Smart Integration of Large-Scale Electric Vehicle Storage into the Grid: Challenges and Opportunities

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***Abstract*— The advent of energy-efficient light duty electric vehicles (EV) is recognized as the game changer for transportation, environment and the electricity grid. However, the preparedness of power grid is critical to see EVs as a strategic capital for the electricity sector and avoid any poor load management. Abreast technical and operational challenges associated with managing the charging demand caused by the penetration of large-scale EVs into the system, it offers a great deal of grid assistance opportunities such as renewable energy storage and ancillary services provision. In fact, smart charging of EVs is researched extensively to enable effective integration of intermittent renewable energy and grid ramping support services. In view of this, this paper outlines the grid integration issues of EVs, covering management, system and practices needed to stabilize the power grid in the near future with mass penetration of EVs in the market. This involves exploring high-tech vehicle-to-grid (V2G) as future energy management solution, especially if the incentives for the participation in grid support services results in lower procurement and maintenance cost of electric car alongside improved grid reliability. The notion of V2G and integration of EVs as energy storage can enable balancing out the energy fluctuations at the grid level, securing green energy propagation for emissions reduction.**

***Index Terms*— Electric vehicle (EV), storage, vehicle-to-grid (V2G), grid-to-vehicle (G2V), ancillary services, electric utility, electricity market.**

I. Introduction

The transportation sector is responsible for 28% of total energy consumption globally. As per International Energy Agency (IEA) [1], it is the second largest source of CO_2 emission, sharing 20% of global greenhouse gases (GHG) emissions. The majority of the energy (about 70%) is utilized on the road transport for the movement of passenger and goods and about 61% of the carbon emissions in the transportation sector comes from the passenger or personal mobility-related vehicles [2]. In India, this sector consumes about 16.9% of total energy, and from it, the road transport accounts for around 80% of GHG emissions [3]. In order to control the emissions from this sector, widespread vehicle electrification i.e. transitioning transportation sector from sole dependence on oil to electricity is necessary. Generating electricity to charge electric vehicles (EVs) produces far lower GHG than the emissions levels produced by the conventional vehicles [4]. These emissions could be even lower as the power sector integrates more and more of the renewable sources in the generation mix over the next few decades. Thus EVs provide a parallel path to clean energy promising reduced GHG emissions, lower oil consumption, and clean air.

In order to achieve national fuel security and at the same time reducing carbon footprint to fulfill its commitment toward climate change Government of India has announced an ambitious target of 100% electric car country by 2030. The associated scheme launched by the Government is named Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME India) under the National Electric Mobility Mission Plan (NEMMP). Under the scheme, the cumulative electric vehicles (EV) sale is targeted to reach around 15 million by 2020, with a further sale of around 6-7 million EVs per year is projected thereon. These EVs includes passenger vehicles (car, jeep, and taxi), commercial vehicles (bus, goods vehicle), two wheelers as well as the three wheelers.

Going by this estimate, there would be around 27 million EVs on the road in India by the end of 2022. If we conservatively assume that half of them would be the EV cars (passenger vehicles), further equally divided into plug-in hybrids (PHEV) and full electric vehicles i.e. battery electric vehicles (BEV), there would 6.75 million of each of the PHEVs and BEVs in the streets in India. Assuming an average battery capacity of 9.5 kWh per PHEV and 21.78 kWh per BEV (average battery capacity of most sought PHEVs and BEVs worldwide), this together represents a total electric storage capacity of 211 GW–66% of the total installed capacity of 315 GW of India as on February 2017 and 120% of Ministry of New and Renewable Energy's (MNRE) ambitious target of 175 GW renewable electricity capacity by 2022. The estimate possesses numerous challenges concerning how these EVs will be charged and what will be their impact on the electric power grid.

Considering the Government's ambitious target and potentiality of EVs toward power and utility sector in India, state-owned Power Grid Corporation of India Ltd. (PGCIL), the central transmission utility (CTU), is also considering developing an EV charging business and setting up charging infrastructure to help the national grid [5]. The public sector unit is also exploring battery energy storage solutions to optimize solar and wind electricity integration to help improve grid stability. Apart from the electric power generation, transmission and distribution infrastructure capacity to support EV load, the build-up of public charging infrastructure is also crucial for the mass adoption of EVs. The fear of inadequate battery capacity to support the driving pattern and lack of charging infrastructure give rise to range anxiety among customers. Therefore, public charging stations are important to overcome the range anxiety issues with potential EV buyers, as most EV owners are expected to rely on it on a daily basis. However, Electric Power Research Institute (EPRI) has predicted that majority of the EV charging, almost 70%, will take place at residential locations overnight [6]. Nevertheless, owners will likely use public charging stations for short-term energy needs like to top off their batteries.

Among others, high vehicle cost, ease and speed of charging, and expensive charging stations are the three main barriers which stand in the way of mass EV adoption. Li-ion battery technology is the greatest contributor to the high EV cost. However, with technological innovations and increasing EV penetration (scale of operations), the battery costs are expected to decrease in future. The U.S. Department of Energy has set the production cost target of EV battery to $125/kWh by 2020 to promote greater EV adoption [7]. To improve ease and speed of charging, publically available rapid charging stations at almost all the major parking points like workplaces, hotels, shopping malls, etc. are needed. Amid technology side, a very low energy density of the designed battery system is also holding back the acceptance of EVs. In order to get a similar range to a gasoline vehicle, the size, weight and cost per kWh of the battery increases manifolds. Another technological barrier is that the nature of electricity doesn't support the range of charging power transfers needed for two minutes refueling like of gasoline vehicles. To overcome this, the DC fast chargers viz. CHAdeMO and Combined Charging System (CCS) with 50 kW charge power as well as the Tesla superchargers (up to 150 kW charge power) are coming up as rapid charging stations, which can deliver the electric range corresponding to 80% of car's capacity in 20 to 30 minutes of charging. Thus, the major barriers in bringing the EVs into the mass penetration can be categorized into:

- Cost (vehicle, charging infrastructure, electricity pricing)
- Vehicle range (range anxiety)
- Access to charging (ease and speed)
- Limited customer knowledge and experience with benefits of EV technology

Utilizing EVs in today's framework presents big challenges as, with mass adoption, there remains uncertainty how large-scale EVs could affect power grid in future. However, alongside socio-economic barriers, the large-scale battery storage capacity of EVs can be an effective distributed energy storage system, easing out the pressure on the power grid and increasing its reliability. With smart charging, the vehicles battery reserves can significantly help with the balancing of the grid. This requires an intelligent integration of EVs with the electric utilities and the grid. Based on this, various techno-economic aspects concerning grid integration of EVs to exploit their battery storage capabilities are explored in subsequent sections of this paper.

II. Vehicle-to-Grid (V2G) Opportunities Through Electric Vehicle Energy Storage System

Vehicle-to-grid (V2G) system can be defined as the capability of EV to operate as energy storage equipment meant for coordinated, controllable bi-directional energy transfer between a vehicle and the electricity grid to maintain its efficient and reliable operation. The primary function of the vehicle is transportation. However, on an average a car is parked more than 90% of the time, leading the researchers to set the base for V2G during these inactivity times to help support the grid through a variety of possible ancillary services. The examples of the potential applications of V2G from the electricity grid point of view are discussed below.

- *Renewable Energy Storage and its Intermittency Mitigation*

Renewable resources, mainly the wind and solar are unpredictable and highly intermittent. There may be excess power generated or shortage of available generation on and off. The energy storage system (ESS) of EVs can be coordinated as an aggregated unit to store the surplus renewable energy when available and discharge it (or a part of it) back to the grid during the times of peak demand as V2G [8]. Thus the aggregation of EV batteries can act as valuable distributed storage resource to the excess or deficient availability of renewable energy, primarily wind and solar. The reduction in their intermittency would further help stabilize the grid.

- *Peak Power Support*

Selective discharging of EV battery storage system during the peak times to support the grid can be referred to as peak shaving through V2G. For the utilities, this can be a good substitute to expensive peaking units to save on infrastructure, operational and maintenance costs of peaking plants and reducing CO_2 emissions. Though, the effectiveness of the V2G system as a peaking resource would rely upon the load demand and generation mix in a region.

- *Regulation Service to the TSO (Frequency Response)*

The energy storage system of EV batteries can act as a good source of rapidly controllable generation or load, i.e., the regulation capacity. Conventionally, frequency regulation service to track minute to minute fluctuations in the demand as well as unintended fluctuations in the generation is catered by online generating units equipped with primary and secondary modes of regulation provision. The primary regulation involves governor action with certain droop characteristics while the secondary regulation applies to automatic control action via automatic generation control (AGC) to bring the area control error (ACE) to zero. Frequency regulation requires quick response, short duration ramp up and ramp down capabilities, a criterion EV battery storage capabilities are compatible to or even better suited.

- *Spinning, Supplemental and Replacement Reserve*

The provision of operating reserves namely, spinning, supplemental or replacement reserve through V2G could be a real possibility. Operating reserves are the generation capacity required to pick up the load quickly in case of contingencies like generation unit failure. The three operating reserves as mentioned are classified based on the response speed and duration of the operation. The spinning reserve is the generation already synchronized to the grid and capable of increasing output quickly to a generator or transmission line outage. The units in supplemental reserve may be offline but are required to reach full output within 10 minutes. Replacement reserves

TABLE I
ELECTRIC VEHICLE CHARGING STANDARDS

SAE J1772 Standard				
Charging type	Voltage level	Power level	Phase	Primary use
Level 1	120 V AC	1.2 – 2.0 kW	Single-phase	Residential & workplace
Level 2 (low)	208 – 240 V AC	2.8 – 3.8 kW	Single-phase	Residential, workplace & public
Level 2 (high)	208 – 240 V AC	6.0 – 19.2 kW	Single-phase	Residential, workplace & public
Level 3	208 – 575 V AC	15 – 96 kW	3-phase	Public
DC charging (DC Level 1, 2 and 3)	200 – 600 V DC	>15 – 240 kW	DC	Public
EPRI Charging Characteristics				
Charging type	Electrical ratings			Primary use
AC Level 1	120 V AC, 12 – 16 A, 1.44 – 1.92 kW, Single-phase			Residential & workplace
AC Level 2	208 – 240 V AC, 12 – 80 A, 2.5 – 19.2 kW, Single-phase			Residential, workplace & public
DC Level 1, 2 and 3	200 – 600 V DC, ≤80 – 400 A, ≤19.2 – ≤240 kW			Public

are classified as the slow responsive operating reserves which are used to bring back the pre-contingency status after the pick-up of spinning and supplemental reserves to an outage disturbance.

- *Peak Shaving and Valley Filling for Load Levelling*

The volatility and constant fluctuations in the load obligate the utilities (system operator) to procure expensive ancillary services like peak power, spinning reserves, etc. in order to maintain safe and reliable operation of the grid. The increased cost of electricity is eventually passed on to the final consumers. However, a levelled load reduces this randomness thereby simplifying the load forecasting and dispatch operations of the operator and hence reducing the requirement of above ancillary services. The lesser the procurement of costly ancillary services by the operator lesser will be the electricity cost to the consumers. The battery storage of EVs can be coordinated in a way so as to fill the load valleys by charging (G2V) and curtail load peaks by discharging (V2G), thereby levelling the load. The fast response speed of the EVs for power up and down in comparison to conventional fossil fuel based plants further complements the suitability of EV storage for load levelling. The mechanism of load levelling by V2G would result in reduced maintenance and operation cost associated with allotting the ramping commitments to conventional units.

- *Congestion Management, Loss Reduction and Voltage Profile Improvement at the DSO Level*

EV storage is a distributed energy resource available at the receiving end (distribution side) of the line. The storage can be coordinated to discharge into the grid (V2G) to prevent the line from getting congested mostly at the times of peak demand. Reducing congestion reduces the possibility of load shedding which may occur due to infrastructure's inability to transmit enough power to the load areas. Curtailing load peaks through V2G or shifting peak loads or a part of it to valley (off-peak) hours would also result in a reduction of line losses since the technical losses are a function of the square of the current. Shaving of the peak power and hence the peak time current would further result in reduced voltage drops and hence an improved voltage profile. Thus, V2G through battery storage system can be utilized to handle congestion relief and improving profile in a system.

- *Grid Reactive Power Compensation*

The EV charger units can be designed to control the real (P) and reactive (Q) power flow directions (four quadrant operation capability) and could provide reactive power support to the utility [9]–[12]. The communication and control strategies are crucial for grid power electronic interface of unidirectional or bidirectional flow capability converters to be utilized for grid reactive power support.

III. Electric Vehicle Charging Functionality

The AC and DC electric vehicle charging power level standards as established by Society of Automotive Engineers (SAE) [14] and Electric Power Research Institute (EPRI)−National Electricity Code (NEC) [15] are summarized in Table I. The charging (G2V) of an EV battery requires AC to DC conversion while the DC power in the battery must be converted to AC in V2G (discharging) i.e. supplying power to the grid. In AC charging, the AC−DC conversion takes place in the vehicles onboard charging system, whereas in DC charging, the electric vehicle supply equipment (EVSE) off-board the vehicle is responsible for AC−DC conversion.

The common voltage and current ratings of 110 V and 16 A in AC Level 1 charging are commensurate with typical residential and commercial applications in the U.S. However, a standard 24 kWh battery of Nissan LEAF will take about 12 hours to fully charge while that of 16 kWh of Chevrolet Volt will be charged fully in about 8 hours with 2 kW maximum defined charge power rate of AC Level 1. This slow charging with AC Level 1 is not preferable and also because of very low power transfer capability the V2G applications would be impractical.

AC Level 2 can supply a maximum of 19.2 kW at 240 V. However, the onboard vehicle chargers are the limiting factor, with power capabilities lower than the Level 2 maximum power rating. It is the vehicle battery management system (BMS) that controls the charging current and hence the power drawn from the EVSE (obviously below its ratings). AC Level

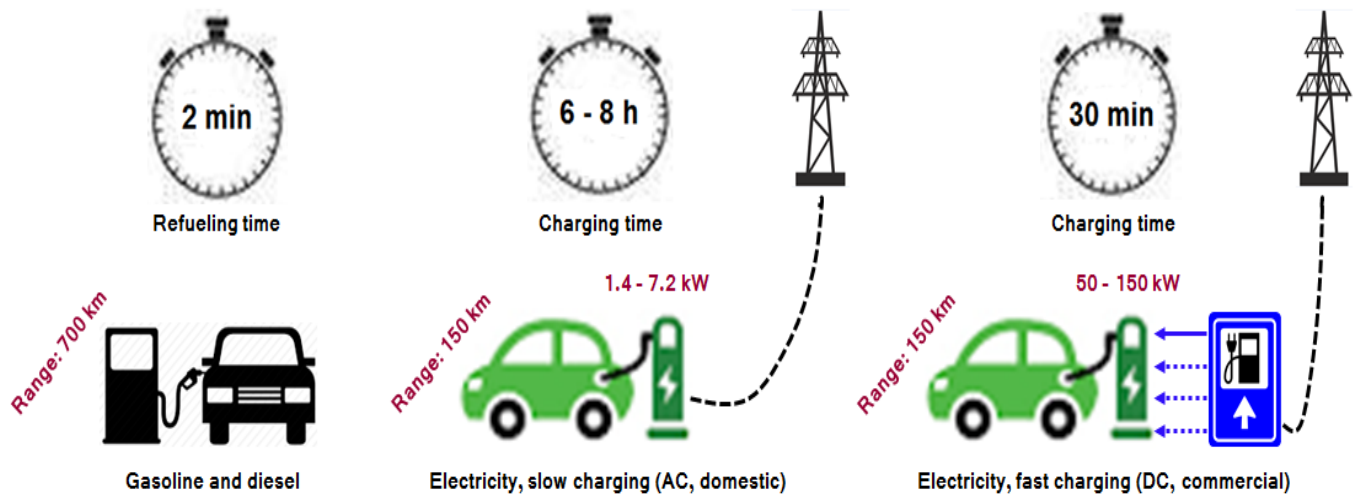

Fig. 1. Electric Vehicle Charging Schemes *(Image adapted from reference [13])*

2 charging is the preferable method for the vehicle charging and also suitable for V2G applications.

AC Level 3 and DC fast charging (DCFC) is analogous in industrial nomenclature and is used in commercial and public applications. It consists of an off board charger which receives AC input at 208–575 V and converts it into the DC power to be supplied to the vehicle battery. The vehicle battery management system controls the off board charger. The DCFCs are also classified as the middle rate (DC Level 2) and high rate (DC Level 3) DCFC. The examples of middle rate DCFC are CHAdeMO and SAE Combo/CCS which supports charging up to 50 kW with range rating maximum defined up to 100 kW. The BYD and Tesla superchargers fall into the category of high-rate DCFC offering charging up to 150 kW with range rating defined maximum up to 200 kW. Most of the vehicle manufacturer now choose to incorporate both, an onboard SAE J1772 AC charger and an off-board CHAdeMO or Combo/CCS DC charger in the EVs. The DCFC EVSE allows significant power transfer capability for two-way power flow in V2G, especially through an aggregation of off-duty vehicles. Figure 1 shows the illustrative schematic of refueling comparison of the gasoline and EV vehicular technologies.

IV. Utility Perspective: Managing the Smart Charging

As the technological innovations are making EVs more and more affordable, their adoption is becoming a reality worldwide. EVs charging consumption creates significant electricity demand requirements. Also, to implement V2G while integrating the EVs into the smart grid, the communication and control requirements for utility managed charging/discharging possesses a big challenge. While the utilities can play a tremendous role in encouraging EV adoption, it faces some challenges with the smart integration of EVs, a few of them are discussed as follows.

- *Operational and Planning Resources for Infrastructure*

The additional EV load will put stress on the aging power grid. Utilities need to upgrade distribution infrastructure like increasing transformer, substation, feeder, and protective devices capacity as well as setting up additional generation and transmission capacity to meet the increased EV demand. The excessive EV load demands would require a huge financial investment in upgrading these infrastructures.

- *Peak Demand Strain*

Balancing the power supply and demand during the peak hours with a slender margin available is a challenging task for the utilities. If a large number of vehicles are plugged at the same time into the grid, the EVSE load could further strain the grid to the breaking point. If charging of EVs is not managed properly, a huge investment in the peak capacity could be required, increasing the cost of electricity to the consumers and hence offsetting a part of the potential benefit of EV adoption. This could also weaken the system reliability. The distribution operators are having to ensure they can cope with extra EV demand to prevent any local power shortages or blackouts in the neighborhood.

- *Geographical Uncertainty: EV Clustering*

Ascertaining the number of EVs in a particular geographical area and at what time of the day these will be charged is also a critical issue. Transformer overload is the first problem at the consumer end. Multiple EVs charging simultaneously from the same transformer require the utilities to plan additional EV demand in advance so as to manage its charging to prevent any overload. The effective demand planning requires the utilities to reach out to customers in advance to know their interest in EV usage. For this, utilities could even tie up the EV dealers/sellers to get notified about the sale of EV in their geography (control area).

- *Requirement of Dedicated Metering and Grid Features*

Dedicated metering in parking areas is required to segregate the energy used by the EVs from residential, commercial or other energy usages. Smart EV charging provides benefits to the grid. These benefits must be reflected by implementing different lower rates, other than the standard residential or commercial rates, for EV charging by the utilities through some regulations. On a preliminary basis, time-of-use (TOU) rate system can be implemented, featuring lower tariffs for off-peak charging. Vehicle tracking to find out which customer is plugged into the grid, its location monitoring and energy usage require accurate metering and integrated robust billing system.

- *Charging Business Models and Utility Involvement in Charging Infrastructure*

The extent of utility ownership and control of electric vehicle charging station, i.e. whether the utility will own all the chargers or it will be owned by independent charger providers (third party), needs to be defined. While utility ownership offers the advantage of inclusiveness of all sections of society to access to charging infrastructure, at the same time there are concerns regarding the cost effectiveness of investments in the EV charging stations by the utilities. To promote a vibrant and competitive EV services market, regulatory challenges for independent party charging stations to enter into the market needs to be curtailed. This requires intelligent adjustment of rules regarding regulation, compliance, permission, inspection etc. Limiting utility ownership on third party EV chargers and its leverage on end-customers and EV charger interface would encourage third party provider to enter into the market with EV investments. In addition, business models for charging services are yet to be developed. There are many evolving questions with smart EV charging like, 1) payment for the utilities which brings the electricity to the independently owned/operated charging stations via its infrastructure, 2) payment dispersion to different parties involved in a public charging station, and 3) vehicle tracking, its location monitoring, and billing to recognize respective customers.

V. V2G System Interconnections: Key Components

V2G system would require integration of various entities to facilitate EVs participation in electricity market to provide load/generation services as an energy storage system. The likely key participants and their functions in the EV and electric utility interconnection are discussed below.

- *Electric Vehicle Supply Equipment (EVSE)*

The EVSE provides the interface between the vehicle's battery storage system and electricity grid or utility supplying electric power. In simple terms, EVSE delivers energy from the electric utility to the EV. The controlled charging and discharging of EV battery necessitates two way power flow and communication capabilities built into the EVSE as well the vehicle. The EVSE can be designed to supply either AC power or DC power to the vehicle as well as control the power levels at which the energy is being delivered. EVSE will be responsible for converting utility fed AC power to DC power in G2V (charging) mode and DC power to AC in V2G (discharging) mode of operation of EVs. The AC Level 1, AC Level 2, and DC charging standards for the EVSE are summarized in Table I. AC Level 2 EVSE is best suited for residential charging since the majority of the charging is expected to take place at vehicle owners' residence only. The controllable EVSE with bidirectional communication capabilities can also play a crucial role in implementing demand response (DR) program of utilities in the presence of advanced metering infrastructure (AMI). Some EVSE suppliers, like ECOtality and Coulomb Technologies, provides EVSE equipped with dedicated energy meter that allows the utility to segregated EV consumption from the other residential consumption for billing purposes [16]. In the V2G system, the location and utilization of EVSE would determine the availability of V2G services at various moments of the day.

- *Battery Management System (BMS)*

The energy storage system (EES) i.e. the battery of an EV consists of cells, modules, packs, battery management system (BMS) and thermal management system (TMS). A single cell is a complete battery in itself; a module is composed of few cells in series or parallel arrangement, and a pack of batteries is composed of few modules placed in a containing for thermal management [17]. Battery management system (BMS) is an assimilation of sensors, communication, computation, and control hardware which takes into account the state of charge (SOC) and state of health of the battery pack to determine the charge and discharge power to/from it. The BMS is the control center which manages the SOC and ensures the required functioning of the ESS [16]. The communication links between the BMS and battery pack as well as BMS and TMS ensures smooth thermal management and accurate SOC determination based on the measured parameters like voltage, current, ampere-hour, and energy throughput. The BMS overrides the capability of EVSE while determining the current flow into the battery during the charging process. Similar to charging process, the BMS will play a central role in the discharge of the battery for V2G support.

- *Vehicle Aggregator*

Participation in V2G services requires a minimum market contract capacity ready to respond to the system operator's signals for grid support. The typical battery capacity of an EV is in few kilowatt hours having a negligible impact on the grid operations. However, an aggregation of a large number of EVs can develop energy storage to produce a significant impact through V2G. It will be tedious for the electric utility or the operator to deal with the individual vehicle owners. The vehicle aggregator will play a role of intermediary entity managing the aggregated groups of the vehicle and providing overall load/generation services to the operator. Hence, the vehicle aggregator provides a single point of contact to guarantee and manage the participation of the EV storage contract made in the market. The aggregator will contract with the grid operator for the commitment of reserve services, receive command signals from the operator and allocate the required services out to the participating vehicles. Principally the vehicle aggregator will be responsible on the whole for 1) vehicle tracking 2), its location monitoring, 3) conformation of the participants, 4) ensuring storage availability, 5) guaranteeing commitment, 6) establishing contract, 7) validation of participation by responding to command signals, and 8) sharing the value created from the grid services out with the connected vehicles. The parties having expertise in the communication network and/or customer application deployment would be most suitable for the role of the aggregators. Based on this, references [8], [16] lists out a few entities suitable for the vehicle aggregator services such as an unregulated utility or a distribution generation manager, an automobile manufacturer, an automotive service provider, a battery manufacturer/distributor, or a mobile communication network provider, etc.

- *ISO / RTO / Electrical Utility*

The system operator would contract with the aggregator through day-ahead or hour-ahead markets and provides command signals to it requesting the grid services through V2G [18]. The vehicle aggregator, EVSE provider and vehicle owners will be compensated by the system operator for providing grid services.

- *The Communication Process*

V2G operations require bidirectionality, and hence modifications to conventional unidirectional EVSE and controls. For smooth management of charging demand as well as V2G services, the connected links for the communications are supposed to be in between – utility/ISO and aggregator, aggregator and EVSE, and EVSE and BMS [16]. The EV BMS would communicate the battery capacity, its SOC and charging/discharging pattern to the aggregator verified through EVSE. The utility will send ramp up and down signals to the aggregator, which will allocate proportional charging/discharging portions out to the participating vehicles through EVSE. The aggregator will receive capacity and energy payments from the system operator and share the value created with the participant vehicles and the EVSE provider. The system operator would verify the aggregator response against the commands issued by it by means of grid balancing signals. The metered data from the EVSE can be used to determine energy savings and greenhouse gases reductions and the information can be communicated to the customers by the utilities through billing or web portals.

VI. Sustainable Integration: The Way Forward

The connectivity and controllability of EV battery storage system, if coordinated suitably, can be a catalyst for a profitable business model for the participating segments by means of grid services (V2G). This requires developing solutions for communications between the various parties involved such as charging station (EVSE), vehicle controls (BMS), vehicle aggregator, customer, utility/system operator, battery supplier and vehicle supplier. Table II lists out some known EV charging network / stations (or EVSEs) and features of charging business models of a few leading networks.

Utilities will be motivated with V2G, as it seems compelling storage resource for load levelling, intermittent renewable sources integration and various ancillary services obligations necessary to maintain safe and reliable operation of the interconnected system. The various grid support services from the perspective of electrical utilities are discussed in Section II. Traditionally, utilities procure these services (ancillary) from the conventional gas or fuel based plants which are expensive, the cost of which is ultimately borne by the consumers in terms of electricity prices. EV owners will be economically benefitted from selling the stored energy and capacity to the utilities offsetting expensiveness of EVs in the initial purchase. Also, the utilities stand a chance to do away procuring these services from the expensive units. As an interim technology, EVs can also provide power to home/building as an emergency backup or supplement the grid power supply known as vehicle-to-home (V2H) / vehicle-to-building (V2B) system. This basically stems from the fact that, battery capacities in modern BEVs are sufficient to provide a single household with power for several days. The basic topology can be charging the vehicles during off-peak hours or from excess available renewable sources, like home solar energy and supplying back to the home/building at the times of peak demand. The example of one of such scheme is the Nissan's LEAF to Home system [21], which can supply electricity from the battery onboard the Nissan LEAF EV to the home distribution board to take out the excess power (Fig. 2). In V2H / V2B system, the complexity of the overall V2G system is reduced as the coordination and communication requirements between the vehicle chargers (EVSE), vehicle aggregator and utility is eliminated.

In V2G, the vehicle owner (or aggregator in turn) has the control over the V2G capability and bidirectional flow thereby acting as a both, the seller and the consumer of electricity. Reduced electricity rates for the charging and economic compensation for V2G services will act as a motivator to vehicle owners only if they are able to overcome the issues of high cost, long charging time, range anxiety and costly EVSE installment with these incentives. In addition to this, as a priority, customers need to maintain sufficient SOC to fulfill their driving needs as well as range buffer for emergency or unplanned trips. However, the ancillary markets are high value (cost), short-duration markets and are highly volatile. Even a capacity commitment, with no energy actually being drawn or supplied, in these markets on a long-term basis can yield a significant revenue stream from energy arbitrage. This can be ascertained from a large-fleet of EVs, the owners of which have a predictable (defined) driving pattern, like home-work-home commute during weekdays, ensuring availability of their vehicles during the parking times to the aggregator for the grid services. However, battery degradation with cycles of charge and recharge would be a matter of utmost concern for the owners, since battery replacement is expected to be an expensive affair. Some applications like regulation would have less effect on SOC depletion and hence on the battery aging, while some applications such as load levelling (peak shaving and valley filling) may cause serious SOC depletion and hence battery wear. Also, the EVs for the real time frequency regulation ancillary services can be coordinated with a bias toward net positive charge cycle to maintain the battery energy level.

To provide two-way power and communication flow capability for the V2G system, the original equipment manufacturer (OEM) would have additional costs of EVSE design and operation. Similarly, the added complexities in the vehicle design and operation would increase its cost. Also, battery degradation in V2G would affect warranty costs on battery packs for the vehicle OEM. Standardization of codes and reg-

TABLE II
TOP ELECTRIC VEHICLE CHARGING NETWORKS [19]

Network name	Coverage	Access	Number of sites / stations	Cost per charge
ChargePoint (Home charging, Level 2)	14 countries, one-quarter are in California	Initial deposit of $25, credit card or mobile app initiation, access to all ChargePoint stations	3084	Determined by the property owner, many stations are currently free
Blink Network – Operated by CarCharging Group (Level 2 and DCFC)	25 U.S. states	By registering credit card with the network	1680	$0.39–$0.79 / kWh – Level 2, $0.49–$0.69 / kWh – DCFC, $0.04–$0.06 / minute – Level 2, $6.99–$9.99 / session – DCFC, kWh pricing – where pemitted
SemaConnect (Offers Level 2)	20 U.S. states and Puerto Rico	$20 RFID recharge card (SemaCharge Pass)	450	Cost varies as determined by the property owner
Shorepower Connect (Mostly truck charging, offers J1772 Level 1 and Level 2)	30 U.S. states (NEMA 5-20, NEMA 14-30, NEMA TT-30 and J1772)	$1 activation fee via credit card	425	Level 1 and Level 2 – $1 / hour, J1772 – Free
GE WattStation (Level 2)	32 U.S. states, D.C. and Puerto Rico	RFID card	270	Prices vary, as established by owners
The Electric Circuit (240 V Level 2 and DCFC)	Largest public charging network in Québec province	$10 initial, after that add amount to Electric Circuit Card	223	Flat fee of $2.5 – 240 V Level 2, DCFC – $10 / hour (billed on minute basis)
EVgo (Level 2 and DCFC)	4 U.S. states and Washington, D.C.	Monthly subscribers using an EVgo card	150	$30 / month plan – unlimited workplace + public charging, $40 / month plan – unlimited home charging
AeroVironment or AV (Level 2 and DCFC)	Oregon, Washington state and Hawaii	One-time activation fee – $15, monthly access – $19.99 / month	60	$7.50 / session – DCFC, $4.00 / session – Level 2
Tesla Superchargers (High rate DCFC)	Europe, China and throughout the U.S.	Available to Tesla models that have been configured to use superchargers	104 (as of 2014)	Free, no cost for electricity

Few other known electric car charging networks around the world are: Autolib / Bolloré (France), BMW ChargeNow (Asia, Europe, USA), Charge your Car (UK), Chargie (UK), Clever (Denmark), Drehstromnetzes (Germany), Ecotricity (UK), ELMO (Estonia), E Mobilita SKUPINA CEZ (Czech Republic), E-Motion Electric (Romania), E-Move (Italy), Enel Drive (Italy), Endesa (Spain), ESB ECARS (Ireland), Fastned (Netherlands), Greenlots (USA, Singapore), Interchage (Europe), Ladanetz (Germany), Kelag (Austria), MOBI.E (Portugal), The New Motion (Netherlands), Park & Charge (Germany, Switzerland, Austria), Plug-in Romania (Romania), RWE Mobility (Germany), Sun Country Highway (Canada, USA, Iceland, Norway), Ubitricity, Virta (Finland), Volta (USA), and Zero Carbon World (UK) etc. [20].

Fig. 2. Nissan's LEAF to Home system [21]

ulations across market regions would be essential in order to make automakers to develop complying V2G capable vehicle products. Utilities may consider incentivizing the automotive and EVSE OEMs also for any GHG emission reductions and clean energy integration in the electricity grid induced by V2G support services. The added V2G activities may affect battery sizing and hence cost to the OEM. Also, V2G would reduce battery life which may not be in the interests of battery manufacturer/supplier unless some other driving force exists. For this, utilizing the batteries at the automotive end of life for energy storage or local distribution support may create a secondary market prospect, justifying the battery application as a grid reliability resource.

VII. CONCLUSION

Various issues concerning collaborative electric vehicle and electric utility interfacing to enable EV for temporary power storage has been discussed in this paper. The access to the public charging station and the ease in charging process is the major hindrance holding back the adoption of EVs at a large scale. There is an essential requirement of developing the charging facilities as simple and fast as filling a tank of a gasoline vehicle at an oil or gas station to promote its widespread adoption. The mobility behavior with long parking durations and the V2G capability of the vehicles provides opportunities to utilize their stored energy for grid support services in electricity markets. The V2G operations would mainly include employing EVs as a storage medium for optimal integration of renewable sources and fulfilling ancillary services obligations of utilities like frequency regulation, peak power and spinning reserves support. The controllability of the battery storage and charging/discharging phenomena can further allow achieving a fairly levelized load by means of valley filling and peak shaving. The availability and functionality electric vehicle charging station (or EVSE) is crucial to enable V2G operations. This requires controllable AC Level 2 or DCFC EVSEs with built-in bidirectional communication and power flow capabilities at strategic locations. For successful integration, the charging/discharging services business models for both vehicles charging for transportation needs as well as battery storage utilization in grid services are to be worked out. This requires addressing utility (or regulator's) concerns regarding metering (or billing) issues and ownership control over the third party (independent) charging stations, by standardizing nondiscriminatory regulations and grid compliance codes for the business models. The V2G and smart integration of EVs as energy storage require unique levels of two-way structured coordination between the key participants namely, electric utilities (ISO/RTO), EVSE OEMs, vehicle aggregator, vehicle owners, BMS, battery manufacturers/suppliers, and automotive OEMs, etc.

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