ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xxx (xxxx) xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: http://www.elsevier.com/locate/rser

Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review

H.S. Das [a,*], M.M. Rahman [b], S. Li [a], C.W. Tan [c]

[a] Department of Electrical and Computer Engineering, The University of Alabama, Tuscaloosa, 35401, USA
[b] Department of Electrical Engineering, King Saud University, Riyadh, 12372, Saudi Arabia
[c] Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Johor, 81310, Malaysia

ARTICLE INFO

Keywords:
Electric vehicle
Standards
Charging infrastructure
Grid integration
Energy internet

ABSTRACT

Transportation electrification is one of the main research areas for the past decade. Electric vehicles (EVs) are taking over the market share of conventional internal combustion engine vehicles. The increasing popularity of EVs results in higher number of charging stations, which have significant effects on the electricity grid. Different charging strat2egies, as well as grid integration methods, are being developed to minimize the adverse effects of EV charging and to strengthen the benefits of EV grid integration. In this paper, a comprehensive review of the current situation of the EV market, standards, charging infrastructure, and the impact of EV charging on the grid is presented. The paper introduces the current EV status, and provides a comprehensive review on important international EV charging and grid interconnection standards. Different infrastructure configurations in terms of control and communication architectures for EV charging are studied and evaluated. The electric power market is studied by considering the participation roles of EV aggregators and individual EV owners, and different optimization and game based algorithms for EV grid integration management are reviewed. The paper specially presents an evaluation on how the future EV development, such as connected vehicles, autonomous driving, and shared mobility, would affect EV grid integration as well as the development of the power grid moves toward future energy Internet and how EVs would affect and benefit the development of the future energy Internet. Finally, the challenges and suggestions for the future development of the EV charging and grid integration infrastructure are evaluated and summarized.

1. Introduction

The conventional transportation system that incorporates an internal combustion engine (ICE) is the major contributor to air pollution [1]. To reduce air pollution and oil dependence in the transportation sector, there has been an increased overall market adoption of electric vehicles (EVs) in recent years. EVs use batteries, ultracapacitors, and fuel cells as energy sources, which have no dependency on fossil fuel and no polluted gas emission. Depending on the EV type, one or multiple of these sources can be used in an EV. The structure and configuration of EVs have already been summarized in several articles [2–4]. To make EVs competitive in the market, a number of challenges need to resolve, such as battery cost, efficient charging strategies, interoperability of the charging stations, and the impact of EV integration to the grid [5]. Moreover, successful growth of EVs over the next decade relies on the development of international standards and codes, universal infrastructures, associated peripherals and user-friendly software [6]. Enormous researchers are working in these areas worldwide. However, a good summary of the progress of EV charging infrastructure and the impact of EV charging on the grid is important for the expansion of the EV market. Several authors summarized charging infrastructure of EVs [7–9], integration of EVs in smart grid [10,11], impact of the vehicle to grid (V2G) technology [12–14], EV and smart grid interaction [15,16] in different publications. However, those reports are quite outdated now due to the rapid progress of this field in recent years.

In this paper, an overview of the current EV market is presented in Section 2. The EV standards, which include the charging standards, grid integration standards, and safety standards, are evaluated in Section 3. The EV charging infrastructure, including the power, control and communication infrastructure, is presented in Section 4. In Section 5, the impacts of EV integration on different aspects of power systems are elaborated, and the EV grid integration techniques are summarized. Lastly, challenges and suggestions for the development of future EV

* Corresponding author.,
E-mail addresses: hdas@crimson.ua.edu (H.S. Das), 437106801@student.ksu.edu.sa (M.M. Rahman), sli@ua.edu (S. Li), cheewei@utm.my (C.W. Tan).

https://doi.org/10.1016/j.rser.2019.109618
Received 18 February 2019; Received in revised form 9 November 2019; Accepted 20 November 2019

List of abbreviations

AC	Alternative current
AEV	All-electric vehicles
BAN	Building area network
BEV	Battery electric vehicle
BTU	British thermal unit
CAA	Canadian Automobile Association
CHP	Combined Heat and Power
CPM	Charging point manager
DC	Direct Current
DCFC	Direct Current Fast Charging
DER	Distributed Energy Resource
DIN	Deutsches Institut fuer Normung
DP	Dynamic programming
DSL	Digital subscriber line
DSP	Digital Signal Processing
DSO	Distribution system operators
EI	Energy internet
EIA	U.S. Energy Information Administration
EDV	Electric Drive Vehicle
EM	Electric motor
EMI	Electromagnetic interference
EREV	Extended range full-HEV
ESS	Energy Storage System
EV	Electric vehicle
EVGI	Electric vehicle grid integration
EVSA	EV supplier-aggregator
FAN	Field area network
FC	Fuel cell
FCEV	Fuel Cell Electric Vehicle
FCHEV	Fuel Cell Hybrid Electric Vehicle
FES	Flywheel energy system
FLC	Fuzzy logic controller
full-HEV	Full hybrid electric vehicle
G2V	Grid to vehicle
GA	Genetic algorithm
GENCO	Generator companies
GHG	Green House Gases
HAN	Home area network
HESS	Hybrid energy storage system
HEV	Hybrid electric vehicle
HBPA-PSO	Heuristics & proportion-based assignment
IAN	Industrial area network
IEA	International Energy Agency
ICE	Internal Combustion Engine
ICEV	Internal combustion engine vehicle
ISO	International Organization for Standardization
IEEE	Institute of Electrical and Electronics Engineers
JEVA	Japan Electric Vehicle association
LSE	Load serving entity
mild-HEV	Mild hybrid electric vehicle
MPG	Miles per gallon
MPGe	Miles per gallon gasoline equivalent
NAN	Neighborhood area network
NN	Neural network
NREL	National Renewable Energy Laboratory
NFPA	National Fire Protection Association
NEC	National Electric Code
NLP	Nonlinear programming
OACS	On-line adaptive EV charging scheduling
ORCHARD	Online coordinated charging decision
PHEV	Plug-in hybrid electric vehicle
PI	Proportional integral
PID	Proportional integral derivative
PLC	Data communication over power line
plug-in HEV	Plug-in hybrid electric vehicle
PSO	Particle swarm optimization
PWM	Pulse Width Modulation
RESS	Rechargeable Energy Storage System
SOC	State of the charge
SA	Supplier agent
SAE	Society of Automotive Engineers
SPDS	Shrunken primal-dual subgradient
TSO	Transmission system operators
UC	Ultracapacitor
UL	Underwriters' Laboratories
V2B	Vehicle to building
V2G	Vehicle to grid
V2V	Vehicle to vehicle
WPT	Wireless power transfer

charging and grid integration infrastructure are presented, and the contribution of EVs to the development of the energy internet is discussed.

2. Current status of electric vehicle technology

The story of EVs started long ago before ICE vehicles were introduced. After several vicissitudes, however, only a small portion of the automobile market was occupied by EVs before. The modern EV technologies are comparatively new, and EVs are now gaining popularity due to several advantages, such as zero emission, no dependency on fossil fuel, efficient, relatively silent, and so on. Research on EVs has been focused on increasing vehicle range and efficiency, reducing the price as well as developing methods for an efficient charging system.

2.1. Electric vehicle status

EVs can be divided into two main categories: hybrid electric vehicles (HEVs) and all-electric vehicles (AEVs) [17,18]. AEVs are equipped with only electric motors powered by electrical sources. AEVs can be further classified into Battery EVs (BEVs) and Fuel Cell EVs (FCEVs). A FCEV does not require an external charging system. However, a BEV relies only on external power from the grid for charging the storage unit. A plug-in hybrid EV (PHEV) is one type of HEVs with an option to recharge its battery from the grid. In this study, BEVs and PHEVs are together named as EVs. Fig. 1 describes the classification of different types of EVs, and the power flow from the energy source to wheels is explained in Fig. 2.

In Table 1, the technical specifications of commercially available EVs released by different manufacturers are presented [19–34]. The approximate charging time required to charge the vehicle from 0% to at least 80% in different charging standards are also shown in the table. Here, Level 1 corresponds to the charging voltage of 110–120 V, Level 2 is of 220–240 V and Level 3 or DC fast charging (DCFC) is of 200–800 V. It can be noticed that the range of an EV based on battery drive is about 100 km for most of the vehicles, and several models have the battery-drive ranges around 200 km–400 km.

2.2. Current and future electric vehicle market

Recent reports show that the number of EVs have reached 3 million thresholds in the year 2017 whereas ten years before there were only

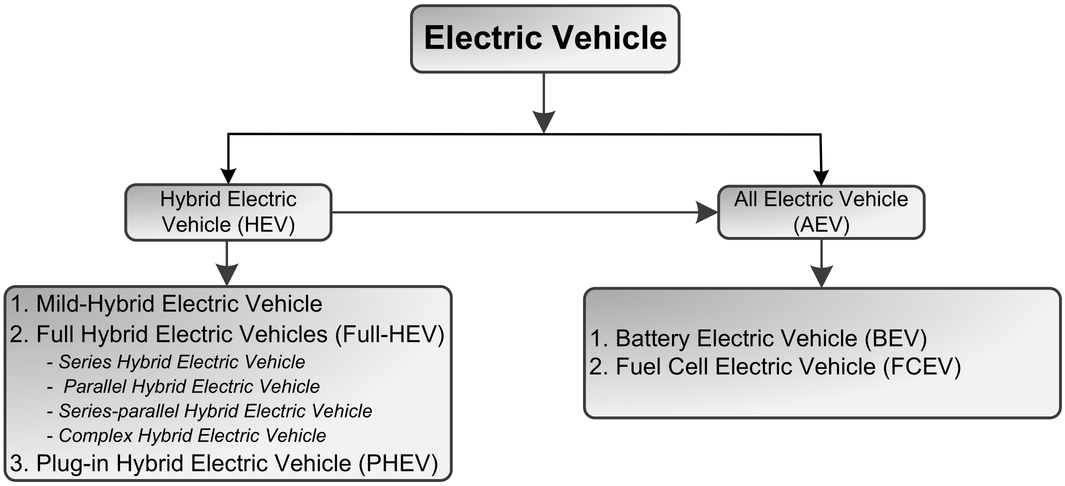


Fig. 1. The classification of EVs [2].

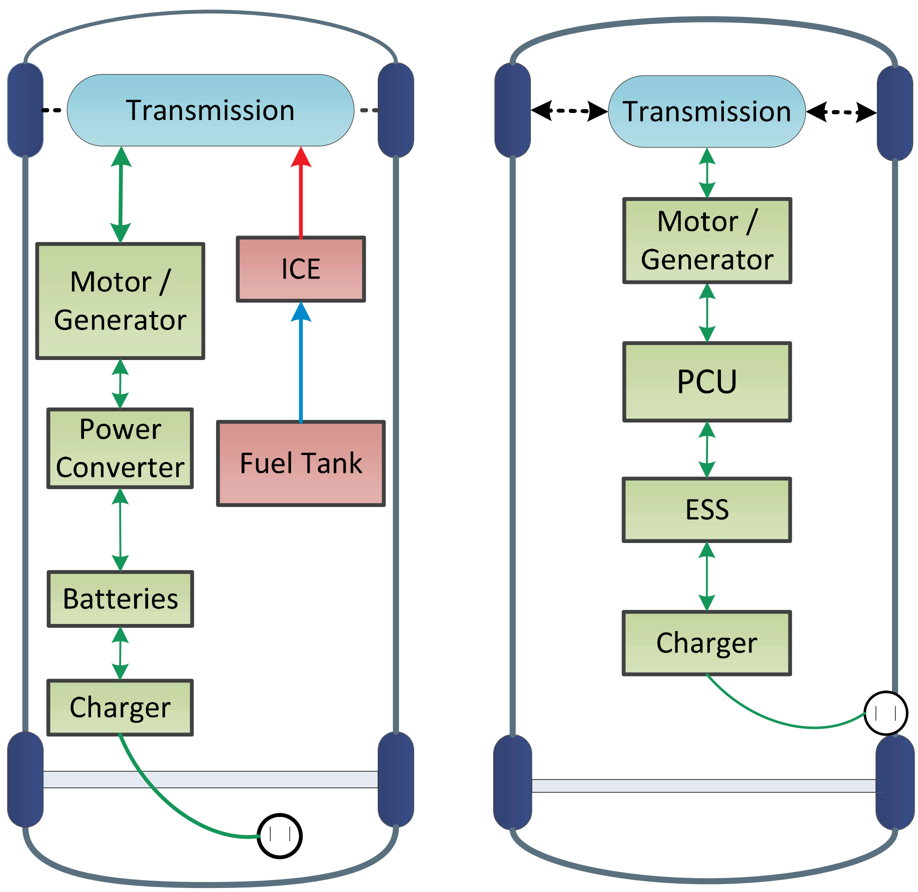


Fig. 2. Power flow in different types of EVs (a) PHEV, (b) BEV.

hundreds of them on the road (Fig. 3) [35]. The list of countries leading the sales of EVs in 2018 is shown in Fig. 4 [36]. Despite numerous advantages of EVs, only a handful of countries are participating in the global EV market. The primary reasons are the high cost and production number being limited. To overcome this issue, most of the vehicle manufacturers have set a production target (Table 2) [28,37]. The Energy Outlook predicts that about 100 million EVs will be on the road worldwide by 2035 [38,39]. According to International Energy Agency (IEA), the target of EV production is set to 548 million by 2040 [37].

2.3. Progress on EV charging and grid integration

Growing EV market results in a large number of EV charging stations, which are the medium for EV grid integration (EVGI). The implemented charging stations can be classified into residential and non-residential types, and can facilitate slow charging (level 1 and level 2) as well as fast charging (level 3 and DC) [41]. The significant portion of EV charging is residential charging with slow charging ports, however, the future charging stations are planned to be built up at commercial places to facilitate them as EV refueling stations which will have all types of

Table 1
Popular commercially available EV and EDV (electric drive vehicle) specifications.

Vehicle model	Manufacturer	model Year	Type	Battery Capacity (kWh)	Range (km)	Charging Time (0%–80%) (h)		
						Level 1	Level 2	DCFC
Prius prime [19]	Toyota	2018	PHEV	8.8	40 (battery)	5.5	2.1	–
Leaf [20]	Nissan	2018	BEV	40	243	35	7.5	0.5
Volt [21]	Chevrolet	2018	PHEV	18.4	85 (battery)	13	4.5	0.33
Bolt [22]		2019	BEV	60	383	–	9.3	1.33
Spark [23]		2016	BEV	19	132	–	7	0.75
Fit [24]	Honda	2014	BEV	20	132	15	3	–
Clarity [25]		2018	PHEV	25.5	75 (battery)	12	2.5	–
Model S [26]	Tesla	2018	BEV	100	506	96.7	10.7	1.33
Model X [27]		2018	BEV	100	465	89	9.5	1.33
Model 3 [28]		2017	BEV	50	354	–	12	52/60
Kia Soul [29]	Kia	2018	BEV	30	177	24	4.8	0.75
Focus [30]	Ford	2016	BEV	23	161	20	3.5	0.5
i-MiEV [31]	Mitsubishi	2017	BEV	16	180	22	6	0.5
e-Golf [28]	Volkswagen	2017	BEV	35.8	201	–	6	1
E-Up [19]		2018	BEV	20	159	–	9	0.5
Zoe [31]	Renault	2017	BEV	41	400	16	4.5	2.67
Twizy [32]		2017	BEV	6.1	100	–	3	–
i3 [22]	BMW	2018	BEV and PHEV	33	183 (battery)	13–16	5	0.5

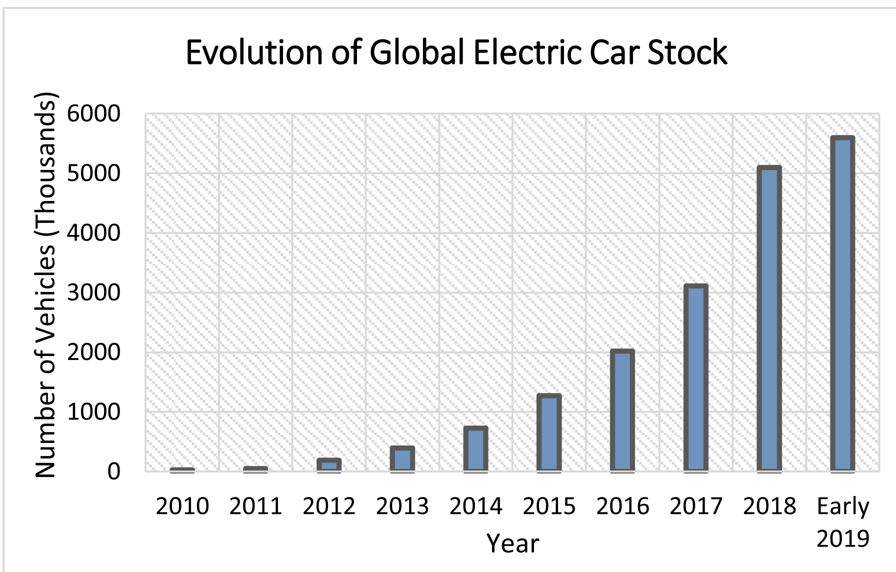


Fig. 3. Evolution of global EV stock.

charging ports [42]. Several commercial charging stations have already been established which have fast charging points and can charge an EV within an hour [43]. For example, until 2018, Tesla has established total 1431 supercharger stations in all over the world from which 694 are in North America, 442 in Europe and 294 in Asia Pacific region [44]. The Canadian Automobile Association (CAA) has declared that with the co-operation of another charging infrastructure company Charge Hub, 7906 charging stations have been established in major cities of Canada [45]. This number includes both fast and slow charging stations. Moreover, bidirectional charging stations are being built up which can help the power system to compensate power deficiency during the peak operation periods [46,47]. More discussions about the charging infrastructure are presented in the following sections.

3. Standards for EV charging and grid integration

The evolution of EVs has created new dimensions in transportation and electric power industry. To operate this new technology uniformly all over the globe, it is essential to standardize every aspect of it. Table 3 describes the worldwide regulatory bodies and their established standards, which oversee different aspects of EVs. From the table, the standardization related to EV charging can be segregated into three areas: EV charging component standards, EVGI standards, and safety standards. Among EV charging component standardization organizations, International Organization for Standardization (ISO) works on standardizing EVs as a whole, and the others work on component level specification.

The grid integration standards handle EV charging/discharging with the grid. During charging/discharging from the grid, EVs act like a distributed energy resource (DER). Thus, the grid interconnection standards of DERs also apply on EVGI. There are two major players in grid interconnection standards, namely The Institute of Electrical and Electronics Engineers (IEEE), and Underwriters' Laboratories (UL).

The safety standards for EV charging and grid integration are defined by most of the abovementioned organizations. However, organizations like The National Fire Protection Association (NFPA) and National Electric Code (NEC) work on safety measures mainly. The standards and codes established by these organizations are elaborated in the subsections below.

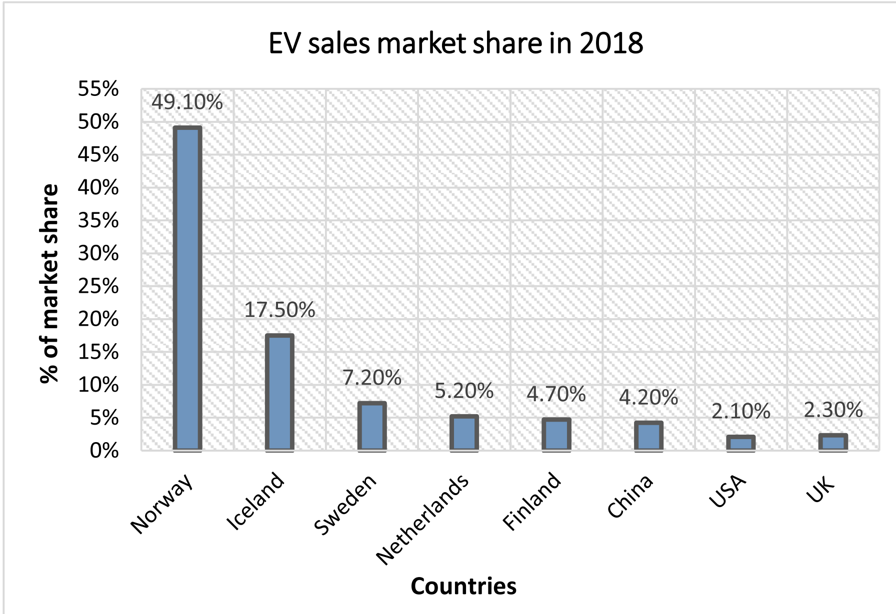


Fig. 4. EV sales market share in 2018.

Table 2
Vehicle manufacturers' announcements on EV target [28,37,40].

OEM	Announcement
BMW	0.1 M EV sales in 2017 and 15–25% of the BMW group's sales by 2025.
Chevrolet	30,000 EV sales by 2017.
Chinese OEMs	4.52 M EV sales by 2020.
Daimler	0.1 M EV sales by 2020.
(smart)	15–25% of sales should be EVs by 2025.
Ford	13 new EV models by 2020.
Honda	Two-thirds of the sales to be electric drive vehicles by 2030.
Renault-Nissan	1.5 M cumulative sales of EVs by 2020.
	30% of yearly sales should be EVs by 2022.
Tesla	0.5 M annual EV sales by 2018.
	25% of total sales would be electric by 2025.
Volkswagen	2–3 M annual EV sales by 2025.
Volvo	1 M aggregate sales and 50% of total sales would be electric by 2025.
Audi	50% of new sales would be EV by 2025.
Porsche	50% of new sales would be EV by 2023.
Toyota	1 million EV sales per year by 2030.

3.1. *Electric Vehicle Charging standards*

There are several standards available worldwide which deal with EV charging infrastructure. SAE and IEEE are used in U.S.A. based manufacturers whereas IEC is vastly used in Europe. Japan has their own EV charging standards named CHAdeMO. China uses Guobiao (GB/T) standard (issued by the Standardization Administration of China and Chinese National Committee of ISO and IEC) for AC and DC charging, where GB/T AC charging standards are similar to IEC standards. The IEC and SAE standards that deal with EV charging are discussed here in detail, because these two are widely used standards. Table 4 shows a summary of the voltage and current levels of IEC and SAE standards. It can be seen that IEC61851 and SAE J1772 have almost the same requirements except for the use of terms. In SAE, level of power called 'level,' whereas in IEC 'mode' is used to determine the level of power.

3.1.1. *IEC standards*

The IEC is a British standardization organization, which develops standards for electrical, electronic, and other related technologies.

3.1.1.1. IEC61851. IEC61851 covers overall standard operation for EV conductive charging systems and applies to onboard and off-board equipment for charging EVs/PHEVs with supply voltages up to 1000 V AC and 1500 V DC [57]. There are a few important sections regarding IEC61851 which are summarized in Table 5.

3.1.1.2. IEC 61980. IEC 61980 provides a standard for WPT system and is applicable for a supply voltage up to 1000 V AC and 1500 V DC. This standard also applies to the WPT system supplied by the on-site storage systems.

3.1.1.3. IEC62196. IEC62196 provides a standard for plugs, socket-outlets, vehicle connectors, and vehicle inlets that are used for conductive charging of EVs [57]. A few important sections in IEC62196 are summarized in Table 6.

3.1.2. *SAE standards*

The SAE is a U.S. based professional association, which develops standards for engineering bodies in different industries.

3.1.2.1. SAEJ2293. SAEJ2293 establishes the requirement of on and off-board charging equipment. This standard has two sections: J2293-1 discusses the power requirements and system architecture for three operating conditions (conductive AC, conductive DC and inductive charging), and J2293-2 discusses the communication requirement and network architecture for EV charging [58,59].

3.1.2.2. SAEJ1772. SAEJ1772 discusses all the equipment ratings for EV charging including circuit breaker current rating, charging voltage rating and so on [60]. The standard is defined for both AC and DC where each of them has 3 levels [7] (Table 4). Most vehicles are being designed to accept a Level 2 AC onboard charging at less than 30 A. SAE DC level refers to DC charging and brings a very high speed of charging. The actual charging rate is limited by battery chemistry, infrastructure, and some other factors though.

3.1.2.3. SAEJ1773. This standard specifies the minimum requirements of inductively coupled charging scheme for EVs [61]. SAEJ1773 establishes explicitly the requirement for manually connected inductive charging systems and elaborates the requirements of software interface

Table 3
Regulatory organizations and standards associated with EV [36,40,48–56].

Organization	Standards	Detail
International Electro-technical Commission (IEC, Britain) [40]	TC21	Standard for all secondary cells and batteries regarding dimension, performance safety, testing, installation & maintenance.
	TC22	Standard for power electronic systems, equipment and their component design, control, protection, monitoring and measurement.
	TC64	Standards for installation and coordination of equipment for protection against electric shock due to equipment installation error and high voltage supply.
	TC69	for different types of EDVs
	IEC61851	Standards related to general charging requirements
	IEC61980	Standards for wireless power transfer (WPT) for EVs.
	IEC62196	Standards for plugs, sockets, and connectors for EV conductive charging.
Society of Automotive Engineers (SAE, United States) [50]	J2293	EV and off board EV Supply Equipment requirements for charging from utility grid.
	J1772	Standard for conductive charging.
	J1773	Standard for contactless charging.
	J2847	Communication standard between EV and utility grid, and off board DC charger.
	J2836	Provides use cases for analog and digital communication between EV and utility grid.
	J2931	Standard for digital communication between EV and utility grid.
	J2954	WPT for EVs.
	J2894	Power quality requirements and testing procedure for EVs.
	J1766, J2344, J2578	Safety requirements for charging.
Japan Electric Vehicle Association (JEVA, Japan) & CHAdeMo Association [51]	C601	Standard for charging plugs and receptacles.
	D001-002	Standardizes the battery characteristics for EV.
	D701-709	Instruction for battery testing.
	G101-105	Quick charging standards
	G106-109	Contactless charging standards
IEEE [52]	P1547	Standards of different aspects of grid connection of DERs
	P2100.1	WPT and charging system standardization.
	P2030	Standard for addressing the interoperability of smart grid
	P2030.1	Draft for electrified transportation infrastructure.
UL [53]	UL2231	Requirements for protection devices for EV charging circuits.
	UL2251	Requirement for charging plugs, receptacles and couplers
	UL2202	Requirements for charging system equipment.
	UL2594	Requirements for EV supply equipment.
	UL1741	Specifications for inverter, converter, charge controller and output controllers used in power system
	UL1741 SA	Supplement draft of UL 1741, defining safety requirements of inverters for grid stability
	UL62109	Safety requirements of inverters used in grid connected photovoltaic systems.
NFPA [54]	70	Safety standards for grid integration of DERs.
	70B	Contains safety measures for electrical equipment maintenance.
	70E	The electrical safety standards in workplace.
NEC [55]	625	Standard for off board charging system, such as conductors, connecting plugs and inductive charging devices.
	626	Requirements for parking lots for electrified trucks, including conductors and other equipment used to charge the trucks.
Deutsches Institut fuer Normung (DIN, Germany) [56]	43538	Specifications of battery systems.
	EN50620	Charging cable specifications.
	VDE0510-11	Specification and testing procedure of Li-ion batteries
Standardization Administration of China (SAC) [36]	GB/T 20234 GB/T 20234.1-2015 GB/T 20234.2-2015 GB/T 20234.3-2015	Standards for plugs, sockets, and connectors for EV conductive charging.
	GB/T 18487.1-2015	EV conductive charging – General Requirements.
	GB/T 18487.2-2001	Standards of EV requirements for conductive connection to AC/DC supply.
	GB/T 18487.2-2017	EMC requirements for off-board EVSE
	GB/T 18487.3-2001	AC/DC EV charging station standards.
	GB/T 34657.1-2017	Interoperability test specifications for supply equipments for EV conductive charging
	GB/T 34657.2-2017	Interoperability test specifications for EVs for conductive charging
	GB/T 27930-2015 GB/T 34658-2017	Communication protocols standard for off board chargers and BMS
	QC/T 895-2011	On board conductive charger standards for EVs
	GB/T 37293-2019 GB/T 37295-2019 GB/T 31525-2015	EV charging/battery swap infrastructure specifications
	GB/T 36278-2018	Technical specification for EV charging/battery swap infrastructure for distribution network interconnection.
	GB/T 51313-2018	EV decentralized charging facility standard.
	GB/T 33594-2017	Charging cable specifications for EVs.
	GB 50966-2014	EV charging station design specification.

Table 4
Summary of voltage and current levels in IEC62196, IEC61851 and SAEJ1772 standards.

Standards	Source	Mode/Level	Voltage (V)	Phase	Max Current (A)
IEC62196	AC	Mode 1	120	Single	16
		Mode 2	240	Single	32
		Mode 3	250	Single	32–250
	DC	Mode 4	600	DC	400
IEC61851	AC	Mode 1	120	Single	16
		Mode 2	240	Single	80
	DC	Mode 4	200–450	DC	80
SAEJ1772	AC	Level 1	120	Single	16
		Level 2	240	Single	32–80
	DC	Level 1	200–450	DC	80
		Level 2	200–450	DC	200

Table 5
Sections in IEC61851 [7].

Section	Explanation
IEC61851-1	- Standard for cable and plug setups to charge EVs Case A: The cable is permanently attached to the EV Case B: The cable is not permanently attached to anything Case C: The cable permanently attached to the charging station
IEC61851-21-1	- On board charger EMC requirements for conductive charging.
IEC61851-21-2	- Off board charger EMC requirements for conductive charging.
IEC61851-23	- Requirements for DC fast charging stations
IEC61851-24	- Digital communication for DC charging control between charging controller in EV and EV supply equipment

Table 6
Sections in IEC62196 [7].

Section	Explanation
IEC62196-1	- Contains general requirements such as plugs, socket-outlets, vehicle couplers and vehicle inlets for EV connectors
IEC62196-2	- Standardizes three types of mains connecting systems which are known as type 1, 2 and 3 to modes 1, 2 and 3
IEC62196-3	- Defines connectors and inlets for fast DC charging

for inductive charging.

3.1.2.4. SAEJ2847 & SAEJ2836. These two standards along with SAEJ1772 specify the communication requirements between an EV and the charging infrastructure. SAEJ2847 specifies the communication requirements and SAEJ2836 defines the use cases and provides the testing infrastructure. Table 7 shows the titles of the subsections where the application areas can be assumed.

3.1.2.5. SAEJ2931. This standard establishes the requirements for digital communication between EVs, EVSE, utility, energy service interface, advanced metering infrastructure, and home area network. To set up a communication network in a smart grid environment for EV charging, the specifications set by SAEJ2931 must be satisfied [62]. There are several subsections of this standard summarized in Table 8.

Table 7
Sections in SAEJ2847 & SAEJ2836.

Section	Titles
SAEJ2847/1-2	Communication between Plug-in Vehicles and the Utility Grid and Plug-in Vehicles and Off-Board DC Chargers.
SAEJ2836/1-2	Use Cases for Communication Between Plug-in Vehicles and the Utility Grid, and Plug-in Vehicles and Off-Board DC Charger, respectively.
SAEJ2836/3	Use Cases for Plug-in Vehicle Communication as a DER.
SAEJ2836/4-6	Use Cases for Diagnostic, Customer, and Wireless Charging Communication for Plug-in Vehicles, respectively.

3.1.2.6. SAEJ2954 & SAEJ2954 recommended practice (RP). This standard is the world's first WPT specification for EVs. The SAEJ2954 specifies wireless charging up to level 2 (7.7 kW) but recently published RP version declared up to level 3 (11 kW). The updated version also provides a standardized testbed for performance measurement and validation of new products from EV manufacturers and infrastructure companies. This standard also includes driving assistance for seamless EV parking, payment establishment and autonomous charging [63].

3.2. Electric vehicle grid integration standards

Three standards and codes are available: IEEE1547, UL1741 and NFPA70 [49–51]. The important aspects of all these standards and codes are presented below.

3.2.1. IEEE1547

IEEE1547 is known as "Standards for interconnecting distributed resources with electric power systems." It is applicable for all DER technologies with a collective capacity of 10MVA or less at the PCC, covers requirements relevant to the performance, operation, testing, safety considerations and maintenance for interconnection of DERs, and emphasizes on the installation of DERs on primary and secondary network distribution systems [64]. Table 9 summarizes the major focus points of IEEE1547.

3.2.2. UL standards

UL published several standards to cover different aspects of grid integration of DERs. Among them, the most significant standard is UL 1741, which discusses the power conversion equipment and their protection device specifications applicable for grid integration of DERs. The other standards are UL 62109, UL 62109-1 and UL 62109-2 and UL 1741 SA. All these standards and their attributes are summarized in Table 10.

3.3. Safety standards for EV

The safety measure is a mandatory part for EV charging and grid integration. Although most of the standardization organizations have safety standards, NFPA and NEC focus particularly on safety and security. The codes concerned to the EV charging and grid integration defined by these two organizations are elaborated below.

3.3.1. NFPA standards

NFPA is a worldwide leader in the provision of fire, electrical and life safety to the public. The standard released by NFPA in the area of EV and its grid integration is NFPA 70 [54], which covers instructions on electrical equipment wiring and safety on the customer side of the PCC. They include:

- Electric conductors and equipment installed within or on public and private buildings and other structures.
- Electric conductors that connect the installations to a supply of electricity and other outside conductors and equipment on the premises.

Table 8
Sections in SAEJ2931 [62].

Section	Explanation
SAEJ2931/1	Defines the architecture and general requirements for digital communication.
SAEJ2931/2-4	Specify a MAC and Physical layer implementation using SAEJ1772 pilot wire and frequency shift keying, narrow band OFDM and baseband OFDM, respectively.

Table 9
Summary of IEEE1547 [64].

Standards	Explanation
IEEE P1547.1	- known as "Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems". - Provides detail test procedure for confirming that interconnection specifications and equipments follow to the test requirements of IEEE 1547.
IEEE P1547.2	- Known as "Application Guide for IEEE 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems". - Provides technical background and application details to make IEEE 1547 user friendly. - Characterizes DERs and associated interconnection issues.
IEEE P1547.3	- Known as "Guide For Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems". - Aids interoperability by offering guidelines for monitoring, data exchange, and control among distributed generators interconnected with an electric power system.
IEEE P1547.4	- Known as "Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems". - Addresses engineering features of how local facilities can operate as "electrical islands'' to supply power during utility power is not available.

Table 10
Summary of UL standards for EV integration [65–68].

Standards	Explanation
UL 1741 [65]	- Covers inverters, converters, charging controllers, and output controllers intended for use in stand-alone or grid-connected power systems compliance with NEC certification and utility specific interconnection needs.
UL 62109 [66]	- UL 1741 is renamed as UL 62109, after harmonized with IEC standards. - Named as "Power Converters for Use in PV Systems" - Specifically discusses the photovoltaic inverter/converter construction requirements and testing. - Has two subsections: UL 62109-1 and UL 62109-2
UL 62109-1 [67]	- Named as "Standard for safety of power converters for use in photovoltaic power systems – part 1: General requirements" - Covers the minimum requirements for designing and manufacturing of power conversion equipment for protection against electric shock, energy, fire, mechanical and other hazards.
UL 62109-2	- Named as "PV Inverter Specific Requirements". - Addresses the inverter specific safety function requirements, such as: total harmonic distortion, DC injection, voltage and frequency control, system isolation protection, labeling and documentation.
UL 1741 SA [68]	- It is a supplement draft standard of UL 1741. - Identifies required inverter functions for optimal grid stability. - Specifies modern smart inverter topographies and their testing approaches. - Important for smart grid integration of DERs

- Optical fiber cable.
- Buildings used by the electric utility that are not integral part of a generating plant, substation or control center.

There are several articles in NFPA 70 where the instructions for different DERs are specified. The articles are summarized in Table 11.

3.3.2. NEC standards

NEC is another standard provider who works on safety measures in the EV industry. It also provides the standards for EV charging equipment.

3.3.2.1. NEC 625. NEC 625 titled as "*Electric Vehicle Charging and Supply Equipment Systems*" provides the standards for off-board EV charging systems. It covers the infrastructure connected to either feeder or branch circuits for EV charging, such as conductors, connecting plugs and inductive charging devices, and provides the installation instructions for EV charging station equipment.

Table 11
Summary of articles of NFPA 70.

Articles	Explanation
230: Services	- Includes provisions and requirements for electrical services to a building
690: Solar photovoltaic system	- Specifies interconnection to the grid requirements. - Focuses on components description and proper wiring technique.
700: Emergency systems	- Includes provisions that apply to emergency power systems and information about interconnection such as transfer switches.
701: Legally required standby systems	- Includes provisions that apply to standby power systems. - Contains information regarding interconnection of standby power such as UPSs and generators.
702: Optional standby systems	- Includes provisions that apply to standby systems that are not required legally. - Contains several information regarding interconnection such as grounding, transfer switches and circuit wiring.
705: Interconnected Electrical Power Production Systems	- Broadly covers the interconnection of alternative energy systems except PV and fuel cell systems. - This article applies widely on EV integration.

3.3.2.2. NEC 626. This standard titled as "*Electrified Truck Parking Spaces*" covers the area of parking spaces for trucks. It defines the specifications for the electrical equipment and conductors external to the truck which are used to charge the trucks. The specifications include circuit breakers, groundings, cable sizes, back feed prevention and so on.

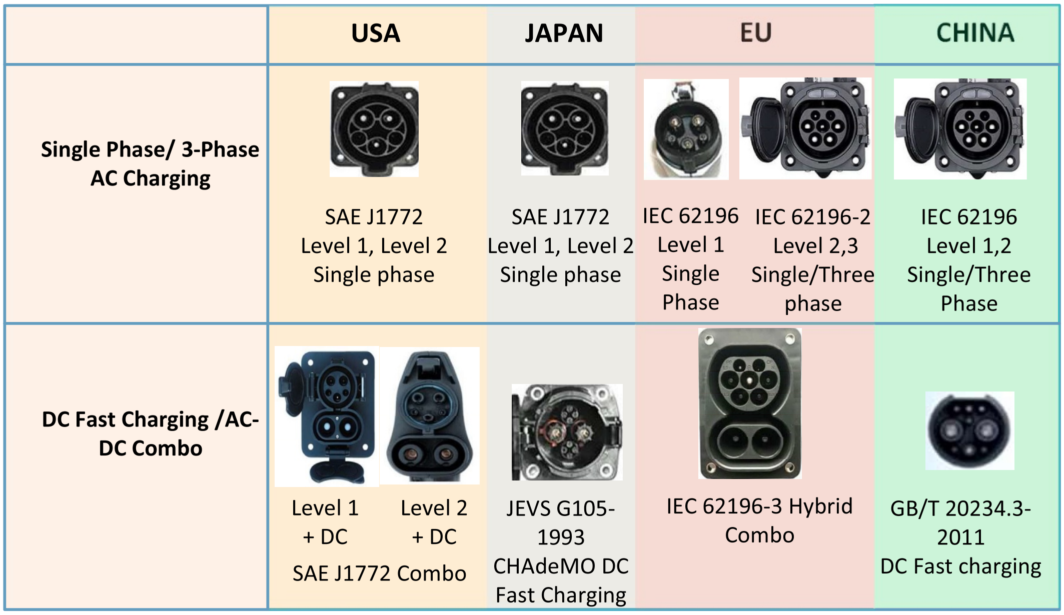
3.4. Application of EV charging standards

Different countries follow different charging standards. The major difference among these charging standards lies in the ports/connectors design. Fig. 5(a and b) shows different charging ports and connectors produced by following different standards, respectively. Manufacturers are trying to come up with a common charging connector solution to avoid the charging standard conflicts [69]. In the U.S., SAE J1772 connectors are used and have both AC and DC charging capability. Tesla has designed its own connector, which also supports both AC and DC fast charging. Tesla also has designed an adapter for other car models, which converts SAE J1772 connectors into Tesla connectors to enable them to use in Tesla supercharging stations. Another popular charging connector named as "combo," which is used in Europe, is shown in the same figure. The combo is produced by adding separate DC charging pins in the existing AC charging connectors. It can be seen from the figure that all these connectors present in the current market are quite different in shape. EV and charging equipment manufacturers are trying to harmonize the charging standards and come up with a universal solution of the EV charging device.

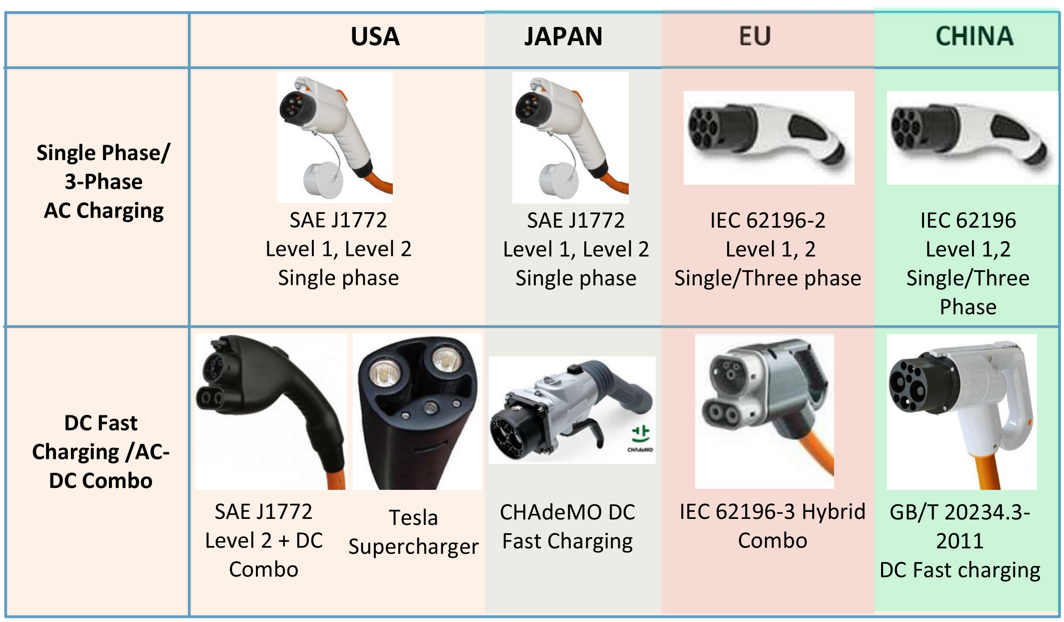
Apart from charging ports and connectors, the standards play a vital role in grid integration. Fig. 6 shows the standards associated with different areas of the grid integration infrastructure. It is clear that different standardization bodies cover different areas of the system. To operate the whole infrastructure, which includes the electric grid, charging stations, charging equipment and the EVs, all these standards are necessary to follow.

4. Electric Vehicle Charging infrastructure

In general, the overall EV charging infrastructure comprises power infrastructure and control and communication infrastructure as shown in Fig. 7.



(a) Charging ports



(b) Charging connectors

Fig. 5. Schematic of charging ports and connectors manufactured from different standards.

4.1. Power infrastructure in EV charging

The power infrastructure (Fig. 8) provides an electric circuit or system for power flow between EVs and the grid [70,71]. It can be classified according to the types of power used, accommodation of the charging circuit, physical contact requirements, and power flow direction (Fig. 9).

4.1.1. Types of power used

EV charging uses either AC or DC power supplies. AC charging has different voltage and frequency levels based on the power system of a concerned country. In terms of the voltage levels, AC charging can be divided into Levels 1, 2 and 3 charging, where level 3 has the highest charging voltage. The Levels 1 and 2 charging facilities can be installed in a private location while setting up of Level 3 charging facilities, involving separate wiring and transformer, requires permission from utility providers and are usually built in public charging stations. At the same voltage level, DC charging is faster and usually has a high charging power capacity [72]. The latest DC fast charging (DCFC) technology can fully charge an EV within as low as 20 min [44,73].

4.1.2. Accommodation of charging circuit

The charging circuit can be accommodated either in a car (on-board charging) or in a charging station (off-board charging) as shown in Fig. 10 [80]. Onboard charger allows the EV owner to recharge their car batteries wherever power supply is available [74]. It is compact in size, lightweight, and low cost but possesses low power delivery capacity to

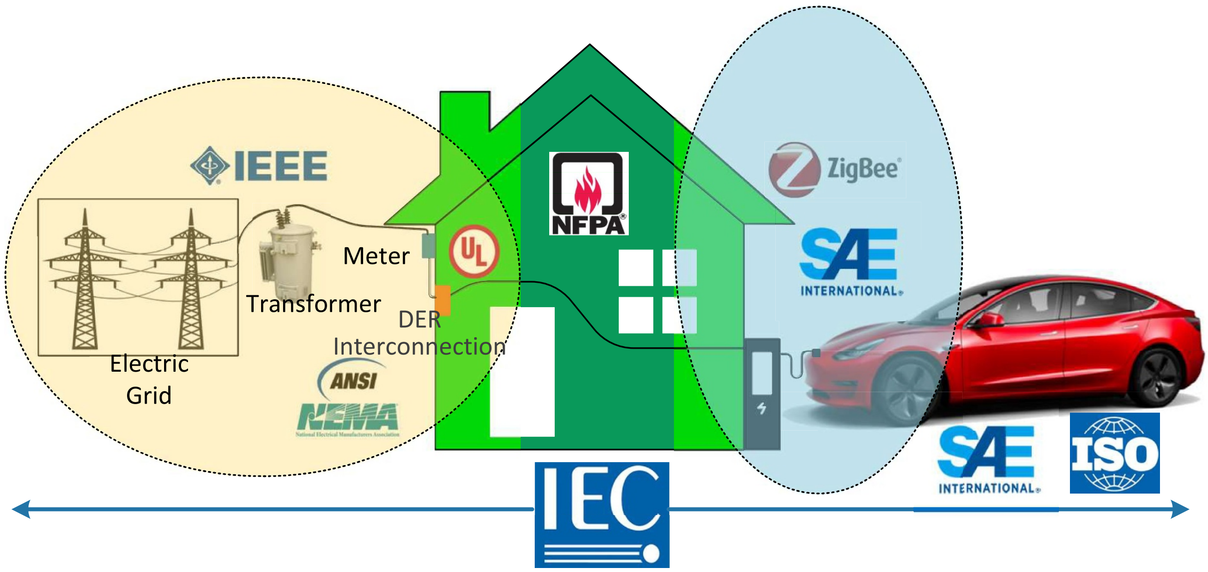


Fig. 6. Different EV charging standards and their application areas.

the EVs [75], which causes a longer charging time and affects the driver satisfaction. Contrarily, off-board EV charger has less concerns in weight and size [76–79] and facilitates multiple charging modes including slow and fast charging schemes in the same infrastructure. However, setting up off-board chargers can be expensive due to the multiple charging schemes within a charging station.

Apart from on and off-board chargers, wireless charging can be considered as a third type of charging system, in which the energizing coils are set up outside the vehicle, but the receiving coil and converter are mounted inside the vehicle [81]. This charging method is convenient for power transfer between the charging stations and EVs.

4.1.3. Physical contact

From the physical contact perspective, the charging topologies can be divided into conductive and contactless charging. A conductive charging system maintains physical contact between the power supply and the battery on-board whereas a contactless charging system transfers power without any physical contact [82,83].

Conductive charging can be subdivided into slow charging (Levels 1 and 2) and fast charging (Level 3 or DCFC). The latest charging stations use DCFC to charge the vehicles, and it is the key to increase the popularity of EVs [84,85]. To make it market's best solution, issues like charging time [86], availability for public access [87], renewable energy sources integration [87,88] and so on are required to be resolved.

Contactless charging system typically uses WPT technology to charge the battery. WPT system can operate in every voltage levels (Levels 1, 2 and 3) and has the power rating up to 20 KW. The recorded efficiency is up to 90% [89]. Based on the charging technology, WPT can be divided into four types namely, resonant inductive, inductive, capacitive and low-frequency permanent magnet coupling power transfer [90–93]. The techniques introduced in different literature until now for WPT, including the operation strategy, capable distance efficiency, and frequency range, are summarized in Table 12 [94–100].

4.1.4. Direction of power flow

Based on the direction of power flow, EV chargers can be classified as unidirectional and bidirectional as shown in Fig. 11 [7].

An EV charger with a unidirectional topology uses a diode rectifier and a unidirectional DC-DC converter for charging control [7]. The unidirectional charger is easy to control because of less complexity. It minimizes battery degradation and has fewer interconnection issues compared to bidirectional types. However, unidirectional chargers cannot provide most of the grid ancillary services [113].

A bidirectional EV charger has a bidirectional grid-connected AC-DC converter and a bidirectional DC-DC converter [114]. This kind of charger can operate in either charging or discharging mode, which enables EVs to provide various ancillary services to the grid. But, the frequent cycling of the discharging power back to the grid can degrade the EV battery lifetime. In addition, the metering and grid stability issues, which involves selling and buying electricity from utilities, makes the process complex.

4.2. Control and communication infrastructure in EV charging

Control and communication system is the fundamental element for real-time monitoring and control of EV charging [115]. Although EV charging represents an additional load demand in the power system, it can be scheduled to reduce the peak demand [116] and charging cost through proper management and coordination of EV charging stations connected with the grid based on the control architecture and communication infrastructure involved in the EV charging as elaborated below.

4.2.1. Control architecture in EV charging

The control structure of EV charging involves the distribution grid, the EV charging stations and EVs, and can be classified according to the mobility, coordination and the control structure as shown in Fig. 12.

4.2.1.1. Vehicle mobility consideration. In this aspect, EV charging infrastructure can be classified into static and dynamic charging. In static charging, the vehicle is considered to be parked in a charging station while charging. On the contrary, dynamic or mobility aware charging scheme considers different temporal movement, such as vehicle arrival and departure time, trip history and any unplanned occasion of EV arrival/departure [117,118], which is more realistic due to the considerations of spatiotemporal relations of EVs but is more complex and requires advanced control infrastructure [119].

4.2.1.2. Charging coordination. In this aspect, EV charging follows two methods: uncoordinated and coordinated charging control. The uncoordinated charging means that EV batteries either start charging immediately when plugged in or start after a user-adjustable fixed delay and continue the charging until they are fully charged or disconnected [120,121]. Uncoordinated charging operations tend to increase the load at peak hours and may lead to overloads in distribution transformers and

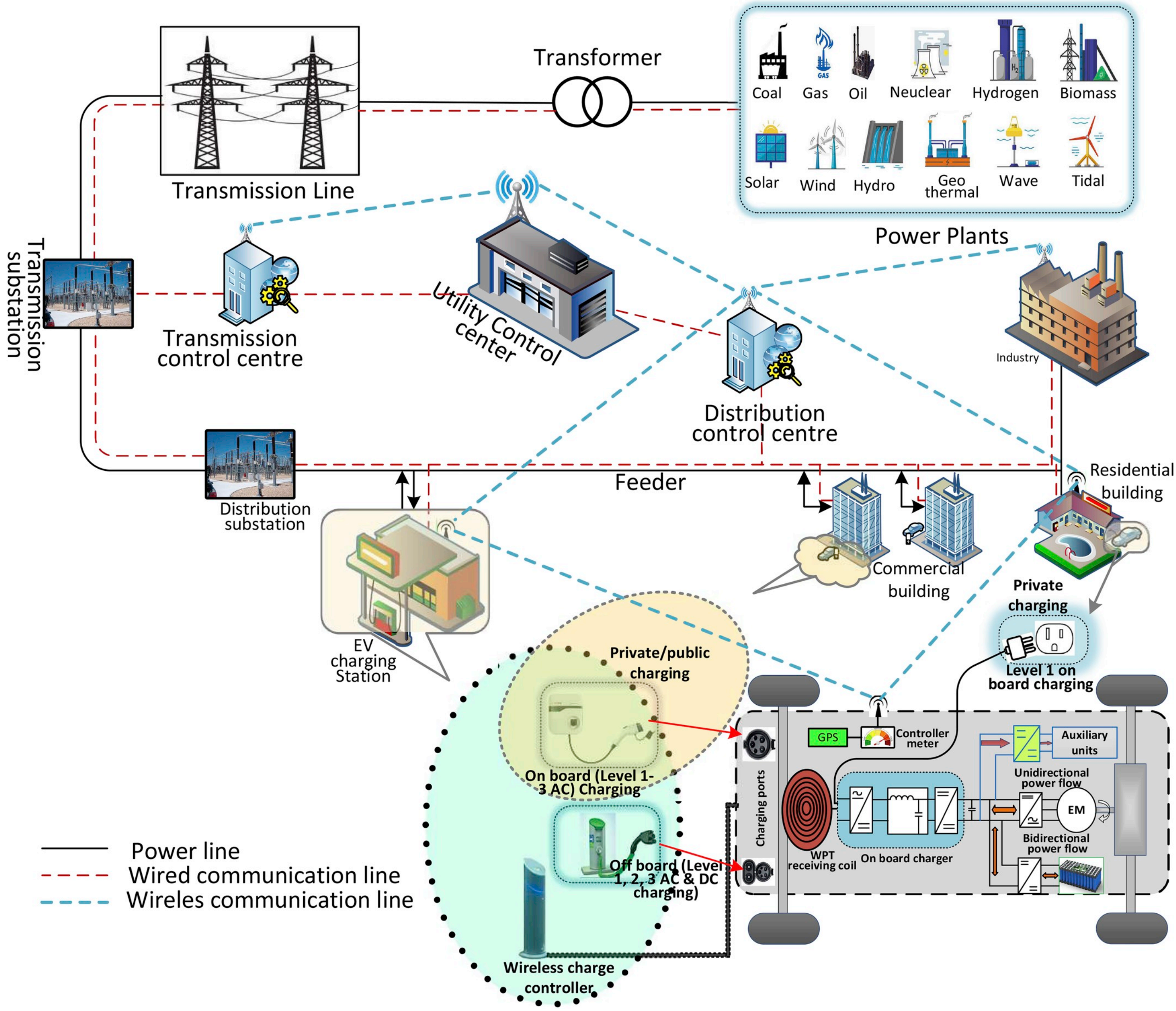


Fig. 7. Schematic diagram of EV charging infrastructure.

cables, increased power losses, and reduced reliability of the grid [122]. Some utility companies offer a dual tariff (cheap night rates) to EV owners as a way to reduce peak loads [123–125].

On the other hand, coordinated or smart charging optimizes time and power demand [126], and reduces daily electricity costs, voltage deviations, line currents, and transformer load surges [122,127]. A simple coordinated charging method is off-peak charging, where the EVs are charged in a specific time of the day when the grid load is minimum. This partially solves the overloading issue, however, determining the specific time information of the day from utility providers is required. In addition, it may affect the EV users' convenience of charging the EV [128].

4.2.1.3. Control structure consideration. The EV charging stations are spatially distributed in the distribution grid. To manage and control the power flow in and out of the EV charging stations, two strategies can be applied: the centralized and decentralized charging strategies [129,130] as illustrated in Fig. 13.

- Centralized Control

The main concept of centralized charging is to utilize the centralized structure to acquire the information from the EVs, process them centrally and provide a global optimal solution considering all the grid and user constraints [53,131–148], in which a master control engine performs the decision making regarding the charging rate and schedule of EVs. The limitation of the centralized charging is that the optimization problem size becomes large with the increase of the vehicle count in a particular area. As a solution to this problem, hierarchical based control architecture is proposed, which segregates the EV loads into a number of groups depending on their locations. The central controller only administers the load demand from the groups, and the groups use a local controller to manage the power distribution to the individual EVs [16,149–156]. The hierarchical control strategy is beneficial in terms of communication and computational requirements. Several other control strategies named as online control [157–160] and real time charging [161–177] are also available which uses centralized structure.

- Decentralized/Distributed Control

Decentralized charging control, also known as distributed charging

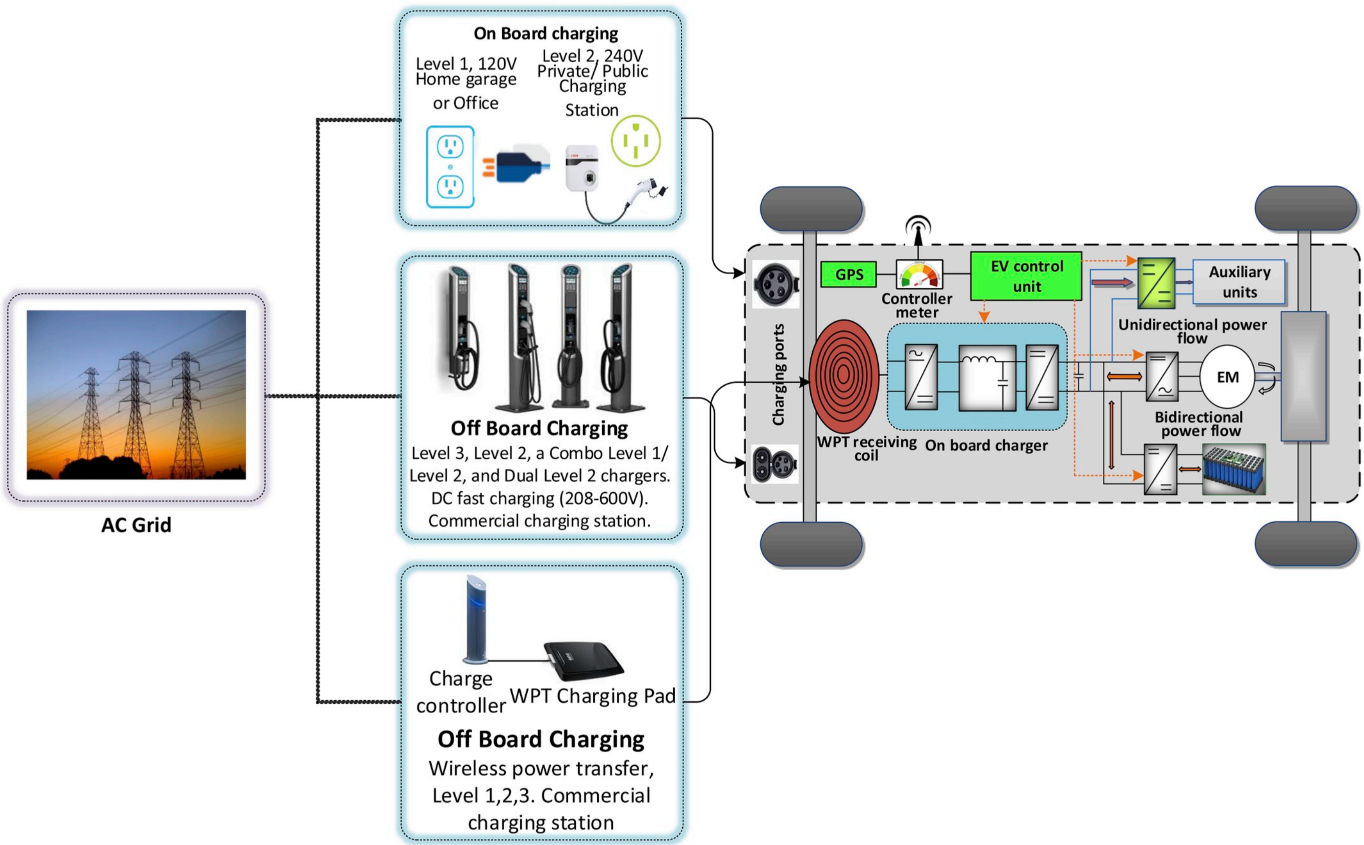


Fig. 8. Power infrastructure in EV charging infrastructure.

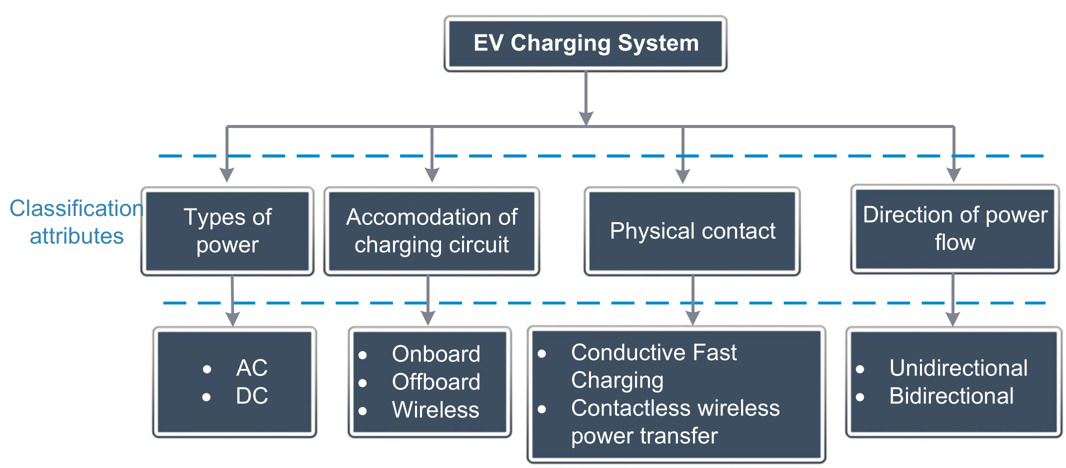


Fig. 9. Classification of EV charging infrastructure.

control, is a strategy where the EV users directly choose their charging schedules [178]. In this type of control, electricity price and user convenience are the main factors to provide the charging decision [179]. As the EV users decide their charging patterns, decentralized control does not provide the guarantee to reach the global optimal solution for the overall system. However, by practicing electricity tariff mechanism and EV user responsible behavior, the EV loads can be matched with the grid requirements.

4.2.2. Communication network for EV charging

An effective communication system between EVs, EVSEs and the grid is necessary for a smart EV charging management [180,181] (Fig. 14). Available communication protocols can be classified into wired and wireless communication technologies [182,183]. These technologies are applied for grid integration of EVs in different private networks, such as home area network (HAN), industrial area network (IAN), building area network (BAN), neighborhood area network (NAN) and field area network (FAN). These networks are used to control and monitor the EV charging/discharging and other domestic use of electricity as discussed below.

4.2.2.1. Wireline communication. The wireline technologies are suitable for long distance data transfer, such as the EV charging stations distributed in big cities. The most popular protocol in wireline

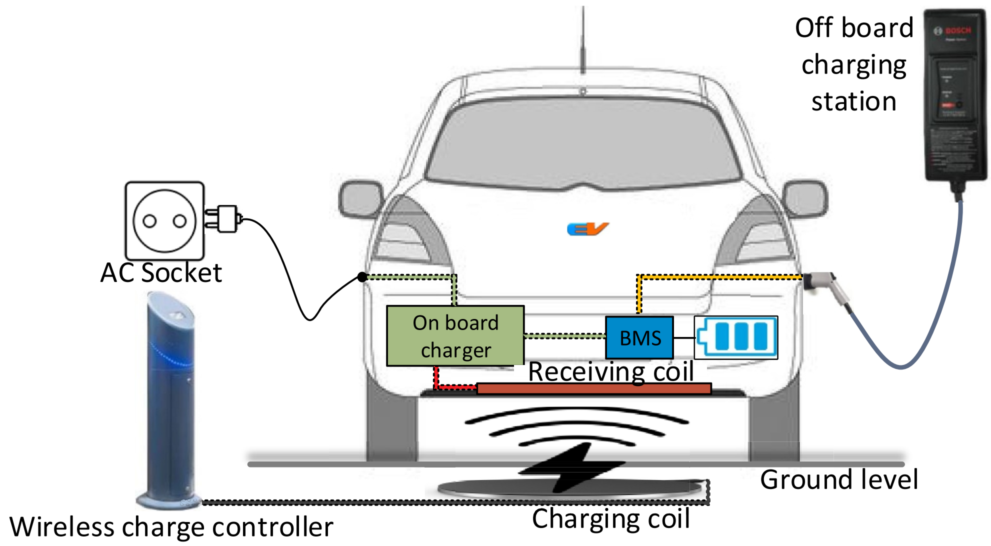


Fig. 10. Possible accommodation of charging circuit in EV.

Table 12
Summary of different types of WPT techniques.

	Techniques	Distance	WPT Efficiency	Operating Frequency
Resonant inductive coupling	Magnetic Resonant Coupling	10's cm range	50%–95%	KHz - MHz [101]
	Magnetic coupled resonance	6–20 cm	50%–80%	Hundreds of KHz [102, 103]
	On-Line Electric Vehicle	around 25 cm	80%	Several KHz [104–106]
	Resonant Reactive Shield	around 15 cm	Improved	Several KHz [107]
Inductive coupling	Inductive coupling power transfer	around 30 cm)	88%	Several KHz to MHz [108, 109]
	Frequency Agile (Qi charge transmitters)	up to 4 cm	Improved	Hundreds of KHz [110, 111]
Capacitive coupling	Electric Field Coupling	around 15 cm	78%	Several MHz [97]
Permanent magnet coupling	Permanent magnet coupling	around 15 cm	81%	150 Hz [112]

communication technology is data communication over power line (PLC) which uses the same power line to send and receive information. The advantage of this protocol is its reliability and robustness to interference [184,185]. Several protocols that use the PLC concept are HomePlug 1.0, HomePlug turbo, HomePlug AV, HD-PLC and UPA [185].

Optical and Digital subscriber line (DSL) protocols can be found in the wireline communication system too. The optical communication protocol has extensively higher data rates (up to several Gbps), and the transmission range is significantly higher (several kilometers) than the PLC. Also, it is resilient against electromagnetic interference. Thus, using this technology, data transfer over a high voltage line is suitable [184,185]. DSL protocol enables digital communication over telephone lines, thus does not require separate infrastructure setup [184].

4.2.2.2. Wireless communication. For complete communication structure, wireless communication is also required, such as for data exchange between the vehicles and the charging stations. It is the prime medium to provide the charging status information to EV users. The wireless communication network is constructed using Wireless LAN devices in a hierarchical mesh structure for interconnection of electrical devices. For EV grid connection, the popular wireless communication technologies include Zigbee, cellular, wifi, WiMAX and satellite networks.

5. EV integration in the power grid

There has been a minimal linkage between the transportation and electric power sectors only until recently. Large-scale electrification of transport has substantially disrupted the traditional business models of electric utilities. Overall, EVs have brought both significant challenges and benefits for the electricity grid.

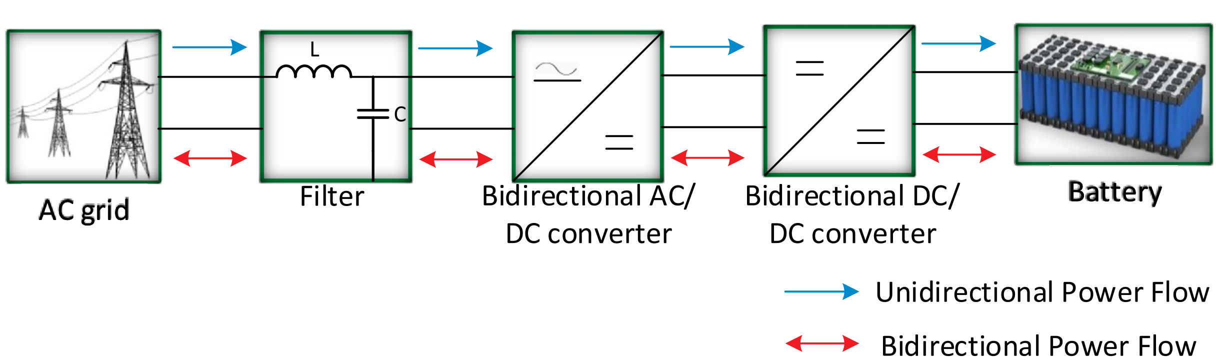


Fig. 11. General topology of unidirectional and bidirectional charger.

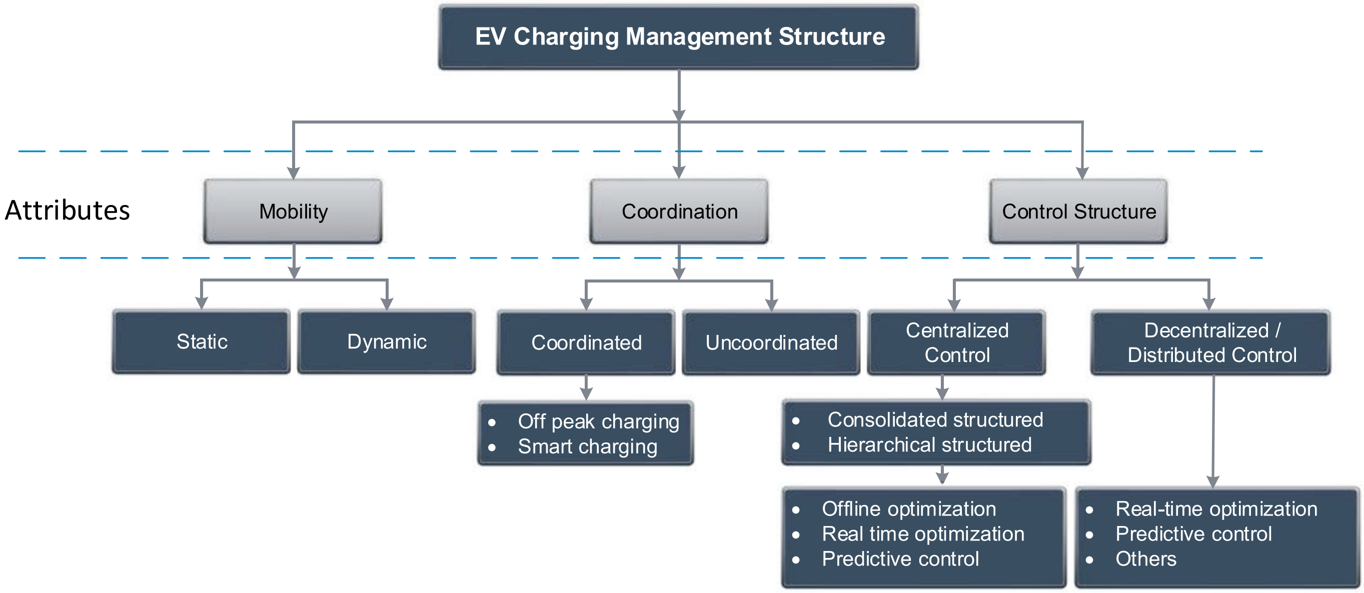


Fig. 12. Classification of control strategies used in EV charging system.

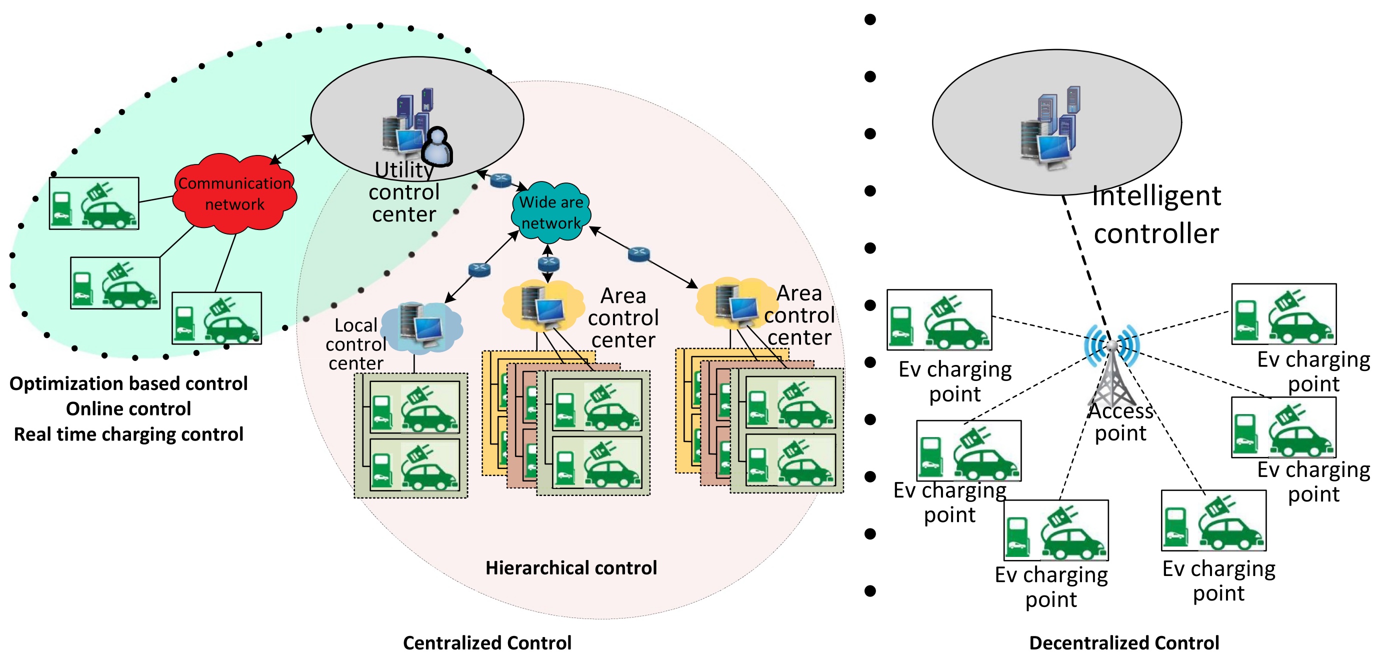


Fig. 13. Centralized and decentralized Control architecture of EV charging system.

5.1. *Impacts of EV integration on the grid*

The impacts of EVGI can be classified into negative and positive. Details are shown in Fig. 15 and discussed in the below subsections.

5.1.1. *Negative impacts*

EVs represent a significant challenge for electric utilities. Excessive integration of EVs into the distribution network can impact the load profile, distribution system component capacity, voltage and frequency imbalances, excessive harmonic injection, power losses and the stability of the distribution grid as summarized in Table 13.

5.1.2. *Positive impacts*

Although excessive EV penetration in the grid can create issues like power quality degradation, rise in peak load and power regulation problems, all these issues can be resolved using advanced power management techniques [199–203]. In Table 14, the positive impacts of EV integration on the grid in a coordinated environment are summarized.

5.2. *EVGI framework*

Traditionally, to charge the batteries of an EV is the primary purpose for the EVGI. However, in today or future smart grid environment, EVs can have another purpose which is to supply power back to the grid and provide ancillary services like harmonic mitigation, reactive power supply, peak power shaving and so on [210]. To serve these purposes, a comprehensive EVGI framework is required, which includes two major areas: technical and market operation areas.

The technical operation area is concerned with the infrastructure and low-level control for power generation, transmission and distribution

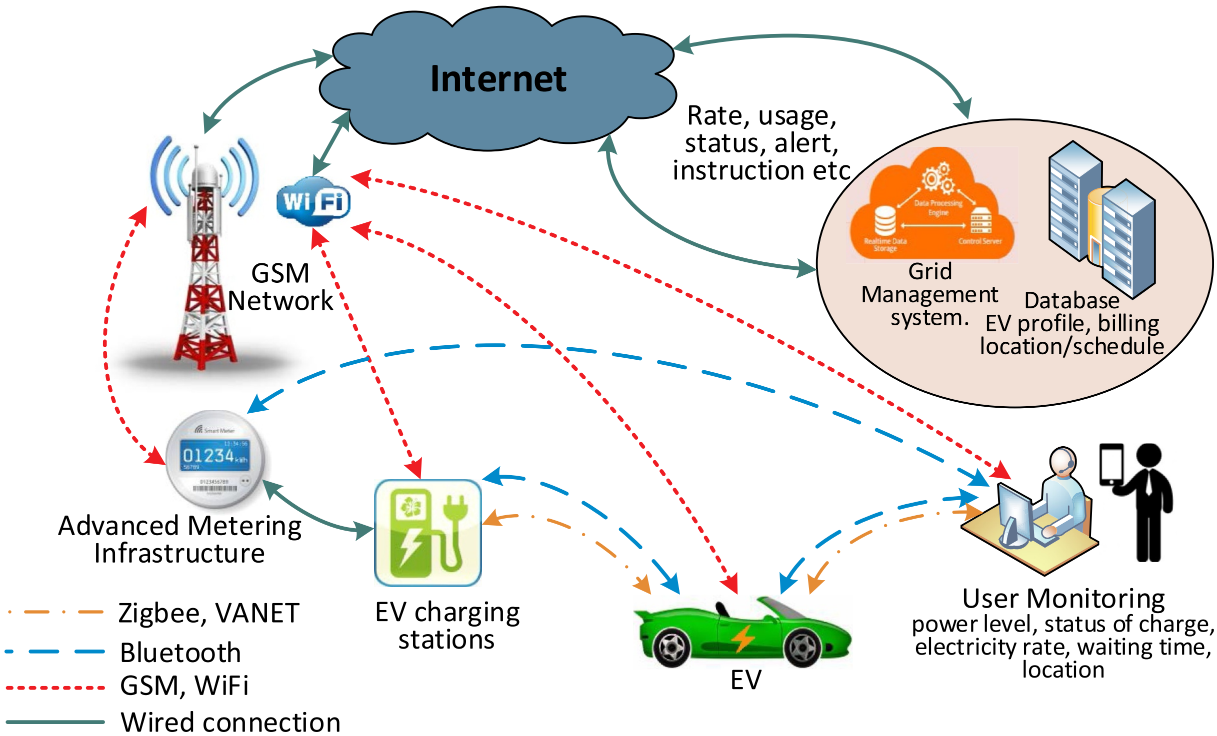


Fig. 14. Communication network for EV charging.

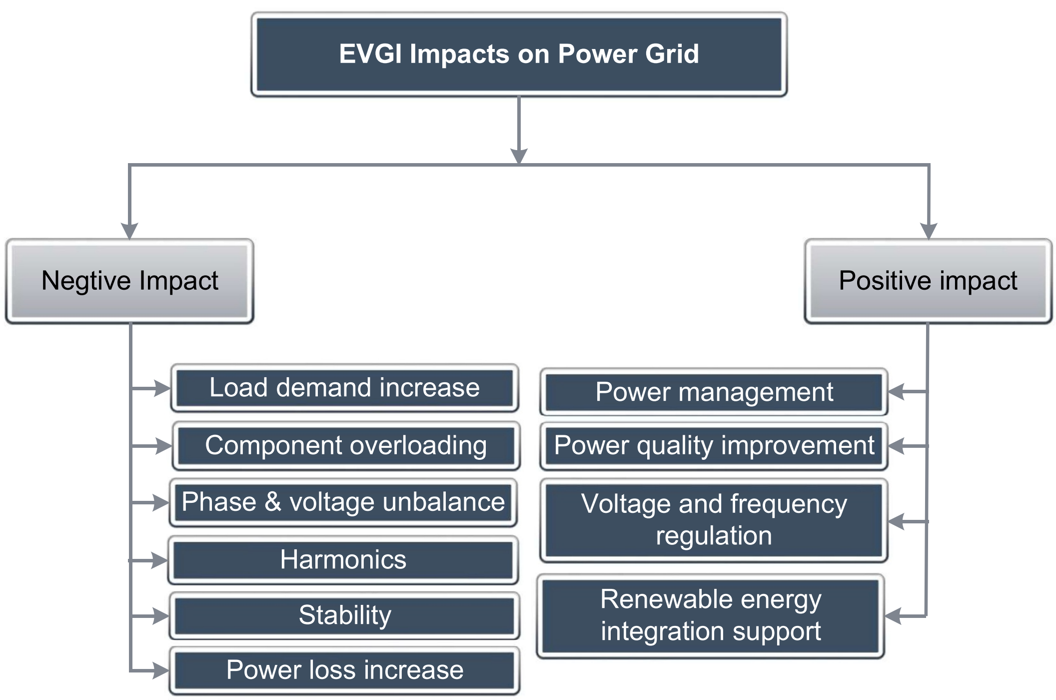


Fig. 15. Impacts of EV grid integration.

management. The power, control and communication infrastructure discussed in Section 4 is a part of the technical operation area. Apart from that, the technical operation also includes low-level management techniques which combine/coordinate among the power, control and communication infrastructure. On the other hand, the market operation includes different types of agents such as generator companies (GENCO), transmission system operators (TSO), distribution system operators (DSO), supplier agents (SA) also known as load serving entities (LSE), private and public electricity prosumers, EV users and so on. To integrate a large number of EVs into the grid, a new entity called EV aggregator is necessary. Basically, an EV aggregator groups the EVs according to EV owners' choice to realize business opportunities in the electricity market. Individual EV's contribution to the market would be insignificant and unreliable, which can be improved by grouping the EVs and operating through EV aggregators. The complete EVGI framework with both technical and market operation is shown in Fig. 16

Table 13
Negative impacts of EV grid integration.

Impacts	Description/method
Load demand increase	- EVGI can add additional loads up to 1000 TWh (25% increase of current levels) [186]. - Uncontrolled EV charging increases load during peak hours which can be a massive problem for utilities [187].
Component overloading	- EVGI in extra large numbers causes additive load demand, which needs to be generated and transmitted. The existing power system components are not designed to handle the extra loads, which can cause component overloading and influence transformer lifespan [188,189].
Phase and voltage unbalance	- EV chargers being single phased, can create phase unbalance if large number of EVs are charged using the same phase [188]. - Current unbalances can create voltage unbalances. - Further EVGI will originate a voltage drop and deviation at interconnection points of EV chargers [190].
Harmonics injection	- The EV chargers are power electronic devices, which generates harmonics during power conversion and causes harmonic pollution in the grid if the penetration is higher. - Some cases conclude that the THD level caused by EV charging is below 1%, however it may increase with the number of chargers connected [191,192].
Power loss	- Large penetration of EVs into the grid causes a massive amount of real power consumption, which leads to power loss in distribution system. - The growth of power loss can reach as high as 40% in the off-peak hours, considering that 60% of the vehicles are EVs connected to the distribution system [193] - Coordinated charging can minimize the power losses as well as maximize the power grid load factor [194]. - Selecting the optimal location and capacity of charging stations can minimizing the power loss in the grid [195].
Stability	- EV loads are nonlinear and draws a large amount power in short duration, which causes instability in the power system [196,197]. - Overall power system becomes more vulnerable to disturbances and it takes longer to return to steady state due to larger penetration of EVs into the grid [192]. - If managed properly, EVGI can increase the stability of the power grid [198].

Table 14
Advantages of EV grid integration.

Advantages	Description/method
Power management	-By using scheduled charging/discharging, better power management can be achieved. - Peak load demand can be met by scheduling discharging during peak hours.
Power quality improvement [74,204,205]	- Voltage surge caused by uncontrolled DER penetration can be solved by controlled EVGI. - Voltage flickers can be smoothed out. - Reactive power can be injected when required. - Harmonics injected by uncontrolled DER can be reduced. - Voltage imbalance can be solved by distributing power flow through phases.
Regulation [206,207]	- Frequency regulation by correcting grid frequency deviation. - Voltage regulation by supplying/absorbing reactive power. - Power flow balance by storing excess power. - Ramping power absorption. - Stability improvement of isolated electric networks.
Renewable energy support [208,209]	- The uncertainty in renewable energy can be suppressed by operating EVs as energy storage. - Using EVs as renewable energy buffer can reduce emission as well as save money.

[211].

5.2.1. *Role of agents in EVGI framework*

The term "Agent" in Fig. 16 is described as a contained program that is capable of controlling their own actions depending on their observation on the operating conditions. Agents in the electric power system should have the characteristics of being autonomous, intelligent, rational and should have learning and incorporating ability [212]. Some agents like GENCOs and LSEs, who act on the wholesale energy market and retail energy market, respectively, are named as *non-regulated agents*. The others like TSO and DSO are named as *regulated agents*. The regulated agents act in natural monopolies, however, consist of incentive-based regulation. Beside these agents, EVGI may require several other agents, such as EV owners, EV supplier-aggregators (EVSA), charging point managers (CPM) and so on. The roles of all these agents are summarized in Table 15.

5.2.2. *Role of EV agregators in EVGI framework*

The EV aggregators act as an interface between the grid and EVs and always take the information of EV drivers, such as charging power demand and connection time via the smart meter, and send them to the grid operators. EV aggregators also have the electricity price and information of charging station locations which are delivered to the EV owners. An EV owner will be benefitted by choosing his aggregator that better fits his needs when several aggregators might coexist in the market. The aggregators will forecast the power demand behavior for the next day and prepare their buy/sell prices through the help of DSO. The DSO analyzes and evaluates the technical feasibility of the demand forecast. If the forecast is acceptable, the aggregator can proceed to the market negotiation. If not, the DSO will ask the aggregator to make the changes needed to make a safe operation [211]. Besides the forecasting of market prices, the aggregator also faces uncertainties in the EV owner's behaviors and preferences. The main sources of uncertainty are departure/arrival times, distances, and preferences (e.g., when and how much to charge the battery).

On the grid side, aggregators will buy electricity from the market at lower prices and they may sell it during the day, at peak hours, taking advantage of their clients' EV storage capability. Aggregators will then compete directly with electricity retailers for energy acquisition and/or with GENCO for selling energy. Also with this approach, it will be possible to have EVs participating in secondary frequency control, through the link of the aggregators with TSO. Additionally, the aggregators can also negotiate with other entities like parking and the battery supplying services for EVs [213]. An overview of the EV aggregators' market activities is shown in Fig. 16.

5.3. *EVGI management techniques*

According to control and communication architecture of EV charging discussed in Section 4, EVGI management can be considered based on EV mobility, coordination, and control structure (Fig. 12). In terms of Coordination, uncoordinated charging means plug-in and charge when needed, which is not suitable for EVGI in the smart grid environment. Therefore, all the EVGI management techniques addressed here are coordinated charging. In terms of Mobility, static-based EVGI requires less information from EVs while dynamic-based EVGI needs more EV dynamic information and therefore is more efficient. Both have their advantages and disadvantages. In terms of Control Structure, EVGI management can be mainly classified into centralized and decentralized/distributed structures/algorithms, where static and dynamic mobility characteristics can fall under both centralized and decentralized/distributed structures. Therefore, for proper review and evaluation, it would be appropriate to categorize them into centralized and decentralized/distributed EVGI management techniques. Those EVGI management techniques are implemented by using different mathematical algorithms, each of which addresses either static or dynamic characteristics in the algorithm development. Based on these natures, the paper presents Table 16 to summarize the centralized charging management algorithms [16,53], [131–150], [151–177] and Table 17 to summarize decentralized/distributed methods [86,178,179,214–243] for EVGI, in

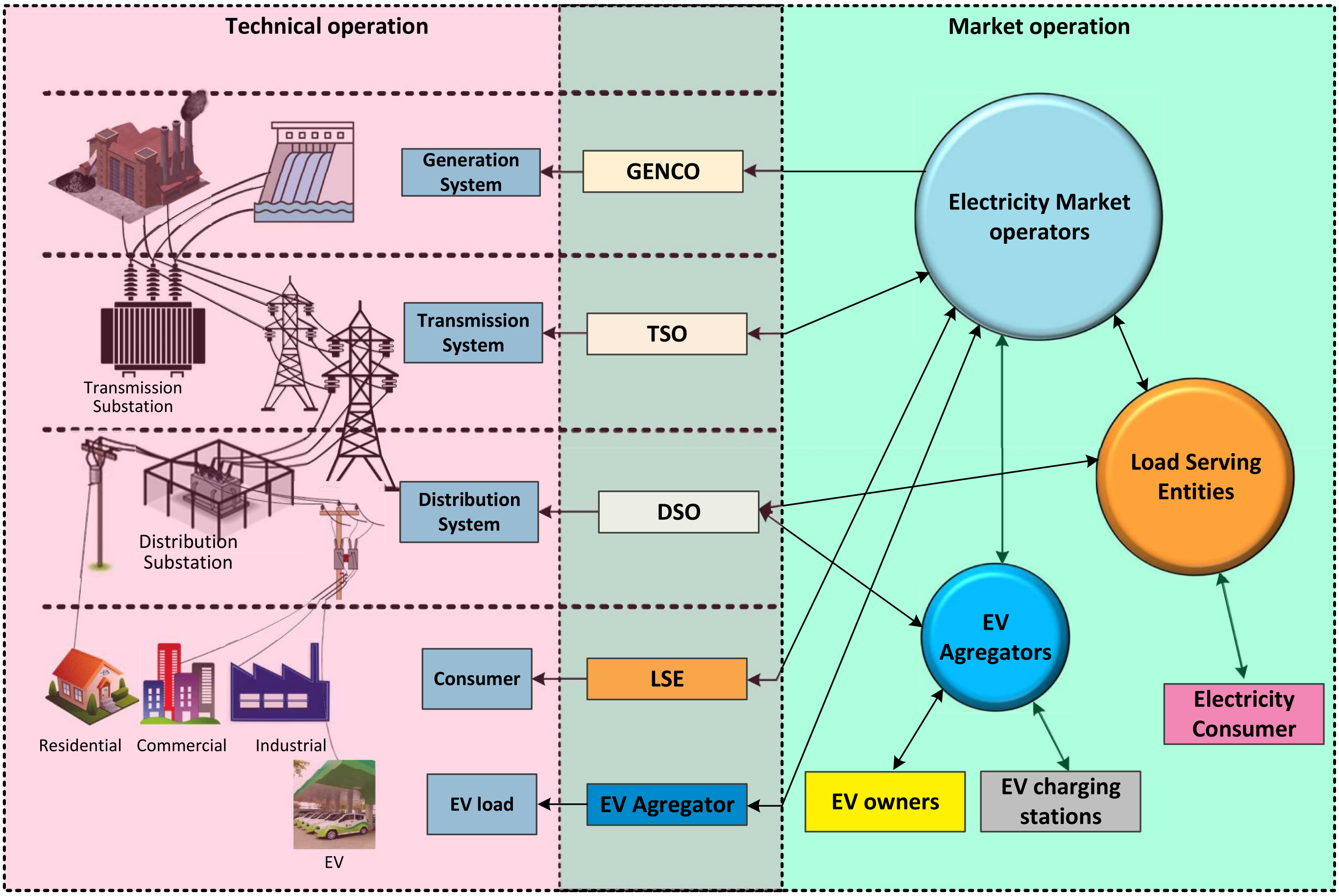


Fig. 16. EV grid integration framework.

Table 15
Role of agents in EV integration framework [211].

Agent Name	Description
GENCO	- responsible for bidding electricity prices into the electricity market. - Ensures profitable power generation and selling to the energy market.
LSE	- Responsible for selling energy to the end users. - Supplier or retailer agent procures the electricity for end users and pays DSO the costs for deregulation and other service costs.
TSO	-Takes care of the operation security of the transmission system - Takes care of the system service procurements like operational reserve and frequency regulation.
DSO	- Takes care of the distribution grid. - Ensures a resilient and secured distribution network. - Provides support to the whole system stability and optimization. - Ensures fair and economic distribution network - Facilitates a competitive energy market.
EV Owner	- Represents each EV and provides load demand to charge the EV battery. - determine the ancillary services EVs can provide through V2G.
EVSA/EV aggregator	- sells the electricity to EV owners - act similar to other wholesale agents.
CPM	- Charging point manager acts as final customer who buys and sells electricity for EV charging/discharging at a charging station

which other sub-classifications include vehicle mobility (static and dynamic), algorithms, objective and constraints of the proposed algorithms.

In centralized charging management (Table 16), the main objective is to provide an optimum charging scheduling based on different constraints, such as grid constraints, price constraints, demand fulfilment and so on. Another attribute of the centralized control algorithms is the vehicle mobility considerations. These control strategies may ignore the vehicle mobility (static) or they can include the randomness in mobility (dynamic). To provide the application examples of the control strategies, the objectives and constraints of several articles are also added in the same table. Among all these centralized charging strategies, real time strategies are latest and they contribute more into smart charging system.

The decentralized/distributed charging mechanisms (Table 17) are one step ahead of centralized charging. They require less computational complexity, can provide real time information on grid loading conditions, and more focused on user convenience. Decentralized charging strategies include optimization based control, predictive control and so on. The strategies mostly incorporate randomness in vehicle mobility and they are more appropriate for real time implementation, due to low computational and communication requirements. Being comparatively new and beneficiary, research area of decentralized/distributed charging is wider. Researchers propose various techniques to minimize energy cost considering a range of limitations in their algorithm. In Table 17, several algorithms are presented to provide an abstract idea.

6. Future development trend of EVGI

Apart from acting as a transportation tool, EVs can operate as electrical loads (G2V), distributed energy storage for the grid (V2G), energy source for other EVs (V2V), energy storage for buildings (V2B), and network communication node [244]. Several new technologies are proposed within the automobile industry that has the potential to increase the usability and effectiveness of EVs in the modern power grid.

Table 16
Summary of different types of centralized system for EV charging management.

Vehicle Mobility	Algorithm	Objectives	Constraints
Static	Linear programming with Fuzzy membership [131,132].	Optimization of total energy cost, total energy loss considering EV charging.	Network security, power quality, and EV charging/discharging constraints.
	Bender's decomposition technique [133,134]	EV charging/discharging scheduling, operational cost minimization.	Grid emissions.
	Nonlinear programming (NLP) [135–137].	EV charging management and scheduling for either multiple charging stations or EV fleet.	Charging price, battery capacity, battery age and remaining charging time.
	Particle swarm optimization (PSO) – Improved particle swarm optimization [53,138,139]	EV charging scheduling. Peak load shaving [139].	Power grid constraints and battery functions. Battery capacity, charging/discharging power limitation.
	Particle swarm optimization (PSO) – Heuristics & proportion-based assignment (HBPA-PSO) [140,141]	EV charging scheduling and control system [140]. EV charging cost minimization [141].	Power grid and battery constraints.
	Artificial Bee Colony [142,143]	Charging schedule focusing minimization of vehicle tardiness. Operation schedule of home appliance and home based EVs to minimize cost.	Grid stability and limitation on maximum power.
	Ant colony optimization [144,145]	Charging scheduling for an EV fleet in a charging station. EV load modelling.	Maximum power supply and maximum power imbalance limitation.
	Dynamic programming [146–148]	EV charging scheduling for reducing peak load demand and charging cost.	Distribution network constraints.
Dynamic	Lagrangian Relaxation method [149–151]	Maximizing the total utility of charging service provider [141]. EV charging scheduling considering bus voltage fluctuation, network power loss [151].	Charge demand fulfillment and Power system capacity (transformer, line flow, bus voltage, power generation) limits.
	Quadratic Optimization [152–154]	Load profile and charging cost optimization.	Customer charging requirements, maximum grid power limit.
	Mixed Integer Linear Programming [16,155,156]	Minimizing frequency deviation of the grid, bidirectional power flow between vehicle and grid, and generating optimal charging/discharging schedule for EVs.	–
	Online coordinated charging decision [157,158].	Minimize charging cost without knowing the future information of EV charging.	–
	On line Multi-objective optimization [159].	The multi-criteria optimization framework includes distribution system losses, rescheduling costs, and wind energy utilization for EV charging.	
	On-line adaptive EV charging scheduling (OACS) [160].	Optimize EV charging schedule to minimize the power flow, and minimize EV charging cost.	Voltage magnitude, three-phase voltage imbalance, and distribution transformer constraints.
	Receding horizon optimization [161,162]	EV charging optimization considering the current and upcoming constraints of the distribution system.	Distribution transformer constraints, phase unbalance, and voltage instability in the distribution network.
	Sliding time window [163,164].	Real-time charging power dispatch and day ahead scheduling.	
	Global and local scheduling optimization [165,166].	Real time charging scheduling as well as day ahead scheduling.	–
	Markov Decision Process [167–169]	Optimal charging schedule considering randomness in traffic conditions and consumer behavior and real time pricing for EV fleet [167]. Jointly control multiple charging stations [168,169].	–
	Day ahead scheduling [170–172]	Day ahead scheduling of flexible small load considering EVs or EV fleet.	
	Model Predictive control [173,174]	Optimal charging schedule with time variant pricing and user charging preference.	
	Risk-aware day ahead scheduling [175–177].	Minimize the charging cost and mismatch between the forecast and actual EV load.	–

The latest technologies include dynamic wireless power transfer (WPT), connected mobility (CM), autonomous or self-driving EVs, EV shared economy and the energy internet. The future of the transportation sector will be revolutionized by using these technologies. In addition, as the future electrified transportation sector is tightly connected with the power grid; it will influence the power and energy network as the technology innovation in the automobile industry develops along these directions.

6.1. Dynamic wireless power transfer

Wireless power transfer is the latest technique to charge/discharge the EVs without any physical contact between source and load. As discussed in section 4.1.3, WPT transfers electrical energy through electromagnetics. There are several advantages of WPT, such as: (1) the physical connection requirement is avoided, which leads to less fault in charging equipment. Also, it helps to start the charging using the software interface (mobile phone, tablet, in-vehicle application). (2) The charging equipment is installed under the ground, which helps to facilitate higher number of EV charging simultaneously in the same size station. In addition, charging equipment is protected from environmental hazards. The next stage of WPT is the dynamic WPT, where the charging equipment is installed under the road. The EVs can charge their batteries while driving on the road [245–247]. A big advantage of the dynamic WPT is the benefit of EVGI with the rapid development of renewable energies. In the United States, many wind and solar power plants are built along the highways, in which the dynamic WPT technology can be integrated with renewable energy technology. For such situation, the electric energy used for charging EVs mainly comes from wind turbines (during the night) and solar photovoltaic arrays (during the day) on both sides of roads, and the power from the main grid can be used as a reserve. This system provides an electric energy source for EVs right close to where the electricity is generated, which helps to reduce the transmission network congestion, reduce power transmission losses, improve the utilization rate of renewable energies, improve power system control and management, and greatly reduce carbon emission from the transportation system. Another future development of WPT is bidirectional power flow facility, which may enable the EVs to assist the grid by providing ancillary services. The EVs can discharge power wirelessly to the grid when the grid load demand is high. It can be done in EV charging stations using static WPT or if the dynamic WPT has bidirectional power flow facility, the EVs can discharge while driving on the road and will not need to stop at any charging station.

6.2. Connected mobility (CM)

Connected mobility (CM) is the concept of communication between vehicle-to-vehicle, vehicle to a roadside base station, passenger, traffic signal, power grid, etc. There are 5 ways a vehicle can be connected to its surroundings and communicate with them [248]: V2I “Vehicle to Infrastructure”, V2V “Vehicle to Vehicle”, V2C “Vehicle to Cloud”, V2P “Vehicle to Pedestrian”, and V2X “Vehicle to Everything”. The V2X technology interconnects all types of vehicles and infrastructure systems with another. Vehicle ad hoc network (VANET) is the communication network created for connected mobility consisting the vehicles, the roadside base stations, and the communication channels. The characteristics of VANET is different from other networks due to being high mobility, rapidly changing network (information, nodes, structure), unbounded network size, time critical and wireless communication dependent [249]. Currently, VANET is used to collect safety related information and apply it to traffic management. However, the usability can be further increased to communicate between autonomous vehicles, charging stations, traffic signals, and distribution grid [89,250]. CM can improve the driving experience, safety, and comfort, whilst reducing congestion and holdups. As an example, only V2V communication implemented in 30% of all road vehicle can reduce 20% of total tail backing [251]. CM concept enhances the use of information technology in vehicles and pushes the vehicle development towards autonomous vehicles. For example, the current development progress of CM is the application of adaptive cruise control, automatic lane keeping, and magic body control. These technologies will also be used in autonomous vehicles. Apart from that, the enhanced application of VANET to ensure V2X communication will overcome the communication barrier for autonomous vehicles. To assess the effect of CM on EVGI, a city driving scenario is needed to consider as shown in Fig. 17. If an EV is required to charge from a charging station (if dynamic WPT is not available), it can charge from different charging stations (station 1 or station 2). Station 1 is closer to the EV, but have higher charging price, also the traffic congestion is high on the road. However, charging station 2 has longer distance, but no traffic on the road and also charging price is lower ($0.15/kWh). If the EV can communicate with the traffic network, power grid network, and other cars to get information about the traffic congestion situation, power grid loading condition, charging price at different charging stations, the owner can determine the most convenient charging station (station 2 in this scenario) with the help of CM. As CM distributes the EVs based on the affecting factors, it improves the grid load management.

6.3. Autonomous electric vehicles

Autonomous or self-driving vehicles are the next generation vehicles, which have the ability to sense their surroundings and act upon it. It is a driverless technology, where the vehicle itself decides the travelling route, identifies road conditions, operates the vehicle to reach the destination set by the user. Six phases of autonomous vehicle development are defined by National Highway Traffic Safety Administration, where L0 is no automated driving, L1 is driver assisted driving; L2 is semi-automated driving, L3 is highly automated driving, L4 is the fully automated driving and L5 is the driverless phase where human will be just passenger [252]. Until now, semi-automated driving phase (L2) is achieved where technologies like adaptive cruise control, automatic lane keeping, magic body control, etc. are implemented and vehicles of this phase are in mass production. The progress on the development of the L5 automated vehicles shows that it will be available in the market by 2035 [253]. In the L5 phase, the characteristics of EVGI will be completely different from those based on the current EVGI technologies. At present, the charging and discharging of an EV is mainly determined and handled by the EV owner based on the owner' travel demand to home or work. As a result, the EV owner usually has to choose a location and time that is convenient to meet the EV owner's travel need which not affecting the EV owner's routine living. Such a charging mechanism may result in a long waiting time and adverse impact of EVGI too, such as transformer overloading, peak load, power network congestion, etc. However, with autonomous EVs in the L5 phase, the charging and discharging of an EV will not be an issue that needs to be worried about by the EV owner. After taking the EV owner to the work, the autonomous EV can find the best place to park the vehicle or determine the best place and time to charge or discharge the vehicle during the day. From the EV owner perspective, the owner can get a favorable payment strategy for charging and discharging of the vehicle. From the EV aggregator perspective, it would be more convenient and efficient for the EV aggregator to play in the competitive power market in the smart grid environment and to be benefitted with more flexible EV management business models. From the electric utility standpoint, EV charging or discharging can be more effectively managed to avoid/reduce the peak load, provide load demand in special cases, participate grid frequency and voltage regulation, and use energy generated from renewable resources. Overall, the autonomous EVs in the L5 phase would result in a totally different business model and higher benefit to the grid for EVGI.

Table 17
Summary of different decentralized/distributed mechanism and system for EV charging.

Strategy	Algorithm	Objectives	Comments
Real time optimization	Non-cooperative game theory [179,214–217]	Minimize the electricity generation cost.	- The constraints are transmission line capacity, distance of EVs and charging stations, and number of ports in the stations.
	Cooperative game theory [218,219]	Optimal scheduling for EV charging/discharging.	- Charging in load valley and discharging in load peak is the win-win strategy for both EV users and the grid.
	Nash Equilibrium [86,220–222].	Fulfill the energy requirement for a large number of EVs ensuring efficient grid operation [220]. Minimize EV charging cost considering the charging requirements and grid constraints.	- The method fulfills the energy requirement by using valley-filling technique. It also maximizes the load factor and minimizes the energy loss. - The constraints are generation capacity and changing electricity price. Peak load shaving is achieved through the game theory approach. - Provides near optimal charging strategies considering the physical constraints.
	Stochastic approach of game theory [223,224].	Peak power reduction and charging cost reduction.	- Has high convergence speed, nearly optimal scheduling result, and moderate load management assuming different penetration of EVs.
	Optimal Decentralized Charging [225–227].	EV charging scheduling	- Has lower computational complexity, thus can be implemented in a real-time environment.
	Shrunken primal-dual subgradient (SPDS) [228,229]	EV charging optimization	- Uses EVs for valley filling and also applicable for DERs and reactive power supplies, and other grid-level services, e.g., minimization of energy cost.
	Nested optimization approach [230]	EV charging optimization	- Requires less computational complexity compared to centralized architecture.
	Probability transition matrix [231]	EV charging optimization	- As no computation is required locally, the computational requirement is low at EV side. - The number of iteration requirement is low which makes it suitable for real-time implementation.
	[232]	minimize the charging cost and provide an optimized charging schedule	- The computational and communication requirement is moderate. - An effective communication between the EVs and aggregator is compulsory to update the load profile.
	Lyapunov optimization and Lagrange dual decomposition Technique [233].	minimize grid energy cost and integrate local renewable energy sources	- The constraints are overloading of distribution grid and random uncontrollable loads.
Model predictive control	Model Predictive control [234].	Energy management of MVDC PV based EV charging station.	- Discusses the efficient operation of a grid-connected EV charging station.
	Decentralized PEV-charging selection algorithm [235].	EV charging optimization	- Focuses on user convenience such as state of charge, charging time and charging cost. - Low speed communication system is sufficient and user data protection is ensured.
Others	Price/quantity-based mechanism [236].	EV charging optimization	- The charging method includes a system operator and a load aggregator, which determines general dispatch and EV charging schedule, respectively.
	Fuzzy logic control [237].	Mitigate the effect of EV charging on the electric power grid	- The proposed EV charger can automatically regulate the battery charging current according to the changes in the grid and EV.
	Plug-and-Play Decentralized Control [238].	EV charging control	- The stability is analyzed by Lyapunov function. The parking lot is able to operate seamlessly for bidirectional power flow with high efficiency.
	Voltage control [239].	EV charging station control.	- Voltage control of common DC bus is proposed for the PV-battery-grid based charging station.
	Fuzzy logic control [239,240].	EV charging station control.	- State of charge of the storage system in the charging station and the voltage of the DC bus are defined as the control variable of the fuzzy logic controller.
	A multi agent-based scheduling algorithm [241–243].	EV charging scheduling.	- The objective is to maximize the profit by designing the pricing policy and to provide an optimal charging schedule for EVs.

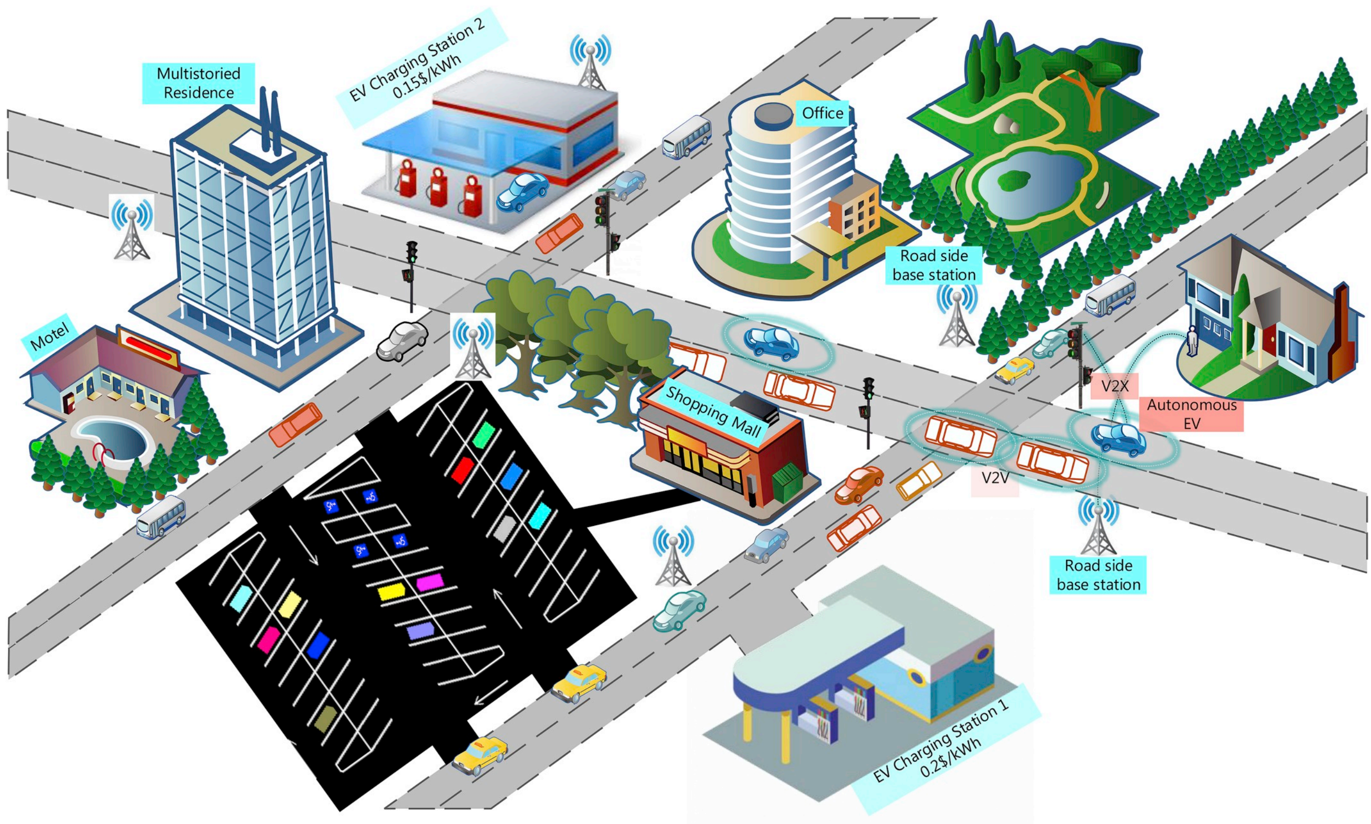


Fig. 17. Illustration of connected mobility and autonomous EV charging scenarion in city.

6.4. EV shared economy

With the technological advancement in EV technologies, a new concept of vehicle ownership may evolve in the near future using the shared economy or collaborative consumption concept. As the vehicles are self-driven, self-charged/discharged, and require lower supervision (only mechanical maintenance), they can change the present vehicle ownership trend. Using the collaborative consumption concept, general people can share the vehicle for their daily travel, and the vehicles are owned by a third party company such as Uber, Airbnb, google and so on [254]. China has already developed car hailing and bicycle sharing services, which is very popular among the users [255]. Individual ownership of EVs that causes problems, such as control and coordination of operation, power grid interaction, data usage and privacy protection, and so on, will be reduced by the vehicle sharing facility [256]. Simultaneously, using internet of things, big data facility, artificial intelligence, and other information technologies, EV companies can optimize the EV operation, power grid and transportation system interaction to meet the travel needs of the general public, at the same time increase the profit margin. Shared economy has the ability to change the EV charging/discharging pattern. Usually, EVs owned by individuals are mostly charged at home or workplace when the vehicle is idle. The idle time for individual EV is high. However, using shared economy, vehicle mobility increases dramatically. As a result, the charging requirement for individual EV increases. As the EV mobility demand increases, and the vehicle charging needs to be faster. Thus, with shared economy, individual EV charging demand will be high in short period. Moreover, with shared economy, the vehicle mobility cannot be specified because it depends on the passenger travelling destinations. It will create a randomness in vehicle charging pattern. The randomness is both in spatial and temporal, and it greatly affects the power grid. To minimize the adverse effect of shared economy on the grid, monitoring of the distribution grid loading and sharing the information with the EVs in real time can be effective. Moreover, real-time pricing in charging and discharging the EVs can also assist in this regard.

6.5. Energy internet

EVs may play a vital role in the development of the energy internet (EI) technology [257]. The EI concept, first introduced by Jeremy Rifkin [258], is to unify the power, transportation, gas, and thermal systems in a single platform as shown in Fig. 18 [259], in which energy can be transformed for heating and cooling using boilers and chillers, or it can be transformed into electrical power by using different types of power plants. One of the vital element in this interrelated network is the EVs and FCEVs because they are connected to energy, power, and transportation network simultaneously. The most challenging part for the interoperability is the communication and control in the EI. The information network collects data from each of the networks, processes and generates optimal operating criteria for each of the networks, and provides the intelligent control algorithm [260].

Also, renewable energy based systems operate as the primary energy source in the EI. The intermittency of renewable energy based systems can be mitigated by efficient EV integration to the EI. Intelligent EV charging methods can be developed to meet power demand/supply needs at each node of the distribution network [261]. With the help of EV aggregators, EVs can act as giant energy storage for the EI. Moreover, ancillary services provided by EVs will make the EI more efficient and reliable.

7. Summary and discussion on EV charging and grid integration

7.1. Challenges and suggestions for EV charging

The popularity of EV highly depends on the factors like driving range, the convenience of refueling, and cost. These factors are mostly

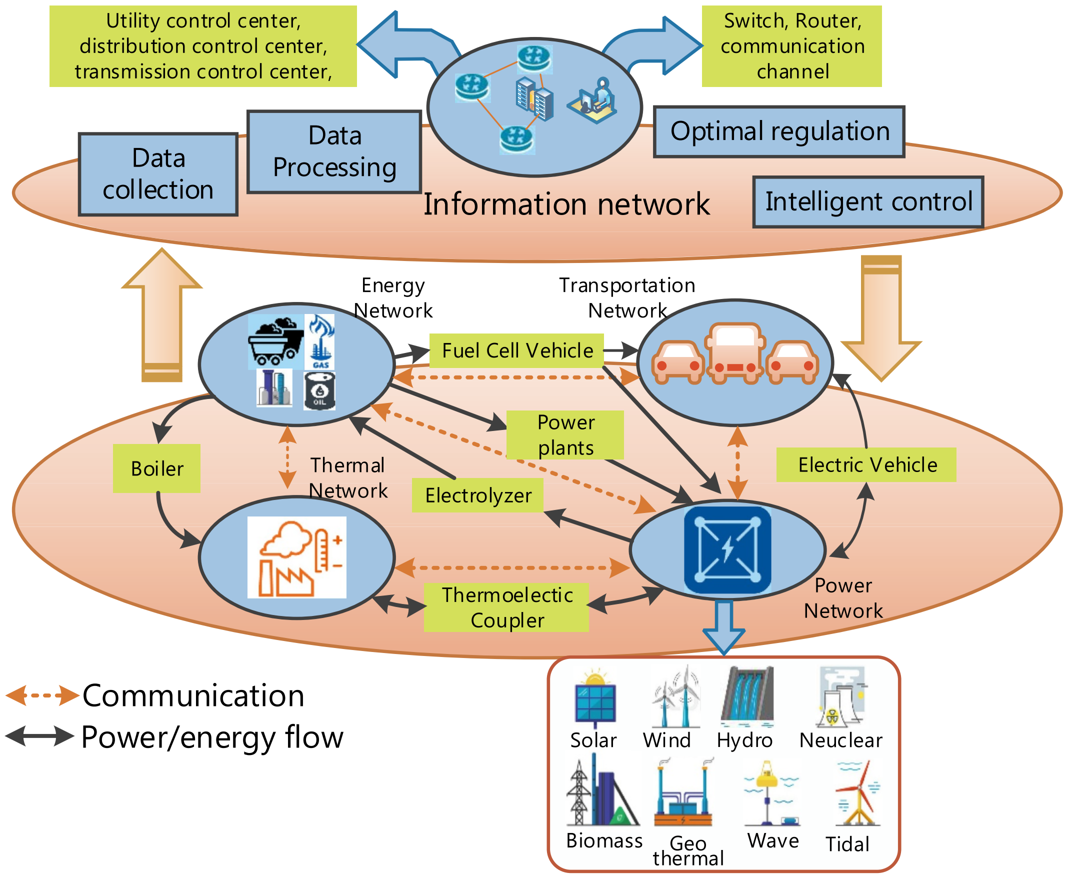


Fig. 18. The energy internet structure.

associated with the EV charging infrastructure. The challenges and suggestions regarding EV charging are pointed out below.

- The standards for manufacturing charging equipment are not common globally. For example, Japan, USA, and Europe use separate charging connector standards [262]. Homogeneity in charging standards and devices can bring the cost down and make EVs more popular in the market.
- At present, not all the EV models support all levels of charging, similarly not all the public charging stations have charging facility for all power levels. Due to this, EV users face difficulties to find convenient charging stations.
- Currently, demand charges are imposed on the fast charging facility users, which requires a user to pay a fixed monthly demand charge and makes the EV owners demotivated towards using EVs since they cannot charge their EVs flexibly based on a flexible electricity rate. Policy modification regarding the fixed demand charge can reduce the dissatisfaction of EV owners [262].
- As charging stations are set up by different companies in different places, charging facility layouts of the charging stations are diverse. The users find it inconvenient to adapt with unalike layouts of charging facilities. A unified charging facility layout similar to ICEV refueling stations will increase the EV popularity.
- The establishment of private fast-charging facilities, such as at home, is still an issue, which normally requires EV owners to have permissions from the local utility providers and government. This lengthy process demotivates EV owners to set up private fast-charging facilities to meet their demands.
- Planning EV charging station locations in cities as well as in highways are important. At present, locations of EV charging stations are planned mostly in cities while most of the highways are yet to be included in the plan, which concerns the EV owners.
- Charging stations can use renewable energy, such as PV or wind energy. However, design and implementation of such charging stations are costly and require large space. Renewable energy based EV charging stations are best suitable in the highways where a lot of unused lands are available.

7.2. Challenges and suggestions for EVGI

The current situation of EVGI can be further improved based on the smart grid technology. The following issues are worth further study for establishing smart grid network where interaction between EVs, power grids, and transportation networks takes place.

- An efficient operational mechanism is mandatory for efficient EVGI. However, the current research is yet to be successful in this regard. For example, EV mobility is not accurately considered in some studies while developing EVGI mechanisms.
- In the modern grid, EVs work as electrical load, transportation media, energy storage, as well as communication nodes. They operate as a channel to interconnect the electricity grid, traffic network, and communication network. Thus, while designing an EV charging scheduling system, the aforementioned factors should be considered.
- At present, the scheduling is performed using off-peak charging [263,264]. Introducing time-variable and charging power level (Level 2 or 3) rates for customers would help to resolve the grid-overloading problem. A coordinated smart charging system with an aggregator is the best option for making the distribution system reliable and stable.

- Currently, wireless charging technologies are designed only for G2V operation. With the advancement of the wireless charging, EVs should facilitate the bidirectional WPT to perform several ancillary services to the grid.

7.3. Discussion on future EVGI development trend

The current development trend of EVGI can be further improved based on the energy internet technology. The following issues are worth further study for establishing energy internet where interaction between EVs, power grids, energy network and transportation networks are unified.

- Presently, dynamic WPT system is in prototype phase. In addition, bidirectional power flow for dynamic charging is not developed yet. Future research should be more focused in this area to develop bidirectional dynamic WPT system.
- Connected mobility implementation requires expansion in VANET technology. If the capacity of VANET can be expanded to integrate power grid, traffic network, EVs and users, it can help to move forward for better EVGI experience.
- Autonomous EVs are now in L2 development phase, which can be accelerated to reach L5. Fully autonomous EVs can offer a lot to transportation network as well as power grid through EVGI.
- With shared economy concept, the benefit of autonomous EVs and EVGI can be fully utilized. Well-developed business model can be beneficiary for EV owner, user, as well as utility companies.
- Energy internet is the future grid structure, where EVs can play a key role by unifying the power, transportation, energy, as well as communication network. A plenty of development in each sector is required to develop a fully functioning energy internet.

8. Conclusion

With the advancement of EV technology, charging infrastructure and grid integration facilities, EV popularity is expected to increase significantly in the next decade. Therefore, further technological advancements such as the suitable smart charging infrastructure, reliable communication systems, and coordinated charging system to quantify the impacts on the power grid are essential to ensure maximum benefits from EVs with distributed generators. Moreover, the Energy Internet could be a future grid technology, which will make the power system fully automated with advanced energy management systems. This paper discusses all the aspects of EV charging and grid integration infrastructure. Having unified standards for EVs and its charging infrastructure all over the world is a primary necessity for EVs to gain popularity in the market. The popular standards related to EV charging and grid integration are discussed elaborately so that future researchers can get a good picture of the specifications required to meet. Besides, different aspects of the existing charging and grid integration infrastructure such as the power, communication, control, and coordination are reviewed in a rigorous manner consisting of their advantages and drawbacks. Suggestions on future research to overcome the current challenges are also presented in this paper. A discussion on the future prospect of EVs proves the necessity of having a review in this research area. It is our intension that this review could provide a clear picture of the state of art of EV charging and grid integration research to the researchers and engineers.

Acknowledgement

The authors would like to pay gratitude to the Department of Electrical and Computer engineering, Graduate School and Library of The University of Alabama for the infrastructure, funding and library supports. Lastly, thanks to our colleagues who have contributed either directly or indirectly to the completion of this work.

References

[1] Abedin MR, Das HS. Electricity from rice husk: a potential way to electrify rural Bangladesh. Int J Renew Energy Resour 2014;4(3):604–9.
[2] Tie SF, Tan CW. A review of energy sources and energy management system in electric vehicles. Renew Sustain Energy Rev 2013;20:82–102.
[3] Hannan M, Azidin F, Mohamed A. Hybrid electric vehicles and their challenges: a review. Renew Sustain Energy Rev 2014;29:135–50.
[4] Hannan M, et al. Review of energy storage systems for electric vehicle applications: issues and challenges. Renew Sustain Energy Rev 2017;69:771–89.
[5] Singh M, Kumar P, Kar I. A multi charging station for electric vehicles and its utilization for load management and the grid support. Smart Grid, IEEE Transactions on 2013;4(2):1026–37.
[6] Arancibia A, Strunz K. Modeling of an electric vehicle charging station for fast DC charging. In: Electric vehicle conference (IEVC). 2012 IEEE International; 2012 [IEEE].
[7] Yilmaz M, Krein PT. Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles. Power Electronics, IEEE Transactions on 2013;28(5):2151–69.
[8] Ahmad A, et al. A review of the electric vehicle charging techniques, standards, progression and evolution of EV technologies in Germany. Smart Science 2018;6(1):36–53.
[9] Zhang Q, et al. Factors influencing the economics of public charging infrastructures for EV–A review. Renew Sustain Energy Rev 2018;94:500–9.
[10] Tan KM, Ramachandaramurthy VK, Yong JY. Integration of electric vehicles in smart grid: a review on vehicle to grid technologies and optimization techniques. Renew Sustain Energy Rev 2016;53:720–32.
[11] Sharma A, Sharma S. Review of power electronics in vehicle-to-grid systems. Journal of Energy Storage 2019;21:337–61.
[12] Habib S, Kamran M, Rashid U. Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks–a review. J Power Sources 2015;277:205–14.
[13] Yilmaz M, Krein PT. Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces. IEEE Trans Power Electron 2013;28(12):5673–89.
[14] Green II RC, Wang L, Alam M. The impact of plug-in hybrid electric vehicles on distribution networks: a review and outlook. Renew Sustain Energy Rev 2011;15(1):544–53.
[15] Mwasilu F, et al. Electric vehicles and smart grid interaction: a review on vehicle to grid and renewable energy sources integration. Renew Sustain Energy Rev 2014;34:501–16.
[16] Faddel S, Al-Awami A, Mohammed O. Charge control and operation of electric vehicles in power grids: a review. Energies 2018;11(4):701.
[17] Knutsen D, Willén O. A study of electric vehicle charging patterns and range anxiety. 2013.
[18] Purwadi A, Dozeno J, Heryana N. Simulation and testing of a typical on-board charger for ITB electric vehicle prototype Application. Procedia Technology 2013;11:974–9.
[19] Volkswagen e-Up. 2018 [cited 2018 July 10]; Available from: http://www.volkswagen.co.uk/new/up-pa/which-model-compare/details/2800; 2018.
[20] Nissan LEAF [cited 2018 July 10]; Available from: https://www.nissanusa.com/vehicles/electric-cars/leaf/build-price.html#configure/AnY/version; 2018. 2018.
[21] Chevrolet volt. 2018 [cited 2018 July 10]; Available from: https://www.chevrolet.com/electric/volt-plug-in-hybrid; 2018.
[22] BMW i3. 2018 [cited 2018 July 10]; Available from: https://www.bmwusa.com/vehicles/bmwi/bmw-i3.html; 2018.
[23] Chevrolet spark. 2016 [cited 2018 July 10]; Available from: https://www.chevrolet.com/cars/spark-subcompact-car/build-and-price/features/trims/?styleOne=399827; 2016.
[24] Honda fit EV. 2014 [cited 2018 July 10]; Available from: https://automobiles.honda.com/images/2013/fit-ev/downloads/Automobile_Magazine.pdf; 2014.
[25] Honda clarity electric.. 2018 [cited 2018 July 10]; Available from: https://automobiles.honda.com/clarity-electric; 2018.
[26] Ford focus. 2018; Available from, https://media.ford.com/content/dam/fordmedia/North%20America/US/product/2016/2016-ford-focus-electric-tech-specs.pdf; 2018.
[27] Tesla model X. 2018 [cited 2018 July 10]; Available from: https://www.tesla.com/modelx; 2018.
[28] Tesla model 3. 2018 [cited 2018 July 10]; Available from: https://www.tesla.com/model3; 2017.
[29] Kia soul. 2018 [cited 208 July 10]; Available from: https://www.kiamedia.com/us/en/models/soul-ev/2018/specifications; 2018.
[30] Ford focus. 2018 [cited 2018 July 10]; Available from: https://media.ford.com/content/dam/fordmedia/North%20America/US/product/2016/2016-ford-focus-electric-tech-specs.pdf; 2018.
[31] Renault zoe. 2017 [cited 2018 July 10]; Available from: https://insideevs.com/new-2017-renault-zoe-ze-40-400-km-range-41-kwh-battery/; 2017.
[32] Renault twizy. 2017 [cited 2018 July 10]; Available from: https://www.guideautoweb.com/en/makes/renault/twizy/2017/specifications/40/.
[33] Toyota prius prime. 2018 [cited 2018 July 10]; Available from: https://www.toyota.com/priusprime/faq/; 2018.
[34] Heydari A, Askarzadeh A. Techno-economic analysis of a PV/biomass/fuel cell energy system considering different fuel cell system initial capital costs. Sol Energy 2016;133:409–20.
[35] Global EV Outlook 2019. International Energy Agency; 2019.

[36] Oron A. Top 10 countries in the global EV revolution. 2018 Edition. InsideEVs; 2019.
[37] Global EV. Outlook. International Energy Agency (IEA); 2017.
[38] Bi Z, et al. A review of wireless power transfer for electric vehicles: prospects to enhance sustainable mobility. Appl Energy 2016;179:413–25.
[39] Zhong Q-C. EV integration and the SYNDEM smart grid architecture. IEEE Transportation Electrification Community; 2017. September 2017.
[40] Carmakers STILL failing to hit their own goals for sales of electric cars. Transport & environment; 2018.
[41] Karali N, et al. Vehicle-grid integration. Lawrence Berkeley National Laboratory; 2017.
[42] Su W. Smart grid operations integrated with plug-in electric vehicles and renewable energy resources. North Carolina: North Carolina State University; 2013.
[43] California electric vehicle fast charging stations. California: California Energy Commission; 2014.
[44] Tesla supercharger station locator. cited 2018 July 16]; Available from: https://supercharge.info/; 2018.
[45] CAA electric vehicle charging station locator [cited 2018 July 16]; Available from: http://www.caa.ca/evstations/; 2018.
[46] Marnay C, et al. Los angeles air force base vehicle to grid pilot project. In: ECEEE 2013 summer study on energy efficiency. France: Toulon/Hyères; 2013.
[47] Millner A, et al. Enhanced plug-in hybrid electric vehicles. In: Innovative technologies for an efficient and reliable electricity supply (CITRES), 2010 IEEE conference on. IEEE; 2010.
[48] Leskarac D, et al. PEV charging technologies and V2G on distributed systems and utility interfaces. Vehicle-to-Grid: Linking Electric Vehicles to the Smart Grid 2015;79:157–209.
[49] Foley A, Winning I, Gallachóir BÓ. State-of-the-art in electric vehicle charging infrastructure. In: IEEE vehicle power and propulsion conference. IEEE; 2010. 2010.
[50] SAE standards. 2019 [cited 2019 28th August]; Available from: https://www.sae.org/standards/.
[51] CHAdeMO protocol development. 2018 [cited 2019 28th August]; Available from: https://www.chademo.com/activities/protocol-development/.
[52] IEEE standard for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces. IEEE Std; 2018. p. 1–138. 1547-2018 (Revision of IEEE Std 1547-2003).
[53] Zhu T, Zheng H, Ma Z. A chaotic particle swarm optimization algorithm for solving optimal power system problem of electric vehicle. Adv Mech Eng 2019;11(3). 1687814019833500.
[54] Association NFP. Nfpa 70: national electrical code. National Fire Protection Assoc; 2017.
[55] National electrical code [cited 2019 28th August]; Available from: https://www.nfpa.org/NEC; 2011.
[56] Deutsches Institut fuer Normung [cited 2019 28th August]; Available from: https://www.din.de/en; 2019.
[57] Kusakana, K., J.L. Munda, and A.A. Jimoh. Feasibility study of a hybrid PV-micro hydro system for rural electrification. IEEE.
[58] Sae j2293-2: energy transfer system for electric vehicles - Part 2: communication requirements and network architecture. SAE International 1997:180.
[59] Sae j2293-1: energy transfer system for electric vehicles - Part 1: functional requirements and system Architecture (stabilized type). SAE International 1997:85.
[60] Sae J1772: SAE surface vehicle recommended practice J1772, SAE electric vehicle conductive charge coupler. SAE International 2001. 51 pages.
[61] Sae J1773: SAE electric vehicle inductively coupled charging. SAE International 2014:35.
[62] Digital communications for plug-in electric vehicles j2931/1. 2012 [cited 2018 August 24]; Available from: https://www.sae.org/standards/content/j2931/1/.
[63] Wireless power transfer for light-duty plug-in/electric vehicles and alignment methodology. SAE International; 2016.
[64] Basso TS, DeBlasio R. IEEE 1547 series of standards: interconnection issues. IEEE Trans Power Electron 2004;19(5):1159–62.
[65] UL 1741: standard for inverters, converters, controllers and interconnection system equipment for use with distributed energy resources. 2010. 2010-01-28 [cited 2018 July 19]; Available from: https://standardscatalog.ul.com/standards/en/standard_1741_2.
[66] UL 62109: power Converters for Use in PV systems [cited 2018 July 17]; Available from: https://lms.ulknowledgeservices.com/catalog/display.resource.aspx?resourceid=495868; 2017.
[67] Picco S. Inverter advancements in UL1741 and UL 62109. 2015.
[68] Ideal power UL 1741 SA advanced inverter features. Ideal Power Inc; 2017.
[69] Budhiraja N. EV charging standards in China and Japan [cited 2018 August 16]; Available from: https://ihsmarkit.com/research-analysis/ev-charging-standards-in-china-and-japan.html; 2018.
[70] Painuli, S., M.S. Rawat, and D.R. Rayudu, A comprehensive review on electric vehicles operation, Development and Grid Stability.
[71] Solectria PVI-15kW-208VAC [cited 2014; Available from: http://www.solar-catalog.com/inverter_m_comm_solectria.html; 2014.
[72] Gjelaj M, et al. Cost-benefit analysis of a novel DC fast-charging station with a local battery storage for EVs. In: Universities power engineering conference (UPEC), 2017 52nd international. IEEE; 2017.
[73] Elsayed AT, Mohamed AA, Mohammed OA. DC microgrids and distribution systems: an overview. Electr Power Syst Res 2015;119:407–17.
[74] Taghizadeh S, et al. A unified multi-functional on-board EV charger for power-quality control in household networks. Appl Energy 2018;215:186–201.
[75] Lee B-K, et al. A PWM SRT dc/dc converter for 6.6-kw EV onboard charger. IEEE Trans Ind Electron 2016;63(2):894–902.
[76] Lee C-S, et al. Study on 1.5 kW battery chargers for neighborhood electric vehicles. In: Vehicle power and propulsion conference (VPPC). IEEE; 2011. 2011. IEEE.
[77] Strnad I, Skrlec D, Tomisa T. A model for the efficient use of electricity produced from renewable energy sources for electric vehicle charging. In: Energy (IYCE), 2013 4th international youth conference on. IEEE; 2013.
[78] Yong JY, et al. Modeling of electric vehicle fast charging station and impact on network voltage. In: Clean energy and technology (CEAT). IEEE; 2013. IEEE Conference on. 2013.
[79] Sparacino AR, et al. Design and simulation of a DC electric vehicle charging station connected to a MVDC infrastructure. In: Energy conversion congress and exposition (ECCE). IEEE; 2012. 2012. IEEE.
[80] Tijani HO, Tan CW, Bashir N. Techno-economic analysis of hybrid photovoltaic/diesel/battery off-grid system in northern Nigeria. J Renew Sustain Energy 2014;6(3).
[81] Musavi F, Eberle W. Overview of wireless power transfer technologies for electric vehicle battery charging. IET Power Electron 2014;7(1):60–6.
[82] Yilmaz M, Krein PT. Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles. IEEE Trans Power Electron 2013;28(5):2151–69.
[83] Morrow K, Karner D, Francfort J. Plug-in hybrid electric vehicle charging infrastructure review. US Department of Energy-Vehicle Technologies Program 2008;34.
[84] Sheikhi A, et al. Strategic charging method for plugged in hybrid electric vehicles in smart grids; a game theoretic approach. Int J Electr Power Energy Syst 2013;53:499–506.
[85] Fox GH. Electric vehicle charging stations: are we prepared? IEEE Ind Appl Mag 2013;19(4):32–8.
[86] Sheikhi A, et al. Strategic charging method for plugged in hybrid electric vehicles in smart grids; a game theoretic approach. Int J Electr Power Energy Syst 2013;53:499–506.
[87] Schroeder A, Traber T. The economics of fast charging infrastructure for electric vehicles. Energy Policy 2012;43:136–44.
[88] CHAdeMO. Desirable characteristics of a public fast charger. 2011.
[89] Cao Y, et al. Intelligent transportation systems enabled ICT framework for electric vehicle charging in smart city. In: Handbook of smart cities. Springer; 2018. p. 311–30.
[90] Wu HH, et al. A review on inductive charging for electric vehicles. In: Electric machines & drives conference (IEMDC). IEEE International; 2011. 2011. IEEE.
[91] Choi SY, et al. Generalized active EMF cancel methods for wireless electric vehicles. Power Electronics, IEEE Transactions on 2014;29(11):5770–83.
[92] Gao L-k, et al. Design of energy feedback mode wireless charging system for electric vehicles. In: Industrial electronics and applications (ICIEA). IEEE; 2013. 8th IEEE Conference on. 2013.
[93] Salem M, et al. A review of an inductive power transfer system for EV battery charger. Eur J Sci Res 2015;134:41–56.
[94] Fujibe H, Kesamaru K. Magnetic field analysis of wireless power transfer via magnetic resonant coupling for electric vehicle. In: Electrical machines and systems (ICEMS), 2013 international conference on. IEEE; 2013.
[95] Krishnan S, et al. Frequency agile resonance-based wireless charging system for Electric Vehicles. In: Electric vehicle conference (IEVC). IEEE International; 2012. 2012. IEEE.
[96] Kotchapansompote P, et al. Electric vehicle automatic stop using wireless power transfer antennas. In: IECON 2011-37th annual conference on IEEE Industrial Electronics Society. IEEE; 2011.
[97] Kim J, Bien F. Electric field coupling technique of wireless power transfer for electric vehicles. In: TENCON spring conference. IEEE; 2013. 2013. IEEE.
[98] Moon H, Ahn S, Chun Y. Design of a novel resonant reactive shield for wireless charging system in electric vehicle. In: 2014 IEEE wireless power transfer conference; 2014.
[99] Shinohara N, Kubo Y, Tonomura H. Wireless charging for electric vehicle with microwaves. In: Electric drives production conference (EDPC). IEEE; 2013. 2013 3rd International.
[100] Ahn S, Kim J. Magnetic field design for high efficient and low EMF wireless power transfer in on-line electric vehicle. In: Antennas and propagation (EUCAP), proceedings of the 5th European conference on. IEEE; 2011.
[101] Baek J, et al. High frequency magnetic resonant coupling wireless power transfer system for middle power charging applications. In: 2016 18th European conference on power electronics and applications (EPE'16 ECCE Europe); 2016.
[102] Wang Y, et al. Research on magnetic coupling resonance wireless power transfer system with variable coil structure. In: Emerging technologies: wireless power transfer (WoW). IEEE; 2017. IEEE PELS Workshop on. 2017.
[103] Chen L, et al. An optimizable circuit structure for high-efficiency wireless power transfer. IEEE Trans Ind Electron 2013;60(1):339–49.
[104] Kim M, et al. A three-phase wireless-power-transfer system for online electric vehicles with reduction of leakage magnetic fields. IEEE Trans Microw Theory Tech 2015;63(11):3806–13.
[105] Shin J, et al. Design and implementation of shaped magnetic-resonance-based wireless power transfer system for roadway-powered moving electric vehicles. IEEE Trans Ind Electron 2014;61(3):1179–92.
[106] Ahn S, Suh NP, Cho D-H. Charging up the road. IEEE Spectrum 2013;50(4):48–54.

[107] Moon H, et al. Design of a resonant reactive shield with double coils and a phase shifter for wireless charging of electric vehicles. IEEE Trans Magn 2015;51(3):1–4.
[108] Brown WC. The history of power transmission by radio waves. IEEE Trans Microw Theory Tech 1984;32(9):1230–42.
[109] Villa JL, et al. Design of a high frequency inductively coupled power transfer system for electric vehicle battery charge. Appl Energy 2009;86(3):355–63.
[110] Loughran J. Qi wireless charging standard emerges victorious; adoption rapidly increasing. In: E&T. The IET; 2017.
[111] Hui SYR, Zhong W, Lee CK. A critical review of recent progress in mid-range wireless power transfer. IEEE Trans Power Electron 2014;29(9):4500–11.
[112] Li W. High efficiency wireless power transmission at low frequency using permanent magnet coupling. University of British Columbia; 2009.
[113] Sortomme E, El-Sharkawi MA. Optimal charging strategies for unidirectional vehicle-to-grid. IEEE Transactions on Smart Grid 2011;2(1):131–8.
[114] Kisacikoglu MC, Kesler M, Tolbert LM. Single-phase on-board bidirectional PEV charger for V2G reactive power operation. IEEE Transactions on Smart Grid 2015;6(2):767–75.
[115] Communications requirements of smart grid technologies. Department of Energy 2010:69.
[116] Uddin M, et al. A review on peak load shaving strategies. Renew Sustain Energy Rev 2018;82:3323–32.
[117] Sortomme E, El-Sharkawi MA. Optimal scheduling of vehicle-to-grid energy and ancillary services. IEEE Transactions on Smart Grid 2012;3(1):351–9.
[118] Sortomme E, El-Sharkawi MA. Optimal combined bidding of vehicle-to-grid ancillary services. IEEE Transactions on Smart Grid 2012;3(1):70–9.
[119] Mukherjee JC, Gupta A. A review of charge scheduling of electric vehicles in smart grid. IEEE Systems Journal 2015;9(4):1541–53.
[120] Van Vliet O, et al. Energy use, cost and CO2 emissions of electric cars. J Power Sources 2011;196(4):2298–310.
[121] Galus MD, Zima M, Andersson G. On integration of plug-in hybrid electric vehicles into existing power system structures. Energy Policy 2010;38(11):6736–45.
[122] Masoum MA, Moses PS, Hajforoosh S. Distribution transformer stress in smart grid with coordinated charging of plug-in electric vehicles. In: Innovative smart grid technologies (ISGT). 2012 IEEE PES; 2012. IEEE.
[123] Rate information – residential rates electric vehicles. 2018 [cited 2018 March 3,]; Available from: https://www.sce.com/wps/portal/home/residential/electric-cars/residential-rates/!ut/p/b1/hc6xDoIwGATgZ_EJerSElrGNpP1RQQQRuxgmQqLoYHx-a8KiiXrbJd8lxzzrmJ_6xzj09_E69edX98kpUlY7qkF232iQWZrIbQgo4gCOAeBLNP7tD8y_E9XYLJAV0nbLRSzlJ7A7yUF5m61LE3EoPoPUInN5GUBTCZCoUNRaCyCZwY-Tt0uHkYbFE6cHVUk!/dl4/d5/L2dBISEvZ0FBIS9nQSEh/.
[124] Plug-in electric vehicles (PEV) [cited 2018 March 3,]; Available from: https://www.newlook.dteenergy.com/wps/wcm/connect/dte-web/home/service-request/residential/electric/pev/plug-in-electric-vehicles-pev; 2018.
[125] Li C-T, et al. Integration of plug-in electric vehicle charging and wind energy scheduling on electricity grid. In: Innovative smart grid technologies (ISGT). 2012 IEEE PES; 2012. IEEE.
[126] Qian K, et al. Modeling of load demand due to EV battery charging in distribution systems. IEEE Trans Power Syst 2011;26(2):802–10.
[127] Fairley P. Speed bumps ahead for electric-vehicle charging. IEEE spectrum 2010;47(1).
[128] Rangaraju S, et al. Impacts of electricity mix, charging profile, and driving behavior on the emissions performance of battery electric vehicles: a Belgian case study. Appl Energy 2015;148:496–505.
[129] Wang R, Xiao G, Wang P. Hybrid centralized-decentralized (HCD) charging control of electric vehicles. IEEE Trans Veh Technol 2017;66(8):6728–41.
[130] Ahmed MA, Kim Y-C. Performance analysis of communication networks for EV charging stations in residential grid. In: Proceedings of the 6th ACM symposium on development and analysis of intelligent vehicular networks and applications. ACM; 2017.
[131] Esmaili M, Goldoust A. Multi-objective optimal charging of plug-in electric vehicles in unbalanced distribution networks. Int J Electr Power Energy Syst 2015;73:644–52.
[132] Yao L, Damiran Z, Lim WH. A fuzzy logic based charging scheme for electric vehicle parking station. In: 2016 IEEE 16th international conference on environment and electrical engineering (EEEIC). IEEE; 2016.
[133] Zakariazadeh A, Jadid S, Siano P. Multi-objective scheduling of electric vehicles in smart distribution system. Energy Convers Manag 2014;79:43–53.
[134] Gao S, Jia H. Integrated configuration and optimization of electric vehicle aggregators for charging facilities in power networks with renewables. IEEE Access 2019;7:84690–700.
[135] Honarmand M, Zakariazadeh A, Jadid S. Optimal scheduling of electric vehicles in an intelligent parking lot considering vehicle-to-grid concept and battery condition. Energy 2014;65:572–9.
[136] Mao T, Zhang X, Zhou B. Intelligent energy management algorithms for EV-charging scheduling with consideration of multiple EV charging modes. Energies 2019;12(2):265.
[137] Houbbadi A, et al. Optimal scheduling to manage an electric bus fleet overnight charging. Energies 2019;12(14):2727.
[138] Yang J, He L, Fu S. An improved PSO-based charging strategy of electric vehicles in electrical distribution grid. Appl Energy 2014;128:82–92.
[139] Hu B, et al. Power grid peak shaving strategies based on electric vehicles and thermal storage electric boilers. In: IOP conference series: earth and environmental science. IOP Publishing; 2019.
[140] Wu H, et al. A scheduling and control system for electric vehicle charging at parking lot. In: Control conference (ASCC). IEEE; 2017. 2017 11th Asian.
[141] Wu H, et al. Dynamic resource allocation for parking lot electric vehicle recharging using heuristic fuzzy particle swarm optimization algorithm. Appl Soft Comput 2018;71:538–52.
[142] García-Álvarez J, et al. Electric vehicle charging scheduling using an artificial bee colony algorithm. In: International work-conference on the interplay between natural and artificial computation. Springer; 2017.
[143] Zhang Y, Zeng P, Zang C. Optimization algorithm for home energy management system based on artificial bee colony in smart grid. In: 2015 IEEE international conference on cyber technology in automation, control, and intelligent systems (CYBER). IEEE; 2015.
[144] Mavrovouniotis M, Ellinas G, Polycarpou M. Electric vehicle charging scheduling using ant colony system. In: 2019 IEEE congress on evolutionary computation (CEC). IEEE; 2019.
[145] Yang S, et al. Load modeling and identification based on ant colony algorithms for EV charging stations. IEEE Trans Power Syst 2014;30(4):1997–2003.
[146] Anand DM, et al. A hierarchical incentive arbitration scheme for coordinated pev charging stations. IEEE Transactions on Smart Grid 2015;6(4):1775–84.
[147] Wu Y, et al. Demand side energy management of EV charging stations by approximate dynamic programming. Energy Convers Manag 2019;196:878–90.
[148] López KL, Gagné C. Optimal scheduling for smart charging of electric vehicles using dynamic programming. In: Canadian conference on artificial intelligence. Springer; 2018.
[149] Qi W, et al. Hierarchical coordinated control of plug-in electric vehicles charging in multifamily dwellings. IEEE Transactions on Smart Grid 2014;5(3):1465–74.
[150] Cheng S, Feng Y, Wang X. Application of Lagrange relaxation to decentralized optimization of dispatching a charging station for electric vehicles. Electronics 2019;8(3):288.
[151] Tian A, et al. Network security-aware charging of electric vehicles. Int J Electr Power Energy Syst 2018;100:42–9.
[152] Xu Z, et al. A hierarchical framework for coordinated charging of plug-in electric vehicles in China. IEEE Transactions on Smart Grid 2016;7(1):428–38.
[153] Rahman MM, et al. Technical assessment of plug-in hybrid electric vehicle charging scheduling for peak reduction. In: 10th international renewable energy congress (IREC). Sousse, Tunisia: IEEE; 2019.
[154] Houbbadi A, et al. A quadratic programming based optimisation to manage electric bus fleet charging. 2019.
[155] Kaur K, Kumar N, Singh M. Coordinated power control of electric vehicles for grid frequency support: MILP-based hierarchical control design. IEEE Transactions on Smart Grid 2018.
[156] Tang Y, et al. Economic analysis on repurposed EV batteries in a distributed PV system under sharing business models. Energy Procedia 2019;158:4304–10.
[157] Tang W, Bi S, Zhang YJA. Online coordinated charging decision algorithm for electric vehicles without future information. IEEE Transactions on Smart Grid 2014;5(6):2810–24.
[158] Yang S, Zhang S, Ye J. A novel online scheduling algorithm and hierarchical protocol for large-scale EV charging coordination. IEEE Access 2019;7:101376–87.
[159] Moeini-Aghtaie M, Abbaspour A, Fotuhi-Firuzabad M. Online multicriteria framework for charging management of PHEVs. IEEE Trans Veh Technol 2014;63(7):3028–37.
[160] Hua L, Wang J, Zhou C. Adaptive electric vehicle charging coordination on distribution network. IEEE Transactions on Smart Grid 2014;5(6):2666–75.
[161] de Hoog J, et al. Optimal charging of electric vehicles taking distribution network constraints into account. IEEE Trans Power Syst 2015;30(1):365–75.
[162] Wang GC, et al. Corrective receding horizon EV charge scheduling using short-term solar forecasting. Renew Energy 2019;130:1146–58.
[163] Shaaban M, Eajal A, El-Saadany E. Coordinated charging of plug-in hybrid electric vehicles in smart hybrid AC/DC distribution systems. Renew Energy 2015;82:92–9.
[164] Diaz C, et al. Understanding model predictive control for electric vehicle charging dispatch. In: 2018 53rd international universities power engineering conference (UPEC). IEEE; 2018.
[165] He Y, Venkatesh B, Guan L. Optimal scheduling for charging and discharging of electric vehicles. IEEE transactions on smart grid 2012;3(3):1095–105.
[166] Li X, Zhang X, Fan Y. A two-step framework for energy local area network scheduling problem with electric vehicles based on global–local optimization method. Energies 2019;12(1):195.
[167] Wan Z, et al. Model-Free real-time EV charging scheduling based on deep reinforcement learning. IEEE Transactions on Smart Grid; 2018.
[168] Sadeghianpourhamami N, Deleu J, Develder C. Definition and evaluation of model-free coordination of electrical vehicle charging with reinforcement learning. IEEE Transactions on Smart Grid; 2019.
[169] Sadeghianpourhamami N, Deleu J, Develder C. Achieving scalable model-free demand response in charging an electric vehicle fleet with reinforcement learning. In: Proceedings of the ninth international conference on future energy systems. ACM; 2018.
[170] Valsomatzis E, Pedersen TB, Abello A. Day-ahead trading of aggregated energy flexibility-full version. 2018. arXiv preprint arXiv:1805.02301.
[171] Valsomatzis E, Pedersen TB, Abelló A. Day-ahead trading of aggregated energy flexibility. In: Proceedings of the ninth international conference on future energy systems. ACM; 2018.
[172] Khodayar ME, Wu L, Li Z. Electric vehicle mobility in transmission-constrained hourly power generation scheduling. IEEE Transactions on Smart Grid 2013;4(2):779–88.

[173] Liu Z, et al. Two-stage optimal scheduling of electric vehicle charging based on transactive control. IEEE Transactions on Smart Grid 2018;10(3):2948–58.
[174] Diaz C, Ruiz F, Patino D. Smart charge of an electric vehicles station: a model predictive control approach. In: 2018 IEEE conference on control technology and applications (CCTA). IEEE; 2018.
[175] Yang L, Zhang J, Poor HV. Risk-aware day-ahead scheduling and real-time dispatch for electric vehicle charging. IEEE Transactions on Smart Grid 2014;5(2):693–702.
[176] Shamshirband M, Salehi J, Gazijahani FS. Look-ahead risk-averse power scheduling of heterogeneous electric vehicles aggregations enabling V2G and G2V systems based on information gap decision theory. Electr Power Syst Res 2019;173:56–70.
[177] Barhagh SS, et al. Risk-involved participation of electric vehicle aggregator in energy markets with robust decision-making approach. J Clean Prod 2019:118076.
[178] Moeini-Aghtaie M, et al. PHEVs centralized/decentralized charging control mechanisms: requirements and impacts. In: North American power symposium. NAPS); 2013. 2013. IEEE.
[179] Ma Z, Callaway DS, Hiskens IA. Decentralized charging control of large populations of plug-in electric vehicles. IEEE Trans Control Syst Technol 2013;21(1):67–78.
[180] Markel T, Kuss M, Denholm P. Communication and control of electric drive vehicles supporting renewables VPPC'09. In: Vehicle power and propulsion conference. IEEE; 2009. 2009. IEEE.
[181] Gadh R, et al. Smart electric vehicle (ev) charging and grid integration apparatus and methods. Google Patents; 2015.
[182] Erol-Kantarci M, Mouftah HT. Energy-efficient information and communication infrastructures in the smart grid: a survey on interactions and open issues. IEEE Communications Surveys & Tutorials 2015;17(1):179–97.
[183] Su W, et al. A survey on the electrification of transportation in a smart grid environment. IEEE Transactions on Industrial Informatics 2012;8(1):1–10.
[184] Ancillotti E, Bruno R, Conti M. The role of communication systems in smart grids: architectures, technical solutions and research challenges. Comput Commun 2013;36(17):1665–97.
[185] Galli S, Scaglione A, Wang Z. For the grid and through the grid: the role of power line communications in the smart grid. Proc IEEE 2011;99(6):998–1027.
[186] Utilities should invest in electric vehicle infrastructure. In: Union of concerned scientists; 2018.
[187] Hadley SW, Tsvetkova AA. Potential impacts of plug-in hybrid electric vehicles on regional power generation. Electr J 2009;22(10):56–68.
[188] Yong JY, et al. A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. Renew Sustain Energy Rev 2015;49:365–85.
[189] Yan Q, Kezunovic M. Impact analysis of electric vehicle charging on distribution system. In: North American power symposium. NAPS); 2012. 2012. IEEE.
[190] Rautiainen A, et al. Case studies on impacts of plug-in vehicle charging load on the planning of urban electricity distribution networks. Institute of Electrical and Electronics Engineers IEEE; 2013.
[191] Bass R, et al. Residential harmonic loads and EV charging. In: Power engineering society winter meeting. IEEE; 2001. 2001. IEEE.
[192] Nguyen V-L, Tran-Quoc T, Bacha S. Harmonic distortion mitigation for electric vehicle fast charging systems. In: PowerTech (POWERTECH). IEEE Grenoble; 2013. 2013. IEEE.
[193] Fernandez LP, et al. Assessment of the impact of plug-in electric vehicles on distribution networks. Network 2011;16:21.
[194] Clement-Nyns K, Haesen E, Driesen J. The impact of charging plug-in hybrid electric vehicles on a residential distribution grid. IEEE Trans Power Syst 2010;25(1):371–80.
[195] Sadeghi-Barzani P, Rajabi-Ghahnavieh A, Kazemi-Karegar H. Optimal fast charging station placing and sizing. Appl Energy 2014;125:289–99.
[196] Shareef H, Islam MM, Mohamed A. A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles. Renew Sustain Energy Rev 2016;64:403–20.
[197] Gómez JC, Morcos MM. Impact of EV battery chargers on the power quality of distribution systems. IEEE Trans Power Deliv 2003;18(3):975–81.
[198] Wu D, et al. Transient stability analysis of SMES for smart grid with vehicle-to-grid operation. IEEE Trans Appl Supercond 2012;22(3). 5701105-5701105.
[199] Azadfar E, Sreeram V, Harries D. The investigation of the major factors influencing plug-in electric vehicle driving patterns and charging behaviour. Renew Sustain Energy Rev 2015;42:1065–76.
[200] Mahmud K, Town G, Hossain M. Mitigating the impact of rapid changes in photovoltaic power generation on network voltage. In: Power and energy conference at Illinois (PECI). IEEE; 2017. 2017. IEEE.
[201] Qian K, Zhou C, Yuan Y. Impacts of high penetration level of fully electric vehicles charging loads on the thermal ageing of power transformers. Int J Electr Power Energy Syst 2015;65:102–12.
[202] Green RC, Wang L, Alam M. The impact of plug-in hybrid electric vehicles on distribution networks: a review and outlook. Renew Sustain Energy Rev 2011;15(1):544–53.
[203] Habib S, Kamran M, Rashid U. Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks – a review. J Power Sources 2015;277:205–14.
[204] Thomson SJ, Rajan E. Power quality improvement using smart parks. In: 2018 International conference on control, power, communication and computing technologies (ICCPCCT). IEEE; 2018.
[205] Zhang W, et al. A multi-agent based integrated volt-var optimization engine for fast vehicle-to-grid reactive power dispatch and electric vehicle coordination. Appl Energy 2018;229:96–110.
[206] Arias NB, et al. V2G enabled EVs providing frequency containment reserves: field results. In: 2018 IEEE international conference on industrial technology (ICIT). IEEE; 2018.
[207] Iqbal S, et al. Aggregated electric vehicle-to-grid for primary frequency control in a microgrid-A review. In: 2018 IEEE 2nd international electrical and energy conference (CIEEC). IEEE; 2018.
[208] Saber AY, Venayagamoorthy GK. Plug-in vehicles and renewable energy sources for cost and emission reductions. IEEE Trans Ind Electron 2011;58(4):1229–38.
[209] Domínguez-Navarro J, et al. Design of an electric vehicle fast-charging station with integration of renewable energy and storage systems. Int J Electr Power Energy Syst 2019;105:46–58.
[210] Wu Q. Grid integration of electric vehicles in open electricity markets. John Wiley & Sons; 2013.
[211] Garcia-Valle R, Lopes JAP. Electric vehicle integration into modern power networks. Springer Science & Business Media; 2012.
[212] Gao F. Optimal GENCO bidding strategy. 2007.
[213] Bessa RJ, Matos MA. The role of an aggregator agent for EV in the electricity market. 2010.
[214] Mediwaththe CP, Smith DB. Game-Theoretic electric vehicle charging management resilient to non-ideal user behavior. IEEE Trans Intell Transp Syst 2018;19(11):3486–95.
[215] Tushar W, et al. Economics of electric vehicle charging: a game theoretic approach. IEEE Transactions on Smart Grid 2012;3(4):1767–78.
[216] Zhaoan F, et al. Power charging management strategy for electric vehicles based on a Stackelberg game. IET Intell Transp Syst 2019. https://doi.org/10.1049/iet-its.2019.0122.
[217] Lee W, et al. Electric vehicle charging stations with renewable power generators: a game theoretical analysis. IEEE transactions on smart grid 2015;6(2):608–17.
[218] Yu R, et al. PHEV charging and discharging cooperation in V2G networks: a coalition game approach. IEEE Internet of Things Journal 2014;1(6):578–89.
[219] Zhao T, et al. Real-time optimal energy and reserve management of electric vehicle fast charging station: hierarchical game approach. IEEE Transactions on Smart Grid 2017;9(5):5357–70.
[220] Karfopoulos EL, Hatziargyriou ND. A multi-agent system for controlled charging of a large population of electric vehicles. IEEE Trans Power Syst 2013;28(2):1196–204.
[221] Cao C, Chen B. Generalized Nash equilibrium problem based electric vehicle charging management in distribution networks. Int J Energy Res 2018;42(15):4584–96.
[222] Laha A, et al. Game theory based charging solution for networked electric vehicles: a location-aware approach. IEEE Trans Veh Technol 2019;68(7):6352–64.
[223] Bahrami S, Parniani M. Game theoretic based charging strategy for plug-in hybrid electric vehicles. IEEE Transactions on Smart Grid 2014;5(5):2368–75.
[224] Ovalle A, Hably A, Bacha S. Optimal management and integration of electric vehicles to the grid: dynamic programming and game theory approach. In: 2015 IEEE International Conference on Industrial Technology (ICIT). IEEE; 2015. p. 2673–9. https://doi.org/10.1109/ICIT.2015.7125492.
[225] Gan L, Topcu U, Low SH. Optimal decentralized protocol for electric vehicle charging. IEEE Trans Power Syst 2013;28(2):940–51.
[226] Xu S, et al. Decentralized charging control strategy of the electric vehicle aggregator based on augmented Lagrangian method. Int J Electr Power Energy Syst 2019;104:673–9.
[227] Mizuno K, Namerilkawa T. Optimization of power flow and scheduling for EV charging based on distributed control. In: 2019 12th Asian Control Conference (ASCC). IEEE; 2019. p. 627–31.
[228] Liu M, et al. Decentralized charging control of electric vehicles in residential distribution networks. 2017. arXiv preprint arXiv:1710.05533.
[229] Liu M. Chance-constrained shrunken-primal-dual subgradient (CC-SPDS) approach for decentralized electric vehicle charging control. 2019. arXiv preprint arXiv:1903.04426.
[230] Chen N, Tan CW, Quek TQ. Electric vehicle charging in smart grid: optimality and valley-filling algorithms. IEEE Journal of Selected Topics in Signal Processing 2014;8(6):1073–83.
[231] Zhan K, et al. A probability transition matrix based decentralized electric vehicle charging method for load valley filling. Electr Power Syst Res 2015;125:1–7.
[232] Zhang L, et al. Coordinating plug-in electric vehicle charging with electric grid: valley filling and target load following. J Power Sources 2014;267:584–97.
[233] Yang B, et al. Distributed control for charging multiple electric vehicles with overload limitation. IEEE Trans Parallel Distrib Syst 2016;27(12):3441–54.
[234] Torreglosa JP, et al. Decentralized energy management strategy based on predictive controllers for a medium voltage direct current photovoltaic electric vehicle charging station. Energy Convers Manag 2016;108:1–13.
[235] Wen C-K, et al. Decentralized plug-in electric vehicle charging selection algorithm in power systems. IEEE Transactions on Smart Grid 2012;3(4):1779–89.
[236] Xi X, Sioshansi R. Using price-based signals to control plug-in electric vehicle fleet charging. IEEE Transactions on Smart Grid 2014;5(3):1451–64.
[237] Teng J-H, Liao S-H, Wen C-K. Design of a fully decentralized controlled electric vehicle charger for mitigating charging impact on power grids. IEEE Trans Ind Appl 2017;53(2):1497–505.
[238] Ghazanfari A, Hamzeh M, Mohamed YA-RI. A resilient plug-and-play decentralized control for DC parking lots. IEEE Transactions on Smart Grid 2018;9(3):1930–42.

[239] García-Triviño P, et al. Control of electric vehicles fast charging station supplied by PV/energy storage system/grid. In: Energy conference (ENERGYCON), 2016 IEEE international. IEEE; 2016.

[240] García-Triviño P, et al. Decentralized fuzzy logic control of microgrid for electric vehicle charging station. IEEE Journal of Emerging and Selected Topics in Power Electronics 2018;6(2):726–37.

[241] Xydas E, Marmaras C, Cipcigan LM. A multi-agent based scheduling algorithm for adaptive electric vehicles charging. Appl Energy 2016;177:354–65.

[242] Rodemann T, et al. Using agent-based customer modeling for the evaluation of EV charging systems. Energies 2019;12(15):2858.

[243] Rahman MS, Oo A. Distributed multi-agent based coordinated power management and control strategy for microgrids with distributed energy resources. Energy Convers Manag 2017;139:20–32.

[244] García-Villalobos J, et al. Plug-in electric vehicles in electric distribution networks: a review of smart charging approaches. Renew Sustain Energy Rev 2014;38:717–31.

[245] Li G, et al. Direct vehicle-to-vehicle charging strategy in vehicular ad-hoc networks. In: 2018 9th IFIP international conference on new technologies, mobility and security (NTMS). IEEE; 2018.

[246] Kosmanos D, et al. Route optimization of electric vehicles based on dynamic wireless charging. IEEE Access 2018;6:42551–65.

[247] Foote A, et al. System design of dynamic wireless power transfer for automated highways. In: IEEE transportation electrification conference and expo (ITEC). IEEE; 2019. 2019.

[248] Vehicle-to-Everything technologies for connected cars. California, U.S.A: Frost & Sullivan; 2017.

[249] Chadha D, Reena. Vehicular ad hoc network (VANETs): a review. Int. J. Innov. Res. Comput. Commun. Eng 2015;3(3):2339–46.

[250] Mouhcine E, Mansouri K, Mohamed Y. Intelligent vehicle routing system using VANET strategy combined with a distributed ant colony optimization. In: International conference on advanced information technology, services and systems. Springer; 2018.

[251] Saldern Sv. How Connected Mobility will succeed in future [cited 2019 June 21]; Available from: http://www.z-punkt.de/en/themen/artikel/wie-vernetzte-mobilitaet-in-zukunft-gelingt/403#section3; 2019.

[252] NHTSA. *Automated vehicles for safety* [cited 2019 June 15]; Available from: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety#issue-road-self-driving; 2019.

[253] Overview of automated vehicle technology. National Highway Traffic Safety Administration; 2019.

[254] Csuvar B. Change on the horizon: future trends in car ownership and its far-reaching implications. 2019.

[255] Wang J, Huang J, Dunford M. Rethinking the utility of public bicycles: the development and challenges of station-less bike sharing in China. Sustainability 2019;11(6):1539.

[256] Katzev R. Car sharing: a new approach to urban transportation problems. Anal Soc Issues Public Policy 2003;3(1):65–86.

[257] Cao J, Yang M. Energy internet–towards smart grid 2.0. In: Networking and distributed computing (ICNDC), 2013 fourth international conference on. IEEE; 2013.

[258] Rifkin J. The third industrial revolution: how lateral power is transforming energy, the economy, and the world. Macmillan; 2011.

[259] Zheng Y, et al. Design of energy internet based on information internet. In: Energy internet and energy system integration (EI2), 2017 IEEE conference on. IEEE; 2017.

[260] Hussain S, et al. The emerging energy internet: architecture, benefits, challenges, and future prospects. Electronics 2019;8(9):1037.

[261] Yuan K, et al. Electric vehicle smart charging network under the energy internet framework. In: Energy internet and energy system integration (EI2). IEEE Conference on 2017; 2017. IEEE.

[262] Haddadian G, Khodayar M, Shahidehpour M. Accelerating the global adoption of electric vehicles: barriers and drivers. Electr J 2015;28(10):53–68.

[263] Mullan J, et al. Modelling the impacts of electric vehicle recharging on the Western Australian electricity supply system. Energy Policy 2011;39(7):4349–59.

[264] Kintner-Meyer M, Schneider K, Pratt R. Impacts assessment of plug-in hybrid vehicles on electric utilities and regional US power grids, Part 1: technical analysis, vol. 1. Pacific Northwest National Laboratory; 2007.