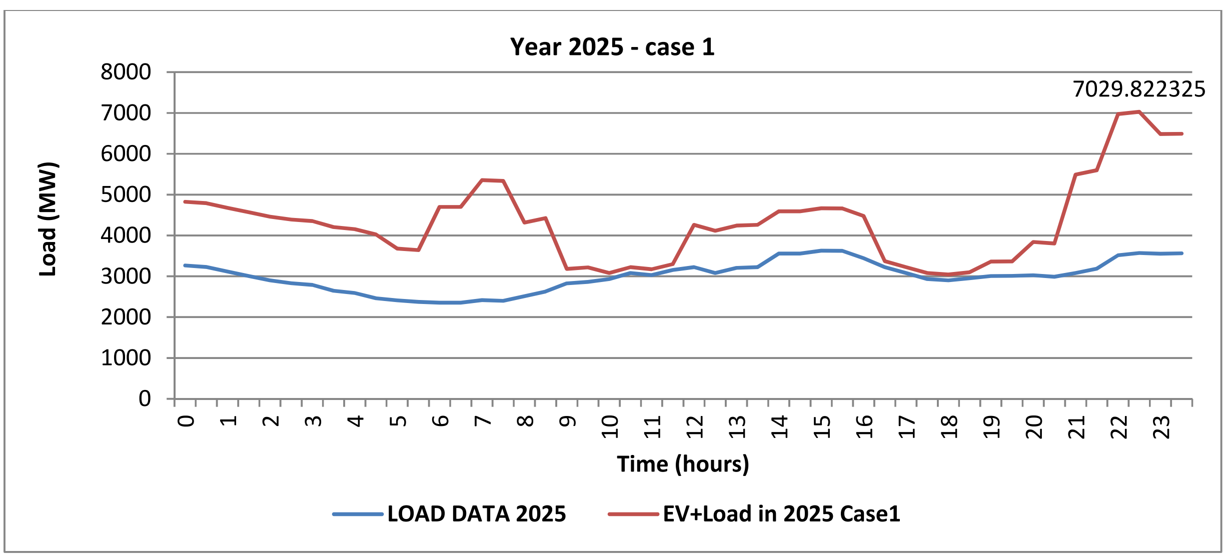

Figure 48: Conventional load curve & total load curve, including EV, for Hyderabad in year 2025 – Case 1

The forecasted peak loading conditions for the EPDS of Hyderabad in the year 2025 is shown in Figure 48. From the above Figure, it can be observed that the peak load, which occurs at around 3 PM when EV is not considered, has now shifted to around 10:30pm in the night when EV load is considered along with the conventional load. The normal peak load, without EV, in the year 2025 is 3629 MW. While, the peak load after EV penetration (EV+Load) has become 7030 MW in year 2025. This shows that the peak load demand in Hyderabd due to EV in the year 2025 will increase by 3401 MW, i.e. around 93%. The peak load of the curve is also shifted from 3 PM to 10:30 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

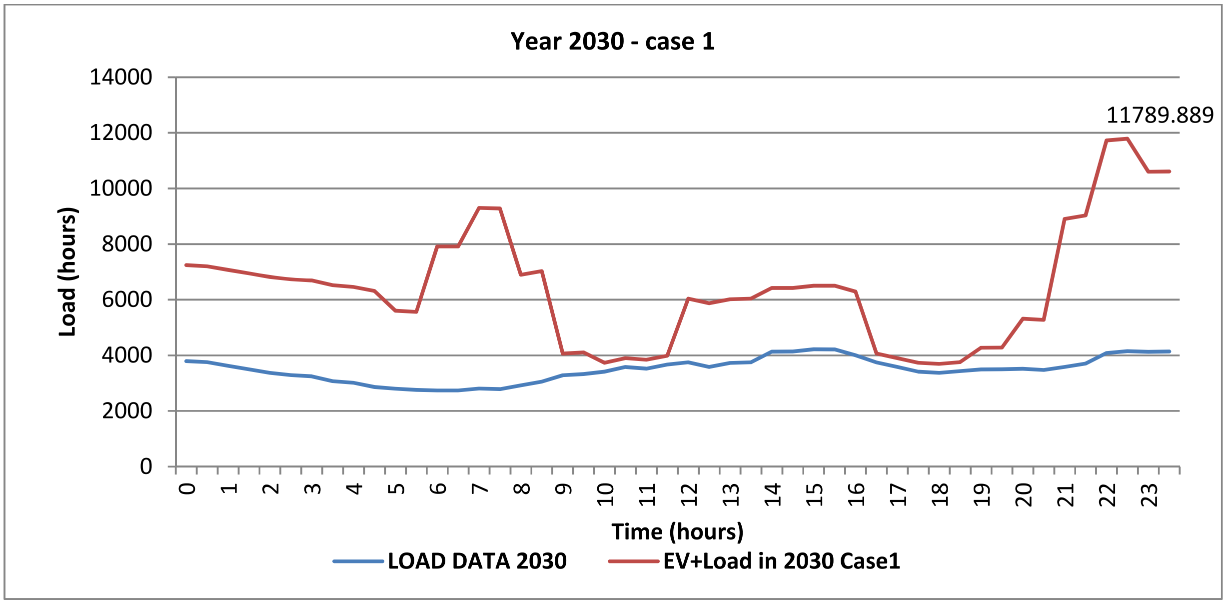

Figure 49: Conventional load curve & total load curve, including EV, for Hyderabad in year 2030 – Case 1

Figure 49 shows the forecasted peak loading condition for the EPDS of Hyderabad in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 4219 MW which occurs at around 3 PM, the peak with EV is of around 11790 MW occurs at 10:30 PM. The load curve shows that the peak load demand in Hyderabad due to EV in the year 2030 will increase drastically by 7571MW, i.e. around 180%. The peak load of the curve is also shifted from 3 PM to 10:30 PM due to the EV owners' behaviour of plugging-in the vehicle in the night for charging.

Case 2: In this case, 70% of total Non-commercial 4-wheelers EVs are charged at home and rest 30% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

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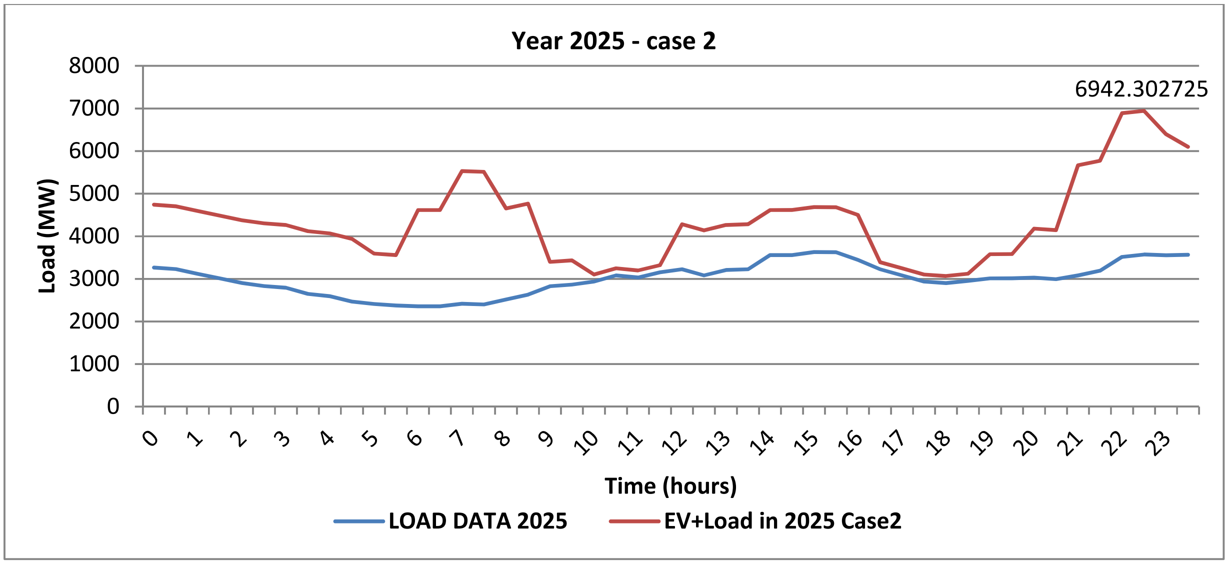

Figure 50: Conventional load curve & total load curve, including EV, for Hyderabad in year 2025 – Case 2

From the above figure, it can be observed that, compared with the conventional peak of 3629 MW which occurs at around 3 PM, the peak of total load curve, including EV, occurs at 10:30 PM with the peak load of around 6942 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been slightly reduced by 88 MW. It is so, because in this case 20% more non-commercial vehicles are being charged from the charging stations before the system peak occurs. Therefore, the charging of more vehicles at the charging station before the system peak load condition helps in flattening the load curve.

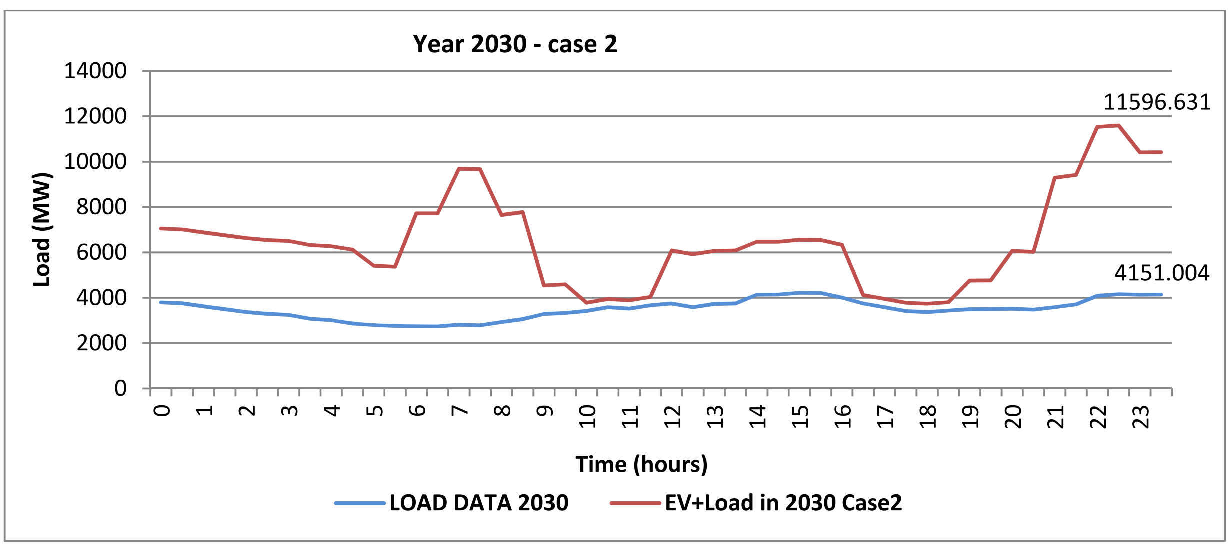

Figure 51: Conventional load curve & total load curve, including EV, for Hyderabad in year 2030 – Case 2

Figure 51 shows the conventional load curve and total load curve, including EV, for Hyderabad in the year 2030. From the above figure, it can be observed that compared with the conventional peak of 4219 MW which occurs at around 3 PM, the total load curve, having EV load included, contains peak of around 11597 MW occurs at 10:30 PM. This shows that the demand of EV load at peak load condition is 174% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required to address this scenario. As in the case of year 2025, in this case also, it needs to be noted that the extra power demand due to EV integration at peak load time, i.e. 10 PM, is 7466 MW which is around 180% more than the conventional load demand at that time. This shows that, in case of Hyderabad, the conventional load is very less than the EV load. Therefore, the EV integration will pose a huge challenge in addressing the extra power demand required by the EVs.

Case 3:

In this case, 50% of total Non-commercial 4-wheelers EVs are charged at home and rest 50% are charged at charging station, keeping other types of vehicle charging same as described in the section 4. The total load curve, including conventional as well as EV load, obtained from the simulation studies is shown in the figure below.

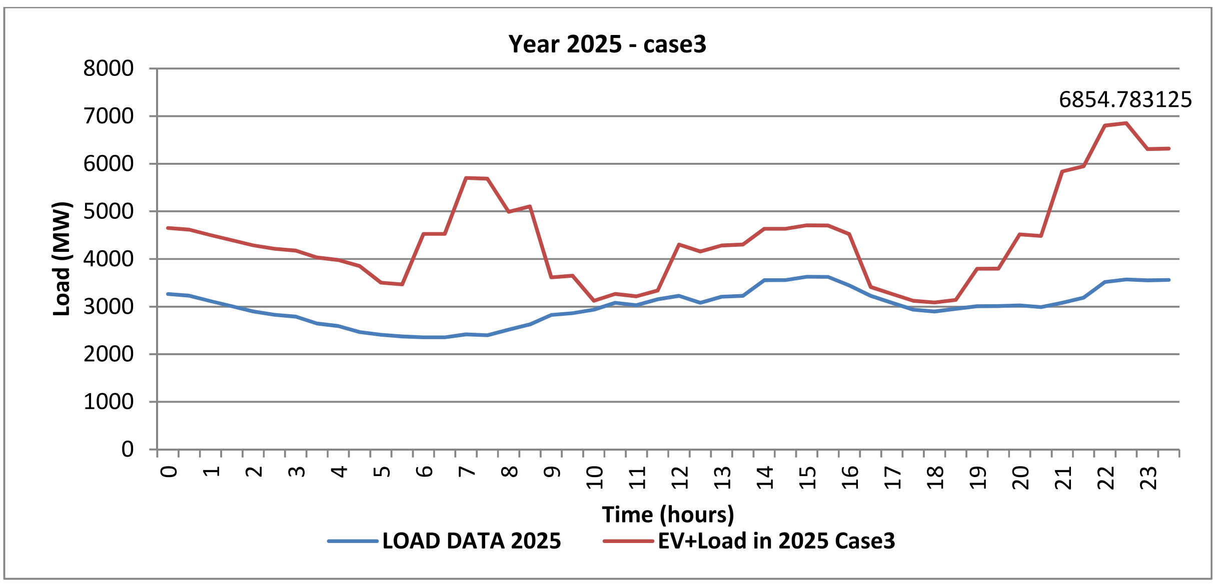

Figure 52: Conventional load curve & total load curve, including EV, for Hyderabad in year 2025 – Case 3

From the Figure 52, it can be observed that, compared with the conventional peak of 3629 MW which occurs at around 3 PM, the peak of total load curve, including EV, occurs at 10:30 PM with the peak load of around 6855 MW. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been reduced by 175 MW. It is so, because in this case 40% more non-commercial vehicles are being charged from the charging stations. Accordingly, the charging of more vehicles at the charging stations helps in reducing the system peak load value. As in previous case, in this case also, it may be considered a case for devising a method of identifying the correct timing and mix of the EV charging at home as well as at charging stations to reduce stress on the EPDS. It is also observed that compared with case 2 of year 2025, when only 30% non-commercial vehicles are charged from the charging station, this case is better in reducing the peak load situation on the EPDS.

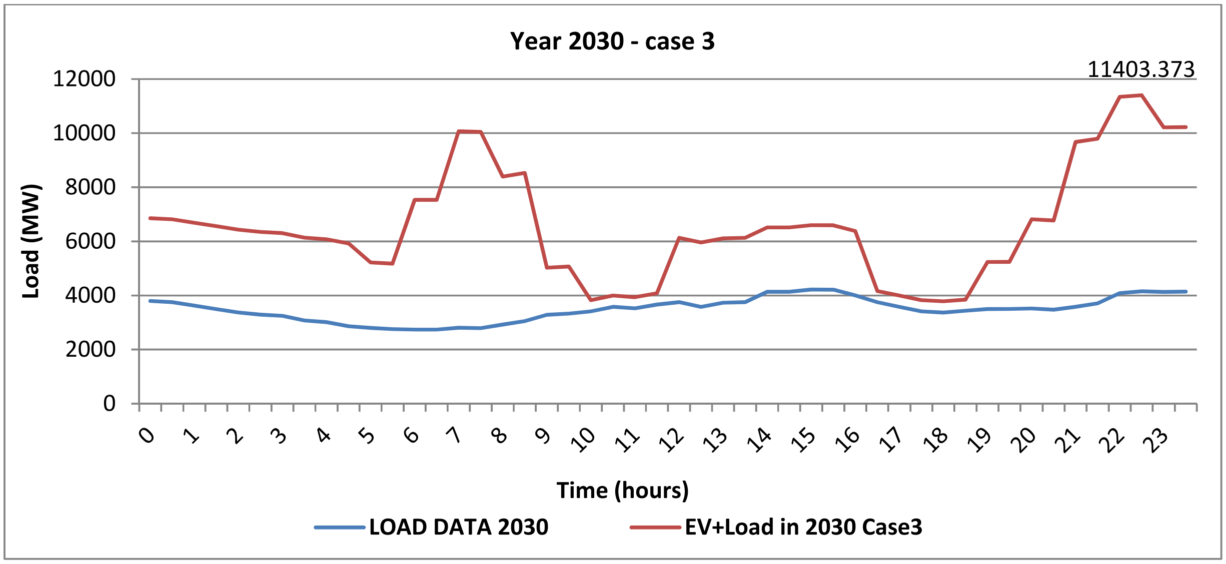

Figure 53: Conventional load curve & total load curve, including EV, for Hyderabad in year 2030 – Case 3

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 53 that, compared with the conventional peak of 4219 MW which occurs at around 3 PM, the peak of total load curve, including EV, occurs at 10:30 pm with the peak load of around 11403 MW. This shows that the demand of EV load is around 170% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required from day 1 to address this scenario. On comparing with the total load curve of case 2 in the year 2030, it is also observed that, in this case, the peak load has been reduced by 193 MW. It shows that shifting of charging of EVs from home to charging stations can play a role in reducing the total system load. Therefore, the charging of more vehicles at the charging stations, before the system peak load condition occurs, will help in flattening the load curve.

Case 4:

In this case, all non-commercial 4-wheelers EVs are charged at charging station, keeping other types of vehicles charging same as described in the section 4. Total load curve, including conventional as well as EV load, obtained from the simulation studies under this case is shown in the figure below.

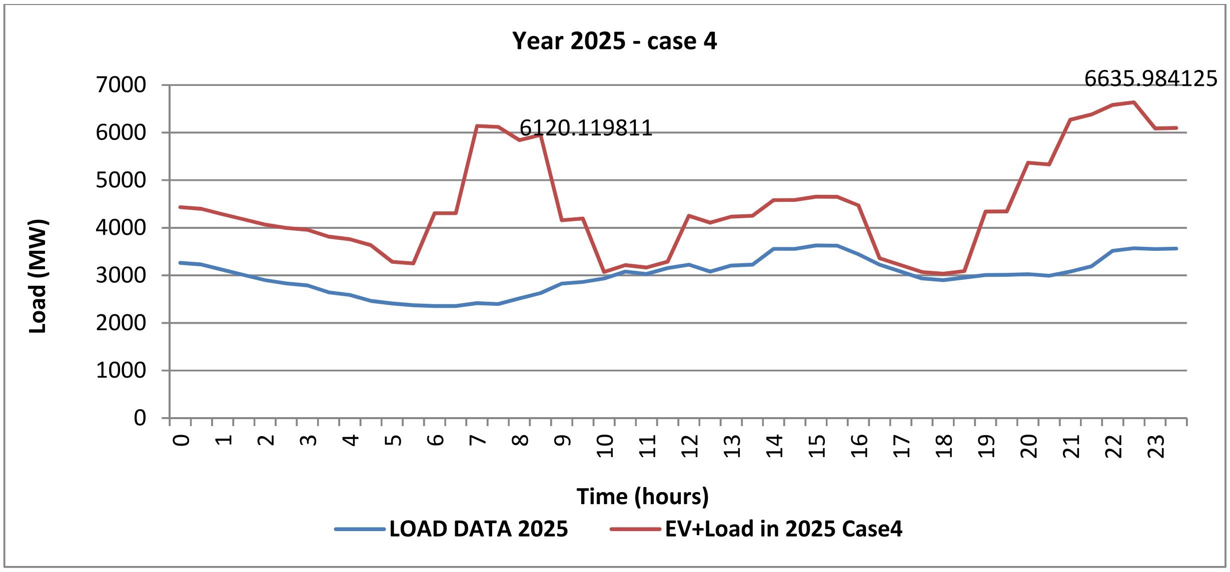

Figure 54: Conventional load curve & total load curve, including EV, for Hyderabad in year 2025 – Case 4

From the Figure 54, it can be observed that, compared with the conventional peak of 3629 MW which occurs at around 3 PM, the total load curve having EV load included contains two peaks. One peak of 6120 MW occurs at 7:30 AM while the other peak of 6635 MW occurs at 10:30 PM. These peaks occur due to EV owners' behaviour of charging their vehicles either in the morning time, before going to work, or in the evening time, after coming from the work. On comparing with the total load curve of case 1 in the year 2025, it also observed that, in this case, the peak load has been drastically reduced by 395 MW, when all vehicles are charged from the charging stations.

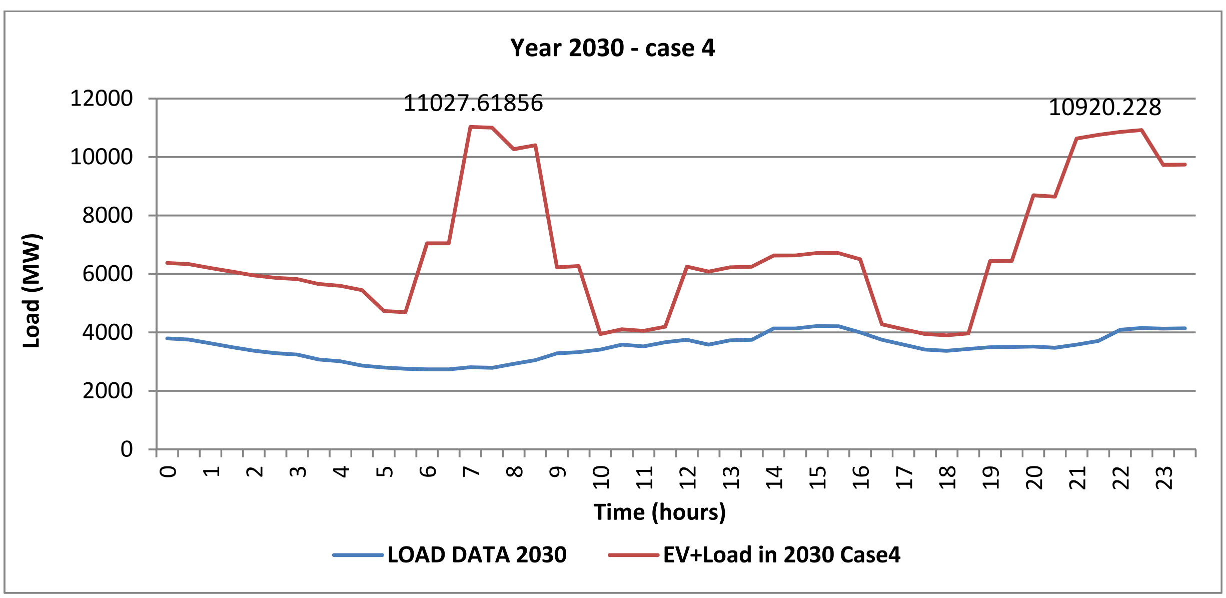

Figure 55: Conventional load curve & total load curve, including EV, for Hyderabad in year 2030 – Case 4

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 55 that, compared with the conventional peak of 4219 MW which occurs at around 3 PM, the total load curve, having EV load included, contains two peaks. One peak of around 11028 MW occurs at 7 AM while the other peak of around 10920 MW occurs at 10 PM. This shows that the demand of EV load is around 161% of the conventional peak load. Therefore, a huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. On comparison with the case 1, 2 and 3 of year 2030, it can be observed that, in this case, the size of peak load is minimum. Therefore, charging of more vehicles at the charging stations, before the system peak load condition occurs, helps in flattening the load curve of Hyderabad. As the EV load requirement surpasses conventional load by 1.61 times, proper planning is required in advance to address this scenario. Further, it also shows that shifting of charging of EVs from home to charging stations by 100% will make the EPDS operation very challenging. Therefore, the dual peak load conditions occurring due EV load needs proper operational measures and needs specific technology interventions and capacity augmentations.

8 Summary of the depth of penetration of the EV loads added to the distribution system of Indian cities

		Year 2025				Year 2030			
		Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Delhi	Peak Load without EV (MW)	8196	8196	8196	8196	9734	9734	9734	9734
	Peak Load with EV (MW)	11092	10828	10917	13016	17865	19553	19481	23992
	% Load changes	35.33	32.11	33.2	58.81	83.53	100.87	100.13	146.48
	Peak Time	11pm	11pm	9:30pm	9pm	10:30pm	10:30pm	9:30pm	8:30pm
Mumbai	Peak Load without EV (MW)	4514	4514	4514	4514	5248	5248	5248	5248
	Peak Load with EV (MW)	6333	6159	6309	7680	10537	10291	11356	16075
	% Load changes	40.3	36.44	39.77	70.14	100.78	96.09	116.39	206.31
	Peak Time	10pm	10pm	9:30 pm	8 pm	10 pm	9pm	8:30am	8:30 am
Kolkata	Peak Load without EV (MW)	2629	2629	2629	2629	3126	3126	3126	3126
	Peak Load with EV (MW)	4341	4314	4287	4220	6896	6829	6763	6596
	% Load changes	65.12	64.09	63.07	60.52	120.6	118.46	116.35	111
	Peak Time	10pm	10pm	10pm	10pm	10pm	10pm	10pm	10pm

Chennai	Peak Load without EV (MW)	4188	4188	4188	4188	4869	4869	4869	4869
	Peak Load with EV (MW)	5877	5815	5752	5596	8962	8824	8686	8511
	% Load changes	40.33	38.85	37.34	33.62	84.06	81.23	78.39	74.8
	Peak Time	10:30pm	10:30pm	10:30pm	10:30pm	10:30pm	10:30pm	10:30pm	9:30pm
Bengaluru	Peak Load without EV (MW)	5009	5009	5009	5009	5824	5824	5824	5824
	Peak Load with EV (MW)	7034	6922	7020	7882	12204	11919	11764	13682
	% Load changes	40.43	38.19	40.15	57.36	109.55	104.65	101.99	134.92
	Peak Time	10pm	10pm	9pm	8:30am	10pm	10pm	7:30am	8:30am
Hyderabad	Peak Load without EV (MW)	3629	3629	3629	3629	4219	4219	4219	4219
	Peak Load with EV (MW)	7030	6942	6855	6635	11790	11597	11403	11028
	% Load changes	93.72	91.29	88.9	82.83	179.45	174.88	170.28	161.39
	Peak Time	10:30pm	10:30pm	10:30pm	10:30pm	10:30pm	10:30pm	10:30pm	7am

9 Conclusion

- From the case study, it is observed that even if, 90% of the vehicles are charged at home in the night (Case 1), still the system is overloaded.
- Case 2 (30% from charging station and rest 70% charging from home) is observed to create least load on the system in the year 2025 in most of the cities considered for the study. However, the same does not apply in the year 2030.
- Case 3 (50% from charging station and rest 50% charging from home) is observed to create least load on the system in the year 2030 in most of the cities considered for the study.
- In case of Kolkata, Chennai, and Hyderabad, the peak load condition is less severe, i.e. size of peak load is minimum, when all vehicles are charged at the charging station.
- The battery capacity for an EV is considered to be 75kWh. If it is being charged by 350kW charger, it will create 350kW peak on the system for around 12 minutes. This peak handling is of a major concern to the utility.
- Although, the charging of the EV is assumed to be once in 2-3 days according to its capacity, considering the human behaviour, it is observed that, he will put the vehicle for charging even if he has travelled just 50 km. Therefore, the utilities have to consider these uncertainties in the load pattern as well.
- The Indian EPDS will face a high load stress when the EVs are charged from the distribution grid.
- Frequent connect and disconnect of EVs to the charging stations, having high power DC chargers, will generate serious power quality issue.
- Charging EVs will cause the generation of more harmonics.
- A huge capacity augmentation is required in the EPDS by year 2030 to address the EV load demand. Accordingly, a proper planning is required by the EPDS operators to address this scenario.
- Taking cues from mobile charging behaviour of the customers, the EV charging may also take place more frequently compared to what is assumed in the document. In that case, the EV load demand will increase further.
- As most of the time the distribution system peak load condition, including EV load, occurs either in early morning or in the late evening. Therefore, Solar PV may not be

able to help in addressing high demand. Hence, alternate energy sources need to be identified to address the peak load condition.

- Out of all the cases discussed for various cities, minimum EV load, as percentage of total conventional load, is 32.11%. This shows that a huge capacity augmentation is required at the distribution level to handle EV load.

10 Recommendations

From the observations of initial analysis, it is recommended that –

- The existing EPDS infrastructure of major cities is not adequate to handle huge EV load coming in near future. Therefore, it is suggested to plan for capacity augmentation of EPDS system.
- Hybrid EVs should also be promoted to reduce stress on the electrical grid.
- Effort should be made to deploy off-grid charging stations powered through renewable energy sources. In cities the modular power plants, generating energy from the waste, can be installed at various locations in the city boundaries or in the large residential/commercial societies. These power plants can be connected to the grid and the dedicated charging stations, with minimal power import from the grid, to serve local population.
- The charging infrastructure should be planned considering the peak load conditions and peak load areas so that the Distribution Transformer (DT) overload can be avoided.
- EV user should be encouraged to charge EV during off-peak period by providing incentives.
- Charging infrastructure in a city should be monitored and controlled remotely so that during peak load conditions the charging stations can be switched off to save the grid.
- Time of Use (ToU) tariff should be imposed on the EV charging so that the EV users are discouraged to charge their vehicle during peak load conditions.
- In cities, where the summer temperature goes beyond 40° C, the performance and safety aspect of the BES of EV needs to be assessed properly.
- The charging at home should be regulated remotely. Based on distribution system loading condition in an area of the city, the charging of vehicle should be enabled or disabled. This will ensure that the vehicles will be charged only when there is not peak load situation in EPDS.
- Optimal location and capacity of the charging stations should be thoroughly studied well before their deployments in the city area.

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