Vehicle to Grid Integration and Strategies for Managed EV Charging in India

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Abstract Electrification of vehicles has its share of benefits and risks to the power distribution companies (DISCOMs). While EV adoption can potentially result in a substantial increase in revenue for DISCOMs from additional electricity sales due to EV charging, charging demand may increase the peak load in the DISCOM's service area. Unmanaged EV charging at the charging stations can hamper smooth power system operations by causing voltage instability, harmonic distortion, power losses, and degradation of reliability indices. To manage or avoid these impacts on the power system, there are both passive and active solutions. The passive solutions include specially designed electricity tariffs or incentives. The active management of charging is either unidirectional active management of charging referred to as V1G, or bidirectional active management of electricity referred to as V2G. Vehicle-Grid Integration (VGI) refers to this entire gamut of EV charging management solutions to mitigate the negative impacts of uncontrolled EV charging on the power system. The benefits of VGI extend beyond EV charging load, as it can provide useful services to the grid. The present paper is a discussion of VGI strategies for India for managing EV charging. The paper presents recommendations for VGI implementation in India.

Keywords Electric vehicle charging · Vehicle to grid integration · Smart charging · Time of use · India

1 Introduction

Globally growing climatic concerns have led to rapid electrification of transportation and the pursuit of sustainable sources of electric power generation. The growing concerns about vehicular emissions, air pollution, and energy security have resulted

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in a shift to clean mobility. Every Electric Vehicle (EV) is a new consumer for the power distribution companies (DISCOMs) and opens up a pathway for additional revenue. One of the primary focus areas for studying the impact of EVs is to examine power generation adequacy. The EV transition is interlinked in the clean transition of the grid, as EV loads are a supporting factor to promote the adoption of renewable sources of energy. Unmanaged EV charging load presents its own challenges for system operation. The impact of the EV charging load on the distribution grid has been an area of interest to researchers [1, 2]. EV charging load can lead to voltage instability, harmonics and impact the reliability of the local distribution grid [3].

The most significantly studied impact of EV charging is its impact on the peak power demand and its effects on distribution system transformers. With the addition of EV charging, DISCOMs can expect an upward shift in their peak load, which will result in purchasing electricity at higher costs to meet the demand [4]. The transmission and distribution losses will increase if the system, and investment is needed to upgrade the network to facilitate the additional load [4, 5]. However, electrification of transport happening in parallel with the rapid smart grid technology implementation presents an opportunity to effectively tackle the challenges from EV charging and use EV as a grid resource. This is possible through the framework of Vehicle to Grid Integration (VGI), which represents the charging strategies and pathways to use EV to provide valuable grid services. VGI represents the ways in which an EV can provide benefits or services to the grid, society, the EV driver, or the charge point operator by optimizing vehicle interaction with the electrical grid to contribute to reliable management of the electricity grid [6]. Two major approaches are primarily adopted to manage EV charging, based on controlling the time and current of charging. The control strategies can be either passive or active in nature [4].

Passive charging management includes strategies for influencing EV charging behaviour using specially designed electricity tariffs or incentives. Active management of charging consists of strategies which are for controlling charging and discharging of EV batteries, which are commonly referred as.

- V1G: Unidirectional active management of charging, such as ramping charging levels up or down
- V2G: Bidirectional active management of electricity, entailing power flow from Vehicle to grid

The entire canvas of VGI has multiple other possibilities, including Vehicle to Home (V2H), Vehicle to Building (V2B), and Battery to Grid (B2G), which are not focused on.

This paper discusses both passive and active management strategies that are relevant to the Indian ecosystem. In the case of India, electrification is not limited to the deployment of electric cars [7]. The mainstay of electrification of India is electric two-wheelers and electric three-wheelers [8]. Indian cities are also gearing up for the electrification of bus fleets [9]. The grid impact of EVs depends on the type of vehicles, the number of vehicles, and their charging pattern. The VGI strategies should be different for every vehicle segment and should also factor in when and where the vehicles are going to be charged. In the case of India, strategies are needed to tackle both residential and public charging. In addition to that, the strategy also needs to include battery swapping, which is a viable option for two and three-wheeler vehicles [10]. The paper presents recommendations for VGI implementation in India. The focus in on the strategies applicable for electric two wheeler and four wheeler charging in residences.

2 Passive Charging Strategies

The first and most common step for EV charging management is to adopt passive strategies to nudge EV consumers to shift their loads with time-sensitive electricity rates. Time of Use (TOU) rates are specially designed electricity tariffs to disincentivise usage during peak demand and incentivise use during off-peak demand [11]. TOU rates are popular in mature electricity markets and are being evaluated as a feasible option for managing EV charging [12]. In the US alone, more than 200 DISCOMs offer TOU rates to consumers and 87% of the current 31 eV charging tariffs are TOU tariff [9, 13]. Studies and pilot projects have shown a positive impact of implementing TOU rates on charging patterns to shift peak demand [12, 13]. ACEEE [13] research has shown that TOU rates are helpful for both EV consumers and the DISCOM. EV consumers save money by charging at off-peak hours with TOU rates, while utilities can reduce peak demand and improve grid stability. TOU is the most passive charging strategy for controlling EV charging load at Indian homes [12]. EPRI research [14] has found that utility TOU rates are very effective in shifting peak loads for all the charging that occurred at Level 2 (230 V).

Apart from the TOU rate, other passive strategies include rebates for low power charging [14]. The rationale behind incentives for low power is that the Level 2 (230 V) and Level 3 (415 V) chargers for electric cars could be 7 and 22 kW, respectively [7]. Even in advanced EV markets, this could exceed the maximum demand of a typical home, leading to additional cost for demand charges and upgrading the grid connection. In the case of India for electric two-wheelers, research has shown that all the chargers are less than 3.3 kW [8]. Research has also shown that the current Indian cars, apart from one model, have chargers that are less than 3.3 kW [7]. Hence unless there is a huge penetration of EVs with chargers more than 7 kW, the adoption of low power charging rebates can be deferred. However, the application of TOU rates might be critical, especially in handling the residential EV charging.

3 Strategy For Residential EV charging

In India most of the State Electricity Regulatory Commissions (SERCs) have introduced flat EV-specific tariffs for public charging. Many of these tariffs are flat tariffs and deemed to be promotional in spirit [11]. Indian regulators are familiar with Time of Day (TOD) rates, which is equivalent to the TOU rate mechanism. However, these rates are currently only applied to industrial and commercial consumers [15–17]. However, currently, these rates are not applicable for EV charging at homes.

Global statistics show that a significant amount of EV charging happens at homes. The current guidelines governing the residential charging of electric vehicles is that the existing tariff will apply [18]. The residential energy rates in India are quite low as they are heavily cross-subsidized. The tariff scheme followed is typically a block rate that increases as consumption increases. Inclining block rates are not a practical solution for EV charging as it is designed to disincentivise high energy consumption [12].

To showcase the impact of block rate and flat rates on EV charging, a sample case study is performed using the existing electricity rate for residential consumers and EV charging in Delhi. In Delhi, the EV charging rate is INR 4.5 per kWh and the residential consumers have a block rate that varies between INR 3–8 per kWh [19]. Only energy charges are examined for this case study for two-wheelers and four-wheelers for an average weekly travel of 300 km. The electric two-wheeler and electric car models are assumed to consume 2.7 and 10.6 kWh per 100 km. This leads to the additional electricity consumption of 40 and 140 kWh for charging the two-wheeler, and the four-wheeler, respectively. The additional cost for EV charging is calculated for a consumer with monthly consumption of 400 kWh and presented in Fig. 1. The results show that for Delhi, the flat rates are better than the block rates. A more detailed analysis, including a TOU rate that offers 20% rebate during off-peak hours, shows that the impact is presented in Fig. 2. The detailed analysis for different monthly energy consumption presented for 4 W charging shows that the relative increase remains higher for block rates. The difference becomes predominantly noticeable when the consumer originally had a lower electricity consumption. Between the TOU rate and flat rate regime, the relative increase remains comparable as there is not much difference in absolute value for a small tariff.

The first challenge to tackle would be associated with the block rate system on consumer bills. In the international markets, the residential energy rates and EV

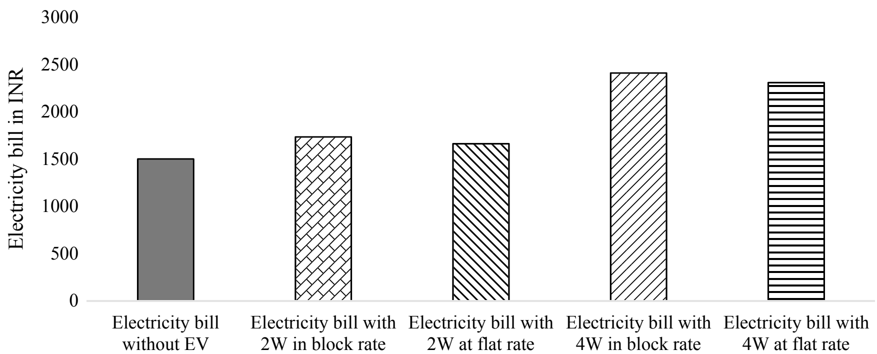

Fig. 1 Increase in residential energy charges under different rate regimes

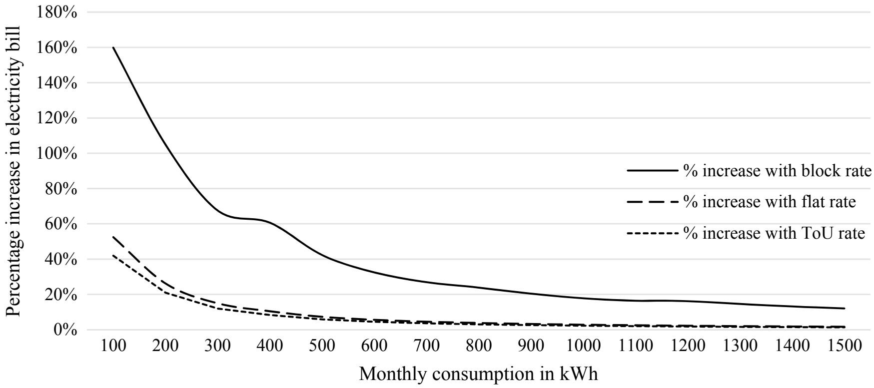

Fig. 2 Comparison of relative increase in residential energy charges in different rate regimes

specific rates as designed as TOU. Some of the utilities in the international market has extended another distinct EV specific tariff for the residential consumers, which comes with a separate meter. This would assist in handling the peak demand from EV charging and other residential energy consumption separately. India could adopt this strategy as with rapid urbanization and increasing appliance penetration, the residential energy consumption is increasing significantly.

It can also be concluded that a significant proportion of EV charging in residences. In the case of India, as there is no TOD tariff for residential consumers, the EV owner has no incentive not to plug the EV into the socket as soon as he reaches home. This leads to a situation where the electric vehicles are charged at the evening peak time. This will significantly impact the evening peak demand and ramping rate when the penetration of EVs increase. The ramping requirement and flexibility requirement are important considerations for a nation that is significantly increasing renewable energy penetration. Passive strategies like TOU rates are relatively easier to implement and but has limited benefits for grid flexibility.

4 Active Charging Strategies

Active charging control methods such as on–off control, increasing or decreasing the charging rate, and supplying power back to the grid will help in exploring additional value streams, especially in the flexible operation of the grid. The application of VGI technologies for grid services using active charging control is in the initial phases. V1G implementation can help in curtailing the rising peak demand, increasing renewable energy penetration, and providing grid support. V2G application though complicated, has the edge over unidirectional charging in extending the value streams from V1G. The value streams from active charging management from V1G and V2G is presented below:

- **Arbitrage opportunities:** The primary driving factor for the consumer to adopt VGI is price arbitrage. While V1G can assist primarily in reducing the cost associated with EV charging, V2G provides a chance for the consumer to earn more revenue using EV as a grid resource. With the implementation of V2G, an EV consumer may act as a prosumer or provide grid services in the local market.
- **Peak shaving:** The grid operator can also effectively use V1G to handle the rising peak demand that can be curtailed by implementing V1G & V2G. While V1G is suited for shifting the EV load to an off-peak period, V2G can help in further reduction of pre-existing peak demand. If a bi-directional flow of power is enabled, the energy stored in the EV may be discharged by the consumer to meet the local power requirement during period of peak demand.
- **Supporting Renewable Energy**: With V1G the EV charging load can be shifted to a period of high solar generation. With V2G, EV can be effectively used to store energy during periods of high renewable energy generation and subsequently use it during another time period. This can ensure higher utilisation of the generated Renewable Energy, and thereby EV can support higher penetration of Renewable Energy in the local grid.
- **Frequency Response:** One of the most sought out applications of EV is in providing grid support by frequency regulation through V1G and V2G. The supply and demand mismatch can be compensated with V1G implementation with increase and decrease of charging current in response to regulation up or down signals. With V2G the more is possible as the EV can be discharged or charged like energy storage units. In this case, the EVs can provide faster frequency response and act as a spinning reserve. To avail the best value proposition from VGI for frequency response and other grid support services, aggregation of EVs is critical.

It should be noted that the active charging strategies do not exist in isolation with the passive load management strategies. The existence of a time-sensitive tariff regime or incentives for low power charging will encourage the adoption of active control strategies. In that sense, it can be said that they are complementary to each other. However, in India, as discussed in the sections above, the application of TOU is limited. Secondly, in the existing TOD regime, the difference between peak and off-peak periods is not too high to encourage a shift to off-peak consumption. The tariff is also not designed now, such that there is a rebate during peak solar generation hours. The methods for determining the effectiveness of the TOU rate are also not in practice.

5 Case-Study For Load Shift

Two value streams from VGI that are particularly important in the Indian context is related to the time shift of loads. One is a shift of EV load from a period of peak demand to an off-peak demand. The second value stream is in a shift to a high renewable generation period during the day. Both of these applications become extremely relevant for India in handling the evening peak demand and ramping up of power plants. Charging of electric two-wheelers and four-wheelers in homes will compound the existing problem. However, the VGI strategy adopted should be based on the regional load pattern. A case study is performed considering three distinct load curve shapes where there are differences in the evening peak demand pattern, as shown in Fig. 3.

These load patterns are derived from the load shapes of the State of Uttar Pradesh, Delhi, and Maharashtra. For the case study, only the load shape is maintained, and the load curves are scaled down to showcase the impact of the EV charging load. In terms of absolute demand, the demand in these States is very high that at a low level of EV penetration, there is not much impact on the load curves. For the case study, the battery capacity for two-wheelers is taken as 2kWh, and for four-wheelers

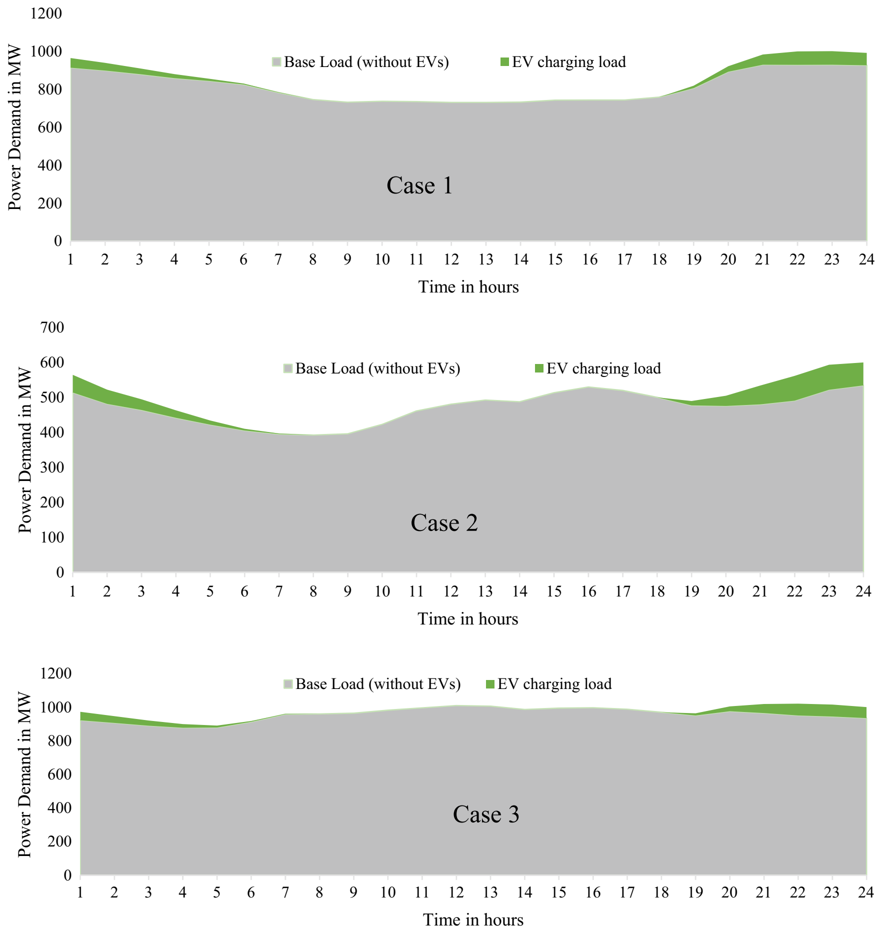

Fig. 3 Case study for EV charging strategies

is taken as 25kWh. Time taken to charge the battery between 30 and 80% is taken as 4 h for two-wheelers and 8 h for four-wheelers. The total number of two-wheelers and four-wheelers across the network are taken as 100,000 units and 10,000 units, respectively. The charge cycle is assumed to start from 6 PM onwards. Two scenarios are discussed for each case to shift the load, shift to an off-peak period at night, and shift to a high solar generation period during the day.

- **Case 1:** In this case, the VGI strategy should be to minimise the EV charging during evening ramping and shift the load after 2 AM when the demand starts to decrease. It also makes to shift demand to day time as the demand is low, especially if the state is planning for increasing share of Solar energy in the generation mix. Both these shifts are possible with passive strategies.
- **Case 2:** In this case, the VGI strategy should be to retain some of the charging during the evening in the 6–9 PM window and shift the load after 2 AM. In this case advanced charging control methods are needed to ensure charging between 6–9 PM, where was TOU rate can help in shift of demand after 2 AM. It is not advised to shift the load to day time unless the state is planning for a very high share of solar generation. In case this needs to be done advanced charge control methods are recommended.
- **Case 3:** In this case, as there no valleys in the demand curve, the strategy should be to distribute the EV charging throughout the day. Here passive charging strategies for time shift will have limited success. Active charging control strategies with aggregation is needed to distribute the load. It is not advised to shift the load to day time unless the state is planning for a very high share of solar generation.

The case study shows that it is important to adopt a mix of strategies to suit the existing load pattern. In some cases while passive charging strategies are effective in handling EV load, in other cases more advanced charging strategies are essential. VGI strategy should be case specific.

6 Discussion and Conclusion

The VGI strategy depends on multiple factors the type of Vehicle, concerns for battery health, and charging technology. The stakeholders have expressed that electric two-wheelers and electric three-wheelers are not good candidates for grid support through VGI. On the other hand, VGI using electric cars and e-buses could work, with favourable economics. Researchers have flagged that the issue of battery degradation with VGI and the impact of VGI on different battery chemistries should be studied further in the Indian context. Another factor affecting VGI is the availability of V2G enabled chargers. The Combined Charging System (CCS) chargers preferred by Indian EV manufacturers are not currently capable of bidirectional charging. Lack of a smart backend communication system with standardised communication protocols is a prerequisite to VGI. For a "smart" charging infrastructure Advanced Metering Infrastructure (AMI) and communication is also critical.

Deriving a foolproof VGI strategy for India involve a variety of stakeholders, including DISCOMs, fleet operators, charging service providers, and Research and Development (R&D) institutions. All stakeholders are positive about the benefits of VGI for DISCOMs. V1G is important in demand response, and V2G can assist in frequency regulation, voltage regulation, black start support, and reliability improvement. However, due to the lack of regulatory framework and incentives, there is uncertainty about the financial attractiveness of VGI. Another significant challenge to implementing VGI in India is the lack of an ancillary service market.

A favourable regulatory ecosystem is a prerequisite for VGI implementation, and the first step is true price signals for electricity. The first and simple step in providing appropriate price signals is implementing TOU electricity rates. Appropriate regulatory provisions are necessary to clearly define how EVs should be treated as a "resource" with its Vehicle with the battery, charging station, and aggregator.

If the Vehicle, along with its battery, is recognised as the resource, the Vehicle may need to have a meter to measure energy transactions. Necessary regulatory provisions should allow the "resource" to move around, and the Vehicle has to be registered as a consumer to the DISCOM. If the charging station is recognised as the "resource", transactional complexity is less with fixed geographical location with specific metering. If the aggregator is defined the "resource", it is a "virtual" and geographically spread out resource.

Enabling EV aggregation and allowing aggregators to participate in energy markets is essential to maximise value proposition from VGI. DISCOMs are an important actor in EV resource aggregation, and multiple operation models are possible with different levels of DISCOM involvement.

- DISCOM can the sole aggregator which would allow them complete control of EV charging or discharging and use it to effectively manage the power system.
- DISCOM can acts as the meta-aggregator, with another aggregator as the intermediary between the customer and the DISCOM. The DISCOM has no direct interaction with the customer, and the aggregator has no direct involvement in the wholesale market.
- DISCOMs and third-party aggregators can both act as aggregators in a competitive electricity market that allows aggregation. It is also possible to restrict the role of DISCOM as an aggregator and allow only other actors to compete.

Existing Indian regulations lack provisions that permit "aggregation" of EVs, to provide grid services. A potential solution would be for FoR to develop a model regulation on resource aggregation. Depending on the scale of aggregation, EVs can deliver to bulk power system and local distribution systems. Aggregated smart charging can offer system services such as demand response, voltage regulation, and other ancillary services and help avoid the need for investment in capacity addition. Unfortunately, India's electricity sector sees limited application of demand response and there is no retail market mechanism for energy and ancillary services. The use of EV to provide frequency regulation and other grid services is also limited as there no retail energy or ancillary market mechanism currently. Moreover, load aggregation is

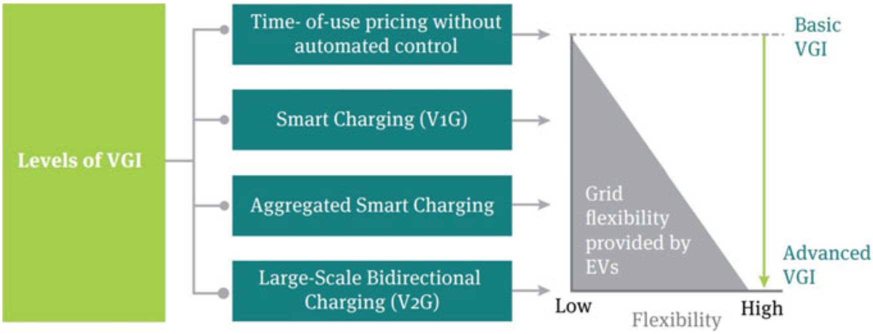

Fig. 4 Vehicle to grid integration strategy and flexibility

not currently not permitted, and aggregators are not allowed participation in energy market.

India is making great strides toward large-scale adoption of renewable generation for decarbonising the grid. The increase in penetration of variable generation increases the need for flexibility in grid operation. Electrification of transport will increase the electricity demand and support in reducing the emissions from the transport sector. Apart from EVs, rapid urbanisation, an increase in the standard of living, and a rise in appliance penetration are factors that will lead to a significant increase in electricity demand in the upcoming years. It should be noted that electrification of transport, while only be one of the leading causes of rapid increase in electricity demand, needs to act as a flexible load to support the integration of variable generation. Hence it is imperative that the VGI strategies for India should factor in the grid flexibility, as shown in Fig. 4. There are four main levels for VGI for India—TOU rates, Smart Charging (V1G), Aggregated Smart Charging, and Large-Scale Bidirectional Charging (V2G). The first two levels can be achieved in India within the existing regulatory framework. Considering the level of maturity of India's e-mobility and power regulatory ecosystem and market mechanism a phase-wise VGI implementation roadmap could be effective for the country.

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