Impacts of G2V and V2G Power on Electricity Demand Profile

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***Abstract*—Successful integration of growing number of energy-efficient electric vehicles (EV) into existing power grid necessitates the study of impacts posed by their adoption in larger numbers. However, their gradual adoption will give sufficient time to the utilities for planning the infrastructure upgrades to prevent destabilization of power network. The work presented in this paper investigates the proportion of energy that can be injected back into the grid by EVs through vehicle-to-grid (V2G) mechanism. The V2G energy profiles are obtained using constant power discharging approach for various power levels (as per charging standards) during the time vehicles are parked. For charging, constant power followed by constant time charging approach is used in succession complying with Li-ion battery charging characteristics together with a constraint of retaining reasonable battery lifetime. The simultaneous effect of V2G power and resulting G2V load on typical daily load curve is figured taking modified IEEE 30-bus as a test system.**

***Index Terms*— Electric vehicle, plug-in hybrid electric vehicle, all-electric range (AER), state of charge (SOC), grid-to-vehicle (G2V), vehicle-to-grid (V2G), utility factor (UF), charging power.**

I. Introduction

The bulk of automobiles in this world uses fossil fuels − the gasoline, oil or diesel for generating the power required for movement. The conversion efficiency of internal combustion engine (ICE) driven vehicles in converting energy in fossil fuels into motion is about 20% on an average [1]. The travel demand for vehicles is forecasted to grow two fold in next 15-20 years up to 2 billion vehicles globally yielding tremendous growth in transportation energy consumption. The discharge of toxic chemicals, primarily CO_2 and other greenhouse gases (GHG), in the process of burning fuel by these conventional ICE vehicles originates severe threats to human and environment about climate change, air pollution, oil scarcity and rising gas prices. All these effects are global in nature and there looms the big challenge in maximizing the return of transportation energy consumption while minimizing these destructive repercussions.

New electricity powered vehicles are encouraging towards transportation electrification, which is critical for the sustainable growth of this sector. These vehicles possess conversion efficiency of about 80 to 90% in converting electrical energy into forward motion, thereby reducing fossil fuel consumption and toxic gas emissions in the course. This new era of electric vehicles (EV) is also vital for the future of auto industry as they share the common perspective of its importance and are banking on the electrification of vehicles. Based on the propulsion mechanism, the battery electric vehicles (BEV)−powered solely by batteries and the plug-in hybrid electric vehicles (PHEV)−compounded with ICE, are the two basic varieties of EV at this point of time in the market [2] - [5]. These EVs can be characterized by their all-electric range (AER) − the range for which they can be driven entirely by electricity.

The increasing number of plug-in EVs will put an additional stress on existing distribution system, like transformers and cables and may perturb its operation mainly during times of peak energy consumption. However, with commitment of utilities and customers toward better management of power and with strategic charging of EVs to reduce load during peak times, the existing grid can still take this additional EV load, without the need of any network reinforcement.

Optimal charging scheme based on hourly spot market price to curtail peak consumption while raising off-peak consumption for obtaining minimum energy cost has been proposed in [6]. However, rigid driving behavior and electrical characteristics of only one type of EV were considered in the work. In [7], voltage constraint based optimization problem is formulated for the charging of EVs to maximize profits to distribution companies while maintaining system voltage profile. In this study, characteristics of EVs and driving behavior of customers have not been elaborated in detail and fixed charging start time of EVs was considered. National Household Travel Survey (NHTS) [8] data has been analyzed in [9] to obtain PHEVs charging profiles for different charging powers. It has been shown that the use of different charging power at different times and price incentive based charging mechanism can alter to some extent the load profile of EVs, to limit peak EV load at conventional peak load time. Charge scheduling strategies to inhibit abrupt change in day ahead market price with increasing penetration levels of EVs has been developed in [10] while considering EVs as price-makers in the electricity market.

EVs grid integration has been maximized in [11] and uncontrolled and smart charging approaches were compared while keeping voltage, congestion, phase imbalances and grid losses in check. Authors in [12] also considered these charging approaches at various penetration level of EVs to test overloading of transformers and cables in LV distribution network which will lead to network reinforcement. Time-of-use tariffs and smart metering techniques to implement smart charging will result in lesser investment in distribution network upgrade and reduced incremental power losses [13]. However, the demand response, which enable consumers to manage

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household loads, will be a part of smart distribution network through which sizable share of EVs can be accommodated without increasing the peak load [14]. A recent research in [15] has found that the additional EV load caused on power system by delayed charging (to fill night valley) of EVs will result in reshuffling of unit commitment and power dispatch, causing changes in generator emissions which are less when compared with peak charging scenario. Stochastic treatment of transportation statistics based on aggregated fleet of vehicles and energy price prediction approach for optimizing charging as well as discharging times and power flows has been employed in [16] and [17].

In contrast to recent research studies done to assess the impacts of increasing number of green-technology based EVs in the system, this work primarily focuses on analysis of real transportation statistics in realizing the EVs daily demand profile to meet the driving needs and V2G services over a day. For this, four different kinds of EVs representing small, midsize and large vehicles in the market are considered. Battery's state of charge (SOC) is evaluated for varied driven mileages considering speed dependent energy consumption under the different courses of driving. The charge and discharge schedules for G2V and V2G power, respectively, are determined based on arrival time, travel time and parking durations for different power levels of EV charging standards given by Society of Automotive Engineers (SAE) [18] and Electric Power Research Institute (EPRI) [4]. The transportation data is extracted from published research project reports of Grid for Vehicles (G4V) under European Union Seventh Framework Program [19] and Joint Research Centre Scientific and Policy Reports of European Commission [20].

The remainder of the paper is structured as following. Section II outlines the transportation attributes and characteristics of EVs considered in this work. In Section III, the process of modelling of G2V and V2G energy profiles is presented. Section IV then combines the result and discussion on EVs electric capacity usage and the impacts of obtained G2V and V2G energy profiles on daily load curve taking modified IEEE 30-Bus as a test system, for various charging and discharging power levels. Finally, Section V concludes with prospective directions of work.

II. Characteristics of Electric Vehicles

The total number of vehicles are assumed to be 0.17 million [10]. Four different varieties of vehicle having characteristics shown in Table I are considered in this study. It has been pointed out in [19], [20] that, the actual consumption by EVs is speed dependent and comes out to be a different count under different driving periods, viz. road, urban, highway and traffic jam, as shown in Table I. Also the real consumption can vary even within the different driving cycles. Nonetheless, in this study, the general trend has been assumed, which results in relative increase of 40%, 60% and 63% in energy consumption from driving period road to urban, highway and traffic jam, respectively.

The division of different kind of EVs contributing towards its market penetration will change with increase in EVs concentration in the market. In this work, EVs penetration percentage is assumed to be 100% and the corresponding composition percentages of different kind of EVs are shown in Table I. It can be seen that, battery electric vehicle (BEV), being the dominating one in the market (having 37% contribution) can be compared with present-day passenger and family cars, having higher ranges than City-BEV, which looks like modern subcompacts designed for civic transport in size, energy consumption and weight. PHEV 30 and PHEV 90, having an AER of 30 km and 90 km, covers a range of 30 km and 90 km without fuel oil, therewith one third and two third of their ranges, respectively, in electrical mode. All these features are retrieved from the trends exhibited in [19]. Table II shows the averaged characteristics of EVs thus obtained based on their composition percentages. The driving pattern of commuters has been characterized by the trips they make for business purpose [19] and the driven mileages for different group of vehicles are obtained accordingly. The vehicles set out for trips are split into 120 different mileage groups. It has been assumed that each mileage group of vehicles complete 40% of their itinerary on road, 30% on urban, 20% on highway and remaining 10% while moving through traffic jam.

A fully depleted battery carries lesser life then a moderate one. The term Depth of Discharge (DoD) is typically used as measure of battery's depletion and it has been assumed that the EV owners limit the battery's DoD to 80% with a view to increase its lifetime.

III. Modeling of G2V and V2G Energy Profiles

Assessment of G2V energy required to complete all the trips of the day will depend upon the number of EVs, driven mileage and energy consumption per km of the vehicles. Whereas, the G2V and V2G energy profiles will be determined by the charging and discharging process, respectively. These two aspects are explored in the following subsections.

A. Hourly G2V Energy to Meet the Driving Needs

The G2V energy required during different hours over a day (T = 24) is obtained as:

$$E^t = \sum_{m=1}^{120} (\,\alpha + \beta + \gamma + \delta\,) \qquad \forall t \in (1, 2, ..., T) \quad (1)$$

where,

$$\alpha = \begin{cases} n_m^t\,(d_m^{tR} \cdot E_{avg}^R) & \forall\ d_m^{tR} \le \mathrm{AER}_{avg}^R \\ n_m^t\,(\mathrm{AER}_{avg}^R \cdot E_{avg}^R) & \forall\ d_m^{tR} > \mathrm{AER}_{avg}^R \end{cases} \quad (1.1)$$

$$\beta = \begin{cases} n_m^t\,(d_m^{tU} \cdot E_{avg}^U) & \forall\ d_m^{tU} \le \mathrm{AER}_{avg}^U \\ n_m^t\,(\mathrm{AER}_{avg}^U \cdot E_{avg}^U) & \forall\ d_m^{tU} > \mathrm{AER}_{avg}^U \end{cases} \quad (1.2)$$

$$\gamma = \begin{cases} n_m^t\,(d_m^{tH} \cdot E_{avg}^H) & \forall\ d_m^{tH} \le \mathrm{AER}_{avg}^H \\ n_m^t\,(\mathrm{AER}_{avg}^H \cdot E_{avg}^H) & \forall\ d_m^{tH} > \mathrm{AER}_{avg}^H \end{cases} \quad (1.3)$$

$$\delta = \begin{cases} n_m^t\,(d_m^{tJ} \cdot E_{avg}^J) & \forall\ d_m^{tJ} \le \mathrm{AER}_{avg}^J \\ n_m^t\,(\mathrm{AER}_{avg}^J \cdot E_{avg}^J) & \forall\ d_m^{tJ} > \mathrm{AER}_{avg}^J \end{cases} \quad (1.4)$$

Here, E^t is the G2V energy required during hour t and n_m^t is the number of m^{th} mileage group of vehicles during hour t. Further, d_m^{tR}, d_m^{tU}, d_m^{tH} and d_m^{tJ} are the kms travelled by m^{th} mileage group of vehicles, respectively, while moving through road, urban, highway and traffic jam; AER_{avg}^R,

TABLE I. CHARACTERISTICS OF ELECTRIC VEHICLES

Vehicle type	Battery capacity (kWh)	Energy consumption (kWh/km)				AER (km)				Composition percentage
		Road	Urban	Highway	Traffic Jam	Road	Urban	Highway	Traffic Jam	
BEV	35	0.130	0.181	0.209	0.212	215	154	134	132	37
City-BEV	16	0.120	0.167	0.193	0.195	107	76	66	65	10
PHEV 90	18	0.150	0.209	0.241	0.244	96	69	60	59	26.5
PHEV 30	12	0.150	0.209	0.241	0.244	64	46	40	39	26.5

TABLE II. AVERAGED CHARACTERISTICS OF ELECTRIC VEHICLES

Average battery capacity (kWh)	Average energy consumption (kWh/km)				Average AER (km)			
	Road	Urban	Highway	Traffic Jam	Road	Urban	Highway	Traffic Jam
18.54	0.1396	0.1944	0.2244	0.2273	133	95	83	81

AER^U_{avg}, AER^H_{avg} and AER^J_{avg} are the average values of AER given by vehicles; and E^R_{avg}, E^U_{avg}, E^H_{avg} and E^J_{avg} are the average values of energy consumed per km by the vehicles, respectively, when they moves through road, urban, highway and traffic jam.

B. State of Charge (SOC) and Proportion of Energy Required

Vehicle's SOC is the quantity of energy remaining when it finally arrives at home after finishing the last trip. The vehicles with daily mileage of D kilometers would retain the the following SOC:

$$\text{Percentage SOC} = \left(\frac{\text{AER} - \text{D}}{\text{AER}}\right) \cdot 100\,, \quad \forall \text{D} \leq \text{AER} \qquad (2)$$

Consequently, the proportion of energy required to get the batteries back to full is the complement of their respective SOCs. The vehicles whose daily mileage takes over their AER (could be possible only with PHEVs) results in zero SOC, i.e. their batteries are depleted all the way, needing 100% charge. The SOC considered in the time of developing the G2V load profiles (as discussed in next section) is the eventual SOC of the battery, i.e. the charge remaining in the battery after completing both the functions during the day - the driving needs as well as the V2G power services.

C. Power Levels for G2V and V2G Energy

Presently, automakers and charging equipment manufacturers are following two standards namely, SAEJ1772 [18] and EPRI-NEC [4], for charging of EVs and are summarized in Table III. Both of these standards are comparable when it comes to specifications of electrical ratings, particularly the charging level, supply voltage, amperes and power. About 90% commuters keep a daily mileage below 85 km with most of the vehicles commuting daily for a distance of about 30 km [19].

The present-day charging infrastructures in the U.S. and in many European countries are still having a limited power capacity. Most of these infrastructures are limited up to 6.6 kW public charging stations. The starting models of most of the automakers, Nissan Leaf and Chevrolet Volt being the leading ones, are limited to maximum charging power of 3.3 kW. However, the upcoming mainstream models are the upgraded one and supports charging at 6.6 kW [21]. In this work, the G2V charging load distribution over a winter weekday is obtained for the charging powers of 1.92 kW, 2.5 kW, 3.3 kW and 6.6 kW. These charging power covers AC Level 1 and AC Level 2 charging of both the standards and adds an electric range of about 11 km, 14 km, 18 km and 36 km, respectively for every hour of charging. Installation of DC charging stations, regarded as fast charging is still debatable as its infrastructure would be very expensive [21]. Moreover, installation of Level 3 AC charging have to wait till mainstream EVs are capable of faster charging. Thus, in this work, EVs load profile have been retrieved till charging power of 6.6 kW covering Level 1 and Level 2 of both the charging standards. Also, substantial amount of energy remains in a fully charged EV battery even after completing all the trips of the day. A part of this energy can be fed back into the grid (V2G) when vehicles are parked to provide power to the grid during the time of peak demand. Based on this, the V2G energy profiles have been developed taking 1.44 kW, 1.64 kW, 1.92 kW, 2.5 kW, 3.3 kW and 6.6 kW as discharge power levels.

TABLE III. ELECTRIC VEHICLE CHARGING STANDARDS

SAEJ1772 Standard			
Charging type	Voltage level	Power level	Phase
Level 1	120 V AC	1.2-2.0 kW	Single-phase
Level 2 (low)	208-240 V AC	2.8-3.8 kW	Single-phase
Level 2 (high)	208-240 V AC	6.0-19.2 kW	Single-phase
Level 3	208-240 V AC	15-96 kW	3-phase
DC charging (DC Level 1, 2 and 3)	200-600 V DC	>15-240 kW	DC

EPRI Charging Characteristics	
Charging type	Electrical ratings
AC Level 1	120 V AC, 12-16 A, 1.44-1.92 kW, Single-phase
AC Level 2	208-240 V AC, 12-80 A, 2.5-19.2 kW, Single-phase
DC Level 1, 2 and 3	200-600 V DC, $\leq$80 - 400 A, $\leq$19.2 - $\leq$240 kW

D. Charging and Discharging Approach

The non-linear charging characteristics of Li-ion battery [22] presently used in EVs is a compelling aspect and plays central role in deciding the charging approach for an aggregated group of vehicles. Charging current, which correlates to charging power, remains constant till battery reaches about 70% of its SOC [19]. From there on, constant voltage charging takes over and current steadily reduces to zero. Therefore, in

TABLE IV. EVs CHARGING TIME FOR VARIED CHARGING POWER

Charging Power (kW)	Charging Time (hrs.)			Electric range added per hour of charging (km)
	CP	CT	Total	
1.92	5	10	15	11
2.5	4	8	12	14
3.3	3	6	9	18
6.6	2	3	5	36

this work, constant power [9] charging approach is used to charge EVs till their battery's SOC reaches 70% of its capacity. The remaining 30% of energy is supplied with constant time [9] charging scheme. In constant power charging approach, charging power is held constant at the levels specified, which results in variable charging time for vehicles depending upon the SOC they carry after finishing the last trip of the day. Constant time charging approach causes charging power to be varied in accordance with the energy need of the vehicles in order to keep the total charging time a fixed duration. Based on the above charging approach, the charging time of EVs for different power levels are shown in Table IV. Constant time charging is a better approach when it comes to managing the peak load of EVs, because it results in lesser peak and also being shifted towards late (valley) hours [9]. However, constant power approach has been tested in discharging of the vehicles to provide V2G energy. It has been assumed that once the vehicles are plugged after arriving, they undergo full charging.

E. Charging and Discharging Moment

It has been assumed that, for charging (G2V), commuters plug their vehicles only at home soon after finishing the last trip, whereas, for providing V2G energy, vehicles are plugged into the grid as soon as they arrive at workplace from home. Figure 1 shows the final arrival time of the vehicles [9], [8], which has been treated as the start of charging time in this work. The arrival of bulk of the vehicles (over 60%) in the evening hours spanning from 15:00 to 21:00 characterizes the routine driving practice of commuters, returning to home after work. In the view of this, 96 different arrival times in the intervals of 15 minute has been considered during the entire day, thereby producing 4 different arrival times per hour. Thereupon, entire mileage group of vehicles were subdivided into these different arrival times at which they arrive all through the day.

The vehicles are supposed to provide V2G energy in the course of active parking duration [20] only, which is the time during which the vehicles are parked at workplace. This duration is considered as 7 hours from the instant of arrival of vehicles from home to workplace. Further, the average driving duration of the vehicles is assumed to be 1.3 hours, resulting in 15.7 hours of inactive parking time [20], which is treated as the duration from the instant of final arrival of the vehicles at home after finishing last trip of the day. This is the slot which is available for the vehicles to refill their batteries (G2V) in order to execute the routine over next day.

F. Utility Factors

Utility factor (UF) [5] is a measure of exploitation of EVs battery capacity and is defined as the actual proportion of driving performed on electricity by EVs to the total distance that could be driven on electricity with its AER. Lower the AER of the vehicles, higher would be their UF.

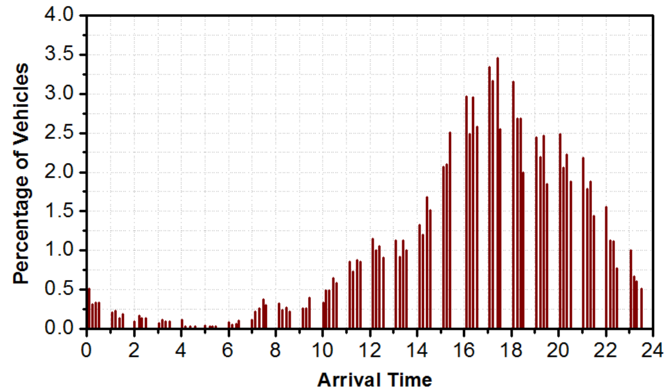

Fig. 1. Distribution of final arrival time of vehicles

$$\mathrm{UF} = \left(\frac{\sum_{m=1}^{x-1} (d_m \cdot n_m) + \sum_{m=x}^{120} (\mathrm{AER} \cdot n_m)}{\mathrm{AER} \cdot N} \right) \quad (3)$$

where, d_m is the distance travelled by m^{th} mileage group of vehicles, n_m is the number of m^{th} mileage group of vehicles, AER is all electric range of vehicles and N is the total number of EVs in the system. The EVs of mileage group ranging from $m = 1$ to $x - 1$ drive a distance less than or equal to their AER, whereas the remaining mileage group EVs ranging from $m = x$ to 120 drive daily for a distance more than their AER. It should be noted that, in the expression of UF, d_m and AER takes the respective value among various EVs based on their driven status, viz. road, urban, highway or traffic jam. Besides this, AER takes the respective average value under different driven conditions while calculating UF for those driving periods. The UFs calulated for different vehicle types and under various driving periods are compiled in Table V. The average UF is the eventual UF attained after considering the percentage travel under various driving conditions and percentage distribution of all four kinds of vehicles at the corresponding penetration level.

It can be observed that, the UF is minimum with BEV which gives the highest AER under all the four driving periods, and is maximum with PHEV 30 which results in the lowest AER in all the four driving conditions. As the traffic jam period results in the lowest possible AER given by vehicles due to highest energy consumption while road driving resulting in vice-versa, the UF attained is maximum under the traffic jam period while it is lowest with the road driving condition. The final average utility factor obtained is 0.544 revealing that only 54.4% of electrical energy stored in the battery of the vehicles is consumed in the trips.

IV. RESULTS AND DISCUSSION

This section examines the G2V load profile as well as the distribution of vehicles discharging load in providing V2G energy under different charging and discharging power levels.

TABLE V. UTILITY FACTORS

UFs based on vehicle type					UFs based on driven type		Average UF
Vehicle type / Driven type	Road	Urban	Highway	Traffic Jam	Driven type	UF	
BEV	0.283	0.389	0.437	0.442	Road	0.439	0.544
City-BEV	0.517	0.634	0.680	0.684	Urban	0.559	
PHEV 90	0.555	0.666	0.708	0.713	Highway	0.605	
PHEV 30	0.689	0.780	0.813	0.819	Traffic Jam	0.614	

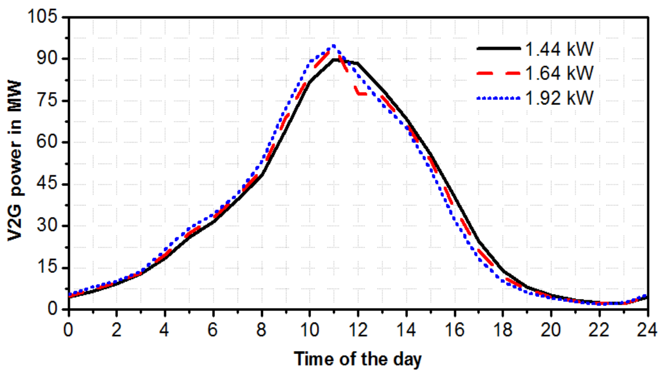

Fig. 2. V2G energy curve for Level 1 discharging powers

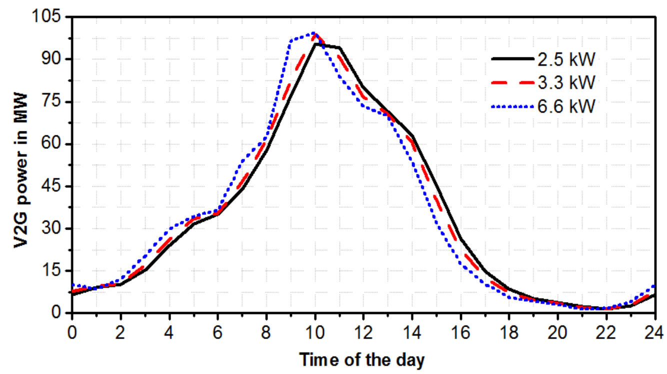

Fig. 3. V2G energy curve for Level 2 discharging powers

A. V2G Energy Profiles

The V2G energy is provided in accordance with constant power approach with an inverter efficiency of 0.93 [23] as soon as the vehicles arrive at workplace from home. The average UF of 0.544 indicates that, energy corresponding to 45.6 % of battery capacity is available and could be injected into the grid. However, it is assumed that, the commuters keep an energy buffer corresponding to a range of 20 km, proportionally under different driving periods for an unanticipated trip, if needed, leaving about 28.15% of battery capacity for V2G supply. This is the average car trip distance of vehicles during weekdays [20] and can vary with commuters driving requirement. The profiles of V2G power over the entire discharging duration for different discharging powers of Level 1 and Level 2 charging standards are shown in Figs. 2 and 3, respectively, and their relevant characteristics are summarized in Table VI. It is observed that, the increase in discharging power levels from Level 1 to Level 2 does not affect the V2G profiles much and results only in the shifting of V2G peak time from hour 11:00 to hour 10:00. This is due to the fact that the actual energy supplied during V2G operation is less accounting only 26.18% (with an inverter efficiency of 0.93) of battery capacity and bulk of the vehicles arrive at workplace in morning hours (in between 08:00 to 11:00 hours), injecting power into grid thereon. As the discharging power increases from 1.44 kW till 6.6 kW, the V2G peak power increases from 89.88 MW till 99.55 MW, whereas the duration of V2G supply comes down from 3.4 hrs at 1.44 kW to 0.7 hrs at 6.6 kW. Nevertheless, the V2G profiles follow relatively similar pattern throughout the day irrespective of the variation in discharging powers.

B. G2V Energy Profiles

The G2V load curves over a regular winter weekday for distinct charging powers of Level 1 and Level 2 charging standards are shown in Fig. 4. The total G2V load is the result of following two parts - (i) the load resulting from the energy consumption due to driving needs and, (ii) the load due to vehicle's battery depletion in providing V2G energy. The actual MW values for these are detailed in Table VII. The total available inactive parking duration of 15.7 hours, limits the minimum charging power to 1.92 kW of Level 1 charging standard because, it necessitates 15 hours of charging to bring the battery back to full from its initial SOC. It can be seen that, the peak G2V load increases steadily (from 192.93 MW to 251.10 MW) as well as shifts toward left (20:00 to 18:00) with increase in charging power from 1.92 kW till 6.6 kW. However, the trend is reversed for minimum G2V load, which decreases (from 43.28 MW to 7.80 MW) and also shifts toward left (10:00 to 06:00) as the charging power increases from 1.92 kW to 6.6 kW. The lowest charging power of 1.92 kW results in flattest charging profile. The crest resulting during evening hours with these power levels is due to the simultaneous charging of sizeable number of EVs as bulk of the vehicles arrive in these hours. Furthermore, the shifting of the crest toward left with the increase in charging power is due to the rapid charging of EVs, advancing the peak EV load nearby peak arrival time of the vehicles. However, the charging profiles follow similar pattern from hour 09:00 to hour 17:00. The relevant attributes of obtained G2V energy

TABLE VI. CHARACTERISTICS OF V2G ENERGY

Discharging power level (kW)	Duration of V2G supply (in hours)	V2G peak power (MW)	V2G peak time
1.44	3.4	89.88	11:00
1.64	3.0	94.55	11:00
1.92	2.5	94.80	11:00
2.5	1.9	95.59	10:00
3.3	1.5	98.99	10:00
6.6	0.7	99.55	10:00

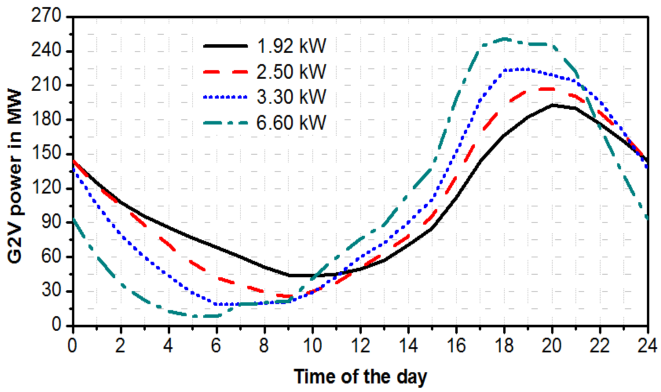

Fig. 4. G2V energy curve for different charging power levels

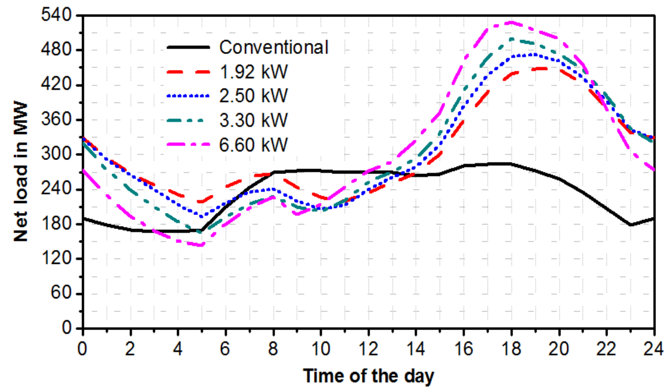

Fig. 5. Net load on modified IEEE 30-Bus system with different charging and discharging powers

TABLE VII. SUMMARY OF G2V AND V2G POWER

Particulars	MWs	Percent of total battery capacity
Aggregated load due to V2G supply	886.77	28.15
Aggregated driving load	1645.89	52.24
Total aggregated G2V load	2532.68	80.39
Aggregated energy already available	618.02	19.61
Aggregated battery capacity	3150.68	-

TABLE VIII. CHARACTERISTICS OF G2V LOAD

Charging power (kW)	Maximum G2V load (MW)	Time of occurrence	Minimum G2V load (MW)	Time of occurrence
1.92	192.93	20:00	43.28	10:00
2.5	206.87	20:00	25.45	09:00
3.3	224.12	19:00	18.39	07:00
6.6	251.10	18:00	07.80	06:00

profiles with different charging powers are outlined in Table VIII. The need of constant power charging to furnish 70% of battery capacity for all mileage group of vehicles results in lesser charging time for the vehicles carrying higher leftover SOC. Whereas, the remaining 30% energy is provided by the constant time charging approach in which the charging power is varied in accordance with the energy need of the vehicles, resulting in fixed charging time, the time far larger than the constant power charging, as shown in Table IV.

From the G2V load curves, it is confirmed that, the lower charging power results in the lesser peak G2V load together with the shifting of large part of it towards the late night hours, offering privilege of night time valley filling. Although, to achieve this, EV owners have to payback in terms of longer charging time. The owners arriving early in the evening and getting sufficient time before the next trip can opt for this power thereby facilitating off-peak charging. Also, the consumers who retain the higher leftover SOC after finishing the last trip can either go for low charging power or can delay their charging to later hours or both, restricting the increase of G2V load during peak arrival times. Impetus on higher concentration of PHEVs in the vehicles' market will also facilitate this because it can run some miles on ICE after battery's depletion thereby averting the need of fast charging during the day at home or at other intermediate locations. Thus, the low charging power along the constant time approach is indeed a smart charging strategy in itself.

C. Impact on Daily Demand Profile

Figure 5 shows the possible effects on the daily electricity demand profile of modified IEEE 30-bus system, which will occur with the introduction of these EVs in the system, under the examined scenario. A typical daily load profile for winter weekdays representing hourly conventional load on the system is used as the basis for demonstrating the impacts of resulting G2V and V2G load/power on electricity demand. It can be seen that, the peak G2V load coincides with the peak arrival time of the vehicles (Fig. 1) and escalates the total load during evening hours much above the conventional peak. Moreover, the peak rises and shifts toward left with the increase in charging power. However, the provision of V2G, in which energy is fed into the grid with arrival of vehicles at workplace; would lessen the actual demand on the system below the conventional load in morning hours lasting till 14:00 hours. Hourly conventional load for the test system is computed for winter weekdays as per IEEE reliability test system [24] with available daily peak load from [25].

The resulting load profiles shown in Fig. 5 are under the scenario when G2V charging load as well as V2G supply are together met with the same power levels of 1.92 kW, 2.5 kW, 3.3 kW and 6.6 kW. Though, these load profiles could be obtained by separately combining these four different G2V charging powers along six distinct V2G discharge powers of 1.44 kW, 1.64 kW, 1.92 kW, 2.5 kW, 3.3 kW and 6.6 kW. Table IX summarizes the resulting impacts on daily load profile when the four different G2V power levels are combined individually with these six distinct V2G discharge power levels. It is observed that, for a particular G2V power level, with increase in V2G discharge power from 1.44 kW till 6.6 kW, the net load on the system reduces during the time intervals 00:00 - 11:00 and 23:00 - 24:00, while it increases during the interval 11:00 - 23:00. The reduction in net load during the time intervals 00:00 - 11:00 and 23:00 - 24:00, with increase in discharge power is first gradual starting from hour 23:00, then slowly picks up as the time approaches the hour 10:00 of the next day, and then again lessens during interval 10:00 - 11:00. For a given G2V charging power level, the maximum reduction in the load occurs during the time interval 09:00 - 10:00. Similarly, the increase in net load during the time interval 11:00 - 23:00,

TABLE IX. IMPACT OF V2G POWER LEVEL ON ELECTRICITY DEMAND PROFILE WITH DIFFERENT G2V CHARGING POWERS

G2V power level (kW)	V2G power level (kW)	Load in the morning with highest variation (MW)	Time interval of the variation	Load in the afternoon with highest variation (MW)	Time interval of the variation	Time intervals of reduction in net load	Time interval of increase in net load
1.92	1.44	251.24	09:00-10:00	295.40	15:00-16:00	00:00 - 11:00 and 23:00 - 24:00	11:00 - 23:00
	6.6	219.57		319.42			
2.5	1.44	232.65	09:00-10:00	306.38	15:00-16:00		
	6.6	200.98		330.40			
3.3	1.44	227.89	09:00-10:00	321.20	15:00-16:00		
	6.6	196.22		345.22			
6.6	1.44	228.33	09:00-10:00	349.17	15:00-16:00		
	6.6	196.67		373.19			

with increase in discharge power is first gradual starting from hour 11:00, then slowly picks up till it maximizes during the interval 15:00 - 16:00, and then again lessens till hour 23:00. For a given G2V charging power, the maximum increase in the load occurs during the time interval 15:00 - 16:00. The actual MW values of net load (with highest variation) during reduction in the time intervals of 00:00 - 11:00 and 23:00 - 24:0, as well as during increase in the time interval of 11:00 - 23:00 are listed in Table IX for two extreme V2G power levels of 1.44 and 6.6 kW.

Also, for all V2G power levels, the net load on the system in the morning hours (between 00:00 - 11:00) reduces as the G2V charging power increases from 1.92 kW till 6.6 kW. Whereas, this trend is reversed after hour 11:00 in the morning, i.e. the net load on the system increases during interval 11:00 - 22:00 with increase in G2V power level from 1.92 kW to 6.6 kW. Between intervals 22:00 - 24:00 the net load increases with increase in G2V power from 1.92 kW to 2.5 kW, but then reduces as the charging power is increased further till 6.6 kW.

V. CONCLUSION

The large proportion of energy remaining in the battery of EVs after accounting for the consumption throughout the driving needs can be injected back into the grid in V2G mode. The V2G mode results in reduction of overall hourly demand on the system in the morning hours while the resulting charging load escalates the demand further in the evening. Also, speed dependent utilization of EVs battery capacity, affecting the resulting AER, is modelled in this work taking into account the four driving courses of road, urban, highway and traffic jam periods. Four different EVs and the driven mileages as per real transportation statistics were considered in calculating the actual charging energy required by the EVs for driving in a day. Based on the arrival times, G2V load profile over a day has been assessed for different charging powers of prevailing standards using the approach suitable with battery's charging characteristics. The G2V charge and V2G discharge power levels will play a significant role in shaping the daily load profile with the addition of grid-connected EVs in the system. It has been observed that the low power charging results in the shifting of considerable G2V load towards night valley hours. The diminished demand due to V2G in morning hours and at midday could reduce the hourly MCP in the course because some costly generators (peaking units) could be kept at bay without the need of scheduling them all the while. Further, renewable generation, primarily the wind energy, could be scheduled to meet the increased EV load during the late evening and night valley hours, which otherwise, mostly is surplus and would have been lapsed.

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