A Comprehensive Review on Level 2 Charging System for Electric Vehicles

Saadullah Khan\textsuperscript{a,}\textsuperscript{b}, Samir Shariff\textsuperscript{a,} Aqueel Ahmad\textsuperscript{a,}\textsuperscript{c} and Mohammad Saad Alam\textsuperscript{a,}\textsuperscript{d}

\textsuperscript{a}Department of Electrical Engineering, Aligarh Muslim University, Aligarh, India; \textsuperscript{b}Department of Electrical Engineering, Tayibah University, Al-Medinah Al-Munawwarah, Kingdom of Saudi Arabia

ABSTRACT

The commercialized deployment and fast adoption of electrified transportation system, i.e. electric vehicles (EVs) and plug-in hybrid-electric vehicles (PHEVs) necessitate the fast, reliable and economical electric vehicle supply equipment (EVSE) infrastructure (i.e. EV chargers). As a matter of fact, EVs are the best supplement of ICEVs due to their energy efficient and environmentally friendly nature. But their wide adoption has checked by the insufficient charging infrastructure in the world. The work presented in this paper provides state of the art review of Level 2 charging technologies for EVs and their sustainable deployment, characteristics, and standards available in the open literature, as well as sustainable smart grid interaction and potential safety measures. The manuscript also forecasts comprehensively a coherent view of the current status, economic assessment, power market operation and control and safety aspects of EVSE to assess the marketable viability of Level 2 charging system. The work will be extremely useful to researchers in this field, industry personals, and investment representatives and groups as a ready reference of the charging system of EVs, with information on significant characteristics and standards of xEV charging system.

1. Introduction

There should be an aggregated development of Electric Vehicles (EVs) as a means of transportation system because of their economic and environmental benefits \cite{1,2} and also environmental worries, scarcity of oil supply, and the ample use and interaction of intermittent renewable sources in power grids, are all causes that are accountable for shifting the focus on plug-in hybrid electric vehicle (PHEV) and fully electrical vehicle (EV) technology. Also, from the distribution system viewpoint, assessment of the reliability of charging services is essential for EVs since sustainable charging facilities would help to promote the use of EVs thereby accelerating their deployment \cite{3}. The EV is not a new concept and has been conceptually and practically available for the last century since the advent of automobiles \cite{4,5}.

The diesel engine exhaust is more prone to cancer in humans as claimed by various health and medical organizations. Diesel motor exhaust (DME) is the main source contributing air pollution effluents in cities \cite{6,7}. The International Agency for Research on Cancer (IARC) \cite{8} has approximately categorized DME as oncogenic to a human being, on the basis of experimental and
epidemiological studies. Moreover, increasing fuel prices and growing public worries on environmental glitches particularly air quality issues related to urban transport [9], global warming [10], etc. have led the worldwide governments and automobile business associations to produce eco-friendly, emission-free transportation means [11], i.e. green transportation systems [12] such as walking, biking, daily public transport, and railway systems, etc. Vehicles, e.g. natural gas vehicle, hydrogen-powered vehicle, hybrid-energy vehicle, electric vehicle, and solar energy vehicle are termed as green vehicles [13].

The future solution for the scarcity of fossil fuel reserves, and also to the environmental problems related to their extensive use, will most probably consist of a large-scale use of EVs in the world. At present, three significant types of EVs to be launched in the automotive market are fully electric vehicles, fuel cell vehicles, and hybrid electric vehicles [14,15]. Battery powered and fuel cell vehicles are propelled only by electrical power, however, presently available HEVs also equipped with an internal combustion engine in their drivetrain architecture [16]. As these vehicles involve the use of high energy storage batteries with an enormous amount of charging requirements, a huge implication of this notion will incite substantial effects in operation and design of electric power system [17], but will also allow and empower the practical use of nonpolluting energy resources.

The electric vehicles (EVs) proving an only viable solution for a sustainable transportation system and showing continuous technological advancement in battery and electrical drivetrain architecture [18]. The ultimate solution is charging the EV from renewable energy sources as discussed in [19–25]. The EVs can also be charged wirelessly as discussed by several researchers [26–28]. Presently, most of the EV charging is done either at residences or for free at around public charging infrastructure managed by municipalities, office buildings, etc. But in reference to the forecasted growth of the EV industry, commercial deployment of charging stations will deliberately be added and placed. And an effective management and regulation of EV charging infrastructure and their development needs to consider the benefits of multiple constituencies viz. local governments, power grid operators, charging station owners, and consumers, [29] etc. As a matter of fact, approx 80% EVs are charged at home (overnight charging) using either a 110 V plug (Level 1) or 220 V (Level 2) plug charger. A more feasible option for EV consumers who don't have home charging facility, they must able to charge at workplaces or at public stations owing to the availability of infrastructure. Typically, EV charging involves some kind of charging equipment with an electrical outlet.

The Automotive Industry has framed a standard developing agency Society of Automotive Engineers (SAE) [30]. For electric car charging, the SAE convoked a committee called ‘J1772’ (‘J1772 plug’ [31], or ‘J-Plug’). In AC charging systems [32], the car has an on-board charger does AC to DC conversion [33–35]. While in DC charging systems, the car has an off-board AC to DC converter charger [36] for the AC-DC conversion [37], and supplying the EV by direct connection to the battery pack and bypassing the on-board AC charging system.

The main difference between charging levels 1, 2, and 3 [38] is the voltage [39]. The PEV charging levels with respect to their locations are described in Table 1. Types of charging levels [40] and their particular power handling capacity are as follows- (i) Level 1 charging system: 120 VAC, 1-phase, 16 amp maximum current and 2-kilowatt of power is used to supply onboard charging system of EVs. NEMA 5-15 connectors of SAEJ1772 are suitable for these type of chargers. (ii) Level 2 charging system: 240 VAC, 1-phase, 12–80 amp maximum current, and 2.9–19.2 kW power is suitable for the charger. IEC 62198-2-Scame and 62198-2- Mennekes connectors, SAEJ1772, IEC 62196, IEC 60309, are typically suitable for

### Table 1. PEV charging levels/locations [31].

| Charging level | % of EVSE | Supply circuit | Charger power | Cost range | Fully charge time | Use |
|---------------|-----------|----------------|---------------|------------|------------------|-----|
| Level 1       | 54%       | 120 VAC 1-phase 20 Amp | 1.4 kW @ 12 amp – 1.9 kW (On-board) | $1,000 or less | 12–20 h/7 h | Level 1 is used by EV owners charging at home but public and commercial charging stations can also be Level 1. Most electric vehicles come with a portable 110 volt charger that will work with any standard home outlet. These chargers can also be purchased if necessary |
| Level 2       | 43%       | 240 VAC 1-phase 40–80 Amp | 7.7 kW–19.2 kW (On-board) | $2,000–$10,000 | 4–6 h/3 h | Most community-based charging stations and some business and home stations will be Level 2 |
| Level 3 / DC fast charging | 3% | 450 VAC/600 VDC 3-phase/DC 200 Amp/400 Amp | 62.5 kW–240 kW (off-board) | $60,000–$100,000 | Under 30 min | Commuters, long trip travelers |

Note: 15 min/10 min 50% in 10–15 min/10 min
these type of chargers. (iii) Level 3 AC charging system: 400 V, 3-phase power is converted from AC to DC and this converted power is directly applied to charge the EVs. Maximum of 32–63 amp of current and 22.1–43.7-kilowatt of power can be supplied by these types of chargers. Connectors used are IEC 60309, Magne charge, IEC 62198-2-Mennekes and 62198-2- Same connectors. (iv) Level 3 DC fast charging system [41] 300–600 V DC is directly supplied to charge EVs. Maximum 400 amp current and 240-kilowatt of power can be supplied by these type of chargers. Connectors used are SAE J 1772 Combo, IEC 62196 Mennekes Combo and CHAdeMO [42].

Another one is IEC 62196 – Europe’s terminology [43]. The European standards-developers gave us a similar-but-different set of terms [44], e.g. Mode 1 – household-type socket-outlet for slow charging, Mode 2 – household-type socket-outlet with an in-cable protection device, suitable for slow charging, Mode 3 – slow or fast charging of EVs using a specific EV socket-outlet with control and protection function installed, Mode 4 – off-board charger to incorporate fast charging, etc.

1.1. The Contribution of this Review Paper
The key contributions of the presented work are as follows:

(i) The objective of this paper is to present an in-depth review of several aspects and methodologies for level 2 charging system and their widespread deployment to cater global xEV demand.
(ii) Several business options to commercialize the charging infrastructure for different customer needs and satisfaction are addressed here.
(iii) Smart grid integrated power market operation with complete economic analysis, and level 2 charging EVSE technology followed by various available standards is proposed.
(iv) To analyze different charger solutions for electric buses, a complete electrified transit network framework is incorporated in the manuscript.

1.2. Organization of the Manuscript
The manuscript is elaborated into seven different sections starting with the introduction and ended up with the conclusion. Section 2 provides a review of current status, market survey and end-user response regarding level 2 charging technology development for electric vehicles in the world. Section 3 focuses on various business opportunities and commercialization activities of level 2 charging system of EVs in global market deployment. And in the Sections 4 and 5, give a detailed interaction with smart grid and power market penetration and operation of electric vehicle charging system, and a brief introduction to EVSEs and their technological advancements and standardization are discussed, respectively. And the last section, i.e. Section 4 briefly discusses the socioeconomic factors of EV charging system with a practical limitation of charging station location for fixed transit fleet system.

2. Literature Review
As the number of PEVs increases, the industrial and commercial facilities need more sophisticated and commercialized electric vehicle charging stations. In this section, first review of the literature on existing charging infrastructure and then other relevant recently published articles that have a practical insight more specifically for EV market and customer survey.

2.1. Globally Level 2 Charging Infrastructure Deployment
In the U.S., to encourage public domain for achieving electrification at all levels, the government has implemented several policies and goals to deploy officially one million EVs by 2015 on the road throughout the nation [45]. Germany with its German National Electric Mobility Platform (NPE) expects about 1,000,000 EVs in the country by 2020 with a forecasted demand of nearly 70,000 public on-street charging spots. Ontario, Canada, The Ministry of Transportation, through its Green Investment Fund is spending $20 million for the development of 500 EV charging stations (EVCSs) at around 250 diverse locations in the province by 2017 [46]. To way-out, the problems encountered in renewable energy exploitation practices in China and to meet the rising demand of energy for electric vehicles, a model for siting a number of places with electric vehicles charging stations is proposed in [47]. As of May 2017 proceedings, around 10 nations (China, Japan, Canada, the Netherlands, France, Germany, Sweden, Norway, the U.S. and the U.K.) have joined hands together to form a multi-government policy forum termed as Electric Vehicles Initiative (EVI). The EVI’s initiative is to accelerate the worldwide adoption of electric vehicles and their charging network. Korea and India are also engaged in the EVI’s happenings, and South Africa continued to be an EVI member till 2016 and remains as a key observer [48]. The government of India and automotive industries, especially, have come forward for the mission of e-vehicles exploration and another substitute of clean fuels to mitigate the tailpipe emissions from the transportation sector. Thus, there is a very first document prepared in 2013, as National Electric Mobility Mission Plan (NEMMP) 2020, on the countryside EV mission, which later declared as an Act in

...
on PHEV market forecasting are consumer choice models, agent-based models, and diffusion and time series models [54].

2.2. EV and Alternative Fuel Vehicle Market Survey

By the mid-2017, an aggregated total of roughly 35,000 new EVs ‘Battery electric vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV)’ have been sold in Canada and approximately 650,000 EVs in the United States. But on per capita basis, the U.S. market is about 2.5 times more advanced than the Canadian one. A majority of the Canadian sales have been supported by purchase price incentives that have been administered in the most populated provinces viz. Ontario, Quebec and British Columbia. Figure 2 shows the electric car stock in different countries up to 2016.

Regardless of apparent energy, environmental, and economic benefits, the electric vehicles are only very slowly establishing to accomplish a place in the global auto market. A number of models have developed so far and many researchers spending much to assess the market penetration rate of formerly available HEV design and latest PHEV and EV design in the U.S. market. The modeling techniques used to characterize these models and use them to signify the marketplace interactions. The three foremost modeling techniques available in the literature on PHEV market forecasting are consumer choice models, agent-based models, and diffusion and time series models [54].

The worldwide governments are promoting their own, extremely significant procurement power, apart from policy agenda, providing vision, and financial motivations/incentives to advance the use of electric vehicles. The Indian government also has signaled the objective to buy 10,000 EVs for its fleet. In the first phase, there will be 1,000 EVs for use at government departments in the National Capital Region (NCR) and Delhi. In tandem with this, Energy Efficiency Services Limited (EESL) is preparing estimates for nearly 4,000 EV charging stations in the region. EESL is a joint venture of NTPC Limited, Rural Electrification Corporation, Power Finance Corporation, and the power grid and established under the Ministry of Power.

Whether working with a commercial business model, ministerial cars, or charging a bus fleet, EV charging stations, and networks requires a consistent power supply. Without this, the charging system will fail. Although Central Electricity Authority data from 2016 revealed India to have a power surplus for the first time, load shedding and power outages remain common, with some parts of India having access to power for less than eight hours
Table 2. International EVSE Manufacturers [56].

| EVSE Manufacturer | Wall, Pedestal, Pole, Portable | Rating | Hose Length | NEMA | Certification | Communication method |
|-------------------|-------------------------------|--------|-------------|------|---------------|----------------------|
| AddEnergie [57]   | Wall                           | 208/240 VAC; 40A | 25ft | 4X | CSA | ‘HomePlug’ PLC Module |
|                   | Any                           | 208/240 VAC; 40A | 25ft | 3R | CSA | LAN – ZigBee; WAN – 3G |
| Wall or Pedestal  | 208/240 VAC; 40A | 20ft | 6R | cUL, UL | LAN – Bluetooth |
| AEROVIRONMENT [58]| Portable                      | 208/240VAC; 20A – L2 & 120V: 12A – L1 | 15 and 25ft | 3R | cUL, UL | None/WiFi, Zigbee, Cellular |
| BMW [59]          | Wall                          | 208/240 VAC; 40A | 18ft | 20ft & | CT600-cUL & others are cUL | None/WiFi; Zigbee, Cellular |
| ChargePoint[60]   | Wall                          | 208/240 VAC; 40A | 18ft | 25ft & | CT402–23ft | LAN – ZigBee; WAN – 3G |
|                   | Bollard                       | 208/240VAC; 40A | 18ft | 2 CT402–23ft | 3R | cUL, UL | LAN – ZigBee; WAN – 3G |
| EFACEC [61]       | Wall/Pedestal                 | 208/240 VAC; 40A | 25ft | 3R | UL, CSA | LAN, 3G, Wi-Fi |
| eMotorWerks [63]  | Wall                          | 208/240 VAC; 40A | 25ft | UL, CSA | LAN – Wi-Fi |
|                   | Adapter                       | NA | NA | 4 | UL | LAN – Wi-Fi |
| EVSE LLC [64]     | Wall/Hanging, Wall or Pedestal| 208/240VAC; 40A | 17ft/20ft/20ft | 3R | UL, CSA | LAN – WiFi; WAN – Cellular |
| LEVITON [65]      | Wall/Pedestal/Roof            | 208/240VAC; 30A, 40A/50A | 12ft/18ft, 6, 3R | cUL | LAN – WiFi, Cellular |
| KeBo (Bosch) [66] | Wall/Pedestal                 | 208/240VAC & EL-50600-A/B – 95–264VAC; 20A/40A | 18ft/25ft | 3R/4X | cUL, UL | LAN – WiFi, Cellular |
| SemaConnect [67]  | Wall, Pedestal, Pole Mount    | 208/240VAC; 40A | 18ft | 3R | CSA | LAN – CMOD or GPRS cellular, Wi-Fi |
| Siemens [68]      | Wall from rear/bottom          | 208/240VAC; 40A | 20ft/14ft | 1-Apr | cUL, CSA | Zigbee, Wi-Fi, Cellular |
| Sun country highway (Clipper Creek) [69] | Wall or Pedestal | 208/240VAC; 20A | 25ft | 4 | cUL, UL | Wi-Fi, CATS, Cellular |
|                   | Pedestal/Ruggedized Level 2 Charger/ (nema 14–50 plug) | 208/240VAC, 40A | 22ft | 4 | cUL | Wi-Fi, CATS, Cellular |
| EvoCharge [70]    | Pedestal mount with cable management | 208/240VAC; 40A | 30ft | 3R | cETL, cUL | Cellular, CATS |

a day. As a result, it is anticipated that much EV charging infrastructure will require supplementary or alternative energy sources (International EVSE manufacturers are listed in Table 2).

As the government is also keen to see an uptake in renewable energy sources it is widely expected that solar energy especially roof-top solar will play a significant role in powering charging sites. The ability to generate, manage and store power from both renewable and grid sources make microgrids a likely element of much EV charging infrastructure. [71]

Manufacturers of commercial Level 1 charging stations include: Telefonix Inc. [72] and Clipper Creek [73]. Manufacturers of commercial Level 2 charging stations include: Bosch [74], Charge Point [60], Clipper Creek [73], Eaton [75], Leviton [65], and Schneider Electric [76]. Manufacturers of commercial Level 3 charging stations include: ABB [77], Aero Vironment [58], Eaton [78], Fuji Electric [79], Schneider Electric [76], and Tesla Motors [80].

2.3. Customer Perspective

From a consumer standpoint, various efforts to understand the adoption of EVs in varying contexts and using different methods are presented in this section. It is natural that consumers vary in their preferences and tastes for novel technologies and products. A significant outline of research activities has presented in the literature whereby consumer acceptance and rejection of EVs is judged on the basis of two broad theoretical fundamentals, i.e. economic theories of preference utilitarianism and behavioral theories, that are presented in [81]. On the other hand, there is a growing stream of research that relates the adoption of EVs to behavioral aspects [82]. Here, there is a more pronounced focus on consumers’ personal beliefs, personality, perception, and emotion as they relate to EV adoption. Other approaches have included the theory of planned behavior, normative theories, consumer innovativeness, Diffusion of Innovation (DOI) theory, lifestyle theory, and grounded theory to link EVs adoption behavior to environmental, attitudinal, symbolic, emotional, and societal factors.

Consumers can be demarcated according to their preferences and likings for new and inventive technology [83], where customer survey is often quantified in terms of willingness-to-pay [84,85]. For example, one consumer might be eagerly enthusiastic for electric vehicles, and at the same time, a second one behaves cautiously, and while a third person could absolutely discard the concept of EV adoption. Similarly, customer demarcation can also be based on the real or probable judgment at the time of purchase of a new technology. A given customer is either an ‘early adopter’, ‘innovator’, or part of the ‘early’ or ‘late’
3. Business Models for Electric Vehicle Charging Station

A business model [87] defines the way in which products or services are delivered, comprising superficial conception of value creation of certain products or services for an end-user customer [88]. It accelerates the introduction of EVs into the private sector of transportation system [89]. It is generally easier to evaluate by spending deliberated thoughts on threats and opportunities as it is internal to one single agent. We are at present seeing a divergence in different business models for the commercial user of charging infrastructure designed and accustomed to the private EV customers. A particular business model should also deploy a structure of smart and coordinated charging management for xEV fleet through cloud-based Charging Management System [90].

3.1. Free EV Charging Points

In spite of the measures that require direct investments by a municipality forum, there are also several controlling parameters that yield less effect on public budgets. The best prevalent is free EV parking at city centers. To attract customers [91] to some of its malls, property developer and real estate company offers free EV charging at some locations. Similarly, e.g. EV manufacturer Mahindra Reva in India has a contract with the Gopalan chain of malls to set-up free charging points at its retail centers [92]. Often, there will be a problem of vehicles unnecessary parking on these spots without charging the vehicles as parking spots are public property. One member stated that virtually 50% EVs occupying the charging spots for only parking purpose, and they are actually charging their cars during the night hours at home [93].

3.2. Regulated Rates for Charging

A set of rules, i.e. regulatory options are implemented to describe the responsibilities of the electric power industry agents, in rolling out public charging infrastructure. Obviously, it is determined and regulated by the certain type of charging station ownership agents and or operate according to previously defined regulatory principles. The definition also covers the investment recovery rules and remuneration of the provided service rules [94]. In the summer of 2017, Tata Power launched Mumbai’s first commercial EV charging station [95], with customers paying rates set by the Maharashtra Electricity Regulatory Commission. Reliance, another private power developer, is also reported to be looking at the EV charging market.

3.3. Reassess EV Charging Network

In India, DISCOM Maharashtra Power Company is looking to use its substations in prime Mumbai and Pune locations as EV charging station sites. In a sign of the challenges, the commercial market presents high costs led DISCOM Bangalore Electricity Supply Co to reassess plans to set-up a smart grid to provide an EV charging network in the city.

3.4. Community Charging Stations

An organic initiative intended to proliferate charging stations beyond city limits [96] thus contributing to the ecosystem that will allow EV use to flourish. Most businesses are connected to the grid and 15 Amp level 2 sockets are common in developing countries like India. The idea is for businesses and organizations located between 40 and 70 km around cities to set-up 15-ampere charging stations. The intention is to allow urban EV owners to extend the range of their journeys by offering out-of-town charging. There is currently 222 community charging stations in the country [97], some offering free charging as an incentive to attract visitors at resorts and malls, for instance, others operate on a commercial basis with customers paying to charge their vehicles. The 15 Amp stations offer slower charging times than the level 3 DC systems, offered at most city-center charging stations.

3.5. Investments by Large Fleet Operators

Another area of growth in EV infrastructure is an investment in charging stations by operators of large fleets, many of which are already switching to EVs. The directions of EV commercialization and development and is directly influenced by the fleet service providers in the market. Fleet operators in France, for instance, formed an association to make the mandate for at least 100,000 BEVs by 2015 [98]. Electric utility companies have involved in EV partnerships. In 2010, the utility companies listed for infrastructure development projects are much greater in number, few of them are named as Oregon’s Portland General Electric, Swiss Energie Ouest Suisse (EOS), San Diego’s Gas and Electric, Tokyo Electric Power Company, Ireland’s ESB, etc. among others. These are important groups mostly empowering the recharging infrastructure and some of them seemingly gaining momentum in the initial phase of the period 2010–2020, as far as their participation in automobility is concerned. Typically, such stations are at main hubs such as bus depots or taxi
companies’ main offices or ranks. In India also taxi aggregator Ola, which operates an EV fleet in Nagpur has set-up 50 charging points across four strategic locations in the city.

3.6. Battery Swapping Stations

The long charging time required by the EV batteries could effectively be eliminated by graceful acceptance of battery swapping stations (BSS) [99]. These are the mediator stations between the customers and power system companies. A typical business and working model is mandatory for the successful displacement of these type of stations, that will, besides providing a fast and consistent battery charging alternatives, allow it to make a revenue-generating station [100]. The most expensive element is the battery used in the vehicle as storage, with the cost increases significantly as storage capacity grows. Affordability means that two and three-wheeled vehicles account for 80% e.g. in Indian domestic vehicle sales. The BSS should ensure the users to have sufficient range by allowing them to swap low batteries for fully charged ones en-route. The network of BSS, like those for EV charging stations, is anticipated to develop a number of business models.

To make a profit from the BSS, it should participate in the market as a service provider in the form of energy storage, demand response, and reserves. The problem of proper scheduling storage capability of the BSS can be viably addressed by time-varying electricity prices, i.e. a concept of real-time pricing (RTP) [101–103]. The low-price period of the day can be exploited to maximize profit by charging the batteries and purchasing the electricity in Grid-to-Battery mode (G2B) [104] and selling the stored energy in high-price periods in Battery-to-Grid mode (B2G) [105,106]. Moreover, BSS can operate in Battery-to-Battery (B2B) mode [107] i.e. charging certain batteries by supplying the same energy that is stored in other batteries form G2B mode.

3.7. Vehicle-to-Grid (V2G) Services

In the prior models, the main purpose is to supply the power for charging the EV batteries reaching the driving requirements of the EV owners. The vehicle to grid (V2G) [108] technology is qualifying a more sophisticated EV charging approach and of course necessitate further technological advancement and prescribed measures. The grid-connected vehicle is a valuable resource that supplies power to the grid and regulates the frequency of supply to optimize power operation and system costs. EVs could also make some profit in exchange. In the V2G mode, the power flow can be unidirectional [109]. This mode required EVs equipped with control systems and inverters to inject power from vehicle to the grid or vice versa, and a smart energy meter that reads the bidirectional energy flow [88].

The EV aggregator [110] will optimize the EV resources in order to charge the storage in some period and discharge them in another period [111]. In addition to provide regulation reserves or to buy or sell the power in real-time (or day-ahead markets), the EV owner could subscribe specific contracts with an Independent System Operator (ISO) [112,113]. In these cases, to fulfill the requirements of market participation, specific communication and metering equipment are required. Though one single unit could provide a complete V2G service, to make business more economical, at least hundreds of units pools an EV aggregator to make a combined capacity in MWs in order to participate in the ISO markets. Therefore, all the presented previous models can be revisited assuming as EVs in the V2G environment. The uncertainty of the EV arrival, the intermittency of the renewable energy, and the variation of the grid power price are taken into account delay-optimal charging scheduling of the electric vehicles (EVs) at a charging station with multiple charge points [114]. Also V2H and H2 V operation is explained in [115,116]

3.8. Successful xEV Charging Infrastructure Deployment Program

Successful advancement in EV charging infrastructure [117,118] faces some difficult, and sometimes opposing, reflections in terms of business models (free or revenue generating), user (mass transit or private EV owner), type (battery swap, community charger or high-speed supercharger), power source (grid, solar or a microgrid managed hybrid) etc. The principle of a business model is to define the method by which the enterprise delivers value to customers, invites the customers to pay for value, and converts those payments to profit [119]. Ensuring the right delivery partner is central to success, so it is worth here to mention the above-listed points to have a good insight into planning a particular project:

- Business model: Choose a partner with experience of delivering EV charging programs for all business models. They will be best placed to understand what is required to meet your specific goals.
- User: Virtually every aspect of mass transit charging infrastructure will differ from that for private EV owners. Be sure your partner has experience in creating both – so can draw upon best practice from a variety of sources.
- Type: Not only will the charging technology differ across types of stations. Planning, permitting,
design and construction needs will also vary. You need a partner who can demonstrate experience in every aspect of the project.

- Power source: EV projects stand or fall on the reliability of the power supply. So you need to choose a partner with considerable expertise in both power generation and power supply projects – from both grid and renewable sources – and the proven ability to integrate them into an EV charging station.
- Finally, the best partner will be one with experience in every aspect of an EV charging programs lifecycle: from concept through to asset management. This will be the partner best able to deliver maximum value from every aspect of your program.

4. Power Market Operation in Smart Grid Environment

The important characteristic of the Smart Grid [120] is to utilize the installed generating capacity in a more better and smarter way. To achieve this, a differential electricity pricing system to provide an option to consumers to shift from high demand periods to low demand periods. And provide the ability for remotely monitor supplies on and off to manage demand locally by utilities. The design and operation of charging stations would be consequently needed.

A market is a place where an environment for demand and supply is realized i.e. buying and selling a certain product or service. Consequently, markets for energy or power (a day ahead, intraday and time of use) [121], ancillary services and so forth. The rules by which this trading platform functions, therefore, is described by a market model. In the electrical power system, the market somehow differs from regulatory options [122]. Charging infrastructure and communication requirements for the onboard charge controller and the energy management controller would essentially be governed by the nature of access to the charging point, i.e. private or public. EV and PHEV charging points can be comparatively a large load in the existing electricity grid. If it is unmanaged, the negative effect can be on the electricity grid, therefore, it is essential to study the impact of EVs on the electricity grid as shown in [123]. An overview to analyze today’s power system integration with EVs is shown in [124].

4.1. xEV Power Market Operation Architecture

Figure 3 proposes the technical and market structure of power management system. The right-hand side column explains the operation of the power market, whereas the technical framework of the operation is explained in the left-hand side column.

In order to operate a large number of EVs parked in a particular area, where the low voltage (LV) and medium voltage (MV) grids are formed, the aggregators are essentially required to serve as an interface for the electricity markets and EVs. The aggregator is a website or a program

![Figure 3. Power market operation framework for EV integrated electric power system [116].](image-url)
primarily capable of grouping EVs in a single entity [125], representing a large size load/storage device to take part in power markets, as explained in [126]. Here we suggest a hierarchical management structure for the aggregator in order to gather and process much complex information, independent from the distribution system operator (DSO), (Figure 3) [88]. Subsequently, each aggregator corresponds to a large geographical area, and hence it must compose of the central aggregation unit (CAU) and the microgrid aggregation unit (MGAU). The CAU accounts for a maximum of twenty thousand clients that are fed by each HV/MV substation communicating with several downstream MGAU which, by their turn, will be located at the MV/LV substation level, with an expected maximum of about four hundred clients each. In order to reduce communications and computational loads, the MGAU is created helping CAU, the central part of the aggregator, in preprocessing the information regarding the group of EVs in LV grid. To enable bidirectional communication, each EV necessarily attached to a specific interface unit i.e. the vehicle controller (VC). Instead, the cluster of vehicles controller (CVC) is designed to regulate the charging of large parking areas (e.g. shopping malls). Under CVC organizational hierarchy, individual EV controllers do not have an active VC communicating with higher controllers in that hierarchy. Normally the CVC will interact directly with the CAU and the VC with the MGAU.

The EVs are showcased as distributed and mobile storage devices especially in the V2G environment. Their optimal placement and selection in power exchange market (e.g. bilateral, day ahead and DISCOM) is explained in [127]. To incorporate the irregular pattern of EVs penetrating in the distribution system, the battery status of each EV should be supervised and controlled in real time by smart grid itself. At present, the battery status of each EV is only maintained by the controller area network (CAN) technology of the on-board battery management system (BMS) [128]. The Simple Network Management Protocol (SNMP) is an essential protocol in several CAN applications.

4.2. Cloud Communication Interfaced IoT Architecture

The communication system is a key element of the smart grid infrastructure. And one of the important benefits for the acceptance of EVs in smart grid is the ability to act as stabilizing components through bi-directional charging units, thereby flattening the local or global peaks [129]. Also, the imbalances, explained in [130], by focusing an important open charge point protocol (OCPP) form security point. The Figure 4 interfaces, when deals with cloud communication environment comprise various wireless sensor networks (WSNs). WSN is defined by a large number of sensor nodes with limited energy capabilities that are located randomly or determinedly in a specific environment. WSNs are forming the key components, and important technologies of the Internet of Things (IoT) [131,132] and Cyber-Physical Systems (CPSs). Internet of Things (IoT), [133] implies the network-based interconnection of regularly practicing entities. It links with the wireless network through the interface by the sensors, electronic

![Figure 4. IoT system architecture [140]](image-url)
identifiers, two-dimensional codes etc. Here WSNs will play a significant role in various application scenarios of the future internet, such as environment surveillance, health care, military battlefield, agriculture monitoring, industrial control, and smart life. The IoT technology helps achieve the communication between man and machine or machine to machine [134]. Three key features of IoT are considerable, intelligent and internet connectivity [135]. Basically, there are four features in IoT: a gathering of data, bilateral communication, handling and response control. Several routing/networking protocols are discussed in [136]. ZigBee (2.4 GHz–868–915 MHz), GSM (900–1800 MHz), GPRS (900–1800 MHz) [137], 3G (1.9–2.17 GHz), WiMAX (2.5, 3.5, 5.8 GHz), and PLC (1–30 MHz) etc. [138] TCP/IP is the de facto standard for computer communications in today's networked world [139].

Figure 4 represents an IoT operation in the internet cloud-connected network [20]. The system consists of an electric vehicle charging station (EVCS) and a Data Concentration Unit (DCU). The DCU is a PLC internet gateway which supports TCP/IP communication and connects the OCS to the UIMS. In this work, PLC is adopted in order to furnish the captioned features into both the EVCS and DCU. Smartphone also has an active role in the EV–EVSE communication.

5. Electric Vehicle Supply Equipment

The 2017 NEC (revised and updated since 1996) Article 625 defines EVSE as

The conductors, including the ungrounded, grounded, and equipment grounding conductors, the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle. [141]

Basically, these are the charging stations and other fixtures outside the EV that provide the electricity required to charge the vehicle's batteries [142]. EVSEs are the gas pumps of EVs.

With the Nissan Leaf and the Chevrolet Volt 2011 release and the Tesla Model S, the 2012 release, the production of plug-in electric vehicles (PEVs) has commenced [143]. Owing to their desirable features i.e. lower CO2 emissions and operational cost, PEVs are likely to draw the attention by the driving public and will ultimately signify a growing portion of the total light vehicle fleet [144].

The SAE J1772 also has defined an AC Level 3 method, but it is never implemented yet. The Level 1 charger is being very slow to benefit a car owner who can plug in for only a limited time period. While DC chargers are 10–20 times more costly than a Level 2 unit and hence too expensive for a general purpose owner who is not using the dc charger as a primary source of income. For these reasons, this article will limit its scope to Level 2 EVSEs (Figures 5).

5.1. Level 2 EVSEs

Primarily EVSEs, particularly those defined for applications under SAE J1772 Level 1 and Level 2, is the

![Figure 5. Level 2 (EVSE) commercial charging station schematic block diagram [134].](image-url)
equipment, not a charger which makes a direct connection with the vehicle battery, but rather functions as an interface assembly between a fixed power distribution system and the onboard vehicle’s charger. In essence, an EVSE is a smart connector that embraces mandatory control and protection features prescribed by SAE and UL standards while connecting the vehicle to the grid. There are many other optional features that must be available to facilitate operation or designed to meet its specific use to authorized persons.

The function of the EVSE is performed via several high power relays that are in the power path. In order to safely operate these relays, sufficient drivers with adequate protective circuitry must be used:

- an overcurrent relay for overloads and short circuits protection
- a contactor switch is used to latch up the supply to the connector and also keep the connection de-energized when not plugged in
- a controller circuit that interfaces with the vehicle’s onboard charging system and serves ground fault protection; it may also have some power metering capabilities as well
- indicators and displays on the exterior to provide status and alarm information and guide the user through the operational sequence
- a cable that connects the EVSE to the charging receptacle on the vehicle
- The conductive connector that plugs into the vehicle.

There are a number of other features that may be either standard or optional, subject to the manufacturer requirements, viz. visual displays and indicators, and the means for permitting the use of the EVSE.

Visual indicators easily viewed from a remote area can allow the user to easily determine the status of the EVSE. Through such colored light indicators, the following status conditions can be conveyed easily:

- The active state of the station which means ac power available (this indicator is required by SAE J1772)
- The vehicle is connected; not charging (Mechanical connection)
- Charging is in progress (Electric connection)
- Alarm or fault.

Displays to show text messages are the important commonly used features. An appropriate display type is essential to allow for easy viewing in a variety of light conditions, for both outdoor and indoor applications. The text messages may be a greeting, instructions for the use of the EVSE, and other messages needed to convey information to the user.

5.1.1. Wireless Communication Interface

Regarding the practicality considerations, the ‘ETSI TS 101 556-1: EV Charging Spot Notification Specification’ and the ‘ETSI TS 101 556-3: Communications System for the Planning and Reservation of EV Energy Supply Using Wireless Networks’ [145]. Also, a concept of in-vehicle communications by using vehicular power line communications (VPLC) is used and according to the latest research, efforts have been focused on the development of LIN, CAN and Ethernet-based protocols over power line [146].
5.2. On-board Level 2 EV Charger Converter Topology

There are four types of conversion system used such as AC to AC converter, DC to DC converter, inverter, and rectifier. There are many DC-DC converters have been developed so far to meet the certain application requirements and can be characterized by many groups as explained in [149]. As far as the discussion in this transcript is concerned, we focus only on unidirectional (2-quadrant) and bidirectional (4-quadrant) DC-DC converter. Currently, there are five types of non-isolated converter topologies being used and studied by researchers in EV application.

Level 2 charger consists of AC-DC rectifier and DC-DC converters or directly from a low-frequency AC to high-frequency AC converter with power factor correction (PFC). Conductive chargers are classified as On-board and Off-board. In On-board chargers, rectifiers and battery current regulators reside inside of the vehicle (Figure 6) [150], whereas rectifiers and battery regulators reside outside the vehicle for off-board chargers [151].

Almost every charging scheme uses AC supply from the grid as a source and converts it to DC supply at an appropriate voltage level for battery charging. In EV applications, excluding bicycles, Level 1 and 2 chargers are designed solely for within the vehicle. And Level 3 charging schemes, conversely, utilizes the charging functions that are separately designed between the charging equipment and the vehicles on-board charger. In low power i.e. Level 1 and 2 applications, the AC to DC conversion power conditioning, the power control unit that brings a variable DC voltage to the controlled battery level, and several filtering components are all cascaded within the charger assembly and can be implemented at a comparatively lower cost value. The BMS [152] is integrated firmly with the battery. BMS monitors a number of battery operating parameters e.g. voltage, current, and temperature and controls the charging rate to provide the required constant current/constant voltage (CC/CV)

5.1.2. Connecting Cable Requirements

The cable that connects the SAE J1772 connector to the EVSE is a specific type required by both UL 2594 and NEC Article 625. Only types EV, EVJ, EVE, EVJE, EVT, or EVJT are permitted. All of these types are intended solely for use as EV cables. Type description; EV: Electric Vehicle Cord i.e. conductors, plus grounding with various optional features such as hybrid data or signal communications, fiber optic cables. Thermost with optional nylon insulation and braiding. The outer covering is also of thermost material for electric vehicle charging in wet locations and for extra hard use. EVJ same as EV cord but with the thinner jacket. Type EVE is same as EV cord, but with thermoplastic Elastomer insulation and coverings and EVJE have a thermoplastic elastomer outer cover, and types EVT same as EV cord, but with Thermoplastic insulation and EVJT same as EV cord but with a thinner jacket and a thermoplastic outer cover [147]. The J denotes the cables intended for hard usage, whereas without the J notation are intended for extra-hard usage, which belongs to the highest UL 62 grade classification for mechanical serviceability. The temperature rating of the cable is 60–150 °C and voltage ratings of 300 V or 600 V.

5.1.3. SAE J1772 Conductive Connector

At the end of the cable is the SAE J1772 connector, which is well defined and standardized. The connector may have several current ratings. The maximum rated current that can be carried by this product is limited by the maximum operating temperature of the housings (105 °C) and temperature rise of the housings (30 °C) [148]. Currently, the most widely available connector is rated 30 A. The handle of the connector is an angled pistol-grip-style shape and it may be hanged on the EVSE in a plug-in-style holder. To un latch the plug from both outlet and the inlet connector on the PEV, a button is provided near the top of the handle. To prevent unwanted disconnection by anyone other than the user, the latch mechanism must include a lock has to allow the connector to be locked in place with a padlock.

Figure 7. Installation costs of electric vehicle charging stations by type (INL Study) (source: energy.gov) [44].
charging profile and it triggers the protection circuits if the battery’s operating limits are exceeded, battery isolation if needed. The EV charger also incorporates CAN bus facility to communicate with another vehicle CAN bus but not necessarily with the charging station.

Safety methods in the moderately low power level charging stations are fairly simple and may be limited to a ground fault sensing device and a circuit interrupting device (CID) or ‘circuit breaker’. Usually, the charger itself has inbuilt comprehensive safety measures on account of the standard BMS operation including safety interconnects and disconnects to safeguard power being connected to the battery charger during a fault. There are also measures to avoid electric shocks, misuse of the power and unintentionally driving the vehicle away while the connector still plugged in.

Concerning the design of public charging stations, as the case for many Level 2 installations presented in this article, it is most likely desirable to equip further intelligence to verify the user authorization by communicating the charging station to charge the vehicle and to incorporate the metering and billing to charge the customer for the energy transferred except charging is done at home or as a free service in the shopping mall, workplace etc.

5.3. Standardization of Electric Vehicle Supply Equipment

The required characteristics and performance of the electric vehicle supply equipment (EVSE) and its components are regulated by several codes and standards. The most widely accepted among these is SAE J1772 [1], and it provides the basic description of the interface. The overall listing standard for EVSEs is UL 2594. UL 2231 is a complementary standard to UL 2594, containing requirements for personnel protection systems. The other significant UL standards that apply to EVSEs includes UL 62 (flexible cords, and cables), UL 50E (enclosures for electrical equipment, environmental considerations), UL 2202: EV charging system equipment), and UL 2251 (plugs, receptacles, and couplers for EVs). Other UL standards for specific components used within the EVSEs are also applied, but they are too numerous to list here [154].

Here some commonly used standards related to charging are listed (Table 3 shows the detail of EV charging standards). Apart of these, SAE J 2981, SAE J 3004, SAE J 3012, SAE J 3097, SAE J 2946, IEC 6185124, SAE J 28364, SAE J 28474, SAE J 29317, IEC 628402, SAE J 28475, SAE J 29312, SAE J 29313, SAE J 29315, SAE J 3009, TS 6185132, TS 6185133, SAE J 2907, SAE J 2908, ISO PAS 19295, IEC TS 6185131, SAE J 2889 and SAE J 2991 etc. are under development [155].

6. Socio-economic Aspects

Level 2 charging can be classified as (1) commercial (i.e. Workplace charging and Fleet charging) and (2) public (i.e. parking venues – structures and lots, and publicly-accessible private venues such as railway stations, restaurants courts, malls, museums, grocery stores, etc.). This demarcation can blur when making generalized distinctions [159].

Utility emphasis on charger location to motivate electric vehicle adoption. The basic norms are that charging sites should be within a short walking distance as per the driver convenience. For DC fast charging, locations would target, for instance, drivers on their way somewhere such as a coffee shop [160]. And for public AC Level 2 charging [161], the chargers need to be placed at a short walking distance to some other attraction or place to justify the EV driver needs of getting rid of range anxiety i.e. running without fuel. Some of the general venues where the person is likely to want to go (restaurants, entertainment venues, major parks etc.) and leave the vehicle for a couple of hours there. The utility also approximating several aspects of a potential charger site. Also key is the vicinity of electric power, of course.

6.1. Charging Venues for xEV Fleet Services

Long dwell times of host venue determines whether it is an appropriate revenue-generating charging site [162]. For instance, dwell or stay times at a particular rest stop or gas station remains only 3 to 5 min, and for the workplace or large retail location venues, the dwell times could last somewhere from 1 to 8 h. This further complicates the situation when very large dwell time venues are selected. For example, an EV will fully charge to 100% capacity in a day or less, if parked at the airport for a whole week, and hence, for many revenue models, the charger revenue generating capacity sacrifices for the consecutive six days. Possibly, Level 1 charging provided at marginal or no cost would be the best solution for these very long dwell time locations.

Also important to consider when discussing dwell time variability is the effect of different power levels. The onboard charger or the Level 2 EVSE limits the AC power to whichever is lower. A vehicle with a 3.3 kW onboard charger will obviously take longer to charge than a vehicle with a more powerful 6.6 kW charger. For calculation purposes, 1kWh provides a range of approximately 3.3 miles (~300Wh/mi). Actual range varies per vehicle and driver. Thus, a battery pack with a usable 20kWh capacity should provide a range of approximately 70 miles. Therefore, 25 miles of range would require about 7.6 kWh. This is an hour and ten minutes charge at 6.6kW or 2.3 h at 3.3 kW.
Table 3. Various standard related to EVs [156,157].

| Standard | Type | Scope and specification | Status |
|----------|------|--------------------------|--------|
| IEC 61851: conductive charging system | IEC 61851-1: 2017 | Defines plugs and cables system | ACD |
|  | IEC 61851-23: 2014 | Explains electrical safety, harmonics, grid connection, and | |
|  | IEC 61851-24: 2014 | DCFC station (DCFC) communication architecture | |
| IEC 62196: socket outlets, plugs, vehicle inlets and connectors | IEC 62196-1: 2014 | Defines EV connector general requirements | WIP |
|  | IEC 62196-2: 2016 | Explains classifications of coupler for different charging modes | |
|  | IEC 62196-3: 2014 | Describes DCFCs inlets and connectors | |
| IEC 60309: socket outlets, plugs, and couplers | IEC 60309-1: 2012 | Describes charging station general requirements | Valid |
|  | IEC 60309-2: 2012 | Explains plugs and sockets sizes with a different number of pins configuration with respect to current supply and no. of phases, defines color codes of connector agreeing to voltage range and frequency. | |
| IEC 60364 | IEC 60364-1: 2009 | Describes buildings electrical installation | Valid |
| SAE J1772: conductive charging systems | SAE J1772: 2016 | Defines AC slow charging connectors and new DCFCs Combo connectors | |
| SAE J2847: communication | SAE J2847-1: 2013 | Defines medium of communication and connecting criteria for EV to the utility under AC level 1 & 2 charging system | Revised |
|  | SAE J2847-2: 2015 | Defines messages used in DC charging | |
|  | SAE J2293 | Defines total EV energy transfer system defines requirements for EVSE for different system architectures | Active |
|  | SAE J2344 | Defines EV safety guidelines | Revised |
|  | SAE J2954: inductive charging | Being developed | |
| UL 2089 | UL 2089: 2015 | The standard for safety vehicle battery adapters | Active |
|  | UL 2594: 2016 | Standard for safety EV supply equipment | Active |
| BS EN 61851 | BS EN 61851-1: 2011 | Part 1: general requirements for conductive charging system of EVs | |
|  | BS EN 61851-21: 2002 | Requirements of EV to connect an AC/DC supply in conducting modes | |
| COC GB/T 18487 [158] | COC GB/T 18487-1: 2015 | EV charging station based on AC supply | |
|  | COC GB/T 18487-2: 2001 | EVs requirements for conductive connection to an AC/DC supply | |
|  | COC GB/T 18487-3: 2001 | EV conductive charging system AC/DC EV charging station | |
| JIS D 0007 | JIS D 0007: 2012 | The basic function of EV quick charger | Active |
| JIS D 1304 | JIS D 1304: 2004 | Efficiency test method of an EV charging system | Active |
| JIS D 61851: conductive charging system | JIS D 61851-23: 2014 | DC EV charging station-based EV conductive charging system | Active |
|  | JIS D 61851-24: 2014 | To control the DC charging, digital communication between EV and a DC EV charging station | |
| ISO 871 | ISO 871-5: 2001 | Electric road vehicles road operating characteristics | Published |
|  | ISO 871-4: 2002 | Electric road vehicles reference energy consumption and range test procedures for passenger cars and light commercial vehicles | |
| ISO PAS 16898 | ISO PAS 16898: 2012 | Electrically Propelled Road Vehicles Dimensions and Designation of Secondary Lithium-ion Cells | Published |
| IEC 61980 wireless charging system [28] | IEC 61980-1 Ed.1.0-NEW ADDITION: 2015 | Electric Vehicle Wireless Power Transfer (WPT) Systems | Active |
| SAE J1773 wireless charging system | SAE J1773: 201406: 2014 | SAE Electric Vehicle Inductively Coupled Charging (STABILIZED Jun 2014) | Stabilized |
| IEEE standard C95.1 | IEEE Standard C95.1: 2006 | Restrict the Frequency Electric Field and Magnetic Field Exposure to Outside Human | |

Also, a cost comparison on the basis of charging venues is given in (Figure 7) [163] which illustrates the installation costs of different level 2 electric vehicle charging stations with respect to their location venues.

6.2. Fully Elec8rified Transit Network System for Battery Electric Buses (BEBs)

The method developed to analyze different charging solutions for electric buses includes a method to find good candidate places to put chargers along the bus line. By analyzing the energy consumption of the bus line different alternative charger systems are designed. For each charger, the charger power is selected and the bus batteries and timetables are adapted for each different charger system, in order to make a fair comparison of them as possible. This step also includes sizing the systems to be robust for several expected types of disturbances in the system. The economics of the different systems is analyzed, by calculating the cost of investments and operation of the bus lines using the different analyzed charger systems. Drawing conclusions on strengths and weaknesses of the compared charging systems [164,165].

Notice that there can be different reasons to analyze the charging system for electric buses, and depending on the purpose the method will partly be changed. This method is designed to analyze how suitable different charging systems will be in the long run if it is assumed that both buses and chargers, as well as the planning of timetables, are adapted to the system being proposed. The result of such an analysis is an indication of which direction the development is likely to go. However, when planning for a specific
bus line here and now the analysis should rather be made for only the buses and chargers offered on today’s market, and then the purpose is to ‘build the best system with the available components’ rather than ‘Finding the best system and show how the components should be adapted for it’. Also includes looking at non-economic factors for where to place the chargers, like building constraints and robustness of the system, (see Figure 8) [166].

Three battery charging concepts have been developed: flash, opportunity, and overnight [167]. The main difference between the three charging concepts is the trade-off between the battery size (i.e. mileage range), chargers power, and charging time. Flash and opportunity charging concepts are fast and on-route charging schemes that correlate to the BEBs schedules. These concepts opt to reduce the battery size while increasing the charger power and frequency of charging [168,169]. Overnight charging concept, on the other hand, is characterized by standard long time chargers with low charger power, and bigger battery capacity [170].

6.3. Economic Analysis Methodology

This analysis uses primarily a top-level approach, more for sensitivity analysis than detailed purposes. The variability for capital and installation costs is such that the general case can provide only top-level analysis. The individual case will always yield more location-specific detail with which to drill down to more accurate costs and revenue.

For each of the non-residential charging classes, the economic analysis comprises estimates of costs (capital and installation costs, operating and maintenance costs, transaction costs and Taxes, and other costs etc.) and revenue (user revenue, capacity factor issues, subsidies, and secondary potential revenue streams e.g. advertising, demand response/grid services, market pull).

Initial capital and installation costs are annualized assuming a 10-year life and 4% cost of money. This factor is 0.123. Thus, for a $1,000 initial capital equipment cost, the equivalent annualized cost would be $123. This analysis does not assume a salvage value at the end of 10 years. After this period, the equipment and installation may very well still have value. In which case, the next 10-year analysis would show a benefit [171].

6.3.1. Costs

Capital investment [172] related to EVSE are available in many styles to accommodate the different types of installations. For example, residential installations use wall-mount EVSE almost exclusively. Non-residential installations typically use pole-mounted units (also called bollard-style), though wall-mounted units are still used. Bollard-style units can have two or more EVSE (also called ports), which significantly lowers the effective installation cost per port. This analysis assumes a per port cost using a dual-port bollard-style EVSE unit because of this cost efficiency (i.e. total dual-port capital cost divided by two). The per port capital cost for a dual-port bollard-style EVSE is in the range of $1,500 to 5,000 USD based on published prices listed on the Government Services Administration website [173]. The price range reflects whether the EVSE has only basic EV charging functionality or full networking.
Incentives and subsidies to EV consumers [174] such as government tax credits and volume discounts may contribute to lowering the capital cost, however, duration of these incentives are limited and discounts are never guaranteed so they should not be considered a permanent cost-cutting solution. Assuming a 10-year life and 4% cost of money, the annualized per port capital cost ranges from $185 to $615.

Installation investment costs [175] range from $3,000 to $10,000 for single port bollard-style units. The range is approximately 20% higher for dual-port bollard units, resulting in a per-port cost ranging from $1,800 to $6,000. Installation costs depend on the number of ports installed, difficulty of electrical panel upgrade, length and type of conduit run, permitting authority, and a host of lesser factors. High variability also results from differences in electrical contractors, geographical location, and local permitting and regulations. For example, a joint report by the Business Council on Climate Change and Bay Area Council [3] states, 'Panel and supply upgrading, trenching, and permitting can range from $1000 to possibly $25,000 + depending on existing infrastructure deficiencies and trench needs.' Assuming a 10-year life and 4% cost of money, the annualized per port installation cost ranges from $221 to $738.

Investment under operation and maintenance head costs are dependents largely on charger utilization. To reach 100% utilization, an EV with a 6.6 kW onboard charger would have to be plugged in and charging 24 h/day. Utilization, here, is defined as actual time charging (as opposed to time plugged in.) With the EV market (number of vehicles on the road) still in its infancy, 100% charger utilization is unlikely.

Realistically, a 20 to 25% capacity factor might be more appropriate when considering the Chevy Volt, Nissan LEAF™ and Mitsubishi iMiEV all currently have 3.3 kW onboard chargers. Over a 24-h period, the total possible energy dispensed is 158kWh for a 6.6 kW EVSE. At $0.10/kWh (the average electrical rate in the U.S.) the daily electricity cost would be $4.00 for 40 kWh (~25% capacity factor.) This rate varies regionally and by the commercial customer.

Another source of variability in electricity costs is Time-of-Use (TOU) rates [176,177], applied by electric utilities to account for the value of the electricity they generate at different times of the day. For example, during peak usage on a summer afternoon, the TOU rate could be many times the TOU rate at 3 am. Thus, in the above example, the operating cost could be much higher than the national average of $0.10/kWh, and even upwards of $0.40/kWh.

Electric utilities often impose a fee called a ‘demand charge’ based on kW usage. For a large industrial facility that uses multi-MW for processes, the demand charge for an incremental 50kW (roughly eight 6.6 kW EVSE charging simultaneously) could be managed by prioritizing loads. However, for a facility with little electrical usage, a parking structure, for example, the demand charge for this same 50 kW could be $500/month (depending on the season and the utility), and it would have minimal load management capability. If the EVSE is network-enabled, the operating cost of wireless communications plus data/back office fees ranges from $10 to $25 per month or $120 to $300 annually.

Maintenance costs for workplace EVSE would be relatively low given the limited access to these chargers compared with the full access to public chargers. For example, a majority of these charger installations would be within gated locations, making vandalism a lesser problem than full access public locations. A semi-annual preventive maintenance program would be on the order of $100/yr per port for a facility with multiple ports, while a public EVSE could require double that cost.

Transaction cost from the charger’s point-of-sale mechanism (RFID, contactless credit card, magnetic swipe, etc.) are typically proportional to the fee for the total charge event to account for credit card transaction costs and overhead. Depending on the network operator this can range from 5% to 7.5% of the transaction. A workplace system of EVSE might use RFID for authentication, but not have any transaction costs, while a public charger that uses a credit card would likely be in this 5–7.5% range.

Taxes and other cost [178,179] should also be considered because all venues which gather revenue from EV drivers could be subject to income tax. The corporate tax is currently 35% for large corporations [180]. For workplace charging, an employer or real estate investment trust may not treat the EVSE system as a profit center and may have no net revenue. They would likely still have to account for this revenue as taxable, but it may ultimately net out. For a parking venue, the EVSE system would likely be expected to carry its weight in profitability, which could mean taxable revenue would play a large role in the price set for the EV driver. The property owner may seek to recover the cost of the property and property taxes via incremental revenue from the EVSE system. This all depends on the property owner’s situation and application for the EVSE.

6.3.2. Revenue
An EVSE site owner/operator will likely expect the primary source of revenue to come from the EV driver. However, unlike the workplace EVSE owner who may only have an expectation to recover electricity and operating costs, the public venue EVSE owner may require
recovery of all costs plus a profit. The profit aspect will be especially important for parking venue and third-party owner/operators.

Many states and municipalities provide subsidies [181] and tax credits for purchasing and installing EV infrastructure, which serve to offset high capital and installation costs. However, as the duration of these incentive programs is limited, they should not be considered a permanent solution. For example, the U.S. Federal government allowed the 30% Investment Tax Credit to lapse at the end of 2011, without any immediate plans for supplying additional financial support. And of course depreciation of the corporation’s capital equipment, often using an accelerated depreciation schedule. They use depreciation to offset income. This may be an important offset for parking venue and third-party owner/operators.

Secondary revenue streams subject to utility demand response and other grid ancillary services promise a potential revenue stream. While many use cases have been identified, actual contracts are likely years away relative to EVSE-related services. The Federal Energy Regulatory Commission (FERC) [182] provides rules and guidelines for energy market services. A US Department of Energy Report [183] indicates a minimum of 100 kW may be required to qualify for entry in some markets. This would be equivalent to a group of 15 or more EVSE. Viridity and Axion Power announced in November 2011 participation in Pennsylvania/Jersey/Maryland Power Pool (PJM) regulation market, stating a projected value ranging from $180,000 to 240,000 per MW of delivered generation. For a 100 kW source, this would be $18,000 to 24,000/yr. Translation of this value to EVSE would be misleading because of the typically low EVSE capacity factor. Advertising is also a potential revenue stream still in the nascent stages for EVSE installations [159].

7. Conclusion

In this review paper, it is argued that the contextual features matter in the location-allocation problems of public EV charging stations due to the variation in supply and demand of these stations across different nations and states. Consequently, the first and foremost objective of this manuscript is to include a detailed review of the level 2 charging system for EVs. Business and commercial segments of charging infrastructure, methodology, and EV market operation are also discussed. However, numerous challenges still need to be addressed. The significant challenges embrace that the economic exploitation is limited by the high cost and low performance of the battery storage systems. Driver range anxiety and charging infrastructure access also has a bound on large scale acceptance. The driver range anxiety problem considerably affects the particular utility and may differ from average high and low range anxiety drivers dilemma. Owing to the large-scale market penetration of EVs, challenges related to technical limitations, infrastructure, market, and policies must also be addressed. Technical challenges and limitations include advancements in battery technology, long charging time and unsatisfactory driving range for EVs. Market and infrastructural barriers are associated with lack of charging infrastructure, lack of dedicated lanes for EVs, and the absence of business models to meet the specific need of these vehicles. Further, battery swapping station and commercial EV fleet charging station should be located at public areas to provide ease of charging the EV. Similar to technical issues, solutions also exist for infrastructural and market barriers and must be addressed in future. For issues related to charging infrastructure installation, a possible solution is to set up charging points in parking garages, hotels and in the basements of buildings. This problem has been addressed by countries like China. A complete business model is viable which may increase consumer confidence in electric vehicles by reducing the upfront investment of commercial consumers. Public perceptions are also needed to address the safety, driving range and cost of EVs compared to ICEVs and make policies in light of them. Accelerating the deployment of the charging system and their infrastructure will fuel economic development, enhance consumer welfare, and new employment prospects are created, and contribute to a climate-safe future.

Nomenclature

| Acronym | Description |
|---------|-------------|
| ACD     | Approved for Committee Decision |
| BEV     | Battery Electric Vehicle |
| BS      | British Standard |
| BSS     | Battery Swapping Station |
| CAMC    | Central Autonomous Management Controller |
| CAN     | Controller Area Network |
| CAU     | Central Aggregation Unit |
| CVC     | Cluster of Vehicles Controller |
| DISCOM  | Distribution Company |
| DME     | Diesel motor exhaust |
| DMS     | Distribution Management System |
| DSO     | Distribution System Operator |
| EV      | Electric Vehicle |
| EVSE    | Electric Vehicle Supply Equipment |
| GB      | GuoBiao Standard |
| GPRS    | General Packet Radio Service |
| GSM     | Global System for Mobile Communication |
| GENCO   | Generation Company |
| HV      | High Voltage |
| IARC    | International Agency for Research on Cancer |
Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Saadullah Khan http://orcid.org/0000-0002-6009-8949
Aqueel Ahmad http://orcid.org/0000-0002-7701-7236
Mohammad Saad Alam http://orcid.org/0000-0003-4008-2680

References

[1] Wirasingha SG, Schofield N, Emadi A. Plug-in hybrid electric vehicle developments in the US: trends, barriers, and economic feasibility. In: 2008 IEEE Vehicle Power and Propulsion Conference; 2008. p. 1–8.
[2] Ahourai F, Huang I, Al Faruque MA. Modeling and simulation of the EV charging in a residential distribution power grid. arXiv1311.6005 [cs]. 2013:1–5.
[3] Cheng L, Chang Y, Wu Q, et al. Evaluating charging service reliability for plug-in EVs from the distribution network aspect. IEEE Trans Sustain Energy. 2014 Oct;5(4):1287–1296.
[4] Chan CC. The rise & fall of electric vehicles in 1828–1930: lessons learned. Proc IEEE. 2013;101(1):206–212.
[5] Moelck WE. Electric propulsion. Science (80-.). 1963 Oct;142(3589):172–178.
[6] Ilar A, Plato N, Lewné M, et al. Occupational exposure to diesel motor exhaust and risk of lung cancer by histological subtype: a population-based case-control study in Swedish men. Eur J Epidemiol. 2017 Aug;32(8):711–719.
[7] Aderibigbe MA, Wara ST, Airoboman AE. Diesel engine generators consumption/emission controls by retrofitting for sustainable environment. In: 2017 IEEE PES PowerAfrica; 2017. p. 143–152.
[8] Mohnen M, Wendt A. A critical review of the relationship between occupational exposure to diesel emissions and lung cancer risk. Crit Rev Toxicol. 2017 Mar;47(3):185–224.
[9] Kopnina H. Vehicular air pollution and asthma: implications for education for health and environmental sustainability. Local Environ. 2017 Jan;22(1):38–48.
[10] Journal I. Performance analysis of various 4-wheelers with IC engines for hybridization. Int J Adv Res Ideas Innov Technol. 2017;3:1322–1327.
[11] Andrienko G, Andrienko N, Chen W, et al. Visual analytics of mobility and transportation: state of the art and further research directions. IEEE Trans. Intell. Transp. Syst. Aug;18(8):2232–2249.
[12] Joshi M, Vaidya A, Deshmukh M. Sustainable transport solutions for the concept of smart city. Sustainable Energy Transp. 2018;21–42.
[13] Cai L, Pan J, Zhao L, et al. Networked electric vehicles for green intelligent transportation. IEEE Commun Stand Mag. 2017;77–83.
[14] Chan CC, Bouscayrol A, Chen K. Electric, hybrid, and fuel-cell vehicles: architectures and modeling. IEEE Trans. Veh. Technol. Feb. 2010;59(2):589–598.
[15] Hu S, Liang Z, Zhang W, et al. Research on the integration of hybrid energy storage system and dual three-phase PMSM Drive in EV. IEEE Trans Ind Electron. 2017;1(1):1–1.
[16] Un-Noor F, Padmanaban S, Mihet-Popa L, et al. A comprehensive study of key electric vehicle (EV) components, technologies, challenges, impacts, and future direction of development. Energies. 2017 Aug;10(8):1217.
[17] Xie D, Chu H, Gu C, et al. A novel dispatching control strategy for EVs intelligent integrated stations. IEEE Trans Smart Grid. 2015;8(2):1–1.
[18] Khan W, Ahmad F, Ahmad A, et al. Electric vehicle charging infrastructure in India: viability analysis. Singapore: Springer; 2018. p. 193–206.
[19] Ahmad F, Alam MS. Feasibility study, design and implementation of smart polygeneration microgrid at AMU. Sustain Cities Soc. 2017 Mar;35:309–322.
[20] Khan S, Ahmad A, Ahmad F, et al. A comprehensive review on solar powered electric vehicle charging system. Smart Sci. 2018 Jan;6(1):54–79.
[21] Ammr SM, Alam MS, Asghar MSJ, et al. Low cost residential microgrid system based home to grid (H2G) back up power management. Sustain Cities Soc. 2017 Oct;36:204–214.
[22] Ahmad F, Alam MS, Asaad M. Developments in xEVs charging infrastructure and energy management system
for smart microgrids including xEVs. Sustain Cities Soc. 2017 Nov;33(September):552–564.

[23] Alam MS. Conceptual framework of a solar PV based high voltage battery charging strategy for PHEVs and Evs. Am J Electr Power Energy Syst. 2013;2(6):137.

[24] Ahmad F, Alam MS. Optimal sizing and analysis of solar PV, wind, and energy storage hybrid system for campus microgrid. Smart Sci. 2018 Apr;6(2):150–157.

[25] Ahmad F, Alam MS. Economic and ecological aspects for microgrids deployment in India. Sustain Cities Soc. 2018 Feb;37:407–419.

[26] Ahmad A, Alam MS, Chabaan R. A comprehensive review of wireless charging technologies for electric vehicles. IEEE Trans Transp Electrif. 2018 Mar;4(1):38–63.

[27] Vatsala, Ahmad A, Alam MS, et al. Efficiency enhancement of wireless charging for Electric vehicles through reduction of coil misalignment. In: 2017 IEEE Transportation Electrification Conference and Expo (ITEC); 2017. p. 21–26.

[28] Ahmad A, Saad Alam M, Varshney Y, et al. A state of the art review on wireless power transfer a step towards sustainable mobility. In: Indicon 2017; 2017 Dec. p. 1–6.

[29] Luo C, Huang Y-F, Gupta V. Placement of EV charging stations-balancing benefits among multiple entities. IEEE Trans Smart Grid. 2015;8(2):1–10.

[30] Knezovic K, Martinenas S, Andersen PB, et al. Enhancing the role of electric vehicles in the power grid: field validation of multiple ancillary services. IEEE Trans Transp Electrif. 2017;3(1):201–209.

[31] Bohn T, Cortes C, Glenn H. Local automatic load control for electric vehicle smart charging systems extensible via OCPP using compact submeters. In: 2017 IEEE Transportation Electrification Conference and Expo (ITEC); 2017. p. 724–731.

[32] Shi C, Tang Y, Khaligh A. A single-phase integrated onboard battery charger using propulsion system for plug-in electric vehicles. IEEE Trans Veh Technol. 2017 Dec;66(12):10899–10910.

[33] Li B, Lee FC, Li Q, et al. Bi-directional on-board charger architecture and control for achieving ultra-high efficiency with wide battery voltage range. In 2017 IEEE Applied Power Electronics Conference and Exposition (APEC); 2017. p. 3688–3694.

[34] Liu B, Qiu M, Jing L, et al. Design of ac/dc converter for bidirectional on-board battery charger with minimizing the amount of SiC MOSFET. In: 2017 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific), Vol. 2; 2017. p. 1–6.

[35] Shi C, Tang Y, Khaligh A. A three-phase integrated onboard charger for plug-in electric vehicles. IEEE Trans Power Electron. 2017;8993(c):1–1.

[36] Yong JY, Fazeli SM, Ramachandaramurthy VK, et al. Design and development of a three-phase off-board electric vehicle charger prototype for power grid voltage regulation. Energy. 2017 Aug;133:128–141.

[37] Prasanna UR, Singh AK, Rajashekar K. Novel bidirectional single-phase single-isolated AC-DC converter with PFC for charging of electric vehicles. IEEE Trans Transp Electrif. 2017 Sep;3(3):536–544.

[38] Awasthi A, Venkitusamy K, Padmanaban S, et al. Optimal planning of electric vehicle charging station at the distribution system using hybrid optimization algorithm. Energy. 2017 Aug;133:70–78.

[39] What is the difference between level 1, level 2, and level 3 electric vehicle (EV) chargers? – Quora. [Online]; [cited 2017 Dec 19]. Available from: https://www.quora.com/What-is-the-difference-between-level-1-level-2-and-level-3-electric-vehicle-EV-chargers

[40] Zhang L, Li Y. Optimal management for parking-lot electric vehicle charging by two-stage approximate dynamic programming. IEEE Trans Smart Grid. 2017 Jul;8(4):1722–1730.

[41] Khan W, Ahmad A, Ahmad F. A comprehensive review of fast charging infrastructure for electric vehicles. Smart Sci. 2018 Mar;1:1–5.

[42] Electric vehicle charging infrastructure / EV battery charging. [Online]; [cited 2017 Dec 29]. Available from: http://www.mpoweruk.com/infrastructure.htm

[43] Rinaldi S, Pasetti M, Trioni M, et al. On the integration of E-Vehicle data for advanced management of private electrical charging systems. In: 2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC); 2017. p. 1–6.

[44] Rezkalla M, Zecchino A, Martinenas S, et al. Comparison between synthetic inertia and fast frequency containment control based on single phase EVs in a microgrid. Appl Energy. 2018 Jan;210:764–775.

[45] Saber AY, Venayagamoorthy GK. One million plug-in electric vehicles on the road by 2050. Proc 12th Int IEEE Conf Intell Transp Syst. 2009:141–147.

[46] Hafez O, Bhattacharyya K. Optimal design of electric vehicle charging stations considering various energy resources. Renew Energy. 2017 Jul;107:576–589.

[47] Ye B, Jiang J, Miao L, et al. Feasibility study of a solar-powered electric vehicle charging station model. Energies. 2015 Nov;8(12):13265–13283.

[48] Electric vehicle landscape and future forward: bringing clarity in commotion. [Online]; [cited 2017 Nov 01]. Available from: https://economictimes.indiatimes.com/industry/auto/news/industry/ev-landscape-and-future-forward-bringing-clarity-in-commotion/articleshow/61181894.cms

[49] Home national automotive board. [Online]; [cited 2018 Mar 29]. Available from: http://www.fame-india.gov.in/

[50] Dhar S, Pathak M, Shukla PR. Electric vehicles and India’s low carbon passenger transport: a long-term co-benefits assessment. J Clean Prod. 2017 Mar;146:139–148.

[51] Sheppard CJR, Gopal AR, Harris A, et al. Cost-effective electric vehicle charging infrastructure siting for Delhi. Environ Res Lett. 2016 Jun;11(6):064010.

[52] Hall D, Lutsey N. Emerging best practices for electric vehicle charging infrastructure. | International Council on Clean Transportation.” [Online]. Available: https://www.theicct.org/publications/emerging-best-practices-electric-vehicle-charging-infrastructure. [Accessed: 18-Jun-2018].

[53] IEA International Energy Agency, Global EV Outlook 2017. IEA, 2017.

[54] Al-Alawi BM, Bradley TH. Review of hybrid, plug-in hybrid, and electric vehicle market modeling Studies. Renew Sustain Energy Rev. 2013 May;21:190–203.
[91] Pauwels K, Weiss A. Moving from free to fee: how online firms market to change their business model successfully. J Mark. 2008 May;72(3):14–31.

[92] Reva charging station | Gopalan Mall Bangalore | Auto News – DriveSpark. [Online]; [cited 2017 Dec 30]. Available from: https://www.drivespark.com/four-wheelers/2013/mahindra-reva-charging-station-gopalan-mall-bangalore-004329.html

[93] Bakker S, Jacob Trip J. Policy options to support the adoption of electric vehicles in the urban environment. Transp Res Part D Transp Environ. 2013 Dec;25:18–23.

[94] San Román TG, Mombè I, Abbad MR, et al. Regulatory framework and business models for charging plug-in electric vehicles: infrastructure, agents, and commercial relationships. Energy Policy. 2011 Oct; (10):6360–6375.

[95] Tata power launches electric vehicle charging infrastructure in Mumbai. [Online]; [cited 2018 Jan 12]. Available from: https://www.tatapower.com/media/PressReleaseDetails.aspx?id=MTM5OQ==

[96] Faridimehr S, Venkatachalam S, Chinnam RB. A stochastic programming approach for electric vehicle charging network design. arXiv. 2017:1–11.

[97] Community charging stations – PlugInIndia. [Online]; [cited 2018 Jan 13]. Available from: http://www.pluginindia.com/charging.html

[98] Dijk M, Orsato RJ, Kemp R. The emergence of an electric mobility trajectory. Energy Policy. 2013 Jan;52:135–145.

[99] Zheng Y, Dong ZY, Xu Y, et al. Electric vehicle battery charging/swap stations in distribution systems: comparison study and optimal planning. IEEE Trans Power Syst. 2014 Jan;29(1):221–229.

[100] Sarker MR, Pandzic H, Ortega-Vázquez MA. Optimal operation and services scheduling for an electric vehicle battery swapping station. IEEE Trans Power Syst. 2015 Mar;30(2):901–910.

[101] Lujano-Rojas JM, Dufo-Lopez R, Bernal-Agustín JL, et al. Optimizing daily operation of battery energy storage systems under real-time pricing schemes. IEEE Trans Smart Grid. 2017 Jan;8(1):316–330.

[102] Wei W, Wang J, Wu L. Distribution optimal power flow with real-time price elasticity. IEEE Trans Power Syst. 2017;8950(c):1–1.

[103] Kim S-J, Giannakis GB. An online convex optimization approach to real-time energy pricing for demand response. IEEE Trans Smart Grid. 2017 Nov;8(6):2784–2793.

[104] Milanes-Montero M-I, Barrero-Gonzalez F, Pando-Acedo J, et al. Active, reactive and harmonic control for distributed energy micro-storage systems in smart communities homes. Energies. 2017 Apr;10(4):448.

[105] Shafie-khah M, Siano P. A stochastic home energy management system considering satisfaction cost and response fatigue. IEEE Trans Ind Informatics. 2017;3203(c):1–1.

[106] Wu H, Pang GK-H, Choy KL, et al. A charging-scheme decision model for electric vehicle battery swapping station using varied population evolutionary algorithms. Appl Soft Comput. 2017 Dec;61:905–920.

[107] Genikomskakis KN, Angulo Gutierrez I, Thomas D, et al. Simulation and design of fast charging infrastructure for a university-based e-carsharing system. IEEE Trans Intell Transp Syst. 2017;3:1–10.

[108] Monteiro V, Exposto B, Ferreira JC, et al. Improved vehicle-to-home (V2H) operation mode: experimental analysis of the electric vehicle as off-line UPS. IEEE Trans. Smart Grid. 2017 Nov;8(6):2702–2711.

[109] Sortomme E, El-Sharkawi MA. Optimal charging strategies for unidirectional vehicle-to-grid. IEEE Trans Smart Grid. 2011 Mar;2(1):131–138.

[110] Rivera J, Goebel C, Jacobsen H-A. Distributed convex optimization for electric vehicle aggregators. IEEE Trans Smart Grid. 2017 Jul;8(4):1852–1863.

[111] Shao C, Wang X, Shahidehpour M, et al. Partial decomposition for distributed electric vehicle charging control considering electric power grid congestion. IEEE Trans Smart Grid. 2017 Jan;8(1):75–83.

[112] Palmintier B, et al. IGMS: an integrated ISO-to-appliance scale grid modeling system. IEEE Trans Smart Grid. 2017 May;8(3):1525–1534.

[113] Ming H, Xie L, Campi M, et al. Scenario-based economic dispatch with uncertain demand response. IEEE Trans Smart Grid. 2017;3053(1):1–1.

[114] Zhang T, Chen W, Han Z, et al. Charging scheduling of electric vehicles with local renewable energy under uncertain electric vehicle arrival and grid power price. IEEE Trans Veh Technol. Jul. 2014;63(6):2600–2612.

[115] Shemami MS, Alam MS, and Asghar MSJ, Reliable Residential Backup Power Control System Through Home to Plug-In Electric Vehicle (H2V), Technol. Econ. Smart Grids Sustain. Energy. 2018, Dec;3(1), p. 8.

[116] Shemami MS, Alam MS, Asghar MSJ. Load shedding mitigation through plug-in electric vehicle-to-home (V2H) system. In: 2017 IEEE Transportation Electrification Conference and Expo (ITEC); 2017. p. 799–804.

[117] Maigha, Crow ML. Cost-constrained dynamic optimal electric vehicle charging. IEEE Trans Sustain Energy. 2017 Apr; 8(2):716–724.

[118] Faisal F. An analysis of electric vehicle trends in developed nations: a sustainable solution for India. J Undergrad Res. 2016:1–8.

[119] Teece DJ. Business models, business strategy and innovation. Long Range Plann. 2010 Apr;43(2–3):172–194.

[120] Farhangi H. The path of the smart grid. IEEE Power Energy Mag. 2010 Jan;8(1):18–28.

[121] Cao Y, et al. An optimized EV charging model considering TOU price and SOC curve. IEEE Trans Smart Grid. 2012 Mar;3(1):388–393.

[122] Giordano V, Fulli G. A business case for smart grid technologies: a systemic perspective. Energy Policy. 2011 Nov;40(1):252–259.

[123] Collins MM, Mader GH. The timing of EV recharging and its effect on utilities. IEEE Trans Veh Technol. 1983 Feb;32(1):90–97.

[124] Lopes JAP, Soares FJ, Almeida PMR. Integration of electric vehicles in the electric power system. Proc IEEE. 2011 Jan;99(1):168–183.

[125] Vagopoulos SI, Balaskas GA, Bakirtzis AG. An investigation of plug-in electric vehicle charging impact on power systems scheduling and energy costs. IEEE Trans Power Syst. 2017;32(3):1902–1912.
utilitydive.com/news/location-matters-utilities-focus-on-charger-placement-to-drive-electric-ve/425276/

[161] Conway T. On the effects of a routing and reservation system on the electric vehicle public charging network. IEEE Trans Intell Transp Syst. 2017 Sep;18(9):2311–2318.

[162] He SY, Kuo YH, Wu D. Incorporating institutional and spatial factors in the selection of the optimal locations of public electric vehicle charging facilities: a case study of Beijing, China. Transp Res Part C Emerg Technol. 2016;67:131–148.

[163] Schücking M, Jochem P, Fichtner W, et al. Charging strategies for economic operations of electric vehicles in commercial applications. Transp Res Part D Transp Environ. 2017 Mar;51:173–189.

[164] Mohamed M, Farag H, El-Taweel N, et al. Simulation of electric buses on a full transit network: operational feasibility and grid impact analysis. Electr Power Syst Res. 2017 Jan;142:163–175.

[165] Mahmoud M, Garnett R, Ferguson M, et al. Electric buses: a review of alternative powertrains. Renew Sustain Energy Rev. 2016 Sep;62:673–684.

[166] Olsson O, Grauers A, Pettersson S. Method to analyze cost effectiveness of different electric bus systems. EVS29 Int Batter Hybrid Fuel Cell Electr Veh Symp. 2016:1–12.

[167] El-Taweel NA, Mohamed M, Farag HE. Optimal design of charging stations for electrified transit networks. in 2017 IEEE Transportation Electrification Conference and Expo (ITEC); 2017. p. 786–791.

[168] Mahmoud M, Garnett R, Ferguson M, et al. Electric buses: a review of alternative powertrains. Renew Sustain Energy Rev. 2016;62:673–684.

[169] Rogge M, Wollny S, Sauer D. Fast charging battery buses for the electrification of urban public transport – a feasibility study focusing on charging infrastructure and energy storage requirements. Energies. 2015 May;8(5):4587–4606.

[170] El-taweel NA, Mohamed M, Farag HE. Optimal design of charging stations for electrified transit networks. Transp Electrif Conf Expo (ITEC), 2017 IEEE. 2017:786–791.

[171] Wang G, Xu Z, Wen F, et al. Traffic-constrained multiobjective planning of electric-vehicle charging stations. IEEE Trans Power Deliv. 2013 Oct;28(4):2363–2372.

[172] Schroeder A, Traber T. The economics of fast charging infrastructure for electric vehicles. Energy Policy. 2012 Apr;43:136–144.

[173] Welcome to GSA Journals. No. December, pp. 2005–2005, 2005.

[174] Sierzchula W, Bakker S, Maat K, et al. The influence of financial incentives and other socio-economic factors on electric vehicle adoption. Energy Policy. 2014 May;68:183–194.

[175] Tulpule PJ, Marano V, Yurkovich S, et al. Economic and environmental impacts of a PV powered workplace parking garage charging station. Appl Energy. 2013 Aug;108:323–332.

[176] Boogen N, Datta S, Filippini M. Demand-side management by electric utilities in Switzerland: analyzing its impact on residential electricity demand. Energy Econ. 2017 May;64:402–414.

[177] Wang F et al. Multi-objective optimization model of source-load-storage synergetic dispatch for building energy system based on TOU price demand response. IEEE Trans Ind Appl. 2017;9994(c):1–1.

[178] Yang T, Long R, Li W. Suggestion on tax policy for promoting the PPP projects of charging infrastructure in China. J Clean Prod. 2018 Feb;174:133–138.

[179] Hines J. Tax policy and the activities of multinational corporations. Cambridge MA; May 1996.

[180] Li S, Tong L, Xing J, and Zhou Y. The market for electric vehicles: indirect network effects and policy design. Soc Sci Res Netw. 2015 Jun;1(1):89–133.

[181] Garcia JL. ENERGY EFFICIENCY AND RENEWABLE ENERGY TAX INCENTIVES FEDERAL AND STATE ENERGY TAX PROGRAMS Renewable Energy and Green Building Tax Incentives Federal and State Energy Tax Programs Introduction to KLEIN HORNIG LLP. p. 1–72. 2011.

[182] Federal Energy Regulatory Commission. Federal energy regulatory commission. [Online]; [cited 2018 Jan 03]. Available from: https://www.ferc.gov/

[183] Goldman C, Hopper N, Bharvirkar R et al. Estimating demand response market potential among large commercial and industrial customers: a scoping study, Berkeley, CA 2007 Jan;1–69.