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INFLUENCE OF PLUG-IN ELECTRIC VEHICLES ON POWER DISTRIBUTION SYSTEM

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Abstract: To carry out forecast on the influence of EV Infiltrate on Electric power distribution system (EPDS) in years 2025 and 2030, a detailed study has been carried out in Mumbai. Typically, we have carry out a summer load curves on the cities for year 2018 which are determined to forecast their estimated load demands in summers of years 2025 and 2030, considering steady electric load growth of the electric vehicle. Subsequently, we have utilized the current motorized vehicle growth rate in the cities, penetration of EVs for years 2025 and 2030 which is also estimated. Considering behaviors of the consumer on various vehicle segments, their vehicle charging patterns are also estimated. According to that, multiple scenarios of charging the vehicle at home and charging the vehicle at charging stations have been considered for carrying out the study. The estimated EV load, are obtained from various study, which is then, compared with the estimated conventional electrical load in the cities

Keywords: *Electric Vehicle (EV), Power Quality, Harmonics, EV load Modeling, Load forecasting, EV penetration*

I INTRODUCTION

They have been a steady increase of energy consumption of fossil fuel in the transportation sector over a last decade. The usage of the internal consumption have been significant on the environmental impact which result in causing global warming The internal combustion engine efficiency is relatively low between 30-40% [1]. Due to the increase in concern on the environment awareness and depletion of oil and fossil in the world, which have been main factor of motivation to find a solution using clean sustainable energy sources. In the last few decades, the renewable energy has been the focus in the world of research, which have encouraged the researcher to harness energy from various renewable resources like solar, wind, hydro power plant etc using modern technology [2]. Sustainable Transport has been the need of world. Sustainable Transport can be obtained only when the transport system rely solely on the energy sources which last for a really long time like energy from sun/or the wind. In other words, we can say that the sustainable transport system needs to have an electric energy source for powering the vehicle. Electric vehicle have been the prominent example set by the government in efforts to reduce the greenhouse gas emission (GHG), which would results in less emission of co2.An electric Vehicle is a device which is powered partially by the electric force derived from the electric motor or traction motor. A charging System is a device which had been used to deliver energy into the rechargeable battery by forcing electric current into it. The power input to the battery and the time required for charging varies with different batteries. The nature, size, material and the electrochemistry of the battery system have been considered for the charging type on the system to be implemented. The charging system will be used to keep constant monitoring on the parameters related to battery like the State of Charge (SOC), maximum voltage and temperature. [3].

The classification of charging power levels has been done on the basis of the power output that the charger can deliver to the battery. It also takes into consideration of power level available in the domestic and commercial utility as well as for the industrial supply.Level-1 uses a standard 110/220V 15A single-phase AC outlet which is common in most households. This of type has been the most considered one as this type of charging can be used at home for overnight charging of the electrical vehicle. The maximum power output in Level-1 charging is 3.5 kW. Level 2 Charging: This type of charging is the most suitable for private and public places where the Electric Vehicles are parked outside the houses. This type of charging is limited to the urban areas and cities. This maximum output for level-2 charging is 19.2Kw.Level-3 Charging: This charging system can be used only for dedicated stations which can help the electric vehicle to charge quickly in a pretty quick time. For this level of charging, it requires a need of infrastructure which can be specifically used in the electric vehicle charging. The voltage levels of these charger stations would be above 480V (three-phase AC) and the power output should be greater than 19.2 kW. This charger can have either AC or DC outputs. Rapid Charging: Any electric vehicle which can be charged within 60 minutes is called a rapid charging. The different levels for charging of electric vehicle have been discussed in the previous section [4]. Charging of electric vehicle does not have a large impact at the macro level as power grids have strong dispatching capacity. However, an uneven distribution of the supply to the electric vehicle can lead to increase in the peak valley difference which will have a negative impact on the life of the utility grid. Charger controller exhibits a high level of total harmonics distortion which degrades the magnetic devices present in the power system [5].

EV batteries can be operated from single phase or three phase supply system. As there is a wide availability of single supply point, EV chargers are connected to this system. Fast charging are always connected to three phase supply for higher power. These EV chargers are basically power electronic convertors which are nonlinear load whose characteristic can produce harmonics in the current and as well affect the voltage profile of the power network. [6]. Higher non -linear loading can cause for nonlinear load for voltage drop and voltage waveform can been distorted. On the other hand, non-linear load can have an adverse effect on the performance of distribution transformer by increasing power losses in the winding and therefore reduces power output. EV charger can be integrated into the power grid or distribution network, which will hamper the power quality. In this paper, impact of EVs on the power distribution network by presenting a load forecasting of the electric vehicle in 2025 and 2030 from the present growth of electric vehicle [7].

II EV LOAD MODELING

EV charging technologies are undergoing constant research and developments. The charges can be categorized into ac or dc which further according to their level of charging level (1-3). Level-1 chargers are used for home based charging while level-3 is used for commercially fast charging. The faster charger can have a power rating which can exceed 200KW and charging duration falls into scales of minutes. Fast charging stations are likely to be compared with fuel charging station. There is a possibility that the fast charging station will become more popular as it would become a convenient charging option for the EV user. Fast charging would be considerable demand on the power demand and will become an important assess on the impact on power system. The established EV charger configuration consists of two stages: an ac-dc convertor at the front end and a dc-dc converter at the battery end. The dc -dc stage is achieved by the required charging current suitable for different state of charge(SOC) condition and cell temperature of the battery. It maintains the ripple content of the charging current within a safe operating status of the battery. An universal input EV fast charger, consist of active rectifier front- end and dc-dc convertor at the battery end is considered for modeling. It consists of various features like unity power factor operation and has the ability to connect to a wide range of input voltages. It provides a regulated dc voltage output independent of the input voltage variations which are maintained within the limits of the modeling. The charger arrangement is shown in following Fig.1. .

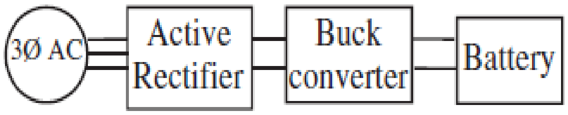

Figure 1. Ev Fast charger Arrangement

Load modeling for power system voltage stability requires identification of load demand variation with respect to the variation in system voltage. This P–V relation is derived analytically for the charger shown in Fig. 1. Analytical expressions for the front end active rectifier (Fig. 2) are derived first [8].The conversion from abc reference frame to dq reference frame is well documented [9,10], and hence not shown here.

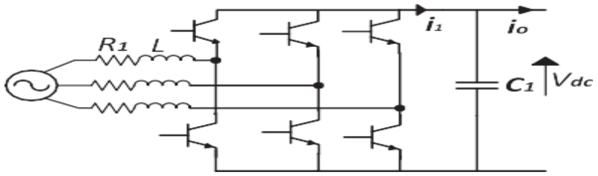

Figure 2. The active rectifier.

$$V_d=L\frac{di}{dt}+R_1i_d-Lwi_q+d_dV_{dc} \quad (1)$$

$$V_q=L\frac{di}{dt}+R_1i_q-Lwi_d+d_qV_{dc} \quad (2)$$

R_1 refers to the total resistance of active rectifier switches (R_s) and parasitic resistance of the input filter (R_L). Inductance of input filter is denoted by L. V_d, V_q, i_d and i_q refers to direct axis and quadrature axis voltages and currents respectively. The d_d and d_q refer to the switching functions in the d_q reference frame. In steady state, (1)–(3) convert to (4)–(6).

$$V_d = R_1 i_d - Lwi_q + d_d V_{dc} \quad (3)$$

$$V_q = R_1 i_q - Lwi_d + d_q V_{dc} \quad (4)$$

$$io = \frac{3}{2}(d_d i_d + d_q i_q) \quad (5\text{-}6)$$

The real and reactive power has been drawn by the charger, in the dq reference frame which has been represented by (7) and (8).

$$P = \frac{3}{2}(V_d i_d + V_q iq) \quad (7)$$

$$Q = (V_d i_q - V_q i_d) \quad (8)$$

The active rectifier controller is shown in Fig. 3. The q axis current is manipulated to achieve unity power factor, while d axis current is used to regulate dc link voltage. It is assumed that the dq frame is rotated at x speed and the d axis is oriented along with the grid voltage vector. So, Vq = 0. Furthermore, the iqref is set to zero in order to achieve unity power factor operation. Hence, under steady state iq = 0 and (4)–(7) become (9)–(12).

$$V_d = R_1 i_d + d_d V_{dc} \quad (9)$$

$$Lwi_d + d_q V_{dc} = 0 \quad (10)$$

$$I_0 = \frac{3}{2}(d_d i_d) \quad (11)$$

$$P = \frac{3}{2}(V_d i_d) \quad (12)$$

By combining (9), (11), and (12),

$$P = V_{dc} i_o + \left(\frac{3R1 i_0^2}{2d^2 d}\right) \quad (13)$$

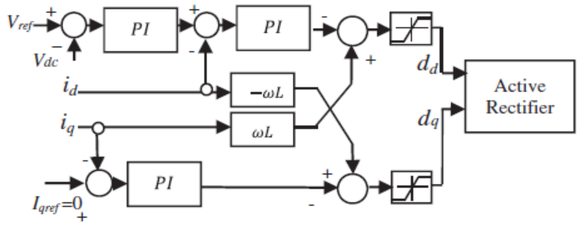

Figure 3. The controller of the active rectifier.

The second stage of the charger consists of a buck converter as shown in Fig. 4.

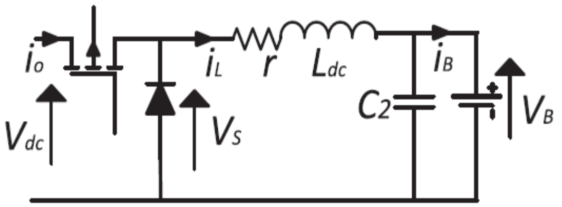

Figure 4. Buck Boost Converter of dc-dc stage Of EV

Considering Fig. 4, the analytical expressions for the second stage can be derived as follow.

$$V_s = V_B + L_{dc}\frac{di_l}{dt} + ri_L \quad (14)$$

$$i_L = i_B + C_2\frac{dV_B}{dt} \quad (15)$$

The charger unit should be modeled along with the modeling of the battery. A battery has been modeled as a variable voltage source (EB) which is connected in series with a resistor (RB1) and a parallel combination of a capacitor (C) and a resistor (RB2) [11] as shown in Fig. 5.

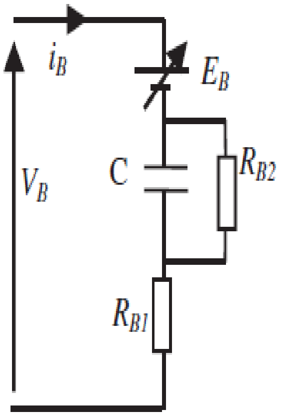

Figure 5. The battery equivalent circuit model

Capacitors can be open circuited for steady state analysis. Hence, the battery equivalent becomes a resistor (RB = RB1 + RB2) in series with a variable voltage source (EB). The steady state representation of (14) and (15) are given by (16) and (17).

$$i_L = i_B \quad (16)$$

$$V_s = V_B + R_B i_B + ri_b \quad (17)$$

Among the battery charging methods, the constant current–constant voltage charging (CC–CV) technique is well established [12,13]. Buck convertor controller maintains constant charging current during first phase charging. Considering the cell voltage and temperature, charging current is determined by the Battery management cell. As cell voltage reaches the predetermined value, a constant reducing current is applied to the battery until it gets fully charged. Lossless switching and continuous conduction mode operation of the buck convertor are considered. The steady state equations can be derived as shown below considering a steady state duty ratio of k.

$$i_B = \frac{i_o}{k} \quad (18)$$

$V_s = kV_B = E_B + ri_B + R_B i_b$ (19)

Combining (13) and (18);

$P=\left(\frac{3R1i_0^2}{2d^2d}\right)+kV_{dc}i_B$ (20)

By combining (9), (11), and (18);

$$d_d = \frac{V_d \pm \sqrt{V_d^2 - \frac{8V_{dc}i_B R_1 k}{3}}}{2V_{dc}}$$

This indicates two possible solutions for d_d.However, the solution associated with positive sign will only leads to a desired converter operation.

$$k = \frac{E_B + Ri_B + R_B i_B}{V_{dc}} \quad (21)$$

It is evident that the power consumption of the charger (20) consists of a supply voltage which is dependent (Pvd, the first term) and an independent term (Pcp, the second term). The second term (Pcp) remains constant under any variation which occurs due to the supply voltage, which follows the behavior of a constant power (P) load. The dd of (22) could be approximated as in (24) when assigned a feasible set of parameter values for R_1, E_B, r, R_B, V_B, i_B, V_{dc} as 0.1m Ω, 420 V,1m Ω, 0.04 Ω, 300 V, 300 A, 600 V respectively.

$$d_d \approx \frac{V_d}{V_{dc}} \quad (22)$$

Hence, the supply voltage dependent (P_{vd}) component can be represented by (23).

$$P = \left(\frac{3R_1 i_B^2 k^2 V_{dc}^2}{2V_d^2}\right) \quad (23)$$

This follows the standard exponential load behavior having a negative value of alpha, as given in (24), where, P0 represents the power consumption of the charger at the reference voltage (V0).

$$\frac{P}{P^0} = \left(\frac{V}{V_0}\right)^{\alpha} = \left(\frac{V}{V_0}\right)^{-2} \quad (24)$$

III CASE STUDY

For forecasting the future of EV penetration in Mumbai in the year of 2025 and 2030,the existing conventional (petrol/diesel/CNG/LPG) vehicle data has been referred. The conventional vehicle data have been taken from the “Vehicles Population as on 31st March, 1998 to 31st March 2017” documents of Motor Vehicles Department, Maharashtra [14]-[16].Using the above collected data of various types of conventional vehicles and their historical growth rates, we would be forecasting the number of conventional vehicles in Mumbai for the years 2025 and 2030 are:

Year	2018	2025	2030
No. of two wheeler	3901369	5764098	7356613
No. of three wheelers	415783	526701	610591
No of Comm. Four wheelers	311954	460898	588235
No of Heavy Comm. Vehicle	213323	249941	275956
No of Non Comm. Four wheelers	1684551	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 are been utilized to analyze the impact of EVs on EPDS of Mumbai.

The existing load profile of Mumbai has been obtained from Maharashtra State Load Dispatch Centre. The load curve have been prepared according to the Maharashtra SLDC daily and monthly reports On 31st May 2018 (peak day)[17]-[19].From the given load curve data, we have verified that the peak load of the day occurs 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. Using load forecasting tool, we have estimated the load demand for year 2025 and 2030 from the given peak load details of Mumbai. The estimated load demand outputs are shown in table below:

Year	MAX(MW)	MIN(MW)
2016	3552	2051
2017	3561	2206
2018	3670	2202
2025	4514	2708
2030	5248	3148

Load forecast for years 2025 and 2030 along with load profile of year 2018 on a hot summer day of Mumbai in month of May is shown in the fig. 6. [20].

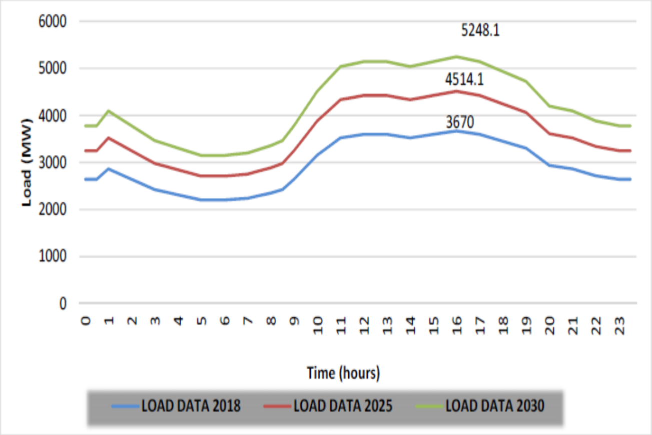

Figure 6. Daily load profile of Mumbai (May)

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 .

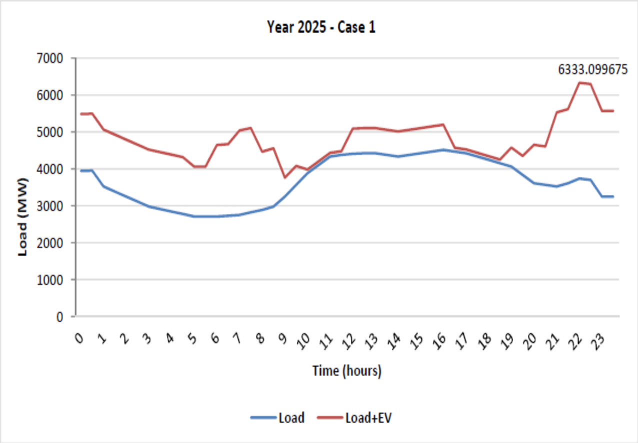

Figure 7. Conventional load curve & total load curve, including EV, for Mumbai in year 2025

From the above Fig. 7,we have observed that the peak load has occured around 4 PM when EV has not been considered, has been shifted to 10 PM in the night when EV load has been 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 which shows that the peak load demand in Mumbai in the year 2025 will increase by 1819 MW, i.e around 40%.

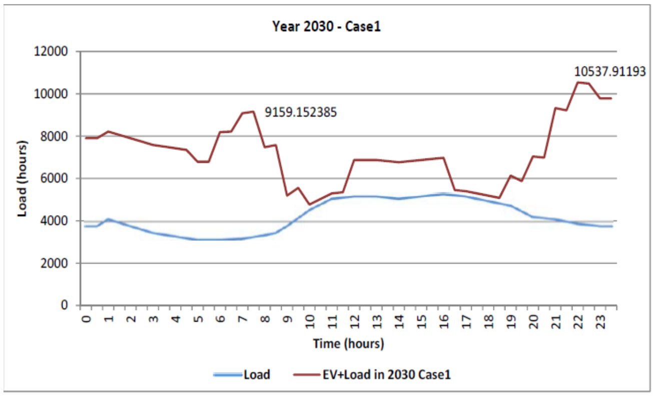

Figure 8. Conventional load curve & total load curve, including EV, for Mumbai in year 2030

From the above fig. 8, It has been observed that the compared conventional peak of 5248 MW occurs around 4 PM, the total load curve including the EV load has two peak values. One peak of value 9159 MW which occurs around 7:30 PM while other peak of around 10537 MW occurs around 10 PM.The two peak values occurs due to EV's owner behavior of getting charged from charging station either in the morning or late in the evening. The curve shows that the peak load in Mumbai due to EV for the year 2030 will increase drastically by 5248 MW, i.e. around 100%.

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.

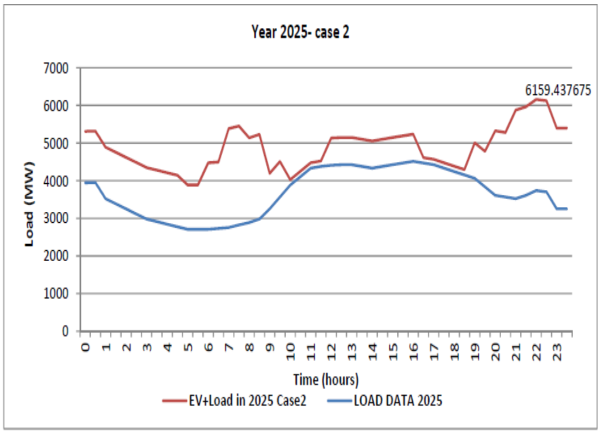

Figure 9. Conventional load curve & total load curve, including EV, for Mumbai in year 2025

From the above fig. 9, It has been observed that with the conventional peak of 4514 MW occurs around 4Pm, the peak load curve, including EV, occurs around 10 PM with peak load of 6159 MW. Therefore , charging of more electric vehicle at the charging station before system peak load condition will help in load flattening the load curve. It needs to be noted that the extra power demand due to EV penetration at peak load time that is around 10 PM, is 2422 MW which is 64% more than the conventional load demand at that time.

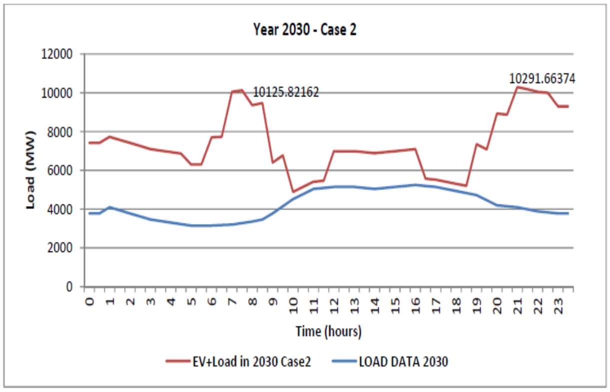

Figure 10. Conventional load curve & total load curve, including EV, for Mumbai in year 2030

From the above fig.10, it been observed that the compared conventional peak of 5248 MW occurs around 4 PM, the total load curve including EV load contains two peaks. One peak is around 10125 MW occurs around 7:30 AM while other peak occurs around 10291 MW at 9 PM. This shows that the EV load demand during peak condition is around 96% of conventional peak load. Therefore, EV integration will pose a huge effect in addressing the extra power demand required by the EVs.

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.

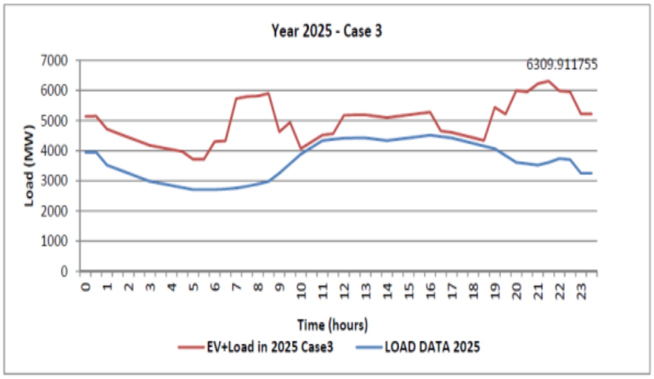

Figure 11. Conventional load curve & total load curve, including EV, for Mumbai in year 2025

From the Fig.11, It has been observed that with the conventional peak of 4514 MW occurs around 4PM, the peak load curve including EV load occurs around 9:30 PM with peak load of around 6309 MW. On comparing the total load curve of case 1, it has been observed that the peak load has been slightly reduced by 24 MW.

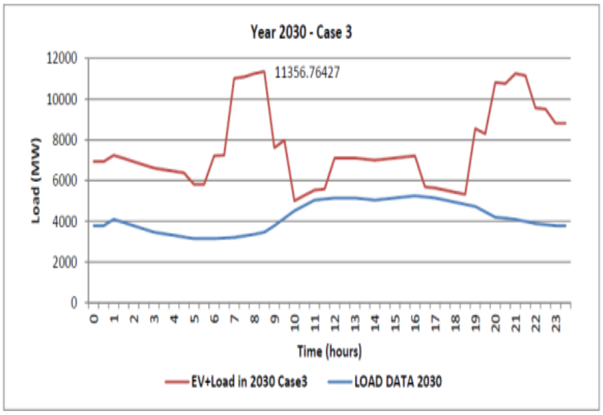

Figure 12. Conventional load curve & total load curve, including EV, for Mumbai in year 2030

As in case of year 2025, in case of year 2030 also, it can be observed from the Fig. 12 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 show that the demand of EV load is about 116% of the conventional peak value which means that the peak load has been increased by 1065 MW.Thefore charging of the more electric vehicle at charging station before system peak load condition will not help in flattening the load curve.

Case 4: All Non-commercial 4-wheelers EVs are charged at charging station, keeping other
types of vehicle charging same

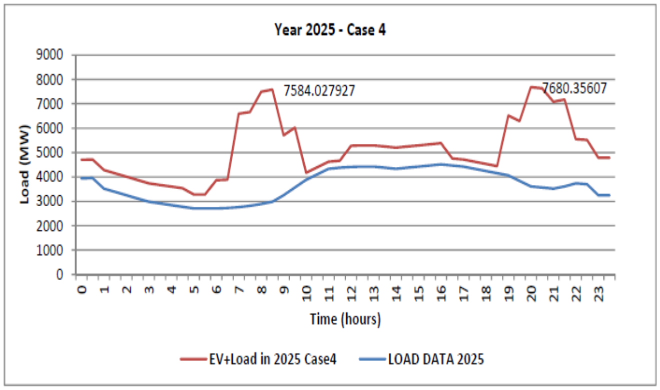

Figure 13. Conventional load curve & total load curve, including EV, for Mumbai in year 2025

From the Fig.13, 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' behavior of charging their vehicles either in the morning time, before going to work, or in the evening time, after coming from the work.

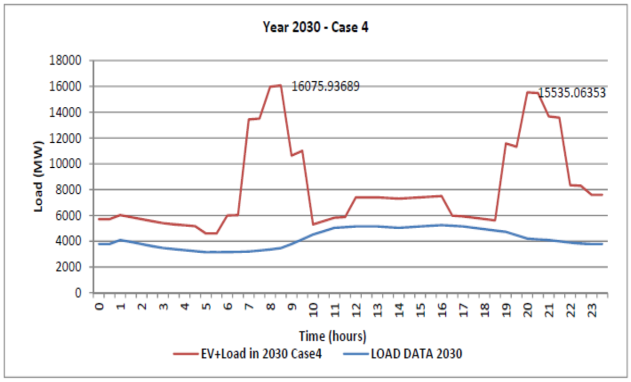

Figure 14. Conventional load curve & total load curve, including EV, for Mumbai in year 2030

As in case of year 2025, in case of year 2030 also, it can be observed from the Figure 14 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 [21].

IV CONCLUSION

From the above case study, it been observed that if 90% of the vehicles are charged at home in the night (Case 1) the system will be overloaded. Case 2 (30% from charging station and rest 70% charging from home) has been observed to create the least load on the system in the year around 2025. The same does not apply for Case 3 (50% from charging station and rest 50% charging from home) has observed that it create least load on the system in the year 2030. The battery capacity is around 75 MW. IF it is being charged by 350 KW, it creates a 350KW peak on the system around 12 minutes. The peak handling is a major concern for the utility system. The Indian EDPS will face a huge load stress when EV charged from distribution grid. Frequent connect and disconnect of EV to the charging substation of high power DC charger, will generate a serious power quality issues.

Charging EVs will cause a generation of increase harmonics. A huge capacity augmentation has been required in the EDPS for the year 2030 which will address the EV load demand. So a proper planning is required by the EDPS operator to address the scenario. IN that case the demand for EV load will increase further. Most of the time the distribution system peak load condition, including EV load, occurs either in early morning or late evening. Therefore solar PV may not be able to cope up to help the addressing high demand. Therefore, we need to find an alternate energy sources which will address the peak load condition.

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

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