Integration of Multifarious Electric Vehicle Charging Infrastructure Flexibility

Applications for India

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***Abstract*— India's national missions to advance renewables, Smart Grid demand flexibility, electric vehicles (EV), as distributed energy resources (DER), provides pathways for sustainable development. Integration of DER diversity such as solar, energy storage, EVs, and demand response (DR) is necessary to address the challenges of supply variability and cost-effective grid integration. The study describes the integration needs of multifarious EV charging infrastructure, and how distribution utilities must engage the customer(s) and use smart grid technologies and market mechanisms to leverage battery-based EVs, as a DER, for grid services. The study reviews global and Indian prerogatives for EV deployments and conducts empirical grid impact analysis. The results show that the utilities must develop EV integration strategies to address electricity reliability and variability of renewable energy resources. Engaging customers' assets and using Smart Grid technologies manage EV and charging infrastructure for market-based programs, the renewable and EV adoption can be accelerated in India. The utilities, system operators, and regulatory agencies can use these results to support integrated electric grid and transportation planning.**

Keywords—electric vehicles; grid integration; flexibility; charging infrastructure; grid impacts; market models

I. Introduction and Background

India's national missions to advance Smart Grids and integrate demand-side flexibility with distributed energy resources (DER) such as the wind and solar energy resources, batteries in electric vehicles (EV), etc., provide pathways for a sustainable development [1]. We define DERs, as distributed generation (DG) resources and demand-side resources installed at the consumers' premises and the distribution grid. The examples include building loads, demand flexibility (used alternatively, as flexible demand or demand response), rooftop solar photovoltaic (PV), EVs, etc. Typical DERs considered in this paper are solar PV, electric vehicles and demand response (DR) for an electricity distribution utility's market integration. With several national missions, Indian plans to deploy six to seven million EVs (hybrid, fuel-cell, and battery-based vehicles that include two-, three-, and four-wheelers) by 2020 and plans the sale of pure electric vehicles only from 2030 [2][3]. India also has large targets of 175 gigawatts (GW) of renewable energy generation by 2022, which comprises of 100 GW Solar, 60 GW Wind, 10 GW Biomass, and 5 GW Small Hydro and have plans for 40% of total generation capacity from non-fossil sources by 2030 [4]. Integration of such DERs like rooftop solar, EVs, and demand flexibility becomes important to address the challenges of supply variability and cost-effective grid integration. The progressive Indian distribution utilities are taking measures such as DR, as an effective tool to address electricity reliability during peak demand and accelerate the deployment of DERs to meet the goals of Indian national missions and future energy technologies.

In India, the grid is managed by changing the output on the generation side by changing the governor mode of operation and there is no or limited provision to change the load on the demand-side except feeder-level demand reduction at times to balance supply and demand. With two-way communication, consumers can help in managing the distribution grid by DR applications. The key questions that arise for the development of advanced technologies for grid integration services in India are—*What are the applications of EVs, as DER? How can EVs and charging infrastructure be a value, as a grid and market resource?*

The objectives, which are also applicable globally, we examine are fundamental aspects of integration of multifarious and large-scale EV charging technologies, battery-based EVs, as a DER, and flexible demand for India-specific applications. Due to size, weight, and range priorities, EVs use Lithium-ion (Li-ion) battery for energy storage. We review the sustainability and DER policies through national missions, electricity infrastructure for grid integration prerogatives, and multifarious charging infrastructure for EV flexibility practices. To assess grid impacts, we conduct a preliminary analysis of energy and power needs for projected EV growth until 2030 to review charging requirements, business models, and grid interoperability. Figure 1. shows this methodology.

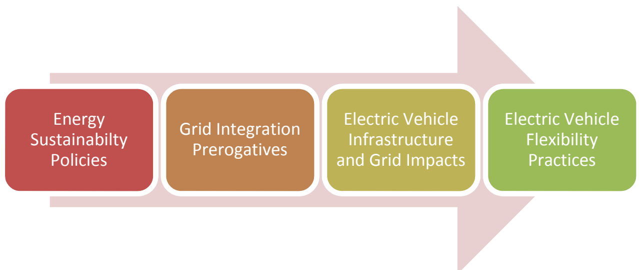

Figure 1. Study Methodology

II. INDIA'S RENEWABLE, DR, AND EV POLICIES

The Indian central and state governments policies—National Solar Mission (NSM), National Electric Mobility Mission (NEMM), National Smart Grid Mission (NSGM), etc.—are in the process of implementation of aggressive renewable generation, electric vehicles (EV), and Smart Grid projects [1]. Within these missions, the performance improvement, technology cost reduction, and enabling the leapfrog of distributed energy resources (DER) have major potential. Within these DERs, electric vehicles (EV) and their demand management play a key role in economics and reliability of the electric grid with variable renewable generation and in reducing the carbon emissions.

A. State of India's Renewable Generation and Integration

With the push from national missions to promote aggressive wind and solar generation renewable portfolio, India has set an ambitious target for the renewable generation capacity addition of 175 GW by 2022 from the extant grid-tied renewable capacity of 45 GW or 26% in 2016 [4], as shown in Figure 2. . This represents 15% renewable energy share among the total generation capacity of 303 GW in 2016. With the ratification of Paris Agreement, India plans to meet 40% of energy needs from non-fossil based resources by 2030. To meet the 2030 goal, the renewable portfolio must exceed 230 GW where over 100 GW may be from solar energy, against the projected total generation capacity of 670 GW [5].

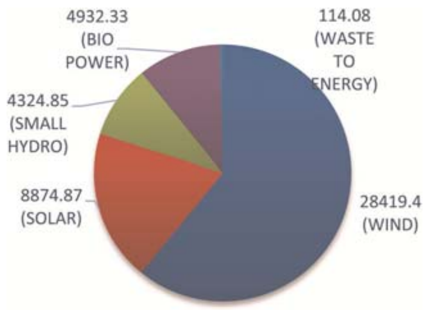

Figure 2. Renewable Energy Installed Capacity (in Megawatts or MW) in India (*Data and Figure source: [1]*)

Of the 175 GW renewable energy target for the year 2022, 40 GW target is from rooftop solar photovoltaic (PV), which acts as a DER among the customers. The rooftop solar installations in India stand at about 1 GW presently [4]. The rest of the solar PV is from MW scale installations, which adds to the spatial and temporal generation variability and integration challenges. Commercial and industrial consumers are aggressively deploying rooftop solar PV on a large unused roof space and, as the PV costs drop and the payback period is lessened. The utility scale tariff in India for solar PV has come down to USD 0.03/kilowatt-hour (kWh) recently, which is technically in grid parity with the large-scale fossil-based generation resources.

B. Electric Vehicles

To decarbonize the transportation sector, in 2012, the Ministry of Heavy Industries (MoHI), Government of India (GoI) NEMM Plan targets significant deployment of EVs. When a cluster of EVs are connected to the grid, the EV batteries could provide a wide range of valuable grid services, from DR and voltage regulation to distribution-level services [6]. Electric utility companies can leverage smart grid infrastructure along with new and innovative tariff structures like Time of Use (TOU) dynamic pricing tariff to tap the flexibility. This will mean, with increasing precision, where, when, and how EVs are charged through a combination of incentives and market structures. By virtue of being a flexible load, EVs can be used to use renewable energy that might otherwise be curtailed during periods of high output and low demand and to respond to real-time fluctuations in renewable output and system ramping needs, thus reducing the need for flexible gas turbines [6]. Two common vehicle-grid integration (VGI) services—V1G and V2G—are used. While V1G is referred to, as one-way power transfer from grid to vehicle which, can act as a DR resource by charging during the off-peak hour using real-time communication when the load and price of electricity is low; V2G is referred to, as two-way power transfer including vehicle to the grid wherein, EV acts as a generator that can also supply electricity to the grid.

C. Demand Flexibility or Demand Response

The Indian utilities have conducted field demonstrations of demand flexibility using automated demand response (AutoDR) to leverage flexibility from customer loads. The implementation of utility demonstrations has shown the value of DR. For example, a demonstration was conducted by a distribution utility, Tata Power Delhi Distribution Limited (TPDDL), to automate DR for commercial and industrial (C&I) customers. Studies have: (1) identified and characterized each category customer's load duration curve and aggregated demand [7]; (2) characterized AutoDR system, including smart meters and advanced metering infrastructure (AMI), data analytics, and standards [8]; and (3) estimated the DR potential in the state of Delhi [9]. Explained further in later sections, the compendium of the study findings show that demand flexibility plays a key role to address electricity reliability, aggressive integration of renewable generation, and enabling the distribution utilities to leverage DR, as a price arbitrage against volatile wholesale electricity prices and demand forecasting errors.

D. Electricity Markets for DR Integration

Many Indian states have issued TOD tariff, which is predetermined and fixed for 6 months or 1-year. The State Electricity Regulatory Commission's (SERC) in India issue tariff well in advance, generally 1 year ahead, which gives incentives to commercial and industrial consumers to shift their load from peak period to off-peak period. The application of DR, as a DER service, in this instance cannot be practiced since there is no real-time or near real-time dynamic pricing tariffs and electricity markets to leverage DR, as a grid resource. The lack of standardized communications between the utility and consumer systems hinders the proliferation of grid automation.

This landscape is changing with some progressive Indian utilities getting state regulatory approvals for electricity rate tariffs that encourage customer assets to participate in DR programs. For example, TPDDL recently received an approval from the SERC to offer automated DR program in Delhi [10]. In a future scenario, distribution utility will send a DR request and the consumer can modify the flexible load or shift the load from peak hours to off-peak hours. The utilities and electricity market structure also play a key role in enabling widespread adoption of EV infrastructure, as a DR resource. Through similar market design, utilities and regulatory entities can set pathways for grid integration.

III. Grid Integration Prerogatives

In India, the deployment of EV ecosystem is nascent. This is true from the global context when considering that EVs represent less than 1% of the total vehicle population. Studies show that countries in the Americas, Europe, and Asia have taken a head start driven by incentives and strong mandates to reduce greenhouse gas (GHG) emissions [11]. While most of the discussions in India are still limited to policies and fora, the Indian ministries have engaged research and demonstration to identify key challenges to accelerate and scale EV adoption and understand their applicability for grid integration services such as DR [12]. This section provides grid integration prerogatives from the global and the Indian context.

Understanding of the electric distribution infrastructure is critical for the grid integration of EVs. Figure 3. shows this infrastructure that is comprised of the service, which is provided by the distribution utilities or service companies, and EV supply equipment (EVSE), commonly referred to, as charging stations or charge points, and used to charge the EVs at varying power levels [13]. In this instance, the meter acts, as the demarcation point for the utility-owned infrastructure and charging infrastructure ownership.

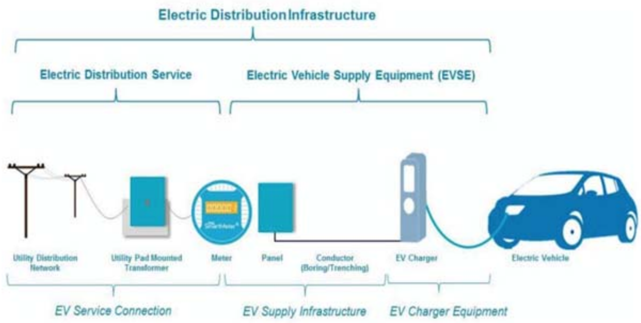

Figure 3. EV Charging Infrastructure (*Figure Source: [13]*)

The EV charging infrastructure supports EV charging through EV service connection (owned and operated by the distribution utility), the supply infrastructure and charging stations (owned and/or operated by the EV-owner, EVSE-owner, or a third-party service provider, including a utility itself). This highlights the challenge in ownership models and grid integration requirements that are multifarious when different charging station and EV technologies and standards are considered—both for power transfer and information exchange. To better understand the grid integration needs in the nascent electric mobility industry, we must analyze the state of similar practices.

A. *Global Practices: Flexible Electric Vehicle Resource*

Many grid integration activities across the world are focused on early-stage demonstration and applications of EVs, as a grid resource using variants of the VGI services Due to concerns of battery life and original equipment manufacturer (OEM) warranty issues, smart charging is commonly practiced [14]. Depending on the OEMs choice, the chemical compositions of Lithium-ion battery technologies vary. Battery chemistry, as a proxy for a grid resource, is assumed negligible. The EV infrastructure is tightly coupled with the EV and charging station characteristics, battery technologies, and electricity markets. The fit of EV batteries with electricity markets is summarized in TABLE I. [6].

TABLE I. U.S. Electricity Markets and Lithium-ion Battery Fit

Electricity System/Markets	EV Battery Storage, as Grid Resource
Transmission System & Peak Generation	• Resource aggregation to improve the performance of the transmission grid by better integrating variable renewable generation. • Support contingency reserves for fast response to any change in supply-side conditions. • Support capacity, as a cost-effective alternative to or replacement of peak generation plants.
Distribution System & Demand Response	• Smart charging to manage power-constrained local distribution transformer from increased BEV load. • Provisioning of flexible peaking capacity and grid-stability improvements at the substation-level. • Fast responding demand responsive resources for peak-load reduction, emergency load curtailment, dynamic pricing, and reduce/shift energy use.
Reserves – Spinning & Non-Spinning	• Suited for high-frequency data exchange for load forecasting and better supply-side planning. • Resource capability for smart charging and fast-response with short notification and response times.
Regulation	• Ability to respond to rapid charge/discharge in response to random deviations of the net load (*forecasted demand – scheduled supply*). • Aggregation and rapid dispatch for smart charging, as a resource to balance grid and maintain frequency tolerance boundaries (up/down).

Additionally, this study highlights innovative VGI applications for India. One such distinct application for India is smart charging of EVs and the use of second-life batteries that can provide fast-responding grid services and improve battery's cost-effectiveness.[1] It must be noted that each resource—EV and battery energy storage—could operate independently, as a grid resource. Their combination increases the reliability and extent of demand flexibility EVs can provide. The results of the demonstration by Pacific Gas and Electric Company (PG&E), a distribution utility in the United States (U.S), and the automotive OEM, BMW, is shown in Figure 4. The results show that on an average, the EV charging (shifting) and battery energy storage combination can provide fast-responding grid services using standardized DR dispatch signals with an average EV resources' share of 20%. The results also show that the extent of response from EV varies depending on the time of the day with share, as high as 50% [15].

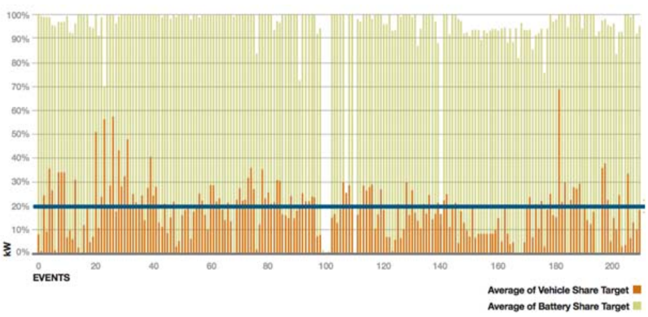

Figure 4. PG&E Demand Flexibility Pilot with BMW Electric Vehicles and Second-Life Batteries (*Figure Source: [15]*)

Another innovation for this demonstration is the onboard charger from the EVs was managed through the onboard telematics, against the EVSE management most of the applications use. This approach is relevant when the onboard telematics becomes advanced and ubiquitous and represents an opportunity in the electricity markets [16].

[1] Batteries that have degraded to 70% to 80% of initial capacity (State of Health) are determined inappropriate for EV use.

B. *Indian Practices: Demand Flexibility*

Considering that India is in nascent stages of EV adoption and do not have mature electricity markets or programs that encourage customer participation for demand flexibility, demonstrations and field tests have focused on DR primarily for C&I customers, as a peak load reduction strategy to address higher summer demand. The DR relevant value is summarized here.

Resource flexibility can address India's peak demand deficit—the shortfall in electricity supply when demand is at the maximum—which was at 4.7% during 2014, according to data by the Central Electricity Authority (CEA) [17]. The deficit has decreased recently and, however, is still large at micro-levels and peak periods. India's grid reliability has been improving with an increase in generation capacity and synchronization of the southern regional grid with the national grid. The power deficit situation is worse in certain regions of the country (i.e., northern, southern). Solutions to address the deficit are either to increase the supply-side generation capacity or to reduce the electricity peak demand through scheduled curtailment. As a key demand-side management resource, DR resources will provide the low-carbon flexible capacity needed to maintain real-time system balance and reliability with the integration of increasing levels of renewable energy resources [18].

As introduced before, this study reviews the results from an AutoDR field demonstration by TPDDL that was conducted to understand the feasibility of customer loads, as a resource to alleviate the peak demand deficit. AutoDR program involves communication and control systems, where customer facilities respond automatically in receipt of an external grid signal. A total of 144 AutoDR customers' 15-minute smart meter data (out of a total of 167 customers) were analyzed for performance in 17 AutoDR events. This analysis contributed towards an aggregated shed potential of nearly 10% of the peak demand (25,259 kW) against a 5/10 baseline. This baseline represents the average of five highest energy-use days per customer from previous ten days, excluding weekends, holidays, and DR event days.

One key finding from studies was the need to consider DR participation grouped by consumer grouping types. This highlights the need to look at EVs, as a unique grid resource, independent or integrated with other DERs. The regulatory proceedings and utility demonstrations in the U.S. are underway to develop sub-metering and dynamic pricing that incentivizes EV customers to offer flexibility and to support aggressive renewable generation goals [13][19].

Globally and even more so in India, there is dearth in understanding the grid impacts caused by the EVs. Though EVs may have a manageable impact on the power grid as a whole, the locational and temporal coincident demand impacts can be significant. At the distribution system level, simultaneous charging of many EVs under a distribution transformer (DT) circuit can overload if the DT does not have the capacity for aggregated charging. The high-density energy storage charging of EVs require low- to high-level of electricity, which can impact the DT and the low voltage distribution system. The EV fleet across DTs when charged simultaneously can demand a significant proportion of the daily load from the distribution grid [11]. Some EV-specific charging challenges to the grid are:

1. Excess distribution system demand
2. Increase in location and temporal system peaks
3. Demand forecasting barriers from variable demand
4. Increased variability from distributed generation

Leveraging the EVs', as a DER grid asset, can alleviate the causality from these challenges. The adoption of EVs must consider charging infrastructure integration to ensure grid impacts and interoperability needs are accounted for.

IV. Infrastructure and Integration

In the U.S. and Europe, and mostly in China, most of the charging infrastructure for both medium- (4-wheelers) and heavy-duty (buses) vehicles is ground-mounted station. Such charging stations benefit from the ease of installation and grid interconnection and support standardized EV charging and integration with the grid. These conductive or wired ground- or wall-mounted charging stations use power cable and standard couplers to charge EVs. Other forms of charging such as inductive or wireless are in development, and pantograph-based conductive charging is used in select deployments for fast charging of larger capacity batteries in buses. Other models for EV charging such as large-scale battery swapping for the medium- and heavy-duty vehicles were tried in the past and have become obsolete due to safety, technology costs, lack of standards, and the need for specialized and expensive equipment. For these reasons, this study focuses on the mature ground- and wall-mounted conductive charging infrastructure that supports standardized communications for networking and remote management.

The multifarious characteristics of charging station power levels and standards (power and communications) are summarized in TABLE II. [6]. Termed, as alternate current (AC) slow chargers—Level 1 and 2—and direct current (DC) fast chargers—DCFC—they are supported by the American, European, and select Asian automotive OEMs (e.g., Japan, Korea). A committee of the GoI has developed Bharat EV Charger Specifications, which the Bureau of Indian Standards (BIS) is expected to review [14].

TABLE II. Charging Station Electrical Characteristics and Supported Standards[2]

Levels	Volt/Current (V/A)	Power (kW)	Charging Station-to-EV Connection	
			Power	*Communication*
Level 1 (AC)	108-120/15-20	~1.4	NEMA 5.15	N/A
Level 2 (AC)	208-240//≥30	~7.2 to 25	SAE J1772	ISO 15118, IEEE 2030.5 (EV to EVSE) OpenADR 2.0, OCPP (Grid)
DCFC	400-800/≥120	≥50	CCS/CHAdeMO/ Tesla Supercharger	

For the EV charging infrastructure, the power and communication standards are mostly uniform across level 1 and level 2 and, to an extent, are standardized in the U.S. and Europe. The DCFC stations are multifarious since they use a diversity of power charging standards, albeit support standardized communications. This creates challenges for automotive OEMs to provide a right connector for drivers so that the vehicles for charging at their supported charging

[2] **Legend:** NEMA (National Electrical Manufacturers Association); SAE (Society of Automotive Engineers); CCS (Combined Charging System); CHAdeMO (CHArge De MOve); ISO (International Organization for Standardization); IEEE (Institute of Electrical and Electronics Engineers); EVSE (EV Supply Equipment, another term for charging station); OpenADR (Open Automated DR, a DR communications standard); OCPP (Open Charge Point Protocol, a EVSE/EV management standard).

stations and to provide an automated power management capabilities for local and remote services. A common EV roaming interoperability challenge across all charging levels is interoperability among multiple utility-owned distribution system infrastructures that have different electricity market rules for DR programs and performance assessment.

Figure 5. illustrates the communications standardization efforts in the U.S. and European countries, including China to address interoperability of multifarious charging stations and vendor technologies to enable technology innovation in new market opportunities for grid services. The charging infrastructure owners have the choice of selecting a charging infrastructure operator to eliminate the possibility of assets being stranded. The charging infrastructure operators enable business and technology competitiveness that benefits EV and charging infrastructure owners. This model can be leveraged by the electric utilities to offer DR services that benefit the EV and charging station owners, and the grid.

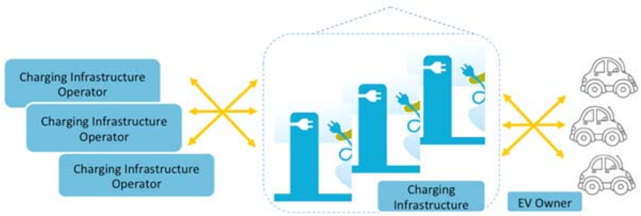

Figure 5. Interoperability Among EV Infrastructure and Ownership Models (*Figure Source: Adapted from ElaadNL, Netherlands*)

Specific to India, the nascent to non-existent state of charging infrastructure must be reviewed to understand the integration with the grid and flexibility service capabilities. Considering the EV charging infrastructure, DR can play an important role in balancing the grid and providing better renewable integration opportunities. For example, stopping and starting EV charging as needed through smart charging mechanisms and advanced communication and actuation technologies. A smart grid solution that integrates EV load management with other DR load controls allows a utility to fully optimize the demand side of the electricity equation to manage electricity supply requirements. An EV aggregator can support utility to manage hundreds or thousands of vehicles, tapering off charging when the grid operator signals that demand is high, and paying customers for the right to manage their charging—while guaranteeing that vehicles will be adequately charged when needed [20].

A. *Charging Initiatives by the Indian Distribution Utilities*

EV charging infrastructure to drive consumer acceptance of EVs is almost non-existent in India. Studies have reviewed early-stage EV charging networks initiated by the Indian distribution utilities, which were triggered by the early years the GoI's subsidy to utilities to promote EVs through corporate and social responsibility programs [11]. The state of Delhi has five electricity distribution utilities—BSES Rajdhani Power Limited, BSES Yamuna Power Limited, TPDDL, New Delhi Municipal Corporation (NDMC), and Military Engineering Services (MES).

TPDDL owns and operates "EV Charging Centers" at five locations across its territory for Mahindra Reva—a specific Indian OEM brand of passenger car—EV owners where an aggregated 200 cars are charged [21]. These charging centers are located in areas with available power capacity and within the 66 kV and 33 kV high- and medium-voltage network, respectively. TPDDL has also installed free public charging stations for 2-wheelers in Delhi with anticipated support to 10,000 vehicles [22]. Two BSES-Delhi affiliates—BSES Rajdhani Power Limited (BRPL) and BSES Yamuna Power Limited (BYPL)—have installed charging infrastructure to encourage the use of EVs. BRPL has installed two charging stations at its offices and at a residential area. It also has a network of 50 charging ports within the 66 kV, 33 kV, and 11 kV network [23][24].

While TPDDL and BSES initiatives can be termed, as early adopters, the aggressive growth of EVs necessitates a consideration of charging infrastructure within the low-voltage grid network and regions closer to customers (e.g., public spaces, residential neighborhoods, workplaces). In the end, these initiatives are a blur of the requisite charging infrastructure and support services to meet the NEMM EV goals and 2030 plans for all-EV sales. These goals represent a leapfrog opportunity to understand the charging infrastructure needs and develop the strategic vision that considers interoperability standards and grid integration at different levels, including innovative operational models for public and private sector EV deployments.

B. *Standardization Initiatives by the Indian Stakeholders*

The key premise is built on the needs for charging infrastructure and their standardized interfaces for cost-effective and secure interoperability with a diverse set of charging station technologies and business models. Standards are key enablers for open interoperable systems and encourage innovation because it enables new business models and services such as the VGI. A recent study—first of its kind to review local needs and conduct bottom-up analysis and propose a city-specific implementation plan for electrification of public transportation [14]. The EV charging infrastructure-specific findings is summarized here.

The findings show that the adoption of aggressive electric mobility goals creates grid service opportunities, using the framework for charging infrastructure and electric power systems integration. Indian agencies such as the Automotive Research Association of India (ARAI), MoHI, and Bureau of Indian Standards (BIS) have initiated committees to review global standardization efforts and propose specific standards applicable to the Indian context. The ARAI's Automobile Industry Standards (AIS) 0138 2016 Defacto standard proposes standards for AC (Part 1) and DC (Part 2) charging stations [25]. The MoHI has proposed charging station specifications (do not cover buses). The specifications include AC chargers, AC public off-board chargers up to a maximum charging rate of 2.5 kW or 3 kW, and DC public off-board chargers [26]. To bring it all together BIS has recently constituted a sectional committee (ETD-51), Electrotechnology in Mobility to review national and global activities and recommend standards. One key recommendation from studies is mandating the BIS recommended standards for EV and charging infrastructure while considering power and communications integration with the electric grid.

C. *Operational Business Models*

While India has initiated early-stage activities for grid modernization, EV adoption, standardization, and demand flexibility, and is beginning to understand the role of EV charging infrastructure, its ownership and operation models (O&M) are least understood and should be critically evaluated for public and private sector EVs. These models determine who and how the charging stations can provide the flexibility services and determine the value proposition.

The charging infrastructure ownership models relative to electric grid helps understand the networking and management needs of charging infrastructure and spatial and temporal access of EVs, as a grid resource. Studies have looked at the global context of three key evolving models of EV charging infrastructure, as described in TABLE III. [6].

TABLE III. BEV CHARGING STATION OWNERSHIP MODELS

Customer	Most widely used model for level 1 with any available 108-120 V outlets and, partially, for level 2 charging by the owners of home, building, and campus
Third-Party	Increasingly popular model for level 2 and DCFCs, where a charging station OEM, or a city/county deploys charging infrastructure in public-spaces, highway-corridors to encourage EV adoption.
Utility	Evolving business model to deploy level 2 and DCFCs in public spaces, along highway corridors, and disadvantaged communities to support aggressive national- and state-level EV adoption and zero-emission vehicle mandates.

Studies have also reviewed these models from the context of existing operations to accelerate the adoption of public electrification of buses, 3-wheelers, ferries, and taxi-fleets, which are all important priority [14]. The real value of EVs against the charging infrastructure models and grid integration can be understood by the impacts excised.

V. GRID IMPACTS: PRELIMINARY ANALYSIS

To value EV, as a grid resource, we reviewed their charging impacts on the grid. This section describes the methodology and results from a preliminary analysis—for energy (GWh) and power (GW)—with projections until 2030 when India plans to transition to all EV sales. While the energy values show the total energy consumed, the power values show the additional peak demand increase to be considered for the grid infrastructure preparedness.

The charging energy and power usage vary significantly across EV classes. While an electric bus or truck may use 100% of battery capacity available every day, passenger cars and two wheelers may use 40% to 50% of battery capacity. The vehicle class, battery technology, charging level, and owner behavior define when, where, and how fast an EV charges. The analysis has the following assumptions:

1. The power requirement is based on EVs that will charge over 3 hours and 10% of EVs are connected charging from the grid at the same time. The connectivity is based on early-stage studies **Fehler! Verweisquelle konnte nicht gefunden werden.**.
2. Commercial EVs (CEV)—buses, three wheelers, trucks, vans, etc.—may charge during the day or night while most of the private EVs (PEV) and two wheelers may charge during the night. The PEV charging pattern is based on early-stage studies **Fehler! Verweisquelle konnte nicht gefunden werden.**.
3. Annual travel distance considered for daily energy use—12,800-kilometers (Km)/year for PEV, two and three wheelers [30], 52,000 Km/year for CEV.
4. The EV battery size is 20 kWh, 125 kWh, 3 kWh and 2 kWh for each PEV, CEV, three-wheeler, and two-wheeler, respectively.[3]
5. Annual new EV sales growth for PEV, CEV, and three-wheelers and two-wheelers are 3%, 1%, 0.2% and 5%, respectively.
6. The EV lifespan is 10 years and the cumulative total is for the EVs sold between 2020 and 2030.
7. Market share in 2020—10% for PEVs and CEVs, 50% for three-wheelers, and 25% for two-wheelers.
8. The effective EV charging levels of 0.98 kW, 38 kW, 0.58 kW, and 0.27 kW for PEV, CEV, three-wheeler, and two-wheeler, respectively.

We projected the 2020 and 2030 EV adoption numbers, as a priori, based on the historical average growth for the respective vehicle class, as summarized in TABLE IV. . The historic growth trend was calculated from the Society of Indian Automobile Manufacturers (SIAM) data [29].

TABLE IV. PROJECTED ANNUAL EV SALES: 2020 AND 2030

Year	Passenger	Commercial	3-Wheelers	2-Wheelers
2020	313,981	71,355	271,205	5,000,566
2030	4,219,638	788,199	553,356	32,581,578
Cumulative	**24,688,176**	**4,916,352**	**4,525,919**	**171,921,961**

Tables V and VI summarize the projected annual energy for the vehicle-miles traveled (VMT) and for years 2020 and 2030, respectively. Results show that a significant capacity addition will be needed in power generation, transmission and distribution infrastructure. Studies show that India's energy and power needs for EV charging in 2030 will be 82,000 GWh/year and 23 GW, respectively [30]. However, these studies consider passenger cars and two-wheelers, and the total energy use by all EV classes is not represented. Based on our analysis results, by 2030, India will need 795 GWh of daily energy to support all EV classes on road by 2030. Annual energy consumption will be at 290 TWh.

TABLE V. ANNUAL ENERGY USE BY ELECTRIC VEHICLE CLASS

Electric Vehicle Class	Wh/Km	Km/KWh	Annual VMT Km	Annual KWh
Passenger	100	10[4]	12,800	1,280
Commercial	800	1.3	52,000	41,600
Three Wheelers	50	20	12,800	640
Two Wheelers	23	43	12,800	294

TABLE VI. 2020 AND 2030 (CUMULATIVE) ENERGY USE

Electric Vehicle Class	2020 (GWh)	2030 (GWh)	% EV
Passenger	1.10	86.58	8
Commercial	8.13	560.33	59
Three Wheelers	0.48	7.94	0.8
Two Wheelers	8.77	138.67	32
Total Daily	**18.48**	**793.51**	
Annual	**6,680**	**289,632**	

Table VI summarizes the power projections for 2020 and 2030 if all EVs are and charging to the grid at the same time.

TABLE VII. 2020 AND 2030 (CUMULATIVE) POWER USE

Electric Vehicle Class	2020 (GW)	2030 (GW)
Passenger	0.37	28.86
Commercial	2.71	186.78
Three Wheelers	0.16	2.65
Two Wheelers	1.34	46.22
Total	**4.58**	**264.50**

[3] The battery capacity for buses and 3-wheelers is in the recommended ranges of the study that considers conditions in Kolkata, India [14].

[4] 5 Km/kWh range is 2016 typical for a U.S. passenger electric car. The range is doubled for India due to smaller and lighter cars at lower speeds, frequent braking, and EV efficiency improvements up to the year 2030.

We take note that different EV classes will charge at different times and locations. Cities with denser population and potential larger EV numbers may create local hot spots on the grid. While studies have shown passenger cars charge at home and work at a reasonably predictive pattern, the same may not be true for CEVs. Based on studies and our modeled analysis, Table VII summarizes the 2030 temporal power estimates range between 20 GW to 54 GW, or 8% to 21% of the total 265 GW power projected for 2030 by EVs.

TABLE VIII. TEMPORAL POWER USE BY ELECTRIC VEHICLE CLASS

Electric Vehicle Class	7 am to 5 pm		5 pm to 11 pm		11 pm to 7 am	
	GW	*EV*	*GW*	*EV*	*GW*	*EV*
Passenger	3	32%	0.43	3%	7.03	65%
Commercial	14.01	25%	23.35	25%	35.02	50%
Three Wheelers	0	-	0	-	0.99	100%
Two Wheelers	4.44	32%	0.69	3%	11.27	65%
Total	**21.22**	**-**	**24.47**	**-**	**54.31**	**-**

Grid reliability must consider the EV power capacity needs and assess impacts from coincidental peaks from other loads against India's total production capacity, which according to the CEA, in July 2017, was 330 GW [31]. The electricity rate tariff and EV charging incentives can play a significant role in managing EV charging impacts on the grid [13]. Dynamic utility rate tariffs influence charging behaviors and can be incentivized from grid infrastructure cost deferrals. Considering that the power use is not uniform during the day, DR from V1G or V2G methods is important, and will significantly influence the supporting grid investment. This strategy also plays a critical role to address the variability of renewable energy.

While building a grid infrastructure to support the projected 172 million EVs in service by 2030 can be a challenge, this also represents an opportunity to the grid companies. By leveraging flexibility from EV infrastructure, electric utilities can improve the off peak utilization of conventional power plants and utilize the wind and solar renewable resources to the highest possible extent. This represents utilities an aggregate revenue opportunity of a conservative $36 billion (INR 1.8 lakh crores) per annum at $0.12/kWh (INR 8/kWh). India's oil import bill in 2016 was $120 billion with an anticipated increase to $230 billion by 2023 [11]. In India, 80% of crude oil imports drive 30% of primary energy, and the majority of this is used by the transportation sector [11]. Replacing oil imports with EVs investments reduces the budget deficit, provides clean air, and a step in the right direction toward Paris climate goals.

VI. FLEXIBILITY PRACTICES AND FUTURE DIRECTIONS

This paper reviewed the Indian prerogatives and market opportunities to boost clean transportation. Focusing on the battery-based EVs, critical analyses were conducted for the key adoption factor, EV charging infrastructure and its correlation to flexible electric grid operations. The results from a preliminary analysis of EV energy and power projections for 2020 and 2030 show temporal and spatial flexibility necessary to meet India's clean energy drivers—transportation electrification and renewable energy. The multifarious charging infrastructure cannot be a determinant for flexibility until technical, business, and policy interventions that leverage EVs, as a grid resource, are addressed. Flexibility services improve the cost effectiveness of EVs. The findings and next steps are classified accordingly where some are applicable globally.

Technical: The interoperability and integration at various levels—EVs and charging stations, charging stations and grid systems, EVs and grid operations—and their relational operation models is a representation of holism that can accelerate and scale India's EV deployments. With a cumulative projected demand of 265 GW and annual energy use of 290 TWh by 2030, a combination of dynamic utility rate tariffs and advanced technologies will play a significant role in demand management and sustainable EV growth. For interoperability, the Indian regulators must mandate the BIS-approved national standards that are aligned with global standards. This strategy shields charging infrastructure network vendor lock-in, enables cost-effective connectivity of EVs with a diversity of charging network, metering, and enables optimal integration with Smart Grid. The results drive innovation, better customer experience, and enablement of flexible grid services.

Business: The energy and power growth projections and the leverage of EV infrastructure with innovative business models and electricity rate tariffs represent the most significant growth opportunity to grid companies with a conservative annual revenue of $36 billion; about $70 billion annual savings in transportation-related oil imports by 2023; and improved energy security and social costs.

Taking cues from global practices, Indian DISCOMs can take initiative in owning and operating the charging infrastructure that also provides them with an ability to offer flexibility services to better manage the grid. With dynamic tariffs, The EV batteries could charge from solar panels during the day or buy cheap electricity from the grid at off-peak hours during the day and supply to home during the night. Large fleets of EVs connected to the grid could be aggregated, as a DR resource to provide grid support and better manage variable renewable energy. The battery banks built with retired EV batteries forming energy storage services for grid support is an underutilized opportunity.

Policy: For the success of EV revolution in India, several policy interventions are required. The Indian Electricity Act does not permit the resale of electricity. A distribution license is required for buying electricity from the grid and selling to an EV. Albeit several DISCOMs and regulators have taken the view that charging of EVs from any commercial category electricity connection may be allowed, as a business service, regulatory intervention is required to ensure investments to set up charging station networks.

Another important required policy support is dynamic tariffs for EV charging. EVs may be classified as a separate category of load and, as a DER; the tariff can be designed accordingly. Specification of such dynamic pricing rates and incentives encourage EVs and charging infrastructure to participate in DR services. With the proliferation of variable renewable energy, there are several intervals in a day when there is surplus generation on the grid and dynamic prices can incentivize EV owners to store this surplus rather than curtailing such generation, as practiced presently.

Policy interventions on the use of retired batteries for grid services must be considered in the EV costs so that the buyers of second-hand batteries can underwrite the partial cost of EV batteries that will reduce the first cost of EVs.

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